Appraising of Streamflow Study and Comparison of Baseflow Separation Methods for Koga River Catchment in the Upper Blue Nile Basin, Ethiopia

Lmatu Amare*

Department of Geology, Debre Markos University, Debre Markos, P.O.Box 269,Ethiopia

*Corresponding author Email: lmatuamare03@gmail.com

Abstract

This research mainly aims to estimate the baseflow contributions and method comparisons in Koga micro-catchment in the northwestern parts of Ethiopia.The two hydrograph separation methods (namely, Chapman and Lyne&Hollick) were applied and compared with their results for the quantification of baseflow contributions.The baseflow separation were compute under sephydro hydrograph separation computing tool. Sephydro is a free, open-source utility for separating streamflow hydrographs into baseflow and surface runoff. This accessible progarm computes baseflow with surface runoff as well the frequncey and duration of measured total streamflow. In tool-recognized systems, the daily mean stream discharge is used as an input to the computer program. It gives an outputs of stream hydrographs as a graphical sketches (plots) on a computer screen and statestical datasets for a baseflow separated stream. The baseflow component has been connected to groundwater discharge during the dry season results of 37.1% and 42.4% were drawn by Chapman and Lyne&Hollick, respectively, while the surface runoff component has been linked to precipitation entering the stream as overland flows of Chapman accounts 62.9% and 57.6% using Lyne&Hollick approach. Therefore, determination of baseflow contribution is vaital for the managements of water resources. The method comparison and a very minute determinant factors was identified based on the analysis result.

Keywords: *SepHydro, Baseflow Contributions, Comparison of Methods, Koga Micro-catchment, Upper Blue Nile Basin*

Introduction

In the dry season, baseflow is the predominant component of streamflow that emerges from underground saturated aquifer zones (Bayou et al., 2021; MacDonald et al., 2021; Qin et al., 2017). The contribution of baseflow to streamflow is critical for both surface and groundwater planning and management systems (Bayou et al., 2021). Practical assessment of baseflow contribution has implications for sympathetic groundwater system function and informing water resource management (Zhang, 2018). The evaluation of baseflow separation methods in comparative studies (Lyne & Hollick, 1979; Chapman, 1991) is frequently based on subjective measures, such as the acceptability of hydrological behavior, rather than a quantitative evaluation to a well-measured and identified baseflow separated hydrograph (Danielescu, 2021; Danielescu et al., 2018) . The baseflow component of simulated streamflow must be generated in a specific way, making it difficult to evaluate using numerical models (Partington, 2012). Despite being strongly influenced by subsurface storage and other manmade activity, such as the Koga dam in the research site, baseflow has a significant impact on river streamflows (Zhang, 2018). In hydrological research and water resource sectors, baseflow analysis is widely employed (Berhail et al., 2012). Baseflow is difficult to comprehend and requires attention in catchment hydrology for water resource management (Qin et al., 2017). The baseflow (drought flow) is derived from the time series stream gauge records using streamflow data as an input (Tenalem et al., 2019; Burns et al., 2010; Sujono, 2004). Acording to Hasseini et al. (2017), the capacity and demand for formative water resources are critical indications in making decisions about how to use water resources safely and how to deal with natural disasters like drought, it was taken as a problem statement for this study. The objectives of this study were to: (1) determine the factors that influence the baseflow; (2) to assess and compare the baseflow separation techniques in a small micro-catchment; and (3) to estimate groundwater contributions to stream (s) using two different techniques.

Materials and Methods

2.1 Descrption of the study area

This research was conducted in the Koga micro-catchment,which is located in the source regions of Upper Blue Nile basin in Ethiopia as depicted in **(Figure 1).** It covers about 244 km^2 from the spring emerges to the times series record stations, and topographicaly, elevation varations of the area lies in between 1886 to 2929 m a.m.s.l from the lower on wards the higher elevation as shown **(Figure 1)**. The climatic conditions or classifications of the study site lies dega (temprate) to weyina-dega (sub-tropical) according to (Gozálbez and Cebrián, 2006; Daniel, 1997). Geology of the study site is mainly a complex undeformed structural block dominated by tertiary volcanic rocks and quaternary basalts (Chorowicz et al., 1998; Nigate et al., 2016). After the field observation and integrated with of previous study, the catchment is formed by volcanic activity in addition to erosion and sedimentation. Hydrogeologicaly the catchment is covered by basaltic fractured rocks with more inter-connections, which have an implications, on water interactions wether from surface waters, subsurfaces and other hydrological elements in the ground system (Nigate et al., 2016). In regional study including the study site, two major aquifer classes were identified based on the mode of origin and rock types; these were extensive aquifers with intergranular permeability and extensively fractured, and weathered volcanics (Ayenew, 2008). The above researchers, gave an incites how much the hydrological study (e.g. baseflow) depends on geology, landforms/topography and climatic conditions of the area.

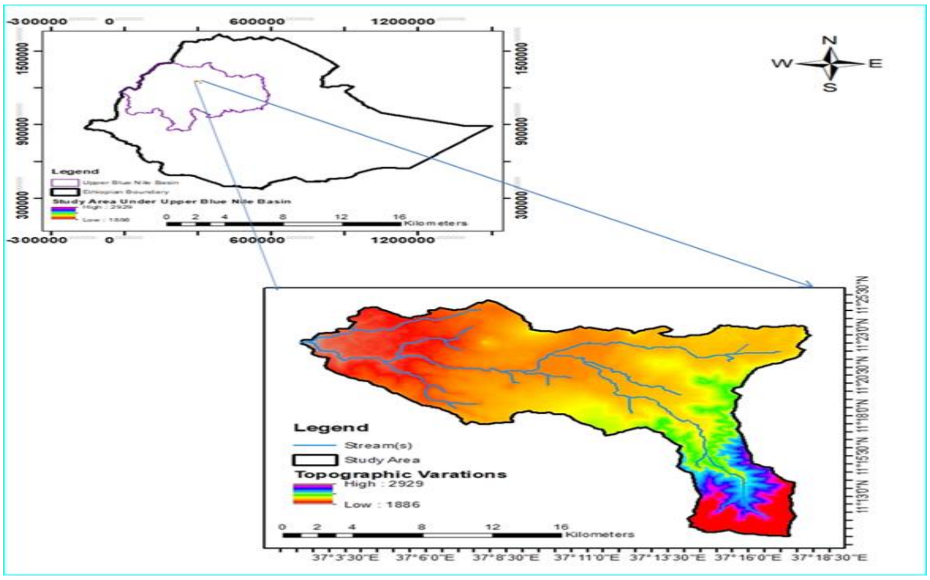


Figure 1 Location map of Koga River Catchement

2.2 Hydrograph (Baseflow) Separation Methods

The present study was used the two baseflow analysis or hydrogaraph separation techniques (namely, Chapman and Lyne&Hollick) they were drawn under sephydro-hydrograph separation computing environment. This computing environment containes the methological frameworks of web developer option, contextual menu, progress tables, statestical and data visualization areas in a user friendly bases. The analysis were made by considering the user friendly interface and handle the streamflow data in the tool recognized fashion, that has been accessed from abbay basin authority at Bahir Dar, Ethiopia. The daily mean streamflow data for the duration of (2000-2008) at Merawi gauge station was separated into baseflow and surface runoffs using the two recursive digital filtering methods. The two baseflow separation methods, applied in the some way or correspondingly, for partitioned streamflows into the quick flow (surface runoff) and delayed flow (baseflow) components.The baseflow analysis was performed using one parameter filter catchment (recession) constants as stated in **(2.2.1, 2.2.2).**

2.2.1 Lyne&Hollick Method

Lyne and Hollick were the first to introduce the hydrograph separation method in 1979 as depicted in **(Table 1)**. It was intended to investigate how streams respond to precipitation in a slow and time-dependent manner. According to the approach, high-frequency signals are associated with surface runoff while low-frequency signals are associated with the base flow component. This approach evaluates the surface runoff component, which is subsequently used to calculate the base flow and stream flow components.

$$q_t = a x q_{t-1} + \frac{(1+a)}{(2)} x (Q_t - Q_{t-1}) \qquad e.q.1$$

Where, q – surface runoff (m^3/s); Q - streamflow (m^3/s); t - the time for which the surface runoff is calculated for determining the baseflow; whereas, α – is a catchment constant, its values ranges from in between 0 and 1.

2.2.2 Chapman Method

The Chapman technique was developed in 1991 in response to the results of the Lyne&Hollick algorithm, which mistakenly predicted a continual streamflow or baseflow even after direct runoff had stopped.

$$b_t = \frac{(3xa - 1)}{(3 - a)} x b_{t-1} + \frac{(1 - a)}{(3 - a)} x (Q_t + Q_{t-1}) \qquad e.q.2$$

Where, b – depict baseflow (m^3/s); Q - streamflow (m^3/s); t - the time for which the baseflow is calculated; α - hydrological recession constant, its values lies in between 0 and 1, to separate the baseflow from streamflow.

Results and Discussion

In this study two baseflow (hydrograph) separation techniques were applied, namely Chapman and Lyne&Hollick for the analysis proficiency. As quantified in methodology part both methods work, under sephydro hydrograph separation computing environments. In the study site baseflow contributions has been well identified. The baseflow quantities in the river catchment has been highly significant as depicted in **(Figure 6 and Table 2).** The two methods are applicable in the study area, as well in similar physiographic and geologic settings as supported by (Tenalem et al., 2019). The contribution of the base flow for both methods Lyne and Hollick accounts for 42.4 percent of total steamflow in the catchment, while Chapman contributes about 37.1 percent. It was determined that the catchment has a significant impact on baseflow throughout the year.

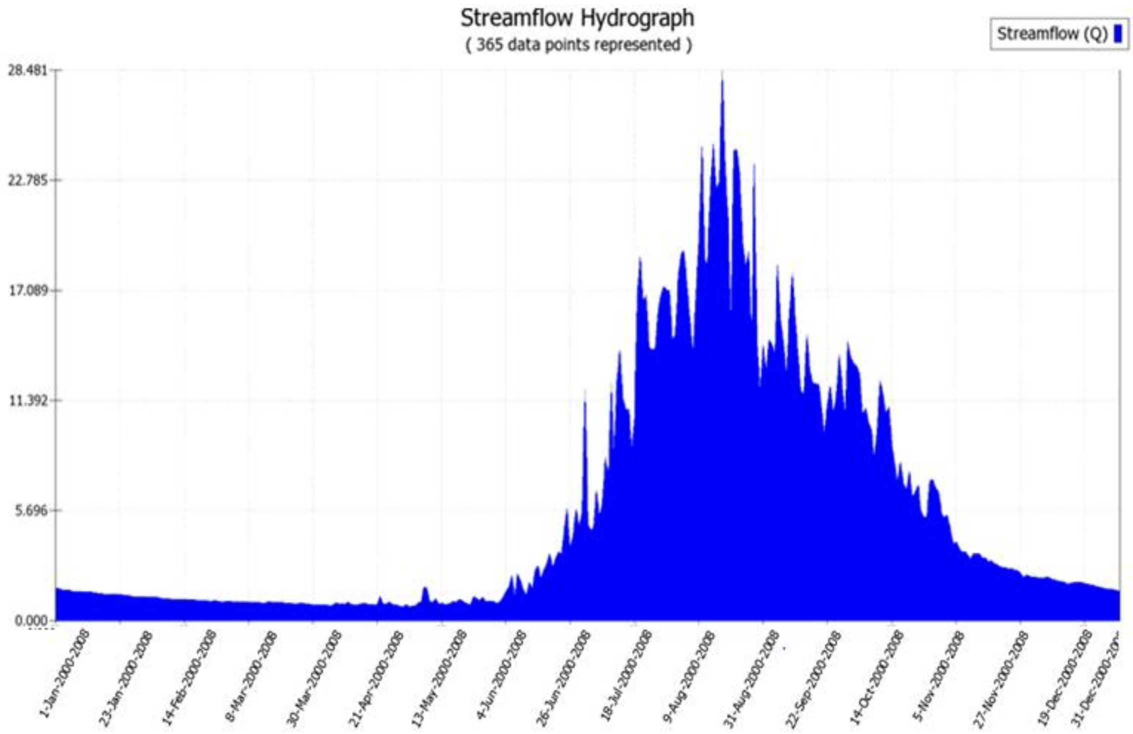
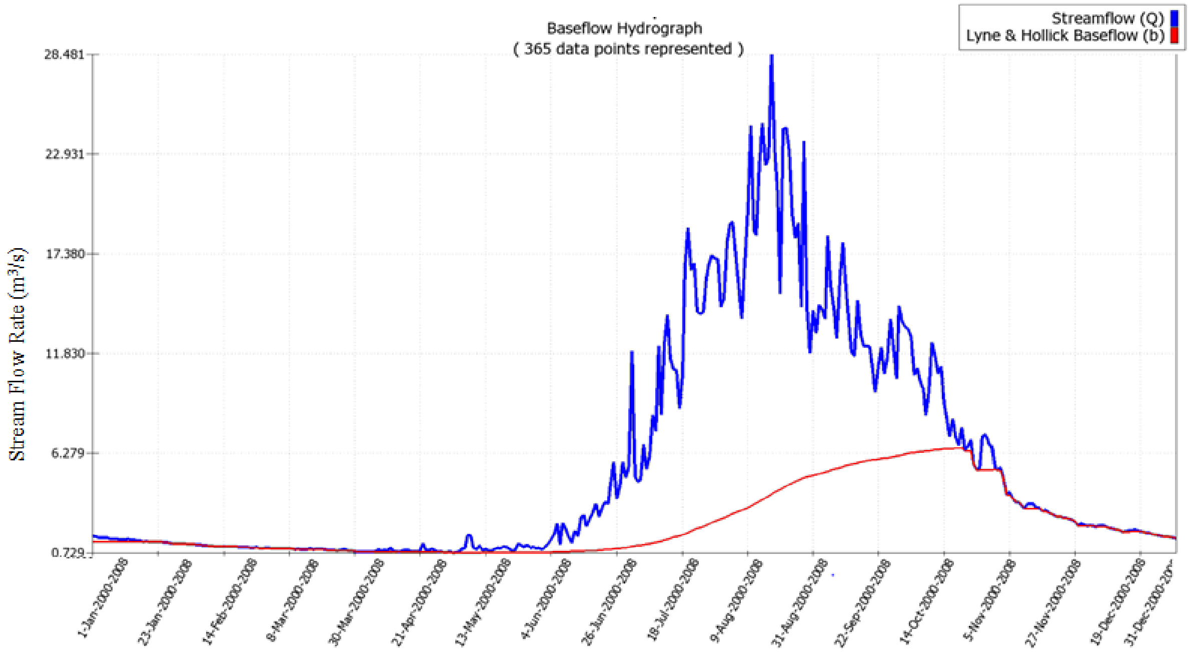
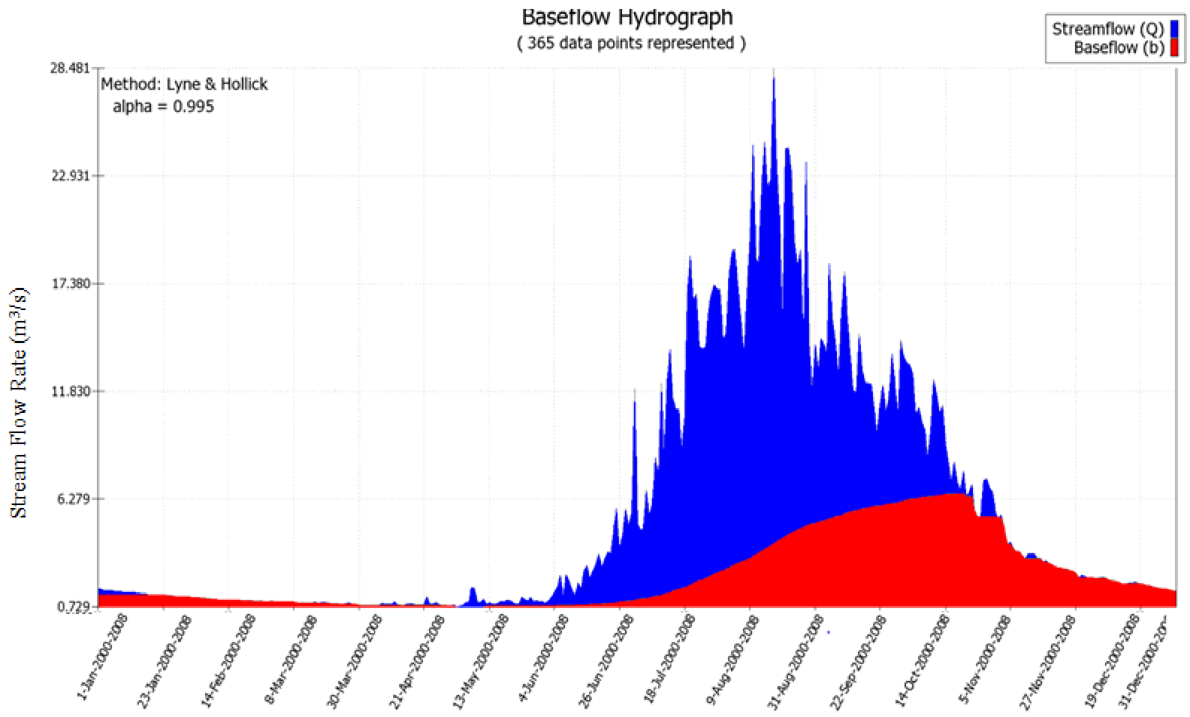


Figure 2. Streamflow hydrograph based on average time series measurements from 2000 to 2008 as yearly flows of the Koga river (Under the SepHydro environment, before the baseflow analysis were made).

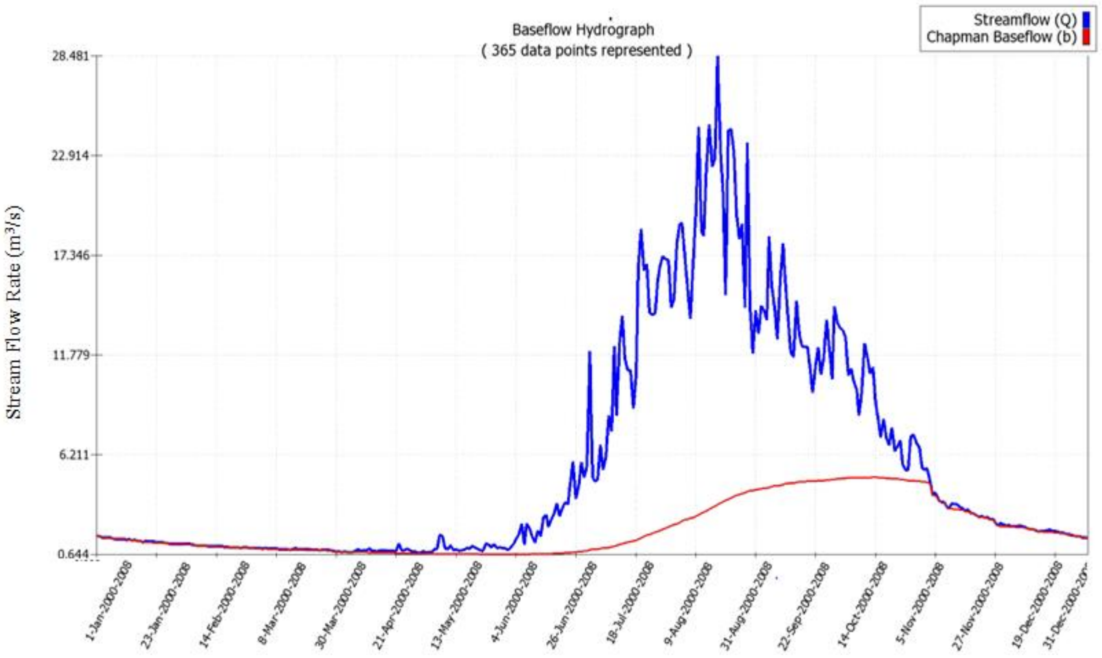


a)

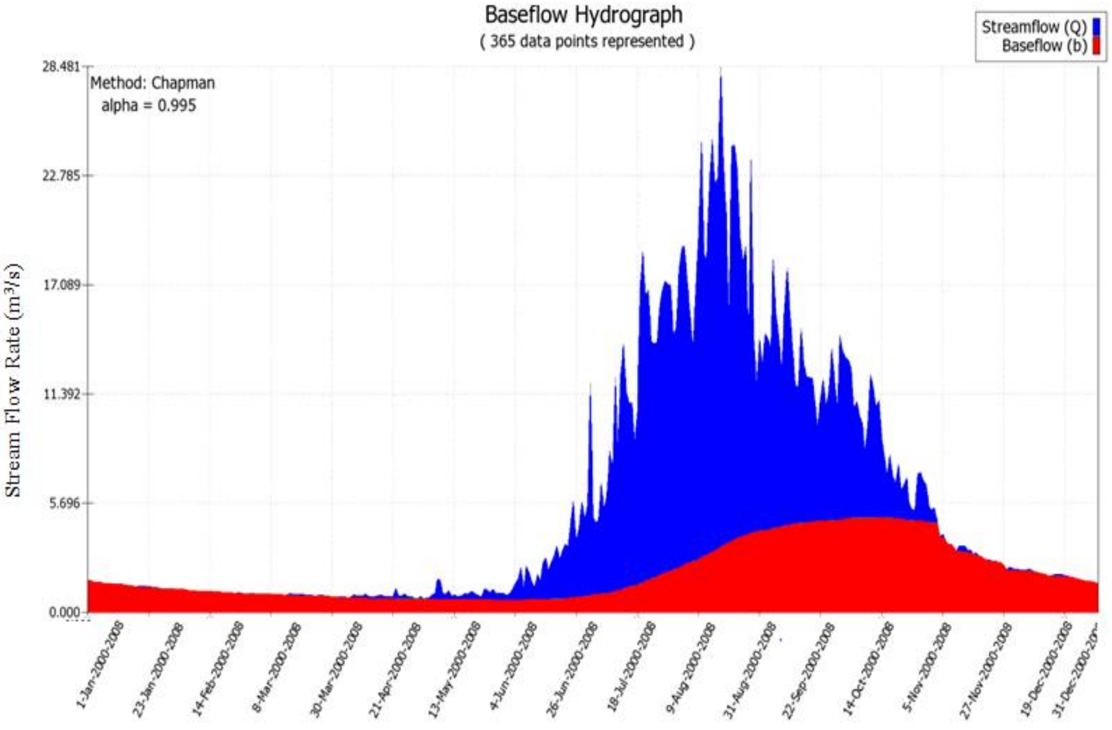


b)

Figure 3. a) and b) depicts high frequency of the streamflow & low frequency of the baseflow curves of a), the massive shaded hydrographs of b) using Lyne&Hollick method



c)



d)

Figure 4**.** Infact c) and d) keep in shape the same thing of a) and b) yet by using Chapman method.

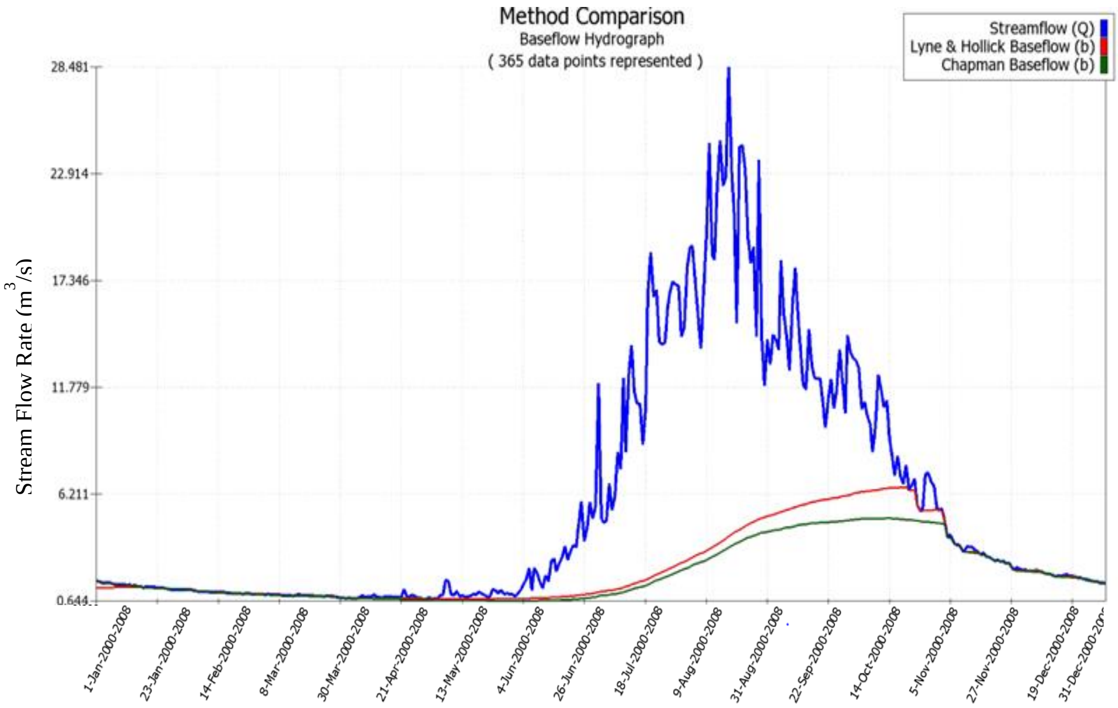


Figure 5. The blue color depicts streamflow (Q), while red and green color shows the baseflows (b) of Lyne&Hollick and Chapman respectively.

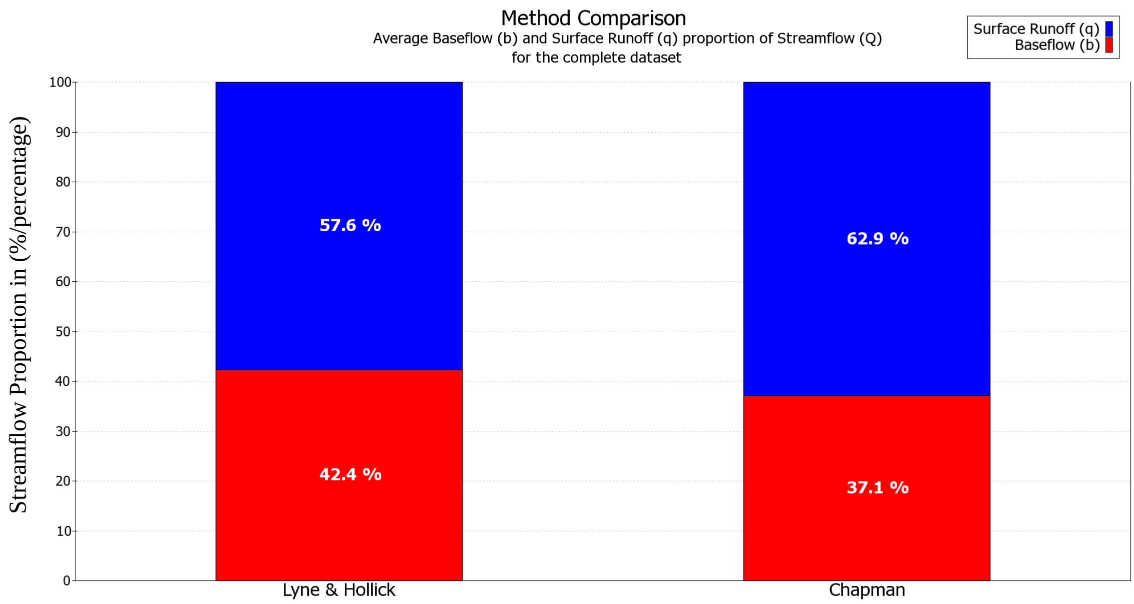


Figure 6. Contribution of baseflow (b), surface runoff (q), proportion of streamflow (Q)for the complete dataset (the blue color indicates surface runoff,while red color the baseflows).

Table 1. Depicts the method, type and requirments for baseflow analysis

Hydrograph Separation Methods Integrated in SepHydro-Environment			
Method	Type	Requerements	Refference

Lyne & Hollick	One parameter filter	α,catchment constant	Lyne&Hollick(1979)
Chapman	One parameter filter	α,recession constant	Chapman (1991)

Table 2. Out of the entire dataset, indicates an average of baseflow, streamflow, the proportion of baseflow with streamflow

Method	Lyne&Hollick	Chapman
b_{avg}	2.375	2.079
Q_{avg}	5.607	5.607
Avg. of b/Q	42.36%	37.08%
b>Q	21.92%	15.07%
b>Q count	80 /365	55 / 365

Table 3. Shows the minimum, maximum, and average (streamflow, baseflow, and surface runoff), as well the standard deviations of surface runoff and baseflow, the baseflow to streamflow ratio, and the input filter parameters for both techniques.

Methods	Lyne&Hollick	Chapman
$Q_{min.}$	0.729	0.729
$Q_{avg.}$	5.607	5.607
$Q_{max.}$	28.481	28.481
$Q_{stdv.}$	6.332	6.332
$q_{avg.}$	3.233	3.528
$q_{max.}$	24.478	25.056
$q_{stdv.}$	5.316	5.526
$b_{min.}$	0.729	0.644
$b_{avg..}$	2.37	2.079
b_{max}.	6.56	4.951
$b_{stdv.}$	1.901	1.503
b>Q count	80/365	55/365
b>Q ratio	0.219	0.151
b/Q ratio	0.424	0.371
Alpha value for both methods	0.995	0.995

Groundwater outflow processes and baseflow separation is thoughtful for understanding the catchment's groundwater system.The annual results of two combined methods demonstrate a similar trend and accepted agreement, with a correlation cooperative of 0.995 as illustrated in **(Figure 3b, Figure 4 c and d, and Table 3)**. In **(Figure 3, Figure 5**) not only depicts a similar trend but also fits a curve matching during the dry season, moreover; in **(Figure 3a, Figure 5)** there is a very minute gaps on the month of january,with the same filter parameter used for driving the baseflow component from the streamflow. It was determined that the catchment has a significant impact on baseflow throughout the aging process. The contribution of the baseflow for two methods combined Lyne and Hollick spell out 42.4 percent of the total steamflow in the catchment, while Chapman explicates 37.1 percent.The greater baseflow to streamflow of b > Q counts 80/365 infers about 21.9%, by the Lyne and Hollick technique, where in Chapman b > Q counts 55/365 implies about 15.1% per year. The average catchment steamflow is devoted to an approximate value of Q was 5.61 m^3/s. The lowest flow (Q) recored in the river catchment was estimated to be 0.73 m^3/s, Moreover; the maximum steamflows (Q) of 28.48 m^3/s was taken as an average of the highest flow. The standard deviation of the total flows of (Q) 6.33 m^3/s was an approximate value, where the average surface runoff (q) lies in between 3.233 to 3.528 m^3/s by Lyne & Hollick and Chapman approachs, respectively. The maximum surface runoff (q) estimated to be 24.478 using the Lyne and Hollick technique, while in Chapman's 25.056 m^3/s. The standard deviation of surface runoff (q) counts 5.316 m^3/s by Lyne and Hollick, in Chapman the surface runoff (q) of 5.526 m^3/s was estimated. The minimum baseflow of (

b) equals to streamflow of (Q) is the same at the values of 0.729 m^3/s in the Lyne & Hollick technique, while the lowest baseflow (b) in Chapman was estimated to be 0.644 m^3/s to some extent the result deviates from the minimum streamflow as depicted in (**Table 3**). For both methods, the average baseflow was 2.375 and 2.079 m^3/s for Lyne&Hollick and Chapman, respectively. Extreme baseflow in Lyne & Hollck 6.564 m^3/s and in Chapman 4.951 m^3/s. The standard deviation of the baseflow of Lyne & Hollick is 1.901 and 1.503 m^3/s in Chapman by using one filter parameter for separation streamflow in the study river catchment.

Conclusions

Results of this study advocates that, the Chapman and Lyne&Hollick techniques performed well in the Koga micro-catchment by providing the contributions of baseflow for groundwater resources evaluation. Contribution of groundwater from Chapman indicates 37.08%, while from Lyne&Hollick 42.36% to in excess of the shallow groundwater or aquifer system of the river catchment. According to the findings, periodic variability disrupts baseflow levels, implying that season is an unusual component that influences baseflow in addition to geology, hydrogeology, and hydrological system controls. Other hydrograph analysis should be conducted to evaluate the veracity of the results as described in this study whenever the baseflow separation must be employed in calculating the amount of groundwater contributions. In water administration practices, several studies will be desired in the upcoming to address the catchment's groundwater resource problems. Groundwater and surface water interaction, stream of water quality management, groundwater potential (catchment hydrogeology) using additional techniques, watershed management implications of (erosion&sedimentation practices) and quantifing groundwater contribution in a changing environment are some of the endorsed issues that will be covered. The outcomes of this study will support for planning, development, and management of water resources in Koga river catchment.

Conflict of interest

The author say publicly that there is no conflict of interest.

Acknowledgements

The researcher expresses heartfelt gratitude to the Abbay Basin Authority for their data sources.

References

Ayenew, T., Demlie, M., & Wohnlich, S. (2008). Hydrogeological framework and occurrence of groundwater in the Ethiopian aquifers. Journal of African Earth Sciences, 52(3), 97–113. **https://doi.org/10.1016/j.jafrearsci.2008.06.006**

Bayou, W.T., Wohnlich, S., Mohammed, M., Ayenew, T. (2021). Application of hydrograph analysis techniques for estimating groundwater contribution in the sor and gebba streams of the baro-akobo river basin, southwestern Ethiopia. Water (Switzerland) 13. **https://doi.org/10.3390/w13152006**

Berhail, S., Ouerdachi, L., & Boutaghane, H. (2012). The use of the recession index as indicator for components of Flow. Energy Procedia, 18, 741–750. https://doi.org/10.1016/j.egypro.2012.05.090

Burns, E. R., Bentley, L. R., Therrien, R., & Deutsch, C. v. (2010). Interpolation de modeètles de facieès avec conservation du flux interstitiel. Hydrogeology Journal, 18(6), 1357–1373. https://doi.org/10.1007/s10040-010-0607-z

Chapman, T. (1991). Comment on evaluation of automated techniques for base flow and recession analyses, by RJ Nathan and TA McMahon. Water Resources Research 27, no. 7: 1783–1784.

Chorowicz, J., Collet, B., Bonavia, F.F., Mohor, P., Parrot, J.F. and Tesfaye Korme (1998). The Tana basin, Ethiopia: intra-plateau uplift, rifting and subsidence. Tectonophysics 295, pp351-367.

Daniel, G. (1997). Aspects and water budget in Ethiopia, Addis Ababa University Press, Ethiopia

Danielescu, S. (2021) SepHydro - a web-based tool for hydrograph separation. Reference Manual. Available at https://sephydro.hydrotools.tech

Danielescu, S., MacQuarrie, K. T. B., & Popa, A. (2018). SEPHYDRO: A Customizable Online Tool for Hydrograph Separation. Groundwater, 56(4), 589–593. https://doi.org/10.1111/gwat.12792

Gozálbez, J. and Cebrián, D. (2006). Touching Ethiopia, 2nd English edition. Shama Publisher.

Lyne, V., and M. Hollick. (1979). Stochastic time-variable rainfall-runoff modelling. In Institute of Engineers Australia National Conference. Publication No. 79/10, 89–93. Barton, Australia: Institute of Engineers Australia.

MacDonald, A. M., Lark, R. M., Taylor, R. G., Abiye, T., Fallas, H. C., Favreau, G., Goni, I. B., Kebede, S., Scanlon, B., Sorensen, J. P. R., Tijani, M., Upton, K. A., & West, C. (2021). Mapping groundwater recharge in Africa from ground observations and implications for water security. Environmental Research Letters, 16(3). https://doi.org/10.1088/1748-9326/abd661

Nigate, F., Van Camp, M., Kebede, S., & Walraevens, K. (2016). Hydrologic interconnection between the volcanic aquifer and springs, Lake Tana basin on the Upper Blue Nile. Journal of African Earth Sciences, 121, 154–167. https://doi.org/10.1016/j.jafrearsci.2016.05.015

Partington, D., Brunner, P., Simmons, C.T., Werner, A.D., Therrien, R., Maier, H.R., Dandy, G.C. (2012). Evaluation of outputs from automated baseflow separation methods against simulated baseflow from a physically based , surface water-groundwater flow model. J. Hydrol. 458–459, 28–39. https://doi.org/10.1016/j.jhydrol.2012.06.029

Qin, J., Ding, Y., Han, T., Liu, Y., (2017). Identification of the factors influencing the baseflow in the permafrost region of the northeastern qinghai-tibet plateau. Water (Switzerland) 9. **https://doi.org/10.3390/w9090666**

Hosseini Duki, S., Morteza Seyedian, S., Rouhani, H., Farasati, M., & Professor, A. (2017). Evaluation of Base Flow Separation Methods for Determining Water Extraction (Case study: Gorganroud River Basin). (2), 54–70. **https://doi.org/10.22077/JWHR.2018.830**

Sujono, J., Shikasho, S., & Hiramatsu, K. (2004). A comparison of techniques for hydrograph recession analysis. Hydrological Processes, 18(3), 403–413. **https://doi.org/10.1002/hyp.1247**

Tenalem, A., Assefa, E., Tilahiun, A.,(2019). Comparison of Different Base Flow Separation Methods and Drought Vulnerability in a Rift Valley area. Journal of Spatial Hydrology Vol.15, No.2

Yang, W., Xiao, C., Zhang, Z., & Liang, X. (2020). Can the two-parameter recursive digital filter baseflow separation method really be calibrated by the conductivity mass balance method? Hydrology and Earth System Sciences Discussions, 1–27. **https://doi.org/10.5194/hess-2020-488**

Zhang, R., Li, Q., Chow, T. L., Li, S., & Danielescu, S. (2013). Baseflow separation in a small watershed in New Brunswick, Canada, using a recursive digital filter calibrated with the conductivity mass balance method. Hydrological Processes, 27(18), 2659–2665. **https://doi.org/10.1002/hyp.9417**