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Performance Analysis of Baseflow Separation Methods: The Case of Rift Valley Lakes Basin, Ethiopia

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Abstract: Adopting the appropriate method to separate baseflow from stream flow is desirable for future low flow prediction, planning, management of water resources, and nourishing the environment as well. Thus, comparing the baseflow separation method is inevitable unfortunately not studied within the basin. Therefore, in this study, seven recursive digital filters (RDF) and two digital graphical (DGM) methods were compared in rift valley lakes basins. All the methods were calibrated manually with the help of BFI 3.0 tool; the performance of each method was checked by R2 and RMSE, taking the separation with maximum R2 and minimum RMSE were taken as appropriate separation method and (Baseflow Index) BFI was calculated by using the baseflow from the suitable method for each catchment. The outcomes of baseflow separation indicate that two methods (exponentially weighted moving average (EWMA) and Lynie-Holick) performed better than the other seven methods; unlikely, local minimum and one parameter methods perform less by both R2 and RMSE. Therefore, these comparisons could possibly elucidate the baseflow prediction in the majority of catchments. Subsequently, existing and forthcoming water resource improvement attempts may employ this estimation approach for low flow forecasting, baseflow trend analysis, as well as planning and designing water resources projects.

Keywords: Baseflow separation method, Digital Graphical, Recursive Digital Filter, Rift Valley

INTRODUCTION

Knowing the amount of baseflow is vital for understanding, identifying, and quantifying streamflow generating mechanisms, especially where baseflow highly supports key ecosystems and supplies perilous dry season water demand (Ibrahim et al., 2021; Werner et al., 2006). Nowadays, baseflow is frequently used to refer to the groundwater contribution to streamflow (Okello et al., 2018; Misra et al., 2011). Furthermore, it can be enumerated as the release of water from both underground water sources and natural water that sustains streamflow amid rainfall periods (Piggott et al., 2005; Smakhtin & Weragala, 2005). As a result, it is crucial input for groundwater resource estimations, water resource conservation, and hydrogeological modeling baseflow (Okello et al., 2018; Zhang et al., 2018).

Baseflow can be measured in the field (e.g. natural and artificial tracer, flow seepage meters, and temperature set in stream beds), but it is extremely challenging to apply these techniques across whole watershed for practical reasons (Shao et al., 2020; Becker et al., 2004), in particular, where the technological advancement is rare like Rift Valley Basin. As a result, in the lack of precise field data but in the presence of a streamflow hydrograph, baseflow is frequently calculated using simple baseflow separation methods. There are numerous methods for baseflow separation available today, even if their applicability and performance are site specific. Tracer-based method, the hydrological simulation, digital graphical method, conductivity mass balance method (CMB), recursive digital filter, and automatic method are among the most commonly used. However, according to (Belete et al., 2015; Nathan & McMahon, 1990) the hydrological simulation method, and conductivity mass balance method require extensive time and manpower resources. Lott & Stewart (2016) evaluated six baseflow separation methods using specific conductance as a tracer. These assessments are quantitative and appear to be more reasonable. However, both hydrologic models and tracer-based methods have important shortcomings in estimating baseflow; Gonzales et al. (2009) compared seven baseflow separation methods to one based on dissolved silicon; Partington et al. (2012) evaluated ten baseflow separation methods using the HydroGeoSphere hydrologic model's reference. Having appropriate baseflow separation method in each catchment, BFI is obtained by the ratio of total baseflow to total stream flow where baseflow is computed by selected baseflow separation method; BFI is the most common indices in low analysis (Abdi & Gebrekristos, 2022).

Hence Rift Valley basin sustain large amount of communities who rely on agriculture mainly by using ordinary irrigation system from those rivers to support their day to day live, therefore the existing water have been used for various current demands like domestic water supply, irrigated agriculture, industries, and for nourishing the environment. Therefore, analyzing the baseflow amount in both wet and dry season have paramount importance for planning, designing and administration of water resources project and supporting ecological processes in a catchment. Thus, implementing comparison of baseflow separation methods in those human dominated catchments of the rift valley will help to devise water management strategies for both the development projects and the environment as well. Large numbers of studies in the past in another topic carried out in the past like; characterizing the spatiotemporal distribution of meteorological drought, modeling sediment yield, transport and deposition, characterization of water level variability respectively by (Tesfamariam et al., 2019; Xie et al., 2020; Belete et al., 2015). Unfortunately, comparison of baseflow separation method in the RVLB is not yet studied. Therefore, the primary objective of the present research is: to compare digital graphical and Recursive digital filter baseflow separation methods, in RVLB, Ethiopia; and specifically (1) to detect the fitting baseflow separation techniques; (2) to estimate overall and wet season baseflow index (BFI) in RVLB.

MATERIALS & METHODS

Study Area

The study was conducted in the third smallest basin, the Rift Valley Basin (RVLB), which encompasses an area of roughly 53,000 km^2 and contains four sub-basins and 14 watersheds. The basin is located between 8°30' N and 4°25' N and 36°30' E and 39°30' E, as indicated in Figure 1 below. It accounts for more than two-thirds of the country's lakes, with eight lakes (i.e. Abiyata, Ziway, Langano, Hawasa, Shala, Chamo, Abaya, and Chew Bahir).

Geological and Aquifer Conditions

The bedrock in the highlands is dominated by basic volcanic rocks (lava and ash, primarily of Tertiary age), whereas the bedrock in the lowlands is dominated by acidicvolcanic rocks (peralkaline silica-rich rhyolitic ignimbrites, including ash and pumice). Weathered and reworked volcanic rocks, silicic tephra, and small alluvial fans are found along the escarpments and the highland border (Figure 1). Eluvial lateritic crusts of clay, silt, and fine sand are also present; and also the RVLB contains two major aquifer classes: I extensive aquifers with intergranular permeability (unconsolidated sediment: alluvium, eluvium, colluvium, and lacustrine sediment) and (ii) extensively fractured and weathered volcanic rocks (basalts, rhyolites, trachytes, and ignimbrites) The latter exhibits variable transmissivity and hydraulic conductivities in relation to the degree of fracturing and weathering, as well as the presence of interbedded palaeosols and alluvial or pyroclastic deposits within the volcanic series (Kebede et al., 2005).

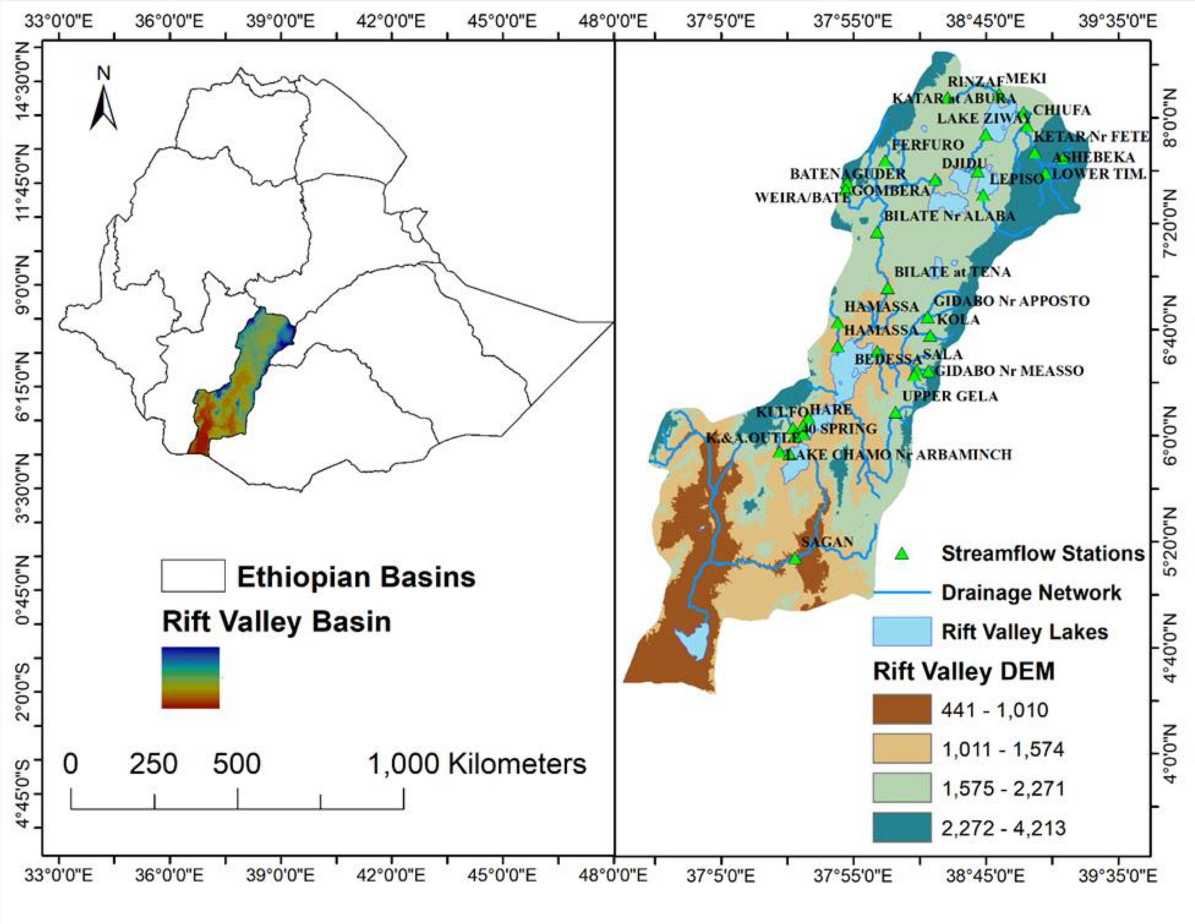

Figure 1. Location map of the study area.

Methods of baseflow separation

Daily streamflow data from the all gauged watersheds where arranged by using Microsoft Excel, and then the data converted to text (*.txt) format. Likewise, Hydro Office imports the file (*.txt) for baseflow separation. Baseflow separation is accomplished through the use of: (i) Seven RDF (Chapman, one parameter, Lynie-Hollick, Bougthon-two parameter, Eckhart filter, Ihacres, and EWMA,); and (ii) Two DGM (Local minimum and Fixed interval).

The study by Sloto & Crouse (1996) describes two digital graphical methods for distinguishing baseflow from the hydrograph (i.e. fixed interval, and local minimum). Local minimum techniques employ the minimal flow for each time interval. On the first step, the interval is calculated by [0.5 (2N-1) days. The empirical value of N is the number of days until runoff is completed is obtained from (Linsley et al., 1982), using N = A0.2, where A is the catchment size in square miles (mil2). Second, to display the hydrograph's baseflow part, the lowest flows for entire time interval are interconnected by a straight line. But fixed interval method uses interval (2N*day) to find the low flow for each time range. This approach is demonstrated by a bar chart intersecting with a line hydrograph at the lowest position for each interval. Move the bar chart until it intersects the minimal portion of the hydrograph to get the baseflow for the range. The procedure is repeated for all intervals on the Hydrograph. On another hand, (Gregor, 2010 & 2012) implemented these graphical approaches into a digital graphical method (DGM) by the HydrOffice software package. The RDF calibration technique is the same as the DGM procedure, although the number and types of parameters are not the same. Table 1 lists the parameters and equations of RDF approaches, along with their references.

Table 1. The seven Recursive Digital Filters

Filter Name	Equation	Reference & Equation no.
One parameter	$Q_{bi)} = \frac{k}{2-k} Qb(i-1) + \frac{1-k}{2-k} Q(i)$	(Chapman, 1999 & 1991) (1)
Boughton	$Q_{bi)} = \frac{k}{1+c} Qb(i-1) + \frac{c}{1+c} Q(i)$	(Boughton, 1993; Chapman, 1999) (2)
IHACRES	$Q_{b(i)} = \frac{k}{1+c} Qb(i\text{-}1) + \frac{c}{1+c} (Q_{(i)} + \alpha^{*}Q(i\text{-}1)$	(Jakeman & Hornberger, 1999) (3)
Lynie and hollick	$Q_{f(i)} = \alpha qf(i\text{-}1) + (Q(i)\text{-}Q(i\text{-}1)) \frac{1+\alpha}{2}$	(Nathan & McMahon, 1990; Lyne & Hollick, 1979) (4)
EWMA	$Q_{bi)} = \alpha Q(i) + (1+\alpha) Qb(i-1)$	(Tularam & Ilahee, 2008) (5)
Chapman	$Q_{f(i)} = \frac{3\alpha-1}{3-\alpha} Q_{f}(_{i\text{-}1}) + \frac{2}{3-\alpha} (Qi - \alpha Q_{(i\text{-}1))}$	(Chapman, 1991; Mau &Winter, 1997) (6)
Eckhardt Filter	$\frac{1 - \text{BFI}max)\alpha Qb(i-1) + (1-\alpha)BFImax * Qi}{1 - \alpha\text{BFImax}}$	(Eckhardt, 2005 &2008) (7)

Where: ($Q_{(i)}$ = Streamflow at day i; $Q_{b(i)}$ = calculated baseflow at day i; $Q_{(i-1)}$ = Streamflow at prior day; $Q_{f(i)}$ = calculated direct runoff at day i; $Q_{b(i)}$ = calculated baseflow at day i; $Q_{b(i-1)}$ = calculated baseflow at prior day; $Q_{f(i-1)}$ = calculated direct runoff at prior day; BFI_{max}= maximum baseflow index k = filter parameter or recession Constant; α= filter parameter; C= filter parameter).

Excel was used to perform additional analysis, interpretation, and visualization of the results. To begin, the Root Mean Squares Error (RMSE) approach is used to monitor the effectiveness of the calibration and validation processes utilizing the various methodologies discussed above. Furthermore, hydrographs with estimated observed discharge and baseflow are utilized to display the separation results graphically. Lastly baseflow index (BFI) is computed for all watersheds and seasons as shown in Equation 8.

$$\text{BFI} = \frac{\sum \text{Bf}}{\sum \text{Qt}} \quad (8)$$

Where:
Bf: Baseflow (m^3/s)
Qt: Total stream flow (m^3/s)

Separation Methods calibration and Performance measure

The calibration results were statistically analyzed by comparing computed baseflow with observed total flow for the dry period, when there was no precipitation and no runoff, for all watersheds in the basin. During this time, it is possible to suppose that direct runoff is near to zero. Likewise, as shown on equation 9 RMSE is used to quantify the goodness of fits between observed and computed baseflow.

$$\text{RMSE} = \sqrt{\frac{(\text{QC} - \text{QO})}{\text{n}}} \quad (9)$$

Where:
Q_c: separated baseflow (m^3/s),
Q_o: measured dry season flow on the river (m^3/s),
n: total sample size.

Reduced RMSE values suggest a significant connection between observed and computed base flow in meantime to obtain the correlation coefficient, analyses are also performed using a scatter plot. Each method's parameter values (Table 1) are input via trial and error over the course of a year. The operation is terminated when the red-curve (computed baseflow curve) is nearby to the measured streamflow curve (blue area curve) for the dry period as shown in Figure 2.

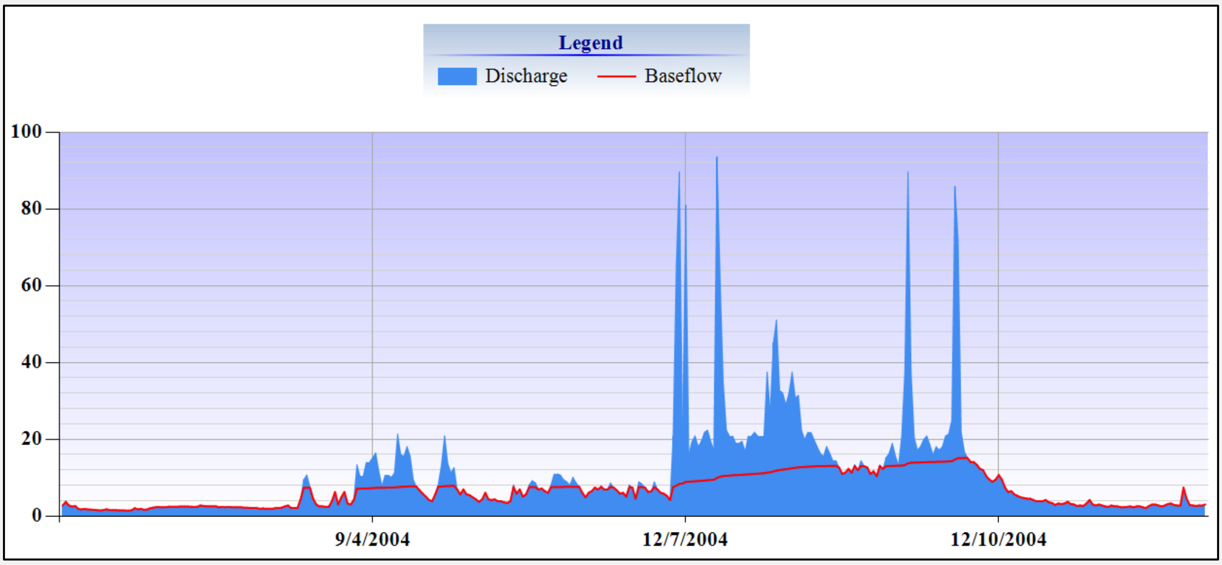

Figure 2. Calibration process of lynie holick baseflow separation method for Kola catchment (zoomed to 2004)

In this study, December to February were the periods used to evaluate the calibration process's performance, assuming that no or little rain falls on the region during this time; in addition, to make it more accurate, the meteorological station within the catchment are checked for zero precipitation received. These calibration methods are being used for every watershed separately. In this study, all parameter values utilized to calibrate every watershed are provided their parameter range from their minimum value to maximum values in the calibration process. Averaging yearly values yields the ideal parameter values for each catchment and approach.

RESULTS AND DISCUSSION

Statistical Analysis: Scatter plot and RMSE

Figure 3 (a) and (b) shows results of calibration over dry season from which statistical analysis is made. All over the catchments the separated (simulated) baseflow captured the dry season discharge in lynie hollick, and EWMA method. In Bilate Tena EMWA method nearly fitted the dry season flow whereas across the remaining catchments of the study area, lynie and holick methods appreciably fitted the observed one.

Figure 3 (a) – (b) Results of calibration over dry season and (c) – (f) shows the scatter plot in representative sample catchment (i.e Badessa and Kola) to illustrate highly performed and less performed separation method; as indicated lynie holick method executed better in Badessa and Kolla by having R2 of 0.91 and 0.96 respectively; whereas two parameters performed less with R2 value of 0.61 and 0.28 in consecutively in both catchments.

The statistical analysis using baseflow separation result for December to February of all year in Table 2 shows the results of R2 values and RMSE for entire methods in Rift valley lakes basin.

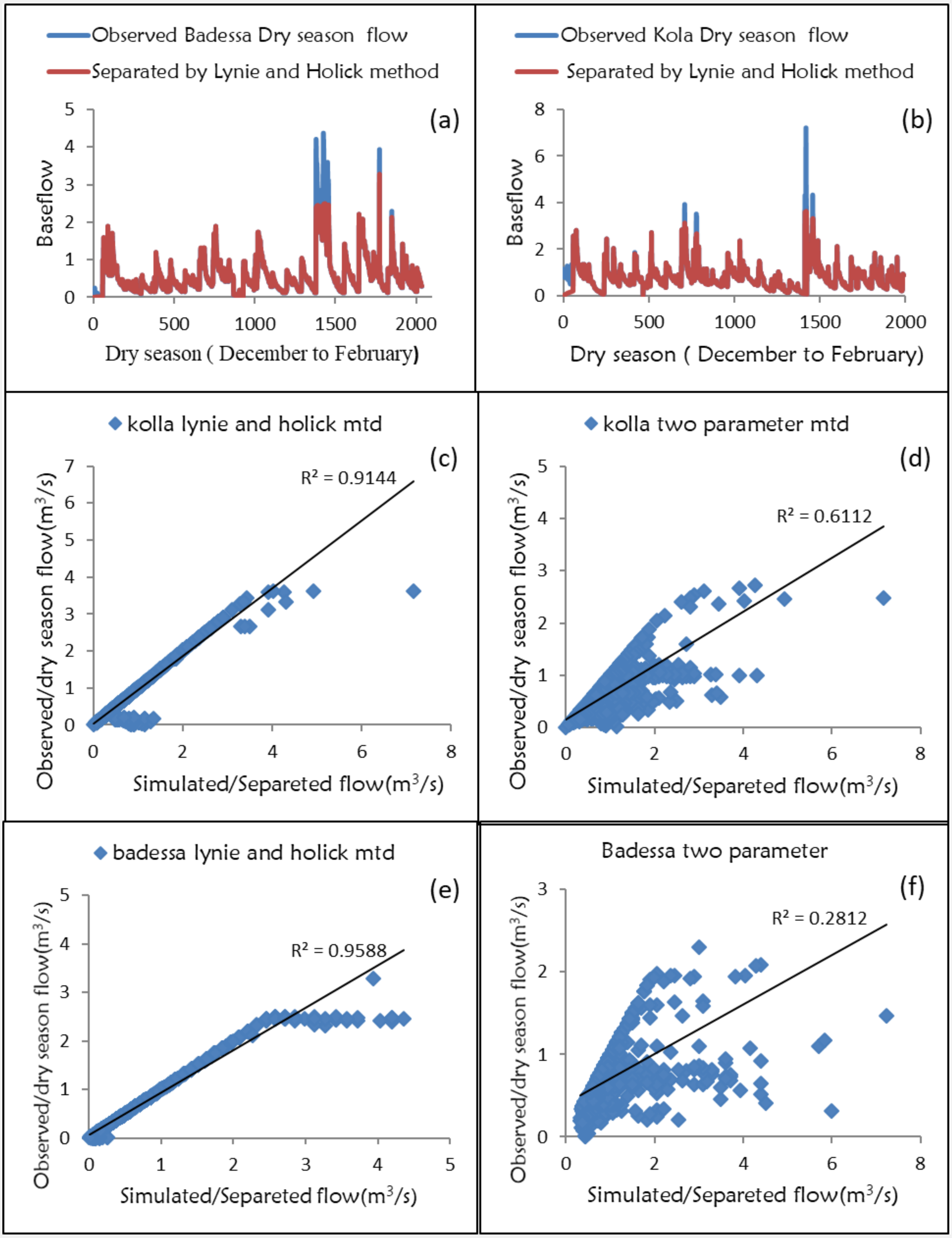

Figure 3. (a) – (b) Results of calibration over dry season and (c) – (f) shows the scatter plot in representative sample catchment

Table 2. R^2 and RMSE of Digital graphical Separation methods

Catchment		Local Minimum	Fixed Interval
Weira	RMSE	0.01	0.01
	R^2	0.22	0.21
Kulfo	RMSE	0.05	0.06
	R^2	0.78	0.80
Hare	RMSE	0.01	0.01
	R^2	0.69	0.59
Gidabo	RMSE	0.01	0.01
	R^2	0.57	0.49
upper Gelana	RMSE	0.01	0.01
	R^2	0.78	0.80
Bilate Tena	RMSE	0.04	0.04
	R^2	0.57	0.49
Kola	RMSE	0.01	0.01
	R^2	0.54	0.46
Badessa	RMSE	0.01	0.01
	R^2	0.62	0.61

The above Table 2 shows Local Minimum method performs better when looking at the RMSE and R2 in most catchment like Weira, Hare, Gidabo, Kola, Bilate Tena and Badessa; but perform less as evaluated through while in Kulfo and, Upper Gelana; when comparison is carried out only between two digital graphical methods only. Nevertheless, for Rift Valley lakes basins, when compared to RDF, neither of the DGM is chosen as suitable separation methods.

In Table 3, RMSE and R2 of seven RDF (i.e one parameter, two parameters, IHACRES, lynie and holick, Eckhardt, EWMA, and Chapman) over all catchments are presented. Table 3 shows that EWMA and Lynie-Holick method calculated base flow more precisely than five other RDF approach in line with (Nathan & McMahon, 1990) research, in which they carried out baseflow separation method in Watersheds of east java regions. Furthermore, these two methods can also calculate BFI more than other separation methods. The two techniques transform heavy rainfall during periods of high flow into greater infiltration regions during periods of precipitation, which considerably increases the groundwater. In contrast, one parameter technique reliably estimates baseflow through both dry and rainy seasons. Everyone else including three RDF approaches (Ihacres, Chapman, Bougthon and two parameter); predict less magnitude of baseflow throughout all time periods. It moreover demonstrates that the Eckhardt filter and local minimum approaches predict baseflow more accurately over wet seasons. While the fixed interval technique estimates baseflow less accurately than the previous two methods. Unlike this study, (Shao et al., 2020; Xie et al., 2020) found Echardt separation methods performs than other separation method in the contiguous United States and Semi-Arid Sandy Area, Northwestern China respectively. In meantime Nathaniel (2017) compared digital graphical methods in Otamiri Catchment and found that fixed interval was the best performer; but in this research local minimum method preferable over fixed interval in most of the catchments in rift valley lakes basin. The possible reason behind this dissimilarity expected to be due to the difference in land use, rainfall pattern, temperature, and availability of groundwater.

Table 3. RMSE and R^2 of Recursive Digital Filters methods Separation in sample catchments

Catchment		One parameter	Two parameters	IHACRES	lynie and holick	Eckhardt	EWMA	Chapman
Weira	RMSE	0.014	0.014	0.013	0.003	0.006	0.003	0.014
	R^2	0.366	0.281	0.333	0.96	0.849	0.971	0.79
Kulfo	RMSE	0.076	0.078	0.057	0.029	0.035	0.03	0.079
	R^2	0.819	0.732	0.857	0.935	0.906	0.929	0.846
Hare	RMSE	0.016	0.014	0.012	0.008	0.01	0.008	0.015
	R^2	0.706	0.568	0.667	0.799	0.727	0.792	0.718
Gidabo	RMSE	0.008	0.007	0.006	0.003	0.003	0.003	0.009
	R^2	0.658	0.689	0.725	0.935	0.914	0.932	0.694
Upper gelana	RMSE	0.012	0.014	0.01	0.005	0.006	0.004	0.015
	R^2	0.847	0.829	0.879	0.969	0.953	0.971	0.856
Bilate tena	RMSE	0.015	0.05	0.047	0.006	0.007	0.006	0.042
	R^2	0.899	0.338	0.421	0.984	0.979	0.985	0.714
Kola	RMSE	0.009	0.009	0.007	0.004	0.004	0.004	0.01
	R^2	0.659	0.611	0.711	0.914	0.894	0.91	0.691
Badessa	RMSE	0.006	0.007	0.005	0.003	0.004	0.003	0.008
	R^2	0.859	0.903	0.861	0.959	0.928	0.953	0.856

Range of parameter values

Table 4 shows the range of parameter value obtained from yearly parameter calibration over the entire recorded stream flow period in eight gauged catchments for each watershed; in two parameter, one parameter, Lynie-Hollick, IHACRES and Eckhardt method of separation parameters (k, c and α) little change over the all study area; but in case of Chapman, Local minimum, Fixed interval, EMWA separation methods parameters (α, N and f) having significant variation within the catchments.

Table 4. Ranges of parameter values obtained for calibration in RVLB

Filter Name	Range of parameter values explored for across the basin				
	k	C	α	N	f
One parameter	0.9-0.997	-	-	-	-
Two parameters	0.955-0.994	0.013-0.024	-	-	-
IHACRES	0.926-0.989	0.009-0.013	0.924-0.996	-	-
Lynie-Hollick	-	-	0.926-0.998	-	-
Chapman	-	-	0.43-0.997	-	-
EWMA	-	-	0.0024-0.011	-	-
Eckhardt	-	-	0.989-0.9994	-	-
Local Minimum	-	-	-	4-16	0.53-0.97
Fixed Interval	-	-	-	11-26	-

Computation of Baseflow Index (BFI)

Computation of baseflow index (BFI) of aver all year and wet season was carried out by using baseflow magnitude separated through highly performed method in each catchment; as most crucial parameter of low flow analysis BFI taken as the most dominant streamflow component in dry season.

Table 5. Baseflow index magnitude

Catchments	Overall BFI	Wet season BFI
Weira	0.357	0.173
Ketar	0.456	0.21
Kulfo	0.618	0.251
Kekersitu	0.332	0.161
Hare	0.625	0.287
Tikur Wuha	0.415	0.172
Gidabo	0.414	0.164
Guder	0.371	0.201
Upper Gelana	0.455	0.189
Gombera	0.294	0.147
Bilate Tena	0.396	0.125
Hamessa	0.235	0.187
Kola	0.558	0.133
Melka Oda	0.412	0.091
Badessa	0.489	0.116

From Table 5; overall BFI indicates catchment like Kulfo, Hare, and Kola base flow is dominant having 61.75%, 62.51%, and 55.37% respectively from total discharge. While in the rest of the catchment in this research, direct runoff is dominant having 51.1% to 76.5% weightage. Unlike of overall BFI, wet season BFI is less than 28.7% in all catchments included in this study, which shows direct runoff is exceedingly dominant stream flow component and their temporal variation of BFI in both condition so this research is alarming that, soon or later the occurrence of flood within all rift valley lakes basin is expected.

CONCLUSION

This study has explored the comparison of Digital graphical and Recursive Digital filter baseflow separation method. In this comparison, seven RDF (EWMA, one parameter, Ihacres, Bougthon two parameter, Chapman, Lynie Holick, and Eckhart filter) and two digital graphical approaches (Local minimum and Fixed interval) were compared in lake dominated basin, rift valley lakes basin. The separation of all methods was carried out manually by changing parameters in each method with the help of BFI 3.0 tool. To check the performance all separation method R2 and root mean square error (RMSE) were used by using stream flow dry season from (December to September) as observed flow while separated flow within those months were considered as simulated or separated flow accordingly Lynie-Hollick, EWMA method performs better than other seven separation methods in the basin, nevertheless none of DGM executes well; and finally baseflow index (BFI) in each catchment are computed the result showed The baseflow is the dominant stream flow component in Kulfo and Hare catchment but in the rest of the catchment direct runoff is highly dominant by using overall BFI. During wet/rainy season, direct runoff is still principal; as a result soon or later the occurrence of flood in every part of the basin is inevitable if necessary precaution and measures are taken. Subsequently, existing and future water resource development attempts may employ this estimation approach for low flow forecasting, baseflow trend analysis, as well as planning and design water resources project.

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