Development of Base Flow Indices for Rivers of Western Ghats, India

By

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ABSTRACT : In the present study is an attempt has been made to relate the baseflow index with non-dimensional topographic parameters derived for 13 catchments in Western Ghat regions of Karnataka state, with areas ranging from 5 km^2 to 600 km^2. The result shows that, the catchmnet size has no effect on baseflow index. However, the regional regression model indicates that, the total stream length, length of main stream and slope index dominates the relationship with baseflow index.

Key word : Baseflow Index; Baseflow Separation; Drainage Index; Slope Index; Regional Regression model

1.0 Introduction

Baseflow is an important genetic component of a streamflow hydrograph, which comes from groundwater and/or shallow subsurface storage. Baseflow may be characterized by its hydrogrpah, which is derived from the total streamflow hydrograph by various baseflow separation techniques. A variety of event-based separation methods are available, which focus on separating baseflow from a flood hydrograph and are eventually aimed at the estimation of surface runoff component of a flood.

There are various types of baseflow separation techniques to generate a baseflow hydrograph for a long-term period of stream flow observations. These techniques normally make use of a filtering procedure of some kind, which allows stream flow time series to be disintegrated into quickflow and baseflow. Perhaps, the most well known techniques of this type are the UK "smoothed minima" method [1] and "recursive digital filter" [2] although other methods to separate baseflow on a continuous basis [3]. Continuous baseflow separation techniques do not normally attempt to simulate baseflow conditions for a particular flood event, nor are they always appropriate for the identification of the origin of baseflow. These methods are rather aimed at the derivation of objective quantitative indices related to the long-term baseflow response of a catchment such as baseflow index (BFI – the ratio of baseflow to total streamflow), which specifically characterised baseflow regime.

Base flow index (BFI) measures the proportion of the long-term river flow that derives from stored sources. This concept was developed by the Institute of Hydrology [4] to describe the effect of geology on low flows. BFI is sometimes referred as "reliability index". It is a non-dimensional ratio which is defined as the volume of base flow divided by the volume of total streamflow (or alternatively, as the ratio between the average discharge under the separated base flow hydrograph and the average discharge of the total hydrograph). BFI may be estimated for every year of record or for the entire observation period [5]. In catchments with high (highly permeable chalk catchments) groundwater contribution to streamflow, BFI may be close to 1, but it is equal to zero for ephemeral streams (relatively impermeable clay catchments). BFI was found to be a good indicator of the effects of geology on low-flows and for that reason it is widely being used in many regional low-flow studies.

Baseflow is a function of a large number of variables that include topographic, geological, soil, vegetational and climatic factors. There have been several studies done elsewhere by relating the BFI with the topographic parameters. The influence of a number of geomorphic parameters on groundwater discharge was examined for Appalachian watersheds. It is found that, groundwater discharge is influenced by drainage density and by average basin slope [6]. In the other study, a conceptual watershed model was formulated to estimate low flow statistics for 23 catchments in Massachusetts. The study reports that, catchment relief and average basin slope had effects on the low flow statistics [7]. A regression analysis for baseflow index in terms of number topographic properties for 164 catchments in Victoria State, Australia. The study found that, topographic variables such as, catchment area, elevation of catchment centroid and length of main stream are significant in defining the baseflow index [8].

In the present study, an attempt has been made to estimate the baseflow index for 13 streams originating from Western Ghats of Karnataka with the catchment area varying 5 km^2 to 600 km^2. The daily mean flow for 10 years was collected from Water Resource Development Organisation, Karnataka Irrigation Department. The algorithm detailed by Gustard et al., 1992 has been used to separate the baseflow from mean daily flows. Also, a regional regression model will be developed relating the non-dimensional topographic parameters such as slope index and drainage index with baseflow index.

2.0 Study area

The Western Ghats locally called as ‘ Sahyadri Ranges’ from an unbroken relief dominating the West Coast of the Indian Peninsula, for almost 600 Km, extending between north latitudes of 8^o and 21^o (Figure.1.). The area selected for the study lies between north latitudes 11^o 30’ and 16^o along the Western Ghats. The Western Ghat range forms a barrier to the monsoon winds originating in the Indian Ocean and moving northeast. Hence rainfall in the region is very heavy during the southwest monsoon, which last between June and October. Annual rainfall exceeds 6000 mm all along the escarpments, with the wettest areas in the region recording about 7800 mm. Rainfall magnitude decreases steadily towards east, to a minimum of 1200 mm in areas bordering the Ghats. More than 90% of the annual rainfall occurs during the four monsoon months with an average number of 120-140 rainy days per year.

Geologically, the study area consists exclusively of Precambrian formations with gneiss and intrusive granites forming the important rock types. The combination of such old rocks and heavy but low intensity rainfall has resulted in a well-developed soil mantle characterisng most of the slopes of the Western Ghats. Soil thickness in the region varies between about 3 m on grassed slopes and about 20 m on well-vegetated slopes. Soils in the surface layer are usually sandy loam, characterised by very high infiltration rates. Forest vegetation in the Western Ghats can be classified into three types: 1. Thick evergreen to semi-evergreen forest occupying vast stretches of the steep Appalachian slopes; 2. The evergreen montane forests confined to the valleys and locally called shola; and 3. pastures, covering extensive areas on the rounded crests of the escarpment of the Ghats.

2.1 Base flow separation method

The present study uses a procedure suggested in low flow studies report (Gustard et al., 1992) to estimate the Base Flow Index using the mean daily discharge. A computer program is applied to smooth and to separate the observed flow hydrogrpah from which the index in calculated as the ratio of the flow under the separated hydrograph to the flow under the total hydrograph. The procedure for calculating the BFI is as follows

1. Divide the mean daily flow data into non-overlapping blocks of five days and calculate the minimum for each of the block and they may be called as Q1, Q2, Q3,…….Qn
2. Consider in turn (Q1,Q2,Q3), (Q2,Q3,Q4), (Qi-1, Qi, Qi+1) etc. In each case if 0.9 times central value is less than other values, then the central value is an ordinate for the base flow line. This procedure is continued till all the data are analysed to provide a derived set of base flow ordinates QB1, QB2, QB3,……. QBn which will have different time periods between them.
3. By linear interpolation between each Qbi values as found above, daily value of QB1 to QBn are estimated
4. If QBi is greater than Qi then QBi is made equal to Qi
5. The volume beneath the base flow line thus separated VB is calculated between the first and last points QB1 to QBn.
6. The volume beneath the recorded mean daily flow Qi and Qn is calculated as VA for the period QB1 to QBn.
7. The base flow index is derived as the ratio of VB and VA

3.0 Analysis of data and Results

Low flow regime of a river can be analysed in a variety of ways dependent on the type of data initially available and the type of output information required. Consequently there exist a variety of low-flow measures and indices. The flow duration curve is one of the most informative methods of displaying the complete range of river discharges from low flows to flood events. It is a relationship between any given discharge value and the percentage of time that discharge is equaled or exceeded, or in other words the relationship between magnitude and frequency of streamflow discharges.

3.1 Base flow separation

The algorithm described earlier has been applied to separate the base flow from the time series of daily mean flow for many gauging stations of west flowing and east flowing river of Karnataka. The algorithm was applied year wise for a period of about 10 years. The base flow index obtained for different years at each of the gauging station are tabulated in the Table.1.

As per the algorithm used to separate the baseflow, the baseflow volume mainly depends on the observed mean daily flows. To understand this relationship, a scatter diagram were plotted for the observed daily flow and separated base flow for all the stations. This relationship was developed with an intention to find the base flow directly from the observed daily discharge at individual sites. To judge the significance of the fitted lines, t-test was performed to check the mean value of the observed and estimated baseflow. From the results, it is, noticed that, the fitted lines are significant at 50% level of significant for most of the sites considered for the analysis.

3.2 Derivation of catchment properties

The catchment properties such as Total Stream length, Length of the main stream. Relief of the catchment, which required for the study was derived from the survey of India, maps at a scale of 1:50,000. The Derived catchment properties are tabulated in the Table.2.

3.3 Identification of homogenous regions

The regionalisation of streamflow characteristics in general is based on the premise that catchments with similar climate, geology, topography, vegetation and soils would normally have similar streamflow responses. The delineation of regions may be accomplished using convenient boundaries based on geographic, administrative or physiographic considerations. The regions that result using such an approach may not always appear to be 'sufficiently' homogeneous. However, this pragmatic approach may appear to be suitable in conditions of limited data availability. Geographically contiguous regions are classified on the basis of residuals from a regional regression model developed to estimate flow characteristics of ungauged catchments. These regions are then delineated by grouping catchments with residuals of a similar sign and magnitude.

Several authors have delineated regions for some specific purpose, which are 'homogeneous' in more general hydrological terms. Huges and James delineated regions in Australia on the basis of general flow and low flow characteristics [9], Midgley et al[10], established 80 hydrological zones in South Africa for the prediction of deficient flow duration frequency and storage-yield characteristics. Grouping of catchment is often performed by means of multivariate statistical analyses. There are several different approaches to hydrological regionalisation, which were variably based on a combination of cluster analysis, multiple regression, principal component analysis and the graphical representation of multi-dimensional data and did not assume the geographical contiguity of resultant homogeneous catchment group. However, in present study, a cluster analysis was applied to the selected parameters such as catchment area, catchment relief, total stream length, slope index and drainage index, to identify the homogeneous groups in the study area. The result obtained from the test with a Dendrogram is given in Figure.3. It can be seen from the Figure.3, the estimated Euclidean Distance between the groups is different. However, with in each group, the Euclidean distance computed between the stations is very small and therefore closely related each other.

From the dendrogram, it found that, there are three groups formed out of 13 stations. The first group contains the stations namely, Amchi, Sagar, Harle Estate, Barchi, Kudumane, Soraba and Donkanala, the second group is, Dasanakatte, Melleshwara and Kalmane, and the third group is Khanapur, Kokkarne and Dusginala. From these groups, it can be noticed that, the station which are having catchment area less then 100 km^2 are formed a group and the streams having a cathcment area more than 100 km^2 and less than 200 km^2 are in one group and more than 200 km^2 are in the third group. Also, other fact is that, the major portion of the catchment area of the first group streams are covered by forest (dry deciduous) and or west flowing rivers having an average rainfall of > 2500 mm in a year. The three stations in second group are east flowing rivers having an average rainfall of about 1500-2000 mm. The landuse of these catchments are in dynamic condition, i.e., these catchments are subjected to constant anthropogenic activities, i.e., the forested area is being converted to the agriculture or for the human settlement. These anthropogenic activities have a great impact on the flow conditions. The research carried out elsewhere, indicated that, there is an appreciable change in the flow condition due to human activities in the catchment and may be true in this case also [11]. However, the impact due to anthropogenic activity could not be attempted, due to the lack of the data on land-use, and other soil-hydraulic parameters.

3.4 Effect of catchment properties on the base flow index

3.4.1 Scaling effect (Catchment area)

It is important to examine if there is a scale effect with catchment size, i.e, if catchment area has an influence on the base flow behavior. The catchment area varies from 5 km^2 to 600 km^2. The plot of the base flow index and catchment area is shown in Figure.4. From the Figure.4, it is noticed that, the base flow index is poorly correlated with the catchment area. This gives an indication that, the size of the catchment does not have any influence on the base flow index. However, some points have formed a group (specially the catchment area ranging from 50 km^2 to 150 km^2). The same dominant processes evidently govern the base flow behavior of all these catchments. This aspect is quite evident from the cluster analysis also. However, for the catchments with area greater than 100 km^2, falls out side the range of the smaller catchments. The studies carried out in Australia have reported that, the large catchments have lower baseflow index[12]. Whereas in the present study, even the streams having the lower catchment area have lower baseflow index. It is not clear if this is a scale effect or if it is the consequence of variability in the transmissivity of the rocks. Two adjacent catchments namely Harle estate and Kudumane having an area of 26 km^2 and 5 km^2 have different baseflow index values, 0.529 and 0.560, respectively, indicating no effect of catchment area on baselfow index. However, the larger catchment basins have lower baseflow index compare to the basins having lower catchment area.

3.4.2 Effect of topographic parameters on baseflow Index

Baseflow index has been plotted against the dimensionless topographic parameters: drainage index ($L/\sqrt{A}$) and slope index ($H/\sqrt{A}$). This is done combining all the catchments considered for the study (Figure 5, Figure.6, and Figure.7.).

From the plots (Figure.5, Figure.6. to Figure 7), no trend is detected between drainage index with the baseflow index and is the same with slope index and baseflow index. However, it can be noticed that, there is a group formed by the slope index with the baseflow index. The stations which are within this group are Dusginala, Donkanala, Sorab, Mavinahole, Khanapur, Sagar, and Kalmane river. The rivers, except Dusginala and Donkanala, all other streams are east flowing river and originate in the foothills of Western Ghats. The major portions in these catchments are covered by forest. These streams have very gentle slope (Table.2.) with less number of streams. These two factor greatly influence the BFI of these streams, which varies between 0.2% to 0.45 %. This gives an idea about the possible contribution from the delayed flow and the ground water resources. However, the analysis of stream–aquifer interaction to estimate the outflow from groundwater resources is beyond the scope of this paper.

3.5 Regional regression model relating base flow index and catchment properties

In the present study, the non-dimensional topographic parameter such as slope index, drainage indexes are being used to establish a relationship with the BFI. The established regional regression equation is given below,

$$BFI = 0.392-0.001*CA+0.001*TSL+0.004*MSL$$

The best fitted equation has R^2 as 0.914. This procedure needs to be tested for a wide range of data from catchments by relating with geology, soil type and vegetation. Many researchers have found that, the

BFI is mainly depends on the geology of the catchment and to some extent on climate(Lacey & Grayson 1998). In the study area, most of the catchment are cover by the Precambrian gneiss underlined by granite, therefore, geology is not considered as a dominant factor even though it has been observed widely, the baseflow mainly depends on geology of the area.

4.0 Discussion

The presence of the baseflow in the selected streams were identified through the flow duration curves, it can be seen from the graphs (Figure.2), the slope of the hydrograph in the non-rainy season is very flat. This slope indicates the presence of the baseflow. Once it is identified, the baseflow was separated using the method described earlier. The yearly baseflow indexes for the selected streams are given in the Table.1. From the Table.1., it is seen that , no appreciable variation in yearly BFI values were observed for selected streams. This could be because of two reasons, firstly, the variation in the rainfall and secondly due to the land-use and land cover changes. Few studies carried out earlier on the land-use and land cover changes in Khanapur and Barchi catchment reported that, forested areas are being converted to agricultural area [13]. The impact of land cover changes on BFI values are not seen in the results. Also, the fact to be mentioned is that, the groundwater developments in these catchments are very less. This may be one of the reasons, why BFI values are not being effect by the changes in land-use and land cover. However, due to the lack of the data on rainfall and land use, the effect could not be studied in the present study.

The regionalisation of for the hydrological region was done using cluster analysis. The Figure.3. Shows that, the streams having less than 200 km^2 are interlinked each other. The dominant factor considered for the classification of the groups is catchment area. The other factors, such as slope index, drainage index and main stream length have no significance. However, the results of proximity index obtained by the cluster analysis indicate that, each of the streams with the groups is closely linked and have low Euclidean distance between them. This however, confirms the homogeneity of the region. Accordingly, two homogeneous regions are identified and are utilised for the analysis.

The regional regression equation shows that, the negative effect of catchment area on base flow index, this is quite evident from the graph (Figure.4.), where in a relation was established between catchment area with baseflow index. However, it is noted that, the total stream length (stream length of all order in the catchment) and slope index have positive effect on baseflow index. This is quite true, also, due to the higher stream network, the water molecule in the catchment is carried to the outlet of the basin including the contribution from ground water resources. Simultaneously, slope has an important role play by driving the water molecule to join the stream network. It is noted that, the higher the slope index, higher the base flow index (Figure. 5 to Figure.7). However, the drainage index has no impact on the baseflow index. Whereas, some of the previous studies have reported the influence of drainage density on low flow behavior. Also, it is observed that, the catchment relief has effect on the baseflow index[7]. The main stream length, which acts as a collector of the water from different order of streams, has positive impact on the BFI values.

5.0 CONCLUSIONS

In the present study, 13 river basins, which originate from Western Ghats, were considered for the analysis with the catchment areas ranging from 5 km^2 to 600 km^2. In this study an attempt has been made to evaluate the effect of topographic parameters on baseflow index. Following are some of the conclusions drawn from the study.

a. There appears to be no effect of catchment size on the baseflow index
b. The topographic parameters like, slope index and catchment relief have shown the influence on the base flow index.
c. Cluster analysis indicates the possible 3 homogeneous regions within the 13 river basin depending on behavior of the annual baseflow index.

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Table. 1. Base flow index for different gauging station considered for the analysis

Name of the watershed	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	Mean
Amchi	0.296	0.274	0.128	0.382	0.249	0.364	0.304	0.296	0.414	0.279	0.299
Dasanakkatte	0.470	0.332	0.502	0.388	0.510	0.540	0.480	0.510	0.523	0.513	0.477
Harley Estate	0.720	0.385	0.566	0.515	0.496	0.521	0.465	0.423	0.664	0.559	0.529
Kalmane	0.475	0.298	0.330	0.409	0.421	0.286	0.421	0.405	0.345	0.308	0.370
Kokkarne	0.298	0.280	0.335	0.426	0.456	0.479	0.408	0.330	0376	0.470	0.386
Kudumane	0.599	0.418	0.511	0.635	0.652	0.701	0.459	0.570	0.560	0.496	0.560
Malleshwara	0.367	0.250	0.272	0.340	0.314	0.365	0.333	0.152	0.376	0.494	0.3267
Sagar	0.431	0.240	0.564	0.389	0.587	0.413	0.573	0.427	0.402	0.529	0.4559
Barchi	0.31	0.326	0.30	0.28	0.276	0.267	0.264	0.198	0.189	0.229	0.2598
Khanapur	0.19	0.222	0.302	0.424	0.294	0.440	0.557	0.362	0.361	0.334	0.338
Sorab	0.202	0.162	0.141	0.251	0.172	0.383	0.480	0.309	0.265	0.392	0.2757
Dusginal	0.448	0.273	0.142	0.239	0.128	0.219	0.142	0.246	0.188	0.250	0.2275
Donkanala	0.322	0.303	0.313	0.239	0.227	0.325	0.055	0.215	0.298	0.306	0.2603

Table. 2. Catchment properties of the selected watersheds

Name of catchment	Catchment area	Total Stream length	Main Stream Length	Catchment Relief	Drainage Index	Slope Index
Amchi	87	67.7	13.4	114	7.26	12.22
Dasanakkatte	135	25.0	39.58	812	26.69	69.89
Harley Estate	26	54.65	9.85	389	10.72	76.92
Kalmane	266	393.3	40.6	320	24.11	19.62
Kokkarne	343	854.91	69.26	1092	46.16	58.96
Kudumane	5	13.55	13.4	337	6.06	150.71
Malleshwara	108	320.35	16.2	1670	30.83	160.70
Sagar	75	53.6	11.95	63.5	6.19	7.33
Barchi	15	45.56	11.08	370	11.76	95.33
Khanapur	540	1186.07	48.392	1872	51.04	7.83
Sorab	119	46.05	20.75	262.6	4.22	24.07
Dusginal	503	949.42	30.20	244	42.33	10.88
Donkanala	95	149.5	19.3	262	15.34	26.88

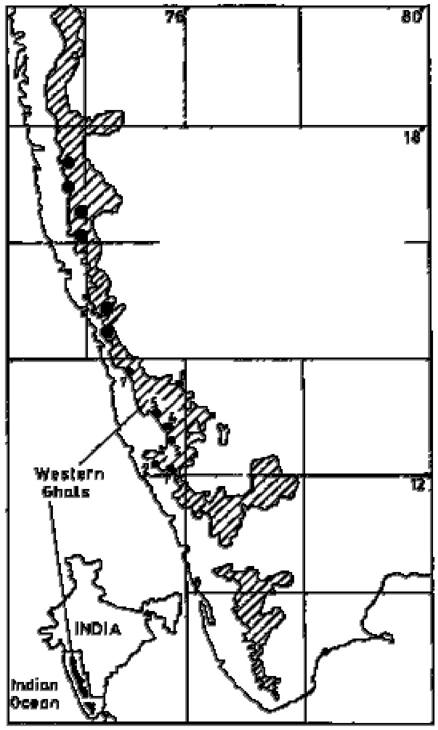

Figure.1. Location of Study Area

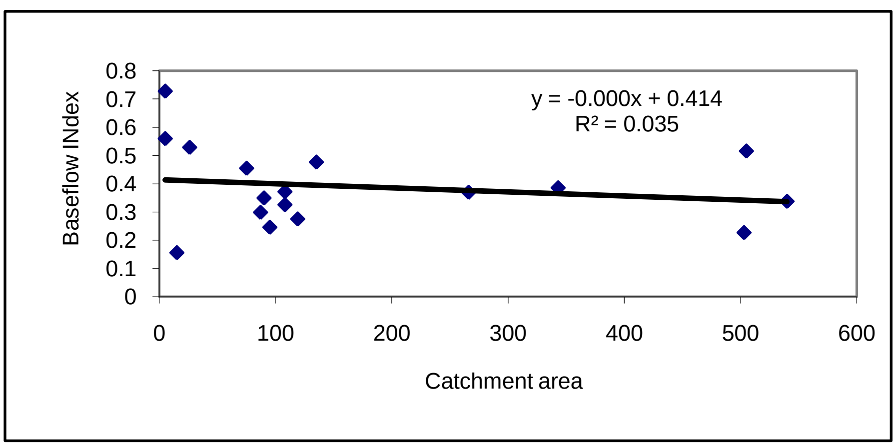

Figure .3. Relationship between Catchment area and Baseflow index

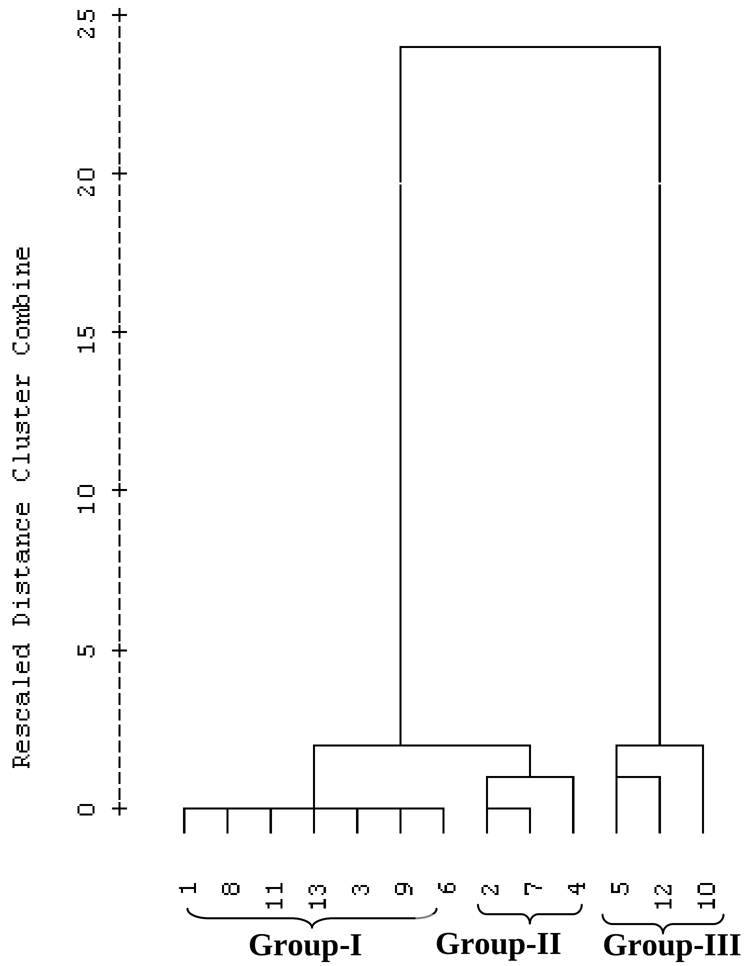

Figure.2. Dendrogram using Average Linkage (Between Groups)

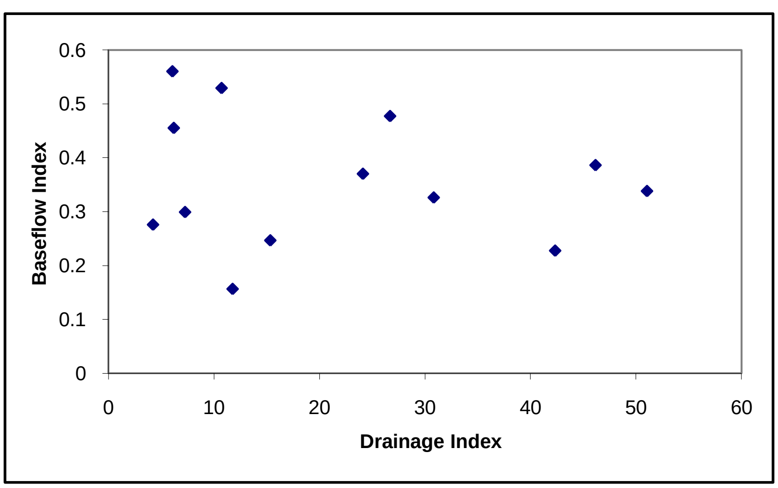

Figure .4 Relationship between drainage index and base flow index

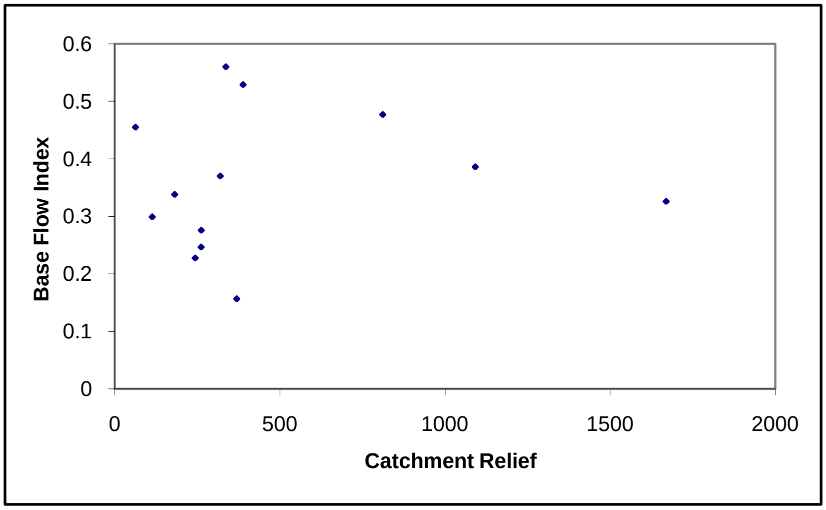

Figure .5. Relationship between Slope index and base flow index

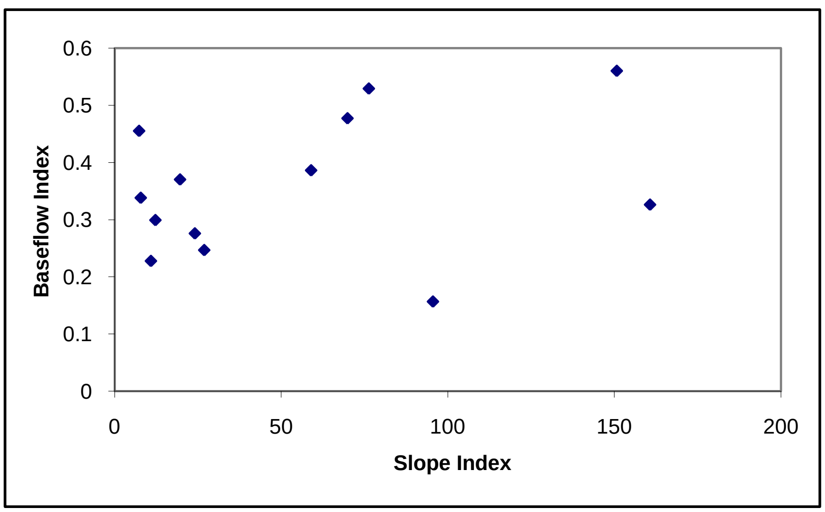

Figure.6 Relationship between Catchment relief and Base flow Index