

Comparative Analysis Of Methods Of Baseflow Separation Of Otamiri Catchment

Nwakpuda Nat. I.

ABSTRACT: The various approaches of separating baseflow from other streamflow components are hinged on their respective strengths and drawbacks with respect to the watershed considered. Little wonder therefore, that this research work has ventured on some methods amongst multitude of emerged methods, to establish the best method(s) of baseflow separation and henceforth address the strength and drawback dichotomy associated with the different baseflow separation methods. The examined methods of baseflow separation used in this work are conveniently categorized into five basic approaches of fixed interval, sliding interval, local minimum, Baseflow Index and frequency analysis. Data for the analyses obtained from Otamiri River at Nekede were utilized for this study and daily recorded streamflow discharge data obtained from the historical records held at the libraries of the Anambra Imo River Basin Development Authority, Owerri and the Nigerian National Meteorological Services. The results of the predictability of the stream flow from the estimated baseflow for all the methods used conformed as evident in the regression analysis and the results showed that the value of the coefficient of simple determination (r^2) was highest in the fixed interval method and least in the frequency analysis method which implies that the fixed interval method was the best method of separating the base flows for Otamiri stream.

Keywords: Baseflow separation, Otamiri streamflow, fixed interval, Sliding Interval, Local Minimum, Baseflow index, Frequency analysis.

1 INTRODUCTION

Runoff hydrograph usually consists of a fairly regular lower portion those changes slowly throughout the year and a rapidly fluctuating component that represents the immediate response to rainfall. The lower, slowly changing portion of runoff is termed base flow. The rapidly fluctuating component is called direct runoff. This distinction is made because the unit hydrograph is essentially a tool for determining the direct runoff response to rainfall. hydrologists and hydro-geologists, generally depending on either the number of components the total flow can be separated into, or the subjective nature of the method of separation. Baseflow separation is the process whereby stream flow hydrograph is separated into its relevant components. The number of water sources or components that contribute to the stream flow can be identified depending on the conceptual model of flow. Some models consider two components of flow (i) Quick flow – the direct response to a rainfall event including overland flow (runoff), lateral movement in the soil profile (interflow) and direct rainfall onto the stream surface (direct precipitation, and (ii), Baseflow – the longer-term discharge derived from natural storages, whereas other models consider more than two components of flow. Analyzing the baseflow component of the streamflow hydrograph has had long history of development since the early theoretical and empirical work of Boussinesq (1904), Maillet (1905) and Horton (1933).

Several useful reviews have been postulated including Hall (1968), Nathan and McMahon (1990), Tallaksen (1995) and Smakhtin (2011) to map this development. The conceptual basis for such analysis can only really apply in small catchments where differential travel times, due to distance from the catchment outlet, play minor role. In larger catchments such as the Imo River Basin the situation is far more complex as baseflow can be affected by a multitude of processes, some dominated by topography, others by subsurface (soils and geology) characteristics and others by spatial variations in rainfall inputs. Further complexities are intensified when runoff processes are considered in more detail. A number of field studies have demonstrated that subsurface runoff processes in some catchments can operate at quite rapid rates (Ward, 2004; Putty and Prasad, 2010), while surface runoff on hill slopes may be re-infiltrated further downslope. It is apparent that, apart from a very few experimental catchments which are comprehensively instrumented, it is extremely difficult to determine what component of the total flow hydrograph can be considered as baseflow. Chemical and isotope tracing studies (Marc et al., 2001), as well as simulation modelling (Haberlandt et al., 2001) offer alternative methods for hydrograph separations, however, they all require extensive time and manpower resources. The study is designed to address the issue of baseflow separation, analyzing and comparing various methods aiming at recommending the most appropriate derived/adopted method for the Anambra Imo River Basin catchment [specifically, the Oramiriukwa River and Otamiri River] of Owerri, Imo State, Nigeria. This also would be applicable / useable in other areas/regions of the country. This is achievable by categorizing the various existing methods of baseflow separation, comparing them and identifying the most appropriate method for adoption for use in baseflow separation to aid design and management purposes. The key objectives of this study are as follows:

- I. Collection of rainfall data [runoff] from the catchment area isolated -- Owerri, Imo State. The driest period is picked as the measured baseflow figure used as a standard for comparison,
- II. Separation of the baseflow from the runoff using the known methods for comparison,

- Nwakpuda Nathaniel I. is currently pursuing Phd. degree program in water resource and Environmental Engineering in the Dept. of Civil Engineering, University of Nigeria, Nsukka, Nigeria, PH-08033401201. E-mail: ninndsp4@gmail.com
- Agunwamba Jonah. C is currently a professor of Water Resources and Environmental Engineering in the Dept. of Civil Engineering, University of Nigeria, Nsukka, Nigeria, PH-08035644561. E-mail: jonah.agunwamba@unn.edu.ng

- III. Comparison of predicted baseflow from different methods with the observed data,
- IV. Examining the relationship between the methods of analysis with the streamflow data,
- V. Derivation of a modified method of baseflow estimation and its verification using observed data.

Graphical / Filtering Separation Methods

Graphical methods for hydrograph separation are useful for separating baseflow from individual storm events as against continual records of data. The technique does not consider physical parameters within catchments and so is arbitrary in nature, and it is difficult to understand what the baseflow component actually represents. For instance the Gray's (1973) method involves drawing a line backwards on the recession limb from the point at which direct runoff ends (point B See Fig.1) until it reaches under the peak of the hydrograph, and is then connected to the event marking the beginning of surface water runoff (point A). The Subramanya's (1994) method is applied in a similar fashion except that the line is drawn backwards from the recession limb until it reaches the point of inflexion on the hydrograph. Graphical techniques that use analytical algorithms include one proposed by the United States Department of Agriculture – Agricultural Research Service (USDA-ARS, 1973) and Nazeer (1989). The method uses a mass balance approach and assumes a two component model. Three equations are used to separate baseflow into periods of recharge of soil moisture, recharge of groundwater and recession. In the first step of the technique by Nazeer (1989), any baseflow separation technique can be used to draw an approximation of the baseflow curve. In the second step, the shape factor of the baseflow curve is calculated (using an algorithm which is related to the time to peak streamflow). The shape of the approximated baseflow curve is procedurally altered until the shape factor correlates with the shape factor of the hydrograph curve.

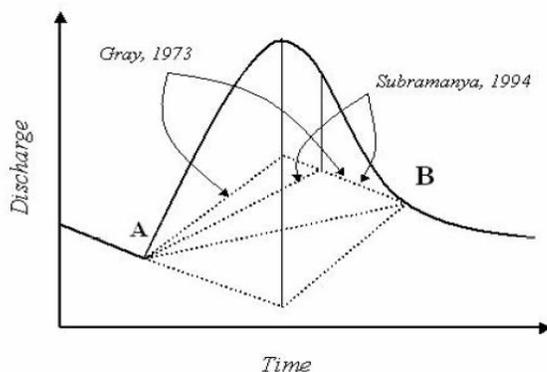


Fig.1 Typical Example of Graphical baseflow separations.

Source: Gray (1973)

Graphical methods are commonly used to plot the baseflow component of a flood hydrograph event, including the point where the baseflow intersects the falling limb. Stream flow subsequent to this point is assumed to be entirely baseflow, until the start of the hydrographic response to the next significant rainfall event. These graphical approaches to partitioning baseflow vary in complexity and include:

1. An empirical relationship for estimating the point along the falling limb where quickflow has ceased and all of the stream flow is baseflow;

$$D = 0.827A^{0.2} \quad ($$

Where D is the number of days between the storm crest and the end of quickflow, and A is the area of the catchment in square kilometers (Linsley et al. 1975). The value of the exponential constant (0.2) can vary depending on catchment characteristics such as slope, vegetation and geology.

- i. The constant discharge method assumes that baseflow is constant during the storm hydrograph (Linsley et al. 1958). The minimum streamflow immediately prior to the rising limb is used as the constant value.
- ii. The constant slope method connects the start of the rising limb with the inflection point on the receding limb. This assumes an instant response in baseflow to the rainfall event.
- iii. The concave method attempts to represent the assumed initial decrease in baseflow during the climbing limb by projecting the declining hydrographic trend evident prior to the rainfall event to directly under the crest of the flood hydrograph (Linsley et al. 1958). This minimum is then connected to the inflection point on the receding limb of storm hydrograph to model the delayed increase in baseflow.
- iv. Using the trends of the falling limbs before and after the storm hydrograph to set the bounding limits for the baseflow component (Frohlich et al. 1994).
- v. Use the Boussinesq equation as the basis for defining the point along the falling limb where all of the streamflow is baseflow (Szilagyi and Parlange 1998).

2.0 METHODOLOGY

2.1 Study Area

The study areas are located in the Anambra Imo River basin catchment coverage area and particularly in the Imo river basin and also involve hydrological stations at Nekede that are along the Otamiri stream which are being gauged/manned by the Anambra Imo River Basin Authority, Owerri, Imo State, Nigeria. Data utilized for this study were the daily recorded streamflow discharge data obtained from the historical records held at the libraries of the Anambra Imo River Basin Development Authority Owerri and the Nigerian National Meteorological Services. Nekede lies about latitude 50 25' 14" and longitude 70 04' 36". Otamiri River flows South from Egbu past Owerri and through Nekede, Ihiagwa, Eziobodo, Olakwoumuisi, Mgbirichi an Umuagwo to Ozuzu in Etche, in the River State, from where it flows to the Atlantic Ocean. The length of the river from its source to its confluence at Emeabiam with the Uramiriukwa River is 3Km (19 mi). It has an annual rainfall of 2,250 to 2500mm, the watershed is mostly covered by depleted rain forest vegetation, with mean temperature of 270 C (810F). The climate of the study area is explained in terms of the seasonal shifting of two air masses, that is the tropical Continental and the Equatorial maritime. The boundary between these two air masses is known as the Inter-tropical front (I. T. F.). The Equatorial Maritime air Mass is characterized by southwest winds which originate at the Gulf of Guinea. These are the main rain bearing winds of the region, occurring mostly from April through October. The Tropical continental mass is that of the dry north-easterly

winds known locally as the Harmattan, which usually prevails December through March.

2.2 Fixed Interval Method

The fixed-interval method assigns the lowest discharge in each interval (2N*) to all days in that interval starting with the first day of the period of record. The method can be visualized as moving a bar 2N* days wide upward until the bar first intersects the hydrograph. The discharge at that point is assigned to all days in the interval. The bar is then moved 2N* days horizontally, and the process is repeated. The assigned values are then connected to define the base-flow hydrograph. The second technique for baseflow separation, the sliding-interval method, finds the lowest discharge in one half the interval minus 1 day [0.5(2N*-1) days] before and after the day being considered and assigns it to that day. The method can be visualized as moving a bar 2N* wide upward until it intersects the hydrograph. The discharge at that point is assigned to the median day in the interval. The bar then slides over to the next day, and the process is repeated. The assigned daily values are then connected to define the base-flow hydrograph. The Third method for this separation , the local-minimum method, checks each day to determine if it is the lowest discharge in one half the interval minus 1 day [0.5(2N*-1) days] before and after the day being considered. If it is, then it is a local minimum and is connected by straight lines to adjacent local minima. The base-flow values for each day between local minima are estimated by linear interpolations. The method can be visualized as connecting the lowest points on the hydrograph with straight lines. The fourth approach for this separation, the Base Flow Index (BFI), the index is calculated as the ratio of the flow under the separated hydrograph to the flow under the total hydrograph. The program calculates the minima of five-day non-overlapping consecutive periods and subsequently searches for turning points in this sequence of minima. The turning points are then connected to obtain the base flow hydrograph, which is constrained to equal the observed hydrograph ordinate on any day when the separated hydrograph exceeds the observed. The frequency duration analysis, the fifth approach for baseflow separation for this work, is a statistical assessment that uses the following relationship for flow data of fixed time period (daily, monthly or annual):

$$P = 100 \left(\frac{m}{\{n+1\}} \right) \quad (1)$$

Where: P = the probability of a given flow that will be equaled or exceeded;

M = the ranked number when daily or monthly flows are arranged in descending order and

N = the total number of observations

3. RESULT PRESENTATIONS AND DISCUSSIONS

3.1 Result Presentations

The baseflow separation analysis results obtained from the daily recorded streamflow discharge data obtained from the historical records held at the libraries of the Anambra Imo River Basin Development Authority Owerri and the Nigerian National Meteorological Services; using the five methods as outlined above are presented below:

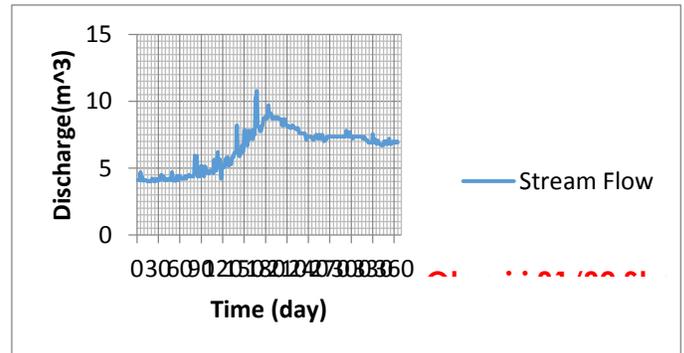


Fig. 2 Streamflow Pattern of Otamiri Stream

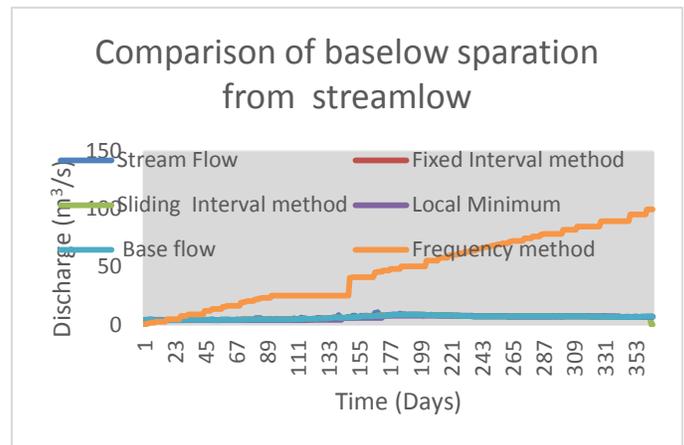


Fig. 3 Graphical display of Baseflow Separation from streamflow for all the methods employed.

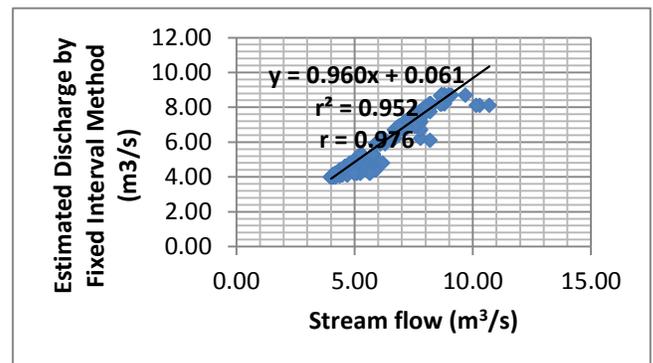


Fig. 4 Predictability of the stream flow from the Base flow Discharge Using the Fixed Interval Method

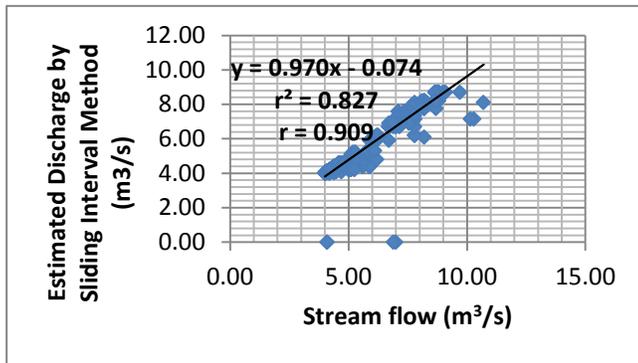


Fig. 5 Predictability of the stream flow from the Base flow Discharge Using the Sliding Interval Method

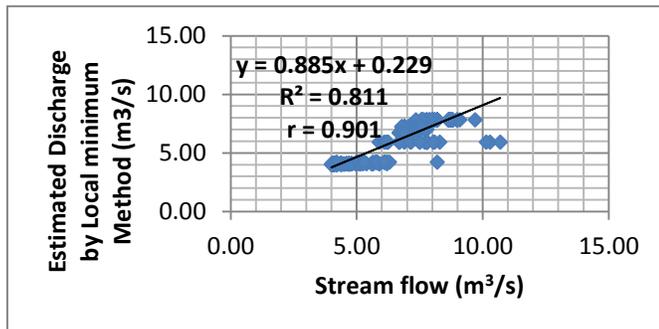


Fig. 6 Predictability of the Stream flow from the Baseflow Discharge Using the Local Minimum Method

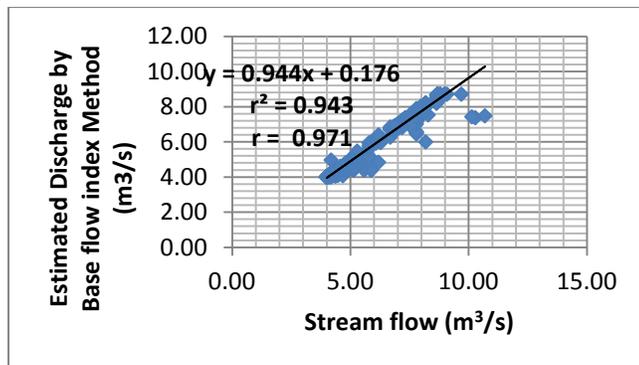


Fig. 7 Predictability of the Stream flow from the Base flow Discharge Using the Base Flow Index Method

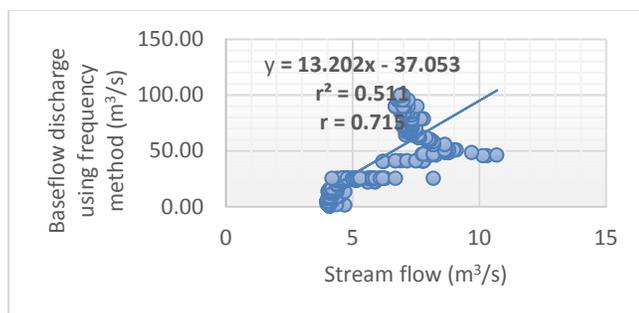


Fig. 8 Predictability of the Stream flow from the Base flow Discharge using the frequency Analysis Method

3.2 DISCUSSIONS

The following points as captured in the regression analysis of all the methods of base flow separation as well as in the graphical comparison of the baseflow separation ability of all the employed techniques are sacrosanct, and the following discussions are evident. As seen from the estimated and presented results, the Fixed Interval Method of baseflow separation (Figure 4) has the highest value of the coefficient of simple determination (0.952), followed progressively by the BFI (figure 7) (0.943), Sliding Interval Method (Figure 5) (0.827), Local Minimum (figure 6) (0.811) and frequency analysis method (8) (0.340), it implies that the Fixed Internal Method is the best method of separating the base flow discharge., as it has the highest percentage accuracy (95.2%) more than any other base flow separation method. Moreover, the fixed Internal Method has the strongest positive relationship (the baseflow values will increase 97.6% linearly as the stream flow values increases) between the value of the base flow discharge separated and the streamflow (defined by its highest value of correlation coefficient of 0.976), compared to the values recorded for other methods. Therefore, the fixed interval method of base flow separation is the most accurate in separating the base flows as high as 95.2% efficient. This shows that the fixed internal method was the best method of separating the base flow for the Otamiri watershed.

4. CONCLUSION

Indeed ,baseflow separation techniques will ever remain dogged as they have in no little measure offer a remedy to the critical challenge of understanding the dynamics of water management issues . Analyzing and separating the baseflow component of the stream hydrograph has had a long history of development since the early theoretical and empirical work of Boussinesq (1904), Maillet (1905) and Horton (1933). Several useful reviews have been written including Hall (1968), Nathan and McMahan (1990), Tallaksen (1995) and Smakhtin (2001) to map this development. Methods of achieving this will always penetrate so as to answer in a more sound way, limitations of various base flow separation techniques. Obviously, joy behooves and fresh hopes established as the fixed interval method, has emerged the most reliable of all for both watersheds. Conclusively, This Analysis has ascertained the best method of base flow separation from the stream flow from Otamiri stream and other streams of similar hydrological characteristics.

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