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RIVER BASIN MANAGEMENT FOR OPTIMUM WATER YIELD

by J. O. Adejuwon

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INTRODUCTION

Mr. Vice-Chancellor, if one looks too far into the past, over most of our academic careers, the so called achievements fade readily into the futility of philosophy, and into an unreal world of thankless jobs completed. If one on the other hand from whatever academic pedestal, looks too far into the future, one sees nothing except one is prepared to find substance in an illusion which essentially is a caricature of the past. This is why, in selecting a topic for this lecture, I have decided to give preference to the moment, to the work at hand. If I have been scheduled to give my inaugural lecture next session, the substance of this address would probably have been written up as another paper. I am not by this trying to play down the grandeur of inaugural lectures in the life of a university. I am only stating the fact that this is a lecture by a struggling student who is aspiring to some level of excellence. The pursuit of excellence is one of the most exciting things in the world. It produces its own triumph, its own joy. It is different from trying to become the master. The status of the master, I have observed, is something that one should fear, especially in this country. It is like a mountain top where the only way forwards takes you backwards and the only way upwards finds you crashing down.

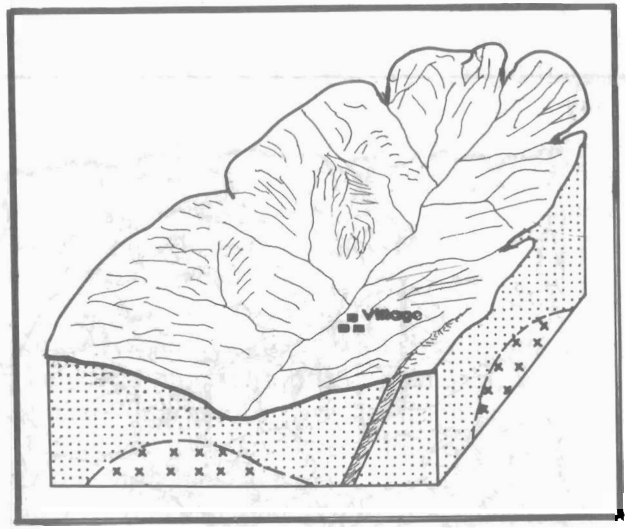
Perhaps the earlier thankless jobs could be made less of a futility if they could be retrieved from the clutches of philosophy and reactivated for service to the community. I have the feeling that what these jobs have given me, and not so much of what they espouse themselves, could be raked up and adopted as some of the blocks in building a better environment for the next generation. It is for this purpose that I am directing my attention to integrative rather than analytical exercises. I am borrowing an idea from Max Ways (1970), to start putting together the world that I have been taught; through analysis, to take apart.

In the course of this lecture, therefore, I intend to outline a set of procedures for refining the well known generalised concept of a river basin into an empirical, predictive model that could be manipulated for the purpose of optimising water yield. As a major objective, this lecture is directed at modelling the river basin for optimum water yield.

A river basin is all of the land surrounding and draining into a stream of river (Fig. 1). Large river basins are made up of smaller river basins while each of the smaller river basins is an aggregate of numerous streams and streamlet basins (Fig. 2). Probably, a more appropriate term to use is a *river catchment area* because few of these features have a true basin form. However, following the recent attempts to design an action programme for the development of Nigerian water resources, the term *river basin* has become more or less entrenched in contemporary usage, and it cannot be avoided merely to achieve descriptive clarity.

Conceptually, the river basin is a specific segment of the earth's surface, set off from adjacent segments by a more less clearly defined boundary, underlain by known rock and soil types and occupied at any given time by a particular grouping of plants and animals. It is a system similar in many respects to the ecosystem of the ecologist. It is structured, it functions as an organic whole, and it involves a throughput of mattter and energy. In this regard, the river basin is an open system characterized by inputs and outputs which are balanced when the system attains a stage of maturity and stability. Water yield, which is being emphasized in this lecture is only one of the outputs of the river basin.

In our usage of the term, a model is isomorphic, that is, it has a one-to-one correspondence in its essential features with a defined real world system. The real world system concerned here is the river basin. However, the model is simple in its presentation and it is amenable to concise and precise specification. It can in fact be stated in simple, well known mathe-



Fig·1 Generalised diagram of a Drainage Basin

matical language. As a scienctific theory, the model is conceived here as potentially falsifiable through empirical verification; but for management purposes, its greatest asset is that it is predictive.

Modelling a river basin as a pathway to explanation is not new in geographical and hydrological studies. However, modelling a river basin as a part of a management action programme has not been seriously tackled. In addition to providing an explanation of the relationships between the components of a river basin system, a management model for optimising water yield must be able to identify certain determining factors that could be used as levers to procure a given desirable change in water production. In other words, this exercise rests on the assumption that given a set of meterological inputs and specific basin characteristics, there is a pattern of human activities in a river basin the adoption of which will produce optimum yields of water.

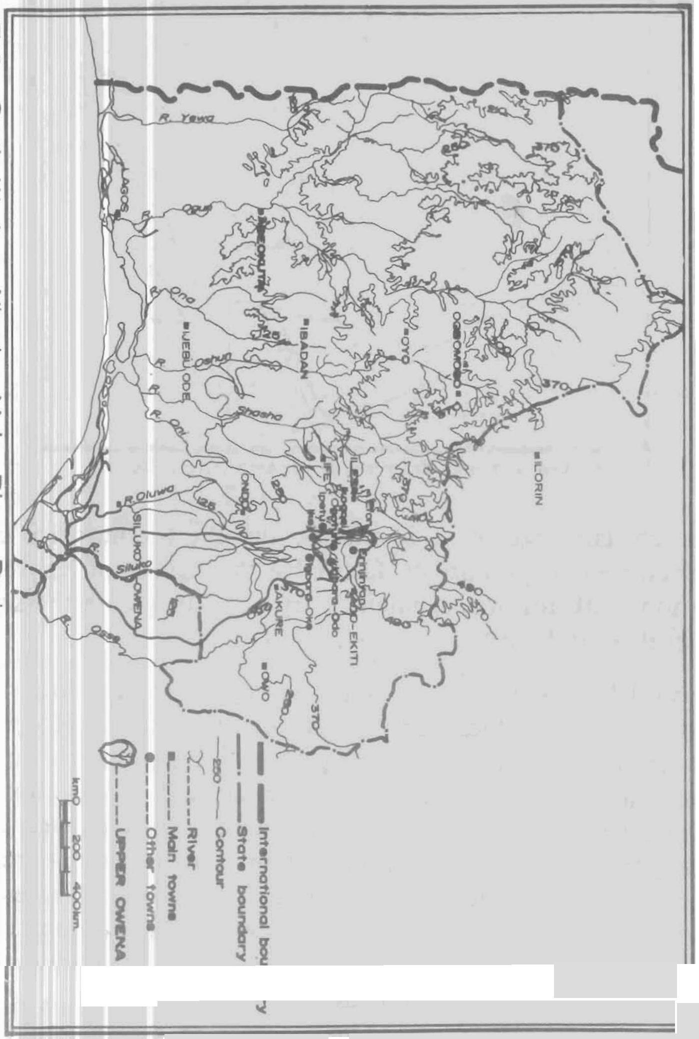


Fig.2. South-Western Nigeria : Main River Basins.

The data used to demonstrate that the model is potentially falsifiable and hence that it can be accorded the status of a scientific theory have been collected in the Upper Owena River Basin in Ondo State (Fig. 3). For these, thanks are due to the University which granted funds in 1976 to study "land-use and other aspects of human intervention in relation to water yield, soil erosion, and sediment yield" in the area.

Starting from January 1977:

(i) measuriing devices have been established on 21 3rd Order stream basins and with these nearly two years of daily field observations have been completed.

(ii) similar observations have been completed on the three 4th order tributary rivers and on the main river at Owena near Igbara-Oke;

(iii) an experimental plot has been established to measure run-off, sediment yield, infiltration capacity on a hill side underlain by quartzite and quartz schists;

(iv) a net-work of 22 rainfall recording stations including six that are automatic has been established (Fig. 3);

(v) water and other samples taken at pre-determined points and times have been analysed for physical and chemical properties including pH, conductivity, transparency, content of up to twelve elements related to water quality, total dissolved solids, suspended solids as well as the bed load.

While the field observations continue, some of the data so far collected are being analysed and processed in various ways for publication.

MODELLING PROCEDURE

The river basin is assumed to be a system made up of interacting components. For our purpose, these components can be resolved into those constituting and those determining water yield. With the objective of management for optimising

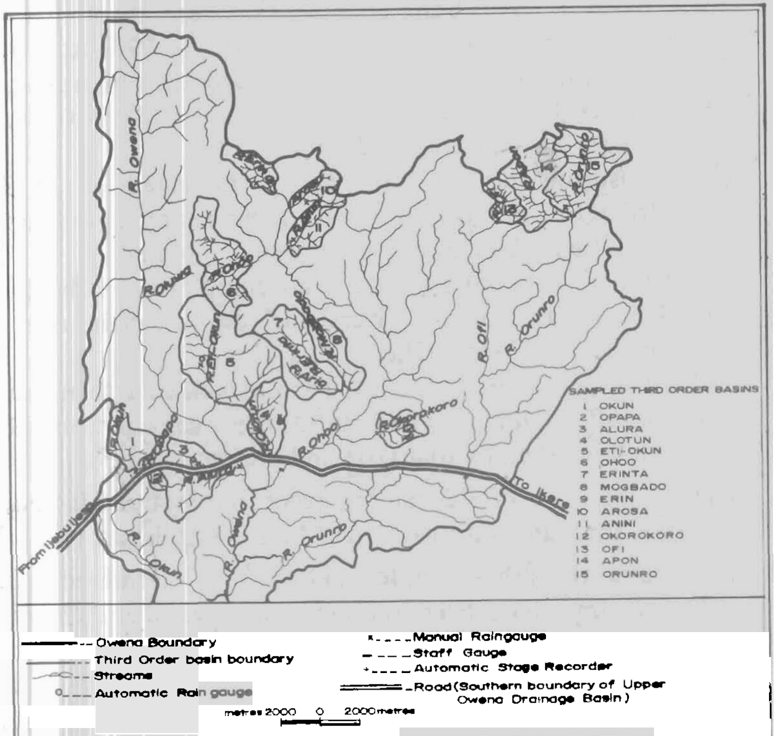


Fig.3. Drainage Composition of Upper Owena and Sampled Third Order Basins

water yield, the modelling procedure being suggested here includes:

(i) identification and measurement of the components of water yield;

(ii) devising a summarizing index for the concept of water yield which by its nature is composed of a multiplicity of variables each with its own measuring scale and hence not easily additive to the other as a way of giving a measure of the whole.

(iii) identification and measurement of the determinants of water yield.

(iv) giving expression to the bivariate relationships between the elements of water yield on the one hand and those of the determining factors on the other;

(v) giving expression to the multivariate relationships between the elements of water yield on the one hand and those of the determining factors on the other;

(vi) derivation of the multiple of functional relationships between each element of water yield and its composite of determining factors;

(vii) derivation of the functional relationship between the summarizing indices of water yield and their multiplicity of determining factors;

(viii) solving the derived equations to obtain the particular functional relationships at which water yield or any combination of its components is optimised.

THE COMPONENTS OF WATER YIELD

The water yield of a river basin simply refers to the water flowing out of the basin through the lowest point on the river. However, water yield is not just the amount of water produced. The quantitative elements refer to physical, chemical, biochemical and biological properties of the water produced. These include primarily the suspended and dissolved loads carried by the stream or the river as well as the type and amount of micro-organic life contained.

Water quality cannot be determined in isolation on the bases of the parameters mentioned above without relating them to quantity. The elements of quality are always given in the form of so much of parts of obnoxious contents per a given unit of volume. In effect, what constitutes a level of quality is not the total amount of nitrogen or potassium, but the proportion of the total amount of water that these constitute.

The quantity of water can also become meaningful only when related to the time during which it was produced. Thus quantitatively, the variables constituting water yield refer to how much is produced per annum of any unit of time. In addition, there are certain variables of yield which are concerned with changes in quantity with time. These are given measures of variability such as the standard deviation of discharge which seek to demonstrate the dynamics of the quantity of yield. By relating quantity to time, the rationale for doing the same for quality becomes obvious. The chemical, physical and biological properties change with time. The amount of suspended and dissolved loads and their various components can be computed on the basis of specific periods of time.

Further, it can be easily realised that the contributions to yield in relation to quantity, quality and time of release are to some extent determined by the size of the river basin. This gives rise to another set of yield variables that have area, length or height as denominators. Among the water yield variables measured or computed in the Upper Owena valley which forms our chief experimental site are the following:

q_1 = Lowest daily discharge during the year (litres/sec.)
q_2 = Highest daily discharge during the year (litres/sec.)
q_3 = Average daily discharge during the year (litres/sec.)

q_4 = Discharge exceeded 99% of the time (litres/sec.)
q_5 = Discharge exceeded 90% of the time
q_6 = Discharge exceeded 50% of the time
q_7 = Discharge exceeded 10% of the time
q_8 = Discharge exceeded 1% of the time
q_9 = Variability index for year
q_{10} = Total volume of yield for year (in 100,000,000 litres)
q_{11} = Number of days without flow
q_{12} = Total run-off (mm)
q_{13} = Run-off as % of rainfall
q_{14} = Number of days from peak flow to the nearest minimum flow
q_{15} = Index of amount of suspended sediments
q_{16} = Relationship of suspended sediment to discharge
q_{17} = Index representing amount of dissolved load
q_{18} = Increase of dissolved sediments with discharge
q_{19} = Highest iron concentration (ppm)
q_{20} = Lowest iron concentration (ppm)
q_{21} = Average iron concentration (ppm)
q_{22} = Highest nitrate concentration (ppm)
q_{23} = Lowest nitrate concentration (ppm)
q_{24} = Average nitrate concentration (ppm)
q_{25} = Highest phosphorus concentration (ppm)
q_{26} = Lowest phosphorus concentration (ppm)
q_{27} = Average phosphorus concentration (ppm)

SUMMARIZING INDEX OF WATER YIELD

One can easily appreciate from the above that water yield is a concept that cannot be directly measured because it is a composite of many variables. The scale of measurement of these variables usually differ and for this reason, comparison among them cannot be easily achieved. It is hence not possible by simple addition to obtain from the variables a summary index that would represent the concept of water yield. In modelling water yield in a river basin, the derivation of such an index becomes imperative if a multiplicity of management action programmes is not the objective. Without such a summarising index what would be possible is a series of models useful in managing the same drainage basin for each of the components of water yield. It is highly probable that because each of these models would be unique in some way, the management programmes derived from them could be contradictory. Certainly, action may be necessary to control specific elements of yield. The field should however be made clear to avoid contradictory action programmes in the case that a multiple of water yield components or the totality of yield needs to be controlled.

From the foregoing, it could be conceptualized that there is set of variables:

$$q_1, q_2, q_3 \cdots\cdots q_n$$

which can be used jointly to describe the concept of water yield. It is now required that a composite index be created which best expresses the concept of water yield or which can most efficiently subsume these non-additive units. To create such an index, one needs to adopt a transformation procedure in which some weights are attached to each variable and thereby by-pass the problem that is created by the non-additivity nature of the components.

Let this transformation be of the form

$$Q = a_1q_1 + a_2q_2 + \cdots\cdots a_nq_n = ax \text{ ----------- } (1)$$

where $a = a_1, a_2, a_3, \cdots\cdots a_n$ and

Q is the index of water yield.

$$q = \begin{bmatrix} q_1 \\ q_2 \\ \cdot\cdot \\ \cdot\cdot \\ q_n \end{bmatrix}$$

The a's are the weights to be attached to values of the variables in creating the index.

Sonaike (1975) has reviewed three main methods for creating this type of index without arbitrarily choosing the weights, that is the values of the a!s. These are Cannonical Analysis, Principal Component Analysis and Factor Analysis. In each case, the correlations among the variables are utilized in determining the weights. Of the three methods reviewed, Factor Analysis appears to offer the most theoretically interpretable and plausible approach for index construction mostly because it recognises that related variables can possess theoretically defined factors common of them as well as factors that are unique to each variable. In the case of Cannonical Analysis, there is an additional defect in that there is the need for another set of variables external to the one we are interested in. For this particular purpose, great care must be exercised in selecting the external set or reference variables so that they can present meaningful relationships to the variables of our interest. The external set would be most useful when as a group they are highly correlated with the one of interest.

Factor Analysis

The use of Factor-Analysis in solving the problem at hand is based on the assumption that the observed correlations are mainly the results of observed regularity in the data. It is assumed that the observed variable is influenced by various determinants, some of which are shared by other variables in the set, called common factors, while others are not and are hence called unique factors. Therefore, the common factors which are hypothetical variables account for the correlations among the variables, while the unique factors account for the remaining variance (including error) of a particular variable. The aim of Factor Analysis is to maximally produce the correlations among the variables.

The basic model of Factor Analysis is:

$$xj = a_{j1}f_1 + a_{j2}f_2 + \ldots\ldots + a_{jm}f_m + d_jU_j \quad U_j$$

$$(j = 1, \ldots\ldots n) \text{ ---------------------------- } (2)$$

where f_l is the lth common factor

U_j is the unique factor of variable j

a_j is the factor loading

(2) can be re-rewritten as:

$$X = AF + DU \text{ ---------------------------- } (3)$$

where $X = (x_1 \ldots x_n)$

$F = (f_1 \ldots . f_m)$

$A = (a_{j_1} \ldots . a_{j_m})$

$U = (U_1 \ldots . U_n)$

$$D = \begin{bmatrix} d_1 & o & o & o \\ o & d_2 & o & o \\ - & - & - & - \\ o & o & o & o \end{bmatrix}$$

There are usually m, much less than n, factors that account for the total variance of all principal variables. The hypothetical factors can be expressed as linear combinations of the original variables i.e.

$$f_i = \sum_{j=i}^{n} b_{ij}x_j \quad \ldots\ldots\ldots\ldots (i = 1 \ldots m) \text{ ------ } (4)$$

$$\text{or } f_i = b_i x \text{ ------------------------ } (4a)$$

The first factor contributes a maximum to the total variance of the original variables, the second factor, uncorrelated with the first, contributes a maximum to the residual variance and so on until the total variance is analysed. The sum of the variances of m factors is equal to the sum of the variances of the original variables. Even when all the factors are obtained, there may still be a residual correlation unaccounted for.

The using Factor Analysis to construct an index, we take the first factor as the best transformation since it contributes a maximum to the total variance. Since this is just one of the factors, there is some loss of information – either the total variance nor the total correlations are accounted for. However, the loss may not be important since the weights, which are the factor loadings and are our primary interests are maximally determined.

Table 1 gives the factor loadings of each variable on each of the seven factors into which the twenty-seven variables have been aggregated. Table 2 gives the eigenvalues and the percentage of variance that each factor is responsible for. Thus, while the first factor which we are adopting aggregates 50% of the variance, the corresponding percentage aggregated on the second factor is only 12.8%. To obtain Q for each river basin, multiply the value of each water variable by the corresponding factor loading and add.

TABLE I

actor Loadings on Fac...

ariables	Factor I
q_1	0.27923
q_2	-0.12310
q_3	0.51073
q_4	0.26501
q_5	0.064.24
q_6	0.68568
q_7	0.30128
q_8	-0.10436
q_9	-0.09270
q_{10}	0.51296
q_{11}	-0.41755
q_{12}	0.91057
q_{13}	0.84464
q_{14}	0.25071
q_{15}	0.28373
q_{16}	0.37290
q_{17}	0.92677
q_{18}	0.92679
q_{19}	0.19545
q_{20}	0.14570
q_{21}	0.39867
q_{22}	0.09695
q_{23}	0.19254
q_{24}	0.15877
q_{25}	0.12374
q_{26}	0.26897
q_{27}	0.19512

TABLE 2

Eigenvalues and % of Variance Loaded on each Factor

Factor	Eigenvalue	Pct. of Var.	Cum. Pct.
1	11.47214	50.1	50.1
2	2.93562	12.8	63.0
3	2.34979	10.3	73.2
4	2.11388	9.2	82.5
5	1.71781	7.5	90.0
6	1.30908	5.7	95.7
7	0.98531	4.3	1100.0

THE DETERMINANTS OF WATER YIELD

The determinants of water yield in a drainage basin can be resolved into four main sets of variables. These include:

(i) the climatic input;
(ii) the nature of the plant cover;
(iii) the surface configuration;
(iv) the soil/saprolite/surface rock complex.

All these are, with water yield, intricately associated in what is generally known as the hydrological cycle. Enough of this concept is widely known in the literature to make any length consideration here of minimal relevance.

The climatic input is largely subsumed by the concept of water balance. The elements of the latter include precipitation, potential evapotranspiration, actual evapotranspiration, ground water status, water dificit and water surplus. For our purpose, the most relevant element of water balance is water surplus which can be obtained in the expression:

$$WS = P + GWL - AE - GWR \qquad \ldots\ldots\ldots\ldots (5)$$

where WS is water surpl

P is precipitation

GWL is water released to the surface from ground water sources.

AE is actual evapotranspiration and

GWR is ground water recharge.

The basin receives its input of water from meteorological sources including rain and other forms of precipitation. Not all the water received by a catchment area is ultimately disposed of as stream or river discharge. A considerable proportion of the meteorological input of water is lost as evapotranspiration which is in fact the reverse of rain as it returns water to the atmosphere. For instance, Ayoade and Oyebande (1978) calculate that while on the average Nigeria receives an annual rainfall of 1400 mm; as much as 1070 mm of this is lost as evapotranspiration, leaving a balance of only 330 mm.

The amount of evaporation and transpiration, when the supply of water is unlimited, i.e. potential evapotranspiration (PE), is primarily a function of the amount of energy available as heat, the vapour pressure of the air and the wind speed. It hence provides a summary index for climatic conditions. Secondly, the amount of evapotranspiration in a river basin depends on the relative importance of lakes and other water surfaces, the soil, the saprolite and surface rocks as earth-bound repositories of water. The rate of evapotranspiration is at a maximum (PE) on open water surfaces and from soil with water above the field capacity level. As surface water

dries up and the surface gets drier, a resistance is built up against evapotranspiration. The actual rate then becomes markedly different from the potential rate. Thirdly, the rate of evapotranspiration varies directly with the type of vegetation especially the rooting system and the degree and type of foliage cover. Indirectly, the vegetation influences evaporation by intercepting rainfall and delaying the percolation of water into the soil. During the period of such delay, the water is available solely by the absorptive capacity of the air with little resistance offered by surface features. A growing plant community also affects the water balance through consumptive use as a result of which the commodity becomes stored up as biomass.

The rate at which water moves through the river basin to its exit depends on the slope of the land, vegetal cover, and the permeability of the soil/saprolite/surface rock complex. Quantitatively, the water produced by each drainage basin differs considerably from rain water. At the point of exit, the water carries a lot of mineral matter in solution and in suspension. The water may also contain in addition myriads of micro-organisms. The amount of dissolved and suspended materials carried by the water is determined primarily by the basin characteristics such as soil, saprolite, surface geology, vegetal cover as well as the methods of agricultural production including the application of pesticides, fertilizers and herbicides. The production and method of disposal of industrial and domestic waste products also contribute to water contamination which now go under the general name of pollution.

In our main experimental area — Upper Owena Drainage Basin — the following determinants are being measured, mapped or monitored:

m_1 = Fine grained gneisses and schists (% of area)

m_2 = Quartzitic rocks (% of area)

m_3 = Medium grained gneisses and granites (% of area)
m_4 = Amphibolites and basic schists (% of area)
m_5 = Coarse grained granites and gneisses (% of area)
m_6 = Index of relief ratio
m_7 = Index of drainage density
m_8 = Index of absolute relief (m)
m_9 = Area (sq. km)
m_{10} = Perennial crops (% of area)
m_{11} = Annual crops (% of area)
m_{12} = Forest (% of area)
m_{13} = Fallow land (% of area)
m_{14} = Urban land (% of area)
m_{15} = Total rainfall (mm)
m_{16} = No of rainy days

For this particular exercise, it is not necessary to consider variables such as humidity and temperature because there is little difference from one part of our major basin area to the other. Fore a model that would be more widely applicable, the number of relevant determining factors must increase.

THE RELATIONSHIP BETWEEN WATER YIELD AND THE DETERMINING FACTORS

The conclusion which one can derive from the foregoing is that the elements of water yield as described earlier are dependent on the determining factors which have been referred to as the basin characteristics. The confidence which one can repose on the management model, which is our primary objective here, rests on the hypothesis that the relationship is significant to the extent that modifications to the determining factors could be used as levers in changing the pattern of water yield. It is hence necessary at this stage to give a quantified measure of the relationship and in

the process, supply a proof of the ***a-priori*** hypothesis. This could be achieved at two main levels including bivariate and multivariate correlation analysis.

Correlation Analysis

A considerable number of logical conclusions and inferences could be drawn from an inspection of the simple coefficients of correlation as depicted in table 3. For example, it could be observed that average daily discharge is significantly correlated with the occurrence of quartzitic rocks and the relief ratio -- the respective correlation coefficients being +0.895 and +0.583. It can also be deduced from the signs of the coefficients that while total annual discharge is significantly and directly correlated with quartzitic rocks, ($r = +0.897$), the same component of water yield is highly and inversely related to drainage density ($r = 0.555$). The last row in the table gives the various coefficients of correlation of the composite index of water yield (Q) with the determining factors. These show that the more significantly correlated factors with this index are:

relief ratio (0.864), fallow land (0.570), total rainfall, (0.355) and area (0.356)

However, there are limitations to the use of simple correlation analysis which need to be discussed further. First, it should be realised that the determining factors do not operate in isolation to produce the various attributes of water yield. Secondly, there are interactions between the variables representing basin characteristics just as there are interactions between the attributes subsumed under the concept of water yield. In view of this, it may be necessary to find a summarising coefficient of correlation that expresses the extent to which the basin characteristics as a group determined water yield.

TABLE 3

Simple Matrix

	m_1	m_2	m_3	m_4	m_5	m_6	m_7	m_8	m_9	m_{10}	m_{11}	m_{12}	m_{13}	m_{14}	m_{15}	m_{16}
q_1	-.144	.666	-.404		-.081	.466	-.279	.494	.159		.333	-.079	.274	.562	-.156	
q_2	.149	.274		-.460		-.192	-.547	.221	.486		-.124	.596	-.388	.069	.338	.427
q_3	-.065	.895		-.402	.012	.583	-.558		.299	-.291	-.128	.097		.183	.317	.328
q_4	-.156	.698	-.399		0.109	.467	-.288	.510	.165	-.418			.292	.548	-.178	-.022
q_5	-.169	.554		-.209	-.240		-.083	.408	.011	-.389	.587		.474	.387	-.469	-.289
q_6	-.120	.942	-.530			.708	-.404	.654	.050		.006	-.041	.466	.240	.226	.290
q_7	-.038	.703	-.557		.237	.317	-.602	.610	.470	-.038	-.305		-.024		.423	.281
q_8	.283	.479	-.381	-.576		.126	-.691		.684		-.398	.293	-.208	.01	.306	.250
q_9	-.042	-.483	.447	-.280		-.444	.147	-.466	-.205	.149	-.196			.131	.290	.249
q_{10}	-.007	.897		-.396	.005	.584	-.555		.293	-.288	-.124	.088		.184	.313	.322
q_{11}	.041	-.724		.306		-.570	.279	-.561	-.14	.362		.160	-.545	-.064	.022	-.030
q_{12}	-.162	.68	-.374		-.082	.880	.099		-.256	-.288	-.067		.43	-.064	.446	.392
q_{13}	-.191	.749			-.131	.873	.071	.453	-.236	-.347	.085		.54	.073	.277	.25
q_{14}	.038	.756		-.459	.022	.412	-.531	.698	.379	-.185		-.128	.335	.081	.045	
q_{15}	-.414		-.063	.196	-.556	.071	-.082		-.106	-.094		-.317	.342	2.84	-.127	-.161
q_{16}	-.129	.719	-.398	-.064			-.374	.423	.229	.03		-.314	.288	.265	.053	-.052
q_{17}	.249	-.735		.134	.286	-.767	.023	-.362	.307	.337	.043		-.448	-.007	-.389	
q_{18}	.404	-.557	.221	.123		-.612	-.182	-.081	.485	.438	-.190		-.577		-.296	-.278
q_{19}		-.506	.661	.05	-.219	-.364	.433	-.558		.318	-.252		-.094	-.001	-.075	-.172
q_{20}	-.071	-.171	.397	-.102		-.103	-.054	-.042	-.123	.003		.062	-.020	-.102	.081	
q_{21}		-.554	.524	-.102	.071	-.573	.089	-.445	-.063	.135	-.075	.271			.023	.127
q_{22}	-.074	-.270	-.270	-.085		-.126	.396		-.216	-.344	-.428	-.126		-.068	.067	-.129
q_{23}	-.157	-.130	-.130		.209	-.014	-.143	-.102	-.306	-.218	.033	.445		.127	.372	.586
q_{24}	-.108			-.151		-.224	-.285	-.367	-.327	.052	-.267	.123		.015	.074	.067
q_{25}	-.196	-.456	-.456	-.099		-.388	.438	-.495	-.066	.889	-.354		-.284	.004	.131	-.400
q_{26}	.594			-.191	.023	-.26	-.127	-.03	.494	.499	-.298		-.566	.009		.125
q_{27}	.047			-.093	-.072	-.576	.274	-.634	-.039	.433	-.074		-.414	.435	.084	-.134
Q	-0.140		-.0.	-0.124		0.864		0.349	-0.356	-0.279	-0.05	-0.150	0.570	-0.196	0.355	0.322

One well known method for achieving this is by calculating the multiple coefficient of correlation (R). This is designed to give quantified measures of the relationship between one dependent variable and a set of independent variables. Starting from the most highly correlated independent variable, the multiple coefficient of correlation is built up step by step until all the variances in the dependent variable have been accounted for. Thus from zero each independent variable makes its own contribution to the value of the coefficient until the latter becomes unity. Squaring the value of the multiple coefficient of correlation at the various stages gives the proportion of the variances in the dependent variable that has been explained by the contributing factors.

Table 4 gives the change in R^2 that each of the determining factors is responsible for. The 10th row of the table is interpreted to mean that factor m_2 (proportion of the basin under quartzitic rocks) explains up to 80 percent of the differences in the quantity of annual discharge in the Upper Owena basin while the rest is explained respectively by m_5 (7 percent), m_{10} (4 percent), m_{16} (3 percent), m_9 (2 percent) and m_1 (1 percent). The last row similarly explains the summary index of water yield in terms of the determining factors. Among the latter, the significant ones are m_6 which explains 75 percent, m_9 (9%), m_{13} (8%) and m_{10} (3%).

Regression Analysis

Related to the simple bivariate coefficients mentioned earlier are regression coefficients which can form the basis of several equations which can be used to predict each water yield variable from a basin attribute with which it is significantly associated. According to King (1969) the regression coefficient is simply the correlation coefficient scaled by the ratio of the standard deviation of the dependent variable. Thus, there is not much that could be achieved

TABLE 4

Multiple Correlation: Contribution of M_5 to R^2 (%)

	m_1	m_2	m_3	m_4	m_5	m_6	m_7	m_8	m_9	m_{10}	m_{11}	m_{12}	m_{13}	m_{14}	m_{15}	m_{16}
q_1	11	44	2		6	7	1	4	8			1		16		
q_2	1	22		11		11	6	3			1	36		5	1	3
q_3	1		80	1	7	1			2	3	1			1		3
q_4	11	49			7	5	1	3	8	1				14	1	
q_5	2	25		7			6	1	1	2	35		3	3	15	
q_6	2	89	1			1					2		1	1	2	1
q_7	1	50			20	6		2	3	12	4				1	1
q_8	4	3	2	15		3	48		6		4	1	7	1	1	5
q_9	7	23	3	22			3	8	1	8	7			4	8	6
q_{10}		80		1	7	1			2	4	1			1		3
q_{11}	3	52		5			3		5	1		3	7	4	9	8
q_{12}	8		1		2	77				1	2				5	4
q_{13}	10	2				76					2		1	5	1	3
q_{14}	2	57		6	4	3	4	1	1	7			2	6	7	
q_{15}	18		8		31	2	5		31						5	
q_{16}	1	52	1	12			1	1		24		1		5	1	1
q_{17}	13	7		1	1	59	5	6	1	3	2		1	1		
q_{18}	24		1			38	19	6	1		2		5		3	1
q_{19}		7	44	4	1	3	1	5		7	4			2	10	11
q_{20}	1	1	16	1	8		8	39	2	3		3	9	4	2	
q_{21}		1	7	2	6	33	3	1		1	7	18			5	16
q_{22}	1	5	21	3		3	9		3	9	16	3		10	11	6
q_{23}	2	1			9	12	1		17	3	12	1		3	5	34
q_{24}	2		26	10		6	2	5	5	12	11	8		4	4	4
q_{25}	1			1		1	3	1		79			1	9	2	2
q_{26}	35			1	1	3	1	1	2	31	14			7		4
q_{27}	5			11	6	4		40	14	8	1			7		4
q_0				2		75			9	3	1		8		2	
	m_1	m_2	m_3	m_4	m_5	m_6	m_7	m_8	m_9	m_{10}	m_{11}	m_{12}	m_{13}	m_{14}	m_{15}	m_{16}

at the simple linear regression level in addition to the inference that could be made from the bivariate correlation coefficient.

The functional relationship between each water yield element and the determining factors, and the functional relationship between composite indices summarising aspects of water yield and the attributes of the river basins represent a higher level of integration in the structure of the management model. These can be derived by adopting the method of multiple regression analysis. As a statistical technique, regression analysis is well known and the mathematical basis of its formulation have been extensively discussed in literature. The linear general form of the resulting equation is usually written as:

$$Y = a + b_1 x_1 + b_2 x_2 + \ldots + b_n x_n + e \qquad (6)$$

where a, b_1, b_2 . . . . . etc are constants.

Y is the dependent variable and

x_1, x_2, are the independent variables

e represents the error term

One necessary requirement of the linear regression model is that the independent variables are not highly correlated among themselves. If this is so, a condition known as multicollinearity exists and is supposed to have serious implications for the estimation of regression coefficients and consequently for model specification. It has been accepted that the problem of multicollinearity is not so serious where, as in our case, a predictive rather than an explanatory model is envisaged, provided that the intercorrelation continues unchanged into the future. However, the latter proviso cannot be guaranteed since it is the object of management to induce changes in the independent variables as levers for desirable changes in the dependent variables. It may hence still be necessary to device a means of overcoming the problems that may be posed multicollinearity. Among the two techniques that could be devised are one which adopts the Principal Components technique and another which applies stepwise regression analysis.

By the method of stepwise regression, the desired equation is achieved through a step by step identification of variables which have the strongest link with the dependent variable. This is repeated until an F-test indicates that the variable just added made an insignificant contribution to the predictive or explanatory capacity of the equation. The remaining independent variables are hence disregarded.

The adoption of the Principal Components method creates problems that make the ensuing equations less useful as bases for devising management action programme which must be based on each of the independent variables rather than groups of them. The problem of multicollinearity is solved by Principal Component simply by collapsing the original variables into linear composites, each of which is, for all practical purposes, uncorrelated. But one cannot easily predict which variables will be highly loaded on each principal component and hence not be certain whether such linear composites could be dealt with in the world of practicality.

The result of the regression exercises are the 30 equations given in table 5. In each of these equations, the independent variables are various combinations of m_1 to m_{16} which have been earlier described as the determining factors. In each of the first 27 of the set of equations, the dependent variable is one of the components of water yield. In equation 28, the dependent variable is the summary index of q_1 to q_{14} which are components of yield pertaining to quantity and its distribution over time. The 29th equation has as dependent variable a similar index combining q_{15} to q_{27} which are elements of yield relating to quality. In equation 30, q which is a quantified measure of the concept of yield as a whole is regressed on the determining factors.

TABLE 5

Regression Equations – Table of Constants, Multipliers and Standard Error

$q_1 = 66.18 - 0.772ml - 0.061m_2 + 0.019m_5 + \ldots\ldots\ldots\ldots = 0.776$

Eq		Costant	m_1	m_2	m_3	m_4	m_5	m_6	m_7	m_8	m_9	m_{10}	m_{11}	m_{12}	m_{13}	m_{14}	m_{15}	m_{16}	S. E.
1	q_1	66.18	-0.772	-0.061	+0.063	0.000	+0.019	+677.2	0.000	-0.105	+1.071	-17.59	-0.233	-0.058	-0.318	-0.029	-0.029	0.000	0.776
2	q_2	7314	+15.63	+15.74	0.000	-17.01	0.000	+9113	-1.345	-9.077	+15.63	0.000	+27.14	+19.78	-13.72	-93.22	+0.090	-31.78	97.49
3	q_3	109.3	-0.824	-0.251	0.000	- 0.181	- 0.482	+940.6	-61.88	0.000	-1.033	+0.266	+1.819	+1.199	0.000	+0.672	+0.154	-2.733	6.851
4	q_4	87.46	-0.660	+0.024	+0.126	0.000	+0.052	+746.89	-23.46	-0.133	+1.397	+0.005	0.000	0.000	-0.398	+0.469	- 0.026	-2.733	0.288
5	q_5	80.28	-0.165	-0.061	0.000	-0.331	- 0.303	0.000	1.583	+0.169	-1.722	- 0.581	+1.003	0.000	-0.732	- 0.506	+ 051	-1.374	5.354
6	q_6	275.5	+0.594	+0.361	+0.313	0.000	0.000	+1.370	-91.10	-0.238	-4.854	0.000	+1.359	+0.545	- 805	- 0.66	+0.097	0.000	2.288
7	q_7	1.133	- 2.25	-0.412	- 0.087	0.000	0.811	- 0.284	-16.83	+0.468	+3.526	-1.853	+0.538	0.000	- 0.724	0.000	+0.370	-4.004	5.886
8	q_8	1440	+5.46	+1.49	+3.73	-0.581	0.000	4454	-494.2	0.000	-27.02	0.000	+1.037	+10.62	-1.052	- 6.059	+1.018	-26.18	16.33
9	q_9	13.17	+0.029	+0.003	- 0.05	0.05	0.000	+10.59	1.056	-0.021	-0.153	-0.039	- 0.075	0.000	0.000	- 0.024	- 0.009	0.000	.03137
10	q_{10}	34.87604	-0.26049	-0.08259	0.000	-0.05654	-0	+303.24397	-19.99913	0.000	-0.44592	+0.09023	+0.59790	+0.38408	0.000	+0.21721	+0.04959	-0.877	2.03587
11	q_{11}	67.44	-3.468	-2.892	0.000	+9.427	0.000	-24.257	0.000	+8.065	+19.261	+5.416	0.000	+6.699	+20.371	+54.48	+0.8465	+13.46	40.65
12	q_{12}	-99.53	-0.826	-1.71	-0.49	0.000	-2.26	+6718	0.000	0.000	-10.55	-2.879	+16.02	0.000	-2.615	-2.059	+1.018	-12.52	10.456
13	q_{13}	-27.26	-0.081	-0.129	0.000	0.000	-0.156	+249.1	-4.245	-0.075	-0.693	-0.255	+992	0.000	-0.119	+0.214	+081	-0.876	1.337
14	q_{14}	790.4	+1.131	+1.391	0.000	-1.276	+0.569	2179	138.486	-1.835	-1.835	+0.530	0.000	- 0.706	-1.487	-7.613	- 0.219	0.000	4.007
15	q15	-0.997	-0.041	0.000	-0.008	-0.001	-0.012	-5.713	-0.645	+0.000	+0.109	+0.016	0.000	+0.010	+0.018	- 0.018	- 0.001	+0.018	.023
16	q_{16}	-3.448	-0.004	-0.009	-0.004	-0.000	0.000	-32.657	+0,321	-0.002	+0.008	+0.039	0.000	+0.018	+0.033	-0.004	-0.002	+0.032	.053
17	q_{17}	-3.966	-0.004	-0.009	0.000	+0.006	-0.002	-32.657	+1.622	+0.012	+0.035	-0.012	0.011	+0.000	+0.014	+0.045	+0.002	0.000	.014
18	q_{18}	.498	+0.005	-0.001	+0.003	+0.003	0.000	-2.849	-0.015	+0.002	-0.019	-0.006	+0.004	0.000	-0.008	0.000	0.001	-0.012	.012
19	q_{19}	64.44	0.000	+0.064	-0.079	-0.160	+0.021	+148.9	-5.064	-0.133	0.000	+0.164	- 0.587	0.000	-0.006	0.000	- 0.048	+0.360	.706
20	q_{20}	-3.787	-0.005	-0.003	+0.003	+0.008	+0.008	0.000	+0.697	+0.006	+0.024	- 0.007	0.000	0.000	+0.006	+0.023	+0.001	0.000	.027
21	q_{21}	.283	0.000	+0.009	-0.013	-0.01	+0.006	-25.75	+1.621	-0.002	+0.009	-0.002	-0.090	-0.031	-0.000	0.000	0.006	-0.000	.045
22	q_{22}	11.45	-0.209	+0.067	-0.153	-0.128	0.000	-253.9	+22.68	0.000	+0.841	-0.144	-1.639	-0.276	-0.000	+0.164	-0.56	+0.718	.875
23	q_{23}	-0.759	+0.002	+0.006	-0.000	-0.000	+0.001	-0.224	-0.200	+0.001	-0.052	+0.991	+0.019	0.000	0.000	+0.029	+0.002	+0.001	.057
24	q_{24}	-4.91	-0.02	0.000	-0.016	-0.003	0.000	-69.13	+4.321	+0.015	+0.72	-0.051	-0.197	-0.051	0.000	+0.063	-0.004	+0.086	.088
25	q_{25}	4446	+2.055	+0.794	0.000	-6.216	0.000	+18.640	-965.4	-6.057	-12.49	+7.305	+4.71	0.000	-10.71	-21.41	-0.573	-9.-49	6.189
26	q_{26}	+173.02	+0.768	0.000	+0.029	-0.228	-0.056	+843.4	-54.54	-0.278	-1.543	+0.433	+1.522	0.000	-0.598	-1.172	0.000	-0.496	.434
27	q_{27}	+1595	+3.571	0.000	0.000	-2.006	-0.516	+54.26	-353.1	-1.890	-15.659	+0.294	+4.184	0.000	-5.223	-5.229	+0.008	-5.427	2.476
28	Q_{1-14}	+1018	-1.86	+0.23	+2.280	0.000	0.000	+18366	-716	-2.073	-13	+5.055	+21.3	+5.086	0.000	0.000	0.000	-17.08	25
29	Q_{15-27}	+819	+0.32	0.000	-0.07	-0.94	0.000	0.000	+15.2	-0.001	-0.045	-7.007	-9.004	-6.002	-6.004	-5.003	-0.001	-0.085	35
30	Q	-4191	+2.26	0.000	+1.85	+3.7	0.000	+3467	0.000	0.000	-4.088	+22.42	+41.6	+22.08	+28.26	+20.00	+1.025	-6.005	35
		Constant	m_1	m_2	m_3	m_4	m_5	m_6	m_7	m_8	m	m_{10}	m_{11}	m_{12}	m_{13}	m_{14}	m_{15}	m_{16}	S. E.

THÈ MODEL

The model we are seeking to specify is in fact the 3(equation in Table 5, i.e.

$$
\begin{aligned}
Q_o = & -4191 + 3467M_6 - 4.88M_9 + 1.25M_{15} \\
& + 28.26M_{13} + 3.7M_4 + 41.6M_{11} + 22.43M_{10} \\
& + 2.26M_1 + 22.8M_{12} + 1.85M_3 + 20M_{14} + 1.03M_8 \\
& - 6.5M_{16} \pm 35 \quad \text{-----} (7)
\end{aligned}
$$

where Q_o is the summary index computed by the meth of Factor Analysis as earlier outlined.

The model can however be directly derived from the first 27 equations in Table 5 which can be written in a matrix form:

$$Q_o = BM \text{ ----------------- } (8)$$

where Q_o is a vector of Q_1 to Q_{27}.

$$\text{i.e. } Q_o = \begin{bmatrix} q_1 \\ - \\ - \\ - \\ - \\ q_{27} \end{bmatrix}$$

B is the matrix of the coefficients of M_1 to M_{16} in equations 1-27 (Table 5).

$$\text{i.e. } B = \begin{bmatrix} b_{1,1} b_{1,2} & \cdots\cdots & b_{1,16} \\ b_{2,1} b_{2,2} & \cdots\cdots & b_{2,16} \\ \cdots & \cdots\cdots & \cdots \\ \cdots & \cdots\cdots & \cdots \\ \cdots & \cdots\cdots & \cdots \\ b_{27,1} & \cdots\cdots & b_{27,16} \end{bmatrix}$$

and $m = (m_1, m_2, \ldots\ldots\ldots m_{16})$

OPTIMUM WATER YIELD

Solution by the Method of Simultaneous Equations

Theoretically, the problem of optimum water yield can be tackled by solving equation (8) to provide the values of m_1 to m_{16} at which q (i.e. totality of Water Yield) is optimum. The first step is to find the desired values of each of q_1 to q_{27}. This is done in a variety of ways. For example, because WHO standard for nitrate content of water is 20 ppm, q_{22} which represents the highest nitrate concentration is set at this value. For similar reasons, the highest concentration of phosphorus q_{24} is set at 1 ppm and that for iron q_{19} at p.3 ppm. q_{11}, which gives the number of days without flow in each stream, is set at zero since it is desirable that water flows every day of the year (Table 6).

Next, these carefully selected optimum values are substituted for q_1 to q_{27} in the regression equations in Table 5 to give a set of simultaneous equations. The solution to these equations gives the required values of m_1 to m_{16} for equation (8) at which Q is optimised.

For a solution to be easily achieved, the number of equations must be equal to the number of unknown variables.

TABLE 6

Desired Values of the Components of Water Yield

q_1	= 15 literes/sec.	q_{15}	= 0.01
q_2	= 600 "	q_{16}	= 1.5
q_3	= 50 "	q_{17}	= 2.3
q_4	= 15 "	q_{18}	= -0.20
q_5	= 25 "	q_{19}	= 0.3 (Fe^{+++}) parts per mill.
	= 45 "	q_{20}	= 0.0 " " " "
q_{17}	= 200 "	q_{21}	= 0.1 " " " "
q_8	= 400 "	q_{22}	= 2.0 (NO_3^-) " " "
q_9	= 0.28 "	q_{23}	= 0.0 " " " "
q_{10}	= 15 (100m litres)	q_{24}	= 1.0 " " " "
q_{11}	= 0 days	q_{25}	= 1 (PO_4^-) " "
q_{12}	= 700 mm	q_{26}	= 0 " " " "
q_{13}	= 50 %	q_{27}	= 0 " " " "
q_{14}	= 100 days		

Where, as it is the case here, the number of equations is more than the number of unknown elements the system is said to be over-determined and certain problems arise which could overcome by adopting a method of least squares solution. The method, by ensuring that none of the equations is redundant in the solution exercise minimises variance and hence provides the best estimates of the independent variables.

Notwithstanding the elegance of the foregoing solution, its usefulness in the world of practicality is not always ensured. In reality, the values given to the determining factors vary between certain limits. For example, most, if not all, of these values are positive. Those given in percentages must not exceed 100 while relief ratio usually lies between zero and unity. A straightforward mathematical solution in the particular case of Upper Owena Drainage Basin gives such unrealistic values as - 34 (number of rainfall days); -260 percent urban land and 121 percent of area covered by fine-grained Gneisses and Schists.

SOLUTION BY COMPARING THE YIELD OF EACH STREAM WITH THE OPTIMUM

Adopting the carefully selected values and using the method of Factor Analysis earlier outlined, that is equation (1), one can derive Q for the hypothetical stream basin with optimum water yield. With the data collected in the field, (q values) one can compute corresponding values for each stream basin. Table 7 gives the optimal measure of Q (Yield) as 679 in the second column. The rest of the column indicates the values of Q for each of the 15 streams' basins. With a Q of 683, the yield of Opapa stream basin is nearest to that of the hypothetical basin with optimum yield. A practical method for solving equations (7) and (8) is hence to adopt the 'm' values of Opapa stream basin which are given in Table 8.

As a check on column 2 (Table 7) computed by using the method of Factor Analysis and the 'q' values of the various streams, column 3 provides values of Q for the various streams by substituting for m in the equation (7). It could be observed that the differences are in every case much less than the standard error which is 35.

Column 4 in Table 7 provides a similar opportunity for comparison based on quantity while column 5 highlights the quality measures. From these, it could be observed that with regards to the amount of water produced and its seasonal distribution, the optimum index is 811. Opapa is again nearest the optimum in this aspect while Okorokoro is again the farthest away. With regard to quality aspects, the best stream is Erinta (Ikogosi), while the most polluted is Ofi

TABLE 7

Stream Yield Compared with Optimum Values

Streams			Q_{1-14}	Q_{15-27}
Hypothetical stream with Optimum Yield	679	-	811	4.3
Okun	370	386	475	15.5
Opapa	684	692	798	22.1
Alura	-84	-73	242	19.5
Olotun	-118	-110	-90	14.5
Eti-Okun	-120	-108	-77	22.9
Ooo	114	118	287	28.8
Erinta	-52	-30	40	9.5
Mogbado	-9	-11	-54	16.1
Erin	51	64	156	32.8
Arosa	-118	-108	-99	21.2
Anini	-3	1	50	34.0
Okorokoro	- 180	-174	-184	44.6
Ofi	-107	-93	-12	63.2
Apon	-111	-99	40	15.6
Orunro	-134	-128	5	50.3

(Ilawe). Such measures as these are useful in selecting streams for water development projects. They also help to identify the ideal combinations of nature and human inputs that result in the optimum yield of water.

MANAGEMENT

The combination of drainage basin characteristics produced by solving the simultaneous equations include elements that cannot be manipulated through any management procedure and therefore such knowledge derived

TABLE 8

Value of the Determining Factors Necessary for Optimum Water Yield

	Q and Q_{1-14} Opapa Stream	Q_{15-27} Erinta
m_1	1%	1%
m_2	77%	77%
m_3	1%	20%
m_4	1%	1%
m_5	20%	1%
m_6	0.137	0.046
m_7	2.63	1.35
m_8	274	274
m_9	2.0	10.56
m_{10}	4%	4%
m_{11}	14%	15%
m_{12}	37%	58%
m_{13}	44%	22%
m_{14}	1%	1%
m_{15}	1719 mm	1438
m_{16}	123 days	115 days

could not be used as levers for bringing about desirable changes in water yield. For example, nothing could be done to change climatic inputs of rainfall and energy, nor could much be done to relief and geology. The reasonable management procedure in tackling this problem is to give realistic values to these parameters before solving for the other unknown but modifiable elements in the simultaneous equations. In an area where absolute relief range between 25 m and 30 m, values in this range may be substituted for m9. Another method is to eliminate such un-modifiable determinants from the regression equations and thus deal strictly with variances that the manageable determinants are responsible for. Ultimately, one is left with a set of values determined for previously unknown variables in the simultaneous equations. These could form the bases of such management procedures that demand changes in human action for the purpose of optimising water yield.

The fact that a particular drainage basin characteristic m2 – cannot be modified by human action does not imply that considerations for it should be left out of the optimisation procedure. If, for example, in a district, it is realised that the best quality water and discharge pattern is associated with certain relief ratios or surface geological types, this may be the rationale for setting areas with such characteristics apart for protection as water reserves. Conversely, if it is realised that below a given intensity of agricultural activity, tolerably good water could still be produced, then areas with higher intensities could be left out while searching for sources of surface water. Similar considerations could be given to types and intensities of industrial production.

CONSEQUENCES OF LACK OF MANAGEMENT PROGRAMMES FOR RIVER BASINS

It is realised that some, if not most, of the water supply schemes in the country have failed to meet the needs of the communities for which they were designed, not because the feasibility studies leading to their design were inadequate, nor because the engineering structures installed to tap the water have become defective, but chiefy because the catchment areas of the drainage basins feeding the reservoirs or the points at which the water is being tapped have not been managed with a consideration for optimum water productivity.

Because of the absence of a programme of drainage basin management, man alters the character of the soil and the land surface through uncontrolled deforestation and destructive

methods of cultivation. As a result, infiltration, capacity of the surface is adversely affected leading to depressed dry season flows and seasonal shortages of water as well as increased peak discharges during the rainy season with their associated destructive floods. It has been established in our area of study that certain streams which were in existence some thirty years ago have now ceased to flow. Also previously seasonal streams have become ephemeral and perennial ones have become seasonal. It should be noted that these changes cannot be explained only by changes in climatic or meteorological input.

Also because due attention has not been accorded river basin management, large amounts of silt and of coarse materials from farmlands have accumulated on the beds of reservoirs to reduce their water holding capacity. These, together with large quantities of dissolved plant nutrients enrich water stored in reservoirs, thus encouraging a profuse growth of aquatic weeds. The latter contribute in no small way to accelerated eutrophication of the reservoir hollows and reduce considerably the quality of the water produced. Uncontrolled growth of weeds also tends to increase considerably the rate of evapotranspiration during the dry season and thereby increase the hazards of water shortage especially whenever the dry season is prolonged.

The main message which this lecture is designed to carry is that in the development of our river basins, an option must be made early for a conservatory rather than an exploitative approach. A strictly exploitative development would lead to an abuse of the river basin with the consequent deterioration of the quality and the quantity of the resources it contains

EXAMPLES OF ABUSED WATERSHEDS

Early in 1977, a number of observations were made relating to the basin of River Opa which is being dammed for the purpose of providing the University community with pipe-borne water. It was established through the analysis of data collected in the river basin that:

i. nearly half of the town of Ile-Ife will be drained into the proposed reservoir.

ii. in the parts of the town drained into the River Opa, little is done to effectively dispose of human and domestic wastes.

iii. part of the Research and Teaching Farm of the University lies within the catchment area of the proposed lake. The greater part of the drainage basin is used for traditional agricultural practice in which cocoa, cassava, maize and yams are the main crops.

iv. preliminary analysis shows a rather heavy load of suspended particulate matter which renders the water reddish brown in colour especially after a heavy downpour of rain.

v. large quantities of orgonochlorine insecticides, copper fungicides and fertilizers are being applied in both the traditional agricultural areas and on the research farm. Smaller amounts of herbicides are being tested on the research farm.

Following these observations, I indicated some environmental hazards which need to be noted and some necessary basin management action that need to be taken in their anticipation and to forestall their undersirable consequences. The hazards include:

i. toxicity of water resulting from increasing concentration of chemical residues.

ii. concentration of such residues along the ecological food chain to make aquatic products such as fish to be unfit for human consumption.

iii. enrichment of water with organic wastes leading to reduced oxygen content and the inability of the lake to support desirable aquatic life.

iv. lack of treatment of sewage and other organic wastes mean the introduction of micro-organisms some of which are likely to be human pathogens which conventional methods of water treatement may not be able to remove completely.

v. enrichment of the water with nitrogen and phosphorus nutrients form. both domestic and agricultural sources may encourage profuse growth of weeds.

vi. accelerated entrophication as a result of a high rate of sediment yield and encorachment on the bed by a profuse growth of weeds.

Some of the suggestions for drainage basin management based on the above and which are now being adopted include the following:

i. Introduction of bye-laws (by the local government to discourage building on the flood plains of the streams draining the town into the Opa River.

ii. Acquisition of such flood plains for the purpose of controlling their use.

iii. Design and construction of smaller filter dams stream.

iv. Scrapping of the bed of the reservoir of top soil, removal of all plant residues and the deepening of all parts, especially the edges that are likely to be shallower than two metres as preparations for impoundment.

v. Laying-out of the University Research Farm in such a way that the part being drained into the Opa system is not used for (a) field cropping and (b) intensive stock rearing. Such areas could be developed strictly to tree cropping.

vi. Banning the use of insecticides or herbicides with mercury (or other heavy metal) bases on the research farm.

vii. Leaving the areas adjacent to the lake and its feeder streams under a thick cover of natural or planted vegetation.

One learns, however, with helpless regret that the engineers whose primary responsibility it is to provide water disdain or at their best wear an expression of cultured amusement at any suggestion that the drainage basins which feed their engineering gadgets with water need to be managed. They do not see in their catalogue of failures the need to listen to opinions from a non-engineering sector of the knowledgeable community. Invariably the problems of a water scheme do not become manifest until some five to ten years after the project has been completed. This is long after the consultants and the contractors have collected their fees. The public and the government would then be left to grope with the problems of water shortage. In stating the negative consequences of contemporary human action or inaction, the environmentalist is infact asking that efforts should be directed at proving him wrong.

However, with regard to at least one of the hazards mentioned earlier in relation to the Opa Water Supply Scheme, the negative consequences are already with us. There are evidences that weeds have started to encroach on the lake even before a litre of water has been pumped from it. *Pistia stratiotes* and *Nymphaea lotus* are already spreading as the water becomes relatively stagnant. With the cessation of streamflow into the lake at the onset of the dry season, one should expect a similar invasion by species of *Lemma.* Given the nature of its drainage basin as described earlier, the weed problem of the Opa reservoir is likely to be worse than that of the Oba reservoir in our sister University at Ibadan which is now being chocked by an ever spreading mat of *Pistia stratiotes.*

The losses of life and property due to the annual flooding of the Ogunpa and other streams in Ibadan are matters of general knowledge. The first devastating floods of these

streams were recorded in 1960. In 1963, there was another series of floods which caused a break in the dam of Eleyele Water Works, swept away the Odo Ona bridge at Moor Plantation and caused considerable loss to property in the commercial centre of the city. During the April 1978 floods, hundreds of houses were destroyed, more than 150 people died and property worth more than one million naira was carried away. While the magnitude of each flood is directly determined by the immediate weather conditions, it should be realised that all areas near stream courses in the city are pre-disposed to devasting floods as a result of the abuse already suffered by the various stream basins. The removal of vegetal cover and its replacement by concrete and other hardened surfaces are the most important factors in this regard. These lead to greatly reduced infiltration capacity of the surface, increased run off and a quickened arrival of rain water falling on the various parts of the basins at the various stream channels. Other factors that make the streams pre-disposed to devastating floods include the hilly terrain of the basins with their large areas of steep slopes, the erection of buildings on the natural flood plains and the general practice of using the streams as the chief mode of the waste disposal.

Knowledgeable people look on with helplessness as more attrocities of stream basin abuses are committed by the same government that is supposed to be much concerned with the problems of floods. The proneness of these streams to flooding were already well-known before the decision was taken to clear the Mokola Hills of planted forests so as to provide the land for the erection of the Premier Hotel and the Cultural Centre both of which have contributed to the flood problems of Ibadan.

The low level of water in the Kainji Lake, which is the main cause of shortage of electricity during the past twelve months is usually ascribed to low rainfall in the catchment area of the lake. It is however not generally realised that droughts with the magnitude of those recently experienced in West Africa had been experienced during several periods in the present century. Since records have been kept, a number of 'drought years' have been identified in the Sahel of West Africa, namely, 1910-1913, 1940/41 and 1947/1948 (Stranz, 1978). It is assumed that these have been taken into account in the design of the Kainji. The only explanation one can give in respect of the present predicament of the NEPA is that the consequences of droughts have become aggravated by an increasing rate of abuse of the various river basins feeding the lake.

One is happy to note that in the instruments establishing them, the various river development authorities (Fig. 4) in the country have been empowered to exercise the following functions:

i. undertake water management schemes of flood and erosion control and

ii. control pollution in rivers and lakes in the authorities' areas in accordance with nationally laid down standards.

However, from the activities of the river basin authorities known to me, only the Niger Delta Basin Authority has embarked upon a programme of basin management directed at pollution control. It would be an unhelpful philosophical exercise to contend or dispute that the case of the Niger Delta would not have been different if the exploitation of its vast resources of petroleum has not been accompanied by 'visible' pollution of air, water and soil as well as considerable damage to vegetal and animal life. In short, the commissioned study of pollution in the Delta is not designed to forestall undersirable consequences but to solve a set of problems that have manifested themselves.

In most of the other basins nothing tangible is being done to prepare a basin management programme. All the activities

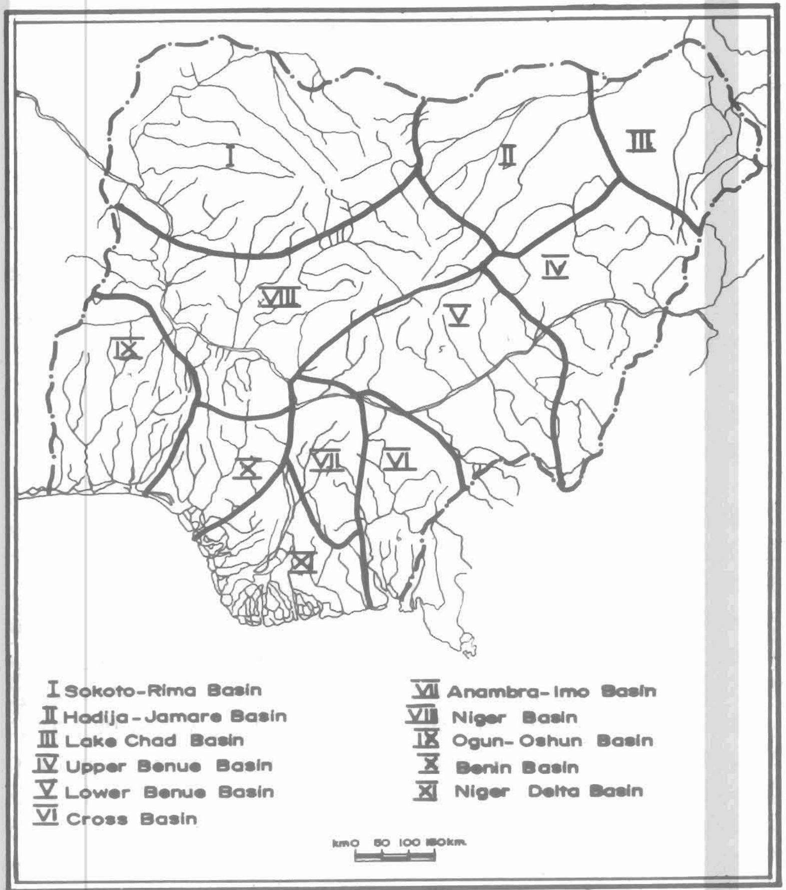


Fig.4. River Basin Development Authorities areas in Nigeria.

of the various consultant firms employed seem to be directed at exploitative rather than at conservatory development. Efforts are directed chiefly at the other statutory functions which are to:

i. undertake comprehensive development of ground water resources for multipurpose use;
ii. construct and maintain dams, dykes, wells or bore holes, irrigation and drainage systems;
iii. develop irrigation schemes for the production of crops and livestock;
iv. resettle persons affected by the works of the schemes specified in ii and iii above.

Our main concern here is that in fulfilling these desirable objectives, the water resources of each basin are not quantitatively depleted and not qualitatively degraded. It is expected that adequate precaustions would be taken so that future generations of Nigerians do not suffer from inadequacy of water because of contemporary action or inaction.

CONCLUSION

In concluding this lecture, I am inviting Mr. Vice-Chancellor and the audience, definitely without the authority of the vast majority of eminent geographers, to consider geography, in essence, as an empirical methodology and not as an empirical science in itself. I hope that by this, I would be providing the only way of resolving the deep rooted enigma of having to identify the philosophical boundaries for the subject in the context of contemporary taxonomy of university disciplines.

The fundamental question which generates this distinctive empirical methodology has been asked by Bunge: "Why are spatial distributions structured the way they are?" Schaefer (1953) in an article "Exceptionalism in Geography: A Methodological Approach" has gone as far as to assert that

"geography must pay attention to the spatial arrangement of phenomena in an area and not to the phenomena themselves – spatial relations are the ones that matter in geography and non other". Berry (1964) also states that "the geographical point of view is spatial: the integrating concepts and processes of the geographer relate to spatial arrangement and spatial distribution, to spatial integration, to spatial interaction and organization and to spatial processes".

All these lead to the conceptualization of geography as spatial analysis'. One would be hard put to the task of giving recognition to spatial analysis *per se* as an end in itself or as an empirical science. However, its singular justification as a field of study is that it offers itself as a useful instrument in a wide spectrum of fields in the scientist's attempts to explore, to describe, to explain and to predict occurrences in the world we live in, that is in fulfilling the objectives of the empircal sciences.

If the integrating concepts and processes of the geographer relate to spatial arrangements, the question arises as to what is being arranged and on what type of space. It should be noted that the model earlier presented is based on differences between fifteen stream basins, fifteen specific segments of the earth's surface. The geographical space is the earth's surface whose attributes, usually referred to as elements of geography include plants and animals, soil and water, farmland and cities. These, the geographer perceives in their locational, distributional and areal dimensions. The observations made on them are analysed, and used as the bases for explanation and prediction. The fact that these attributes form the objects of study of the empirical sciences explains the usually intriguing intersection of geography with these other disciplines.

Because spatial organization cannot be considered in isolation form these attributes of the earth's surface, the geographer traditionally treads on grounds which some people in their own professional wisdom regard as their personal preserves. What I would request such people to do more often is to ask themselves (1) whether the problems which the geographer is attempting to solve are relevant to the understanding of the world we live in, (2) whether the geographer's methodology is scientifically valid and (3) whether there are existing more efficient approaches to the solution of these same problems.

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