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Attribution and Streamflow Sensitivity Analysis in the Upper Blue Nile River Basin Using a Top-down Modeling Framework

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ABSTRACT

This study applied the Budyko framework and elasticity method to quantify the relative contribution of climate and watershed characteristics to streamflow changes in 95 watersheds in the Upper Blue Nile River Basin (UBNRB). The Water and Energy Processes (WEP) model was successfully verified and used to simulate the streamflow and potential evapotranspiration of the watersheds. The study period was divided into base (1983-1998) and change (1999-2018) periods based on Pettitt's test to assess the changes in streamflow. Precipitation showed moderate fluctuations during the study period (1983-2018) with an increasing trend. However, potential evapotranspiration exhibited very low fluctuation, leading to a lower contribution to streamflow changes than precipitation. The watershed characteristics coefficient (ω) decreased overall during the study period. Nearly 81% of the UBNRB watersheds had aridity index values between 0.6 and 1.1, indicating humid conditions. Watersheds with higher aridity index and lower ω were more sensitive to streamflow change. Streamflow in the UBNRB tended to increase more due to changes in watershed characteristics than due to climate variations. Nearly 68% of the watersheds showed an increase in streamflow during the change period due to the combined effects of climate and watershed characteristic variations. Overall, the Eastern and Southern source regions and the Northwestern lowlands of the basin were highly affected by these changes. These areas need more attention to sustainably manage the basin's water resources.

Keywords: Streamflow sensitivity; Budyko framework; Attribu-tion analysis; Blue Nile River

1. INTRODUCTION

Streamflow is a key water cycle component that provides water for human consumption, irrigation, ecological demand, and industrial uses. Changes in streamflow could stem from various factors, including changes in precipitation and temperature patterns as well as anthropogenic activities such as water withdrawals and land use changes [1–3]. Sensitivity and attribution analysis of streamflow is one of the tools for understanding the effect of the driving factors of streamflow change [4–6]. The results of such an understanding inform better water management decisions.

The Budyko hypothesis [7] is a widely used framework for streamflow sensitivity and attribution analysis [8,9]. It is a powerful method that illustrates the strong relationships between water availability and energy balance at larger spatial and temporal scales [10,11]. A study by [12] applied the Budyko framework and Fu's solution [10] to model the water balance relationships of the UBNRB. Based on the analysis of monthly and annual streamflow from 20 catchments, the study identified areas with distinctive evaporation ratios and runoff coefficients. The Budyko framework and Fu's solution were applied to quantify streamflow sensitivity to climatic and watershed characteristics factors. Additionally, the study separated the contribution of these factors to overall mean annual streamflow changes. Previous studies often treated the entire basin as a single unit to estimate runoff sensitivity, thereby overlooking spatial heterogeneity. of climate and watershed characteristics in the basin. However, this study subdivided the UBNRB into 95 smaller sub-basins and analyzed the streamflow, climate, and watershed characteristics information to reflect the actual conditions. Therefore, the objectives of this study are to (1) estimate streamflow sensitivity to climatic and watershed characteristics variation and (2) separate the relative contribution of climate and watershed characteristics on the mean annual streamflow of UBNRB. The results of this study can be used to inform water resources planning and management in the UBNRB.

2. Materials and Methods

2.1 The study area

The Upper Blue Nile River Basin (UBNRB) (Figure 1 (a)) is located in northwestern Ethiopia and contributes more than 60% of the annual Nile River flow [13]. As climate change raises the temperatures and modifies precipitation patterns, the region will likely face periodic water and food insecurities [14,15]. Given the potential future challenges of the region, it is imperative to understand how different factors such as climate and local watershed alterations affect water availability in the basin.

2.2 Methodology for investigation

Pettit's test [16] was used to identify if there was a point change in the streamflow series during the study period 1983-2018. Additionally, the Budyko framework (equation 1) was employed to describe the basin's mean annual water balance as a function of precipitation and evapotranspiration.

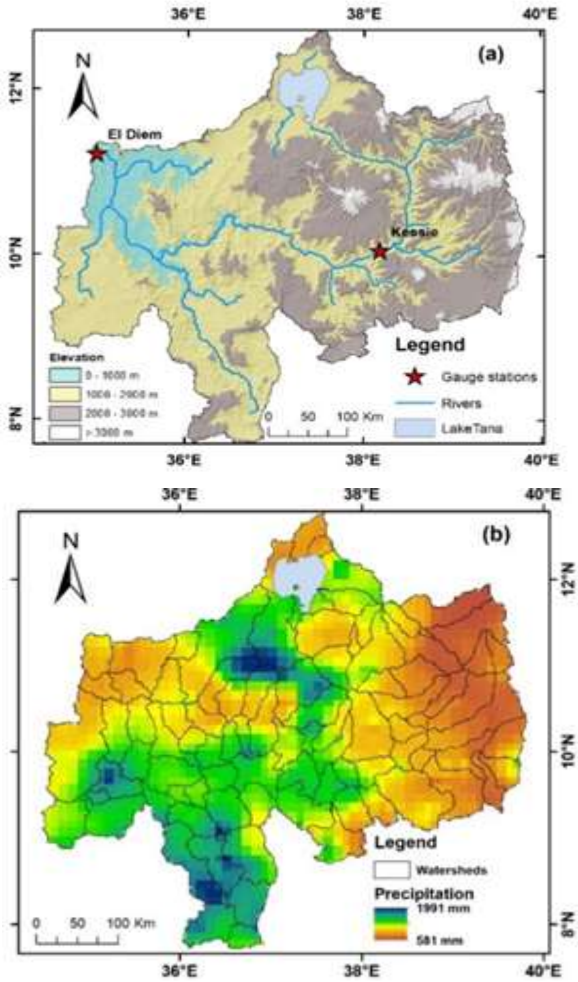


Fig 1a. Digital Elevation Map of the Upper Blue Nile River basin with Model calibration gauge stations, and Fig 1b. Mean annual precipitation from ENACTS dataset

$$\frac{E}{P} = f(E_0/P) \quad \text{--- (1)}$$

where E is actual evapotranspiration, E_0 is potential evapotranspiration and P is precipitation.

The Budyko framework provides solutions for understanding the water balance of an area and how it is affected by changes in climate, topography, and human activities such as land use and water management [7,17–19]. It is based on empirical observations of water and energy balance in different regions. It can be used to assess the impact of climate change and anthropogenic changes on water resources.

One of the key features of the Budyko framework is its ability to describe the relationship between precipitation and evaporation in arid and humid conditions [12,20,21]. The framework can identify areas where precipitation exceeds potential evapotranspiration (i.e., humid conditions) and vice versa. This information can be used to inform water management decisions, such as the implementation of water conservation measures.

Another important aspect of the Budyko framework is its consideration of the impact of climate change and anthropogenic changes on water resources. The framework can be used to assess the potential impact of changes in precipitation and evapotranspiration on water balance and to identify areas particularly vulnerable to water scarcity.

Numerous Budyko-type empirical relationships have been proposed to include other explanatory factors such as watershed characteristics [11,22,23], plant available water [24,25] and soil water holding capacity [26].

Specifically, this study applied the Budyko-type equation given in equation 2. The equation was developed by [10] and revisited by [11].

$$\frac{E}{P} = 1 + \frac{E_0}{P} - \left[1 + \left(\frac{E_0}{P}\right)^{\omega}\right]^{1/\omega} \quad \text{--- (2)}$$

Where ω is the watershed characteristics coefficient and the remaining variables are defined in equation 1.

The watershed characteristics coefficient represents the integrated effects of catchment characteristics such as vegetation cover, soil properties and catchment topography on the water balance of a watershed. Two important assumptions need to be made to estimate the sensitivity of streamflow to climate and catchment characteristics changes: steady-state water balance and negligible transient changes in storage over time [4,5]. For a steady state condition, a time scale is required whereby catchment storage changes are negligible compared to the magnitudes of other fluxes such as precipitation, evapotranspiration and streamflow. The suitable time scale for such conditions would be an annual scale. The second assumption requires negligible transient changes in storage so that the change over time in the catchment is from one steady state to another. Based on these assumptions, the proportional change in streamflow due to climate and watershed characteristics can be formulated using the Budyko framework. The catchment's water balance at a mean annual scale can be given using the first assumption: P = E + Q, where P is precipitation, E is evaporation, and Q is streamflow. As a result, equation 2 can be easily computed for mean annual streamflow as follows:

$$Q = [P^{\omega} + E_0^{\omega}]^{1/\omega} - E_0 \quad \text{--- (3)}$$

Applying partial differentiation to equation 3, yields the sensitivity of Q to climatic factors (P, E_0) and the catchment characteristics coefficient (ω) can be expressed as:

$$\frac{\partial Q}{\partial P} = \left[1 + \left(\frac{E_0}{P}\right)^{\omega}\right]^{(1/\omega - 1)} \quad \text{--- (4)}$$

$$\frac{\partial Q}{\partial E_0} = \left[1 + \left(\frac{P}{E_0}\right)^{\omega}\right]^{(1/\omega - 1)} \quad \text{--- (5)}$$

$$\frac{\partial Q}{\partial \omega} = [P^{\omega} + E_0^{\omega}]^{1/\omega} . \left[\left(-\frac{1}{\omega^2}\right) . \ln(P^{\omega} + E_0^{\omega}) + \frac{1}{\omega} . \frac{1}{P^{\omega} + E_0^{\omega}} . (\ln P . P^{\omega} + \ln E_0 . E_0^{\omega})\right] \quad \text{--- (6)}$$

The partial differential terms on the left side of the equations represent sensitivity coefficients, also known as elastic coefficients. An elastic coefficient measures the responsiveness of runoff to changes in a given factor, and a higher value indicates that changes in that factor have a larger impact on runoff [10,27 -28]. For example, if the elastic coefficient for precipitation is high, an increase in precipitation will lead to a larger increase in runoff. The term E_0/P in equation 4 is the aridity index. The aridity index reflects the balance between precipitation and potential evapotranspiration and can help identify arid areas in the basin. An area with an aridity index of more than one is defined as arid. The catchment characteristics coefficient (ω) can be estimated by minimizing the difference between measured and estimated streamflow for various values of ω. In this study, we estimated ω for each watershed by minimizing the errors between WEP simulated streamflow and streamflow estimated by equation 3. Based on the negligible transient storage change assumption, the total differential of Q can be expressed as:

$$\boldsymbol{dQ = \frac{\partial Q}{\partial P}.dP + \frac{\partial Q}{\partial E_0}.dE_0 + \frac{\partial Q}{\partial \omega}.d\omega} \qquad \text{--- (7)}$$

Where dP, dE_0 and dω represent precipitation, potential evapotranspiration and watershed characteristics changes between the base and change periods.

2.3 Data sources

In this study, different spatial and station datasets were used. The HYDRO1k DEM was acquired from USGS for watershed delineation. Precipitation and temperature information were derived from the Enhancing National Climate Services (ENACTS) datasets of the National Meteorology Agency of Ethiopia. Landcover datasets from NASA and USGS were also utilized. Soil information was extracted from the FAO database. To calibrate and validate the hydrologic model, streamflow information obtained from the Ethiopian Ministry of Water and Energy was used. The mean annual precipitation derived from the ENACTS dataset is shown in Figure 1 (b). The temporal extent of the hydrometeorological datasets used spans from 1983 to 2018.

2.4 Hydrological simulation

To generate streamflow for the watersheds in the UBNRB, the Water and Energy Processes (WEP) hydrological model was used. The WEP is a distributed hydrological model capable of simulating various hydrological processes, including evapotranspiration, surface runoff, and sub-surface runoff [29,30]. In this study, the model was used to simulate the streamflow of UBNRB during 1983-2018. Based on the DEM data, 95 watersheds of the basin were delineated (Figure 1 (b)), and streamflow at the outlets of these watersheds was used to examine runoff sensitivity and quantify the contribution of climate and watershed characteristics to streamflow change.

The model was calibrated during 1992-2004 and validated during 2005-2014 using data from two calibration sites: Kessie and the basin outlet (El-Diem) stations (Figure 2). Evaluation metrics such as the Kling-Gupta efficiency (KGE), Nash Sutcliff Efficiency (NSE), and Percent Bias (PBIAS) [31,32] were used to assess model performance.

3. RESULTS AND DISCUSSIONS

3.1 Model performance

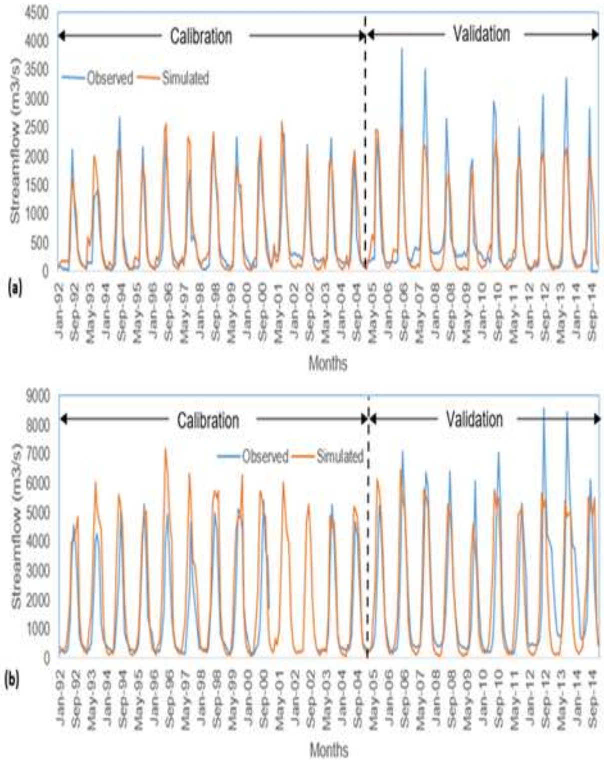


Fig 2a. Calibration and validation outputs of the WEP model simulations at Kessie, and Fig 2b. El-Diem gauge stations

Table 1. Evaluation metrics results for calibration and validation periods

Metrics	Calibration (1992-2004)		Validation (2005-2014)	
	Kessie	El-Diem	Kessie	El-Diem
KGE	0.82	0.57	0.85	0.77
NSE	0.78	0.41	0.79	0.54
PBIAS	15.42	41.26	-7.63	-1.83

The simulated streamflow of UBNRB at two locations is compared with observed discharges (Figure 2). The location of these gauge stations is given in Figure 1 (a). The performance of the model during calibration and validation is shown in Table 1.

Good values of the goodness of fit indices were obtained at the internal both flow stations during the calibration period. However, during the validation period, the performance measures except the PBIAS show a slight reduction. Nevertheless, the model was able to reproduce the flow patterns during this period.

3.2 Streamflow and climate patterns

Figure 3 visually represents the changing trends in annual mean precipitation, potential evapotranspiration, and runoff in UBNRB from 1983 to 2018. The trend for annual mean precipitation is relatively stable, with some fluctuations (Figure 3 (a)). At a 5% significance level, 55.79% of the watersheds show an insignificant upward trend. This suggests that the amount of precipitation received in the UBNRB has not changed significantly over the study period.

Similar insignificant increasing trends of mean annual precipitation in most UBNRB areas are also reported in [33]. The trend for potential evapotranspiration is shown in Figure 3 (b).

Overall, an increasing trend in annual potential evapotranspiration has been observed, although the trend is not statistically significant. This indicates that, while there is a general rise in potential evapotranspiration, it is not substantial enough to be considered a significant change.

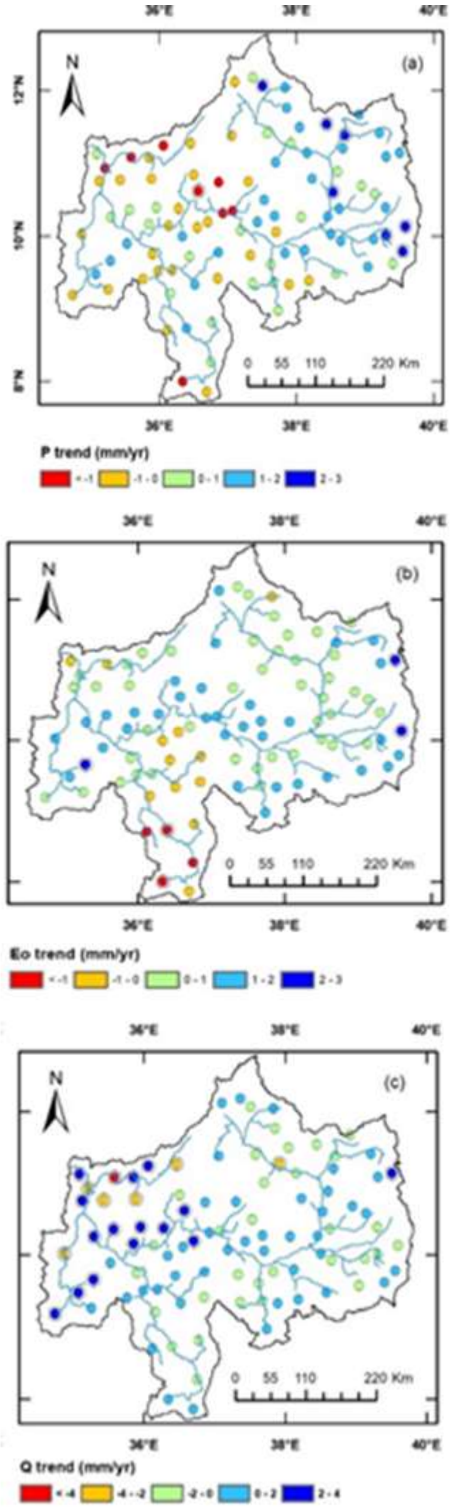


Fig 3a. Trends in annual mean Precipitation
Fig 3b. Mean potential evapotranspiration, and Runoff from 1983 to 2018. Dots with circles indicate statistically significant trends at the 5% significance level

Figure 3(c) shows that 57 watersheds (60.00%) exhibit upward runoff trends, while 32 watersheds (33.68%) show downward trends. The general upward trends of runoff in most of the watersheds may suggest that the water retention capacity of the UBNRB system is being altered due to modifications in catchment responses, likely resulting from land use/land cover changes [33,34]. These changes in runoff patterns highlight the dynamic nature of the watershed and the impact of external factors on its hydrological processes.

3.3 Sensitivity of runoff

Figure 4 illustrates the sensitivity of runoff in each watershed to changes in climatic and watershed characteristics, showing how these factors vary with the aridity index and underlying surface parameters. The solid lines represent the theoretical values of elastic coefficients for various aridity index and watershed characteristics values, while the red dots represent the actual elasticities of each watershed. In general, the UBNRB watersheds exhibit precipitation elasticities of 0.6-0.9. This indicates that an increase of 1 mm in precipitation results in an increase of 0.6-0.9 mm in runoff, suggesting that a larger fraction of the precipitation becomes surface runoff. Most watersheds (77 or 81.1%) have aridity index values between 0.6 and 1.1, with 65 possessing a value below one. Evapotranspiration elasticity in UBNRB mostly varies between -0.5 and -0.2, accounting for 81.1% of the watersheds (Figure 4(b)). This result indicates that an increase of 1 mm in potential evapotranspiration results in a decrease of 0.2-0.5 mm in runoff. The UBNRB watersheds generally exhibit watershed characteristics elasticities between -400 and zero, indicating that an increase of 1 unit in ω results in a decrease of up to 400 mm in annual runoff (Figure 4(c)).

3.4 Analysis of attribution

Figure 5 shows the contribution of climate and watershed characteristics to changes in mean annual streamflow in the 95 watersheds in the UBNRB. Catchment

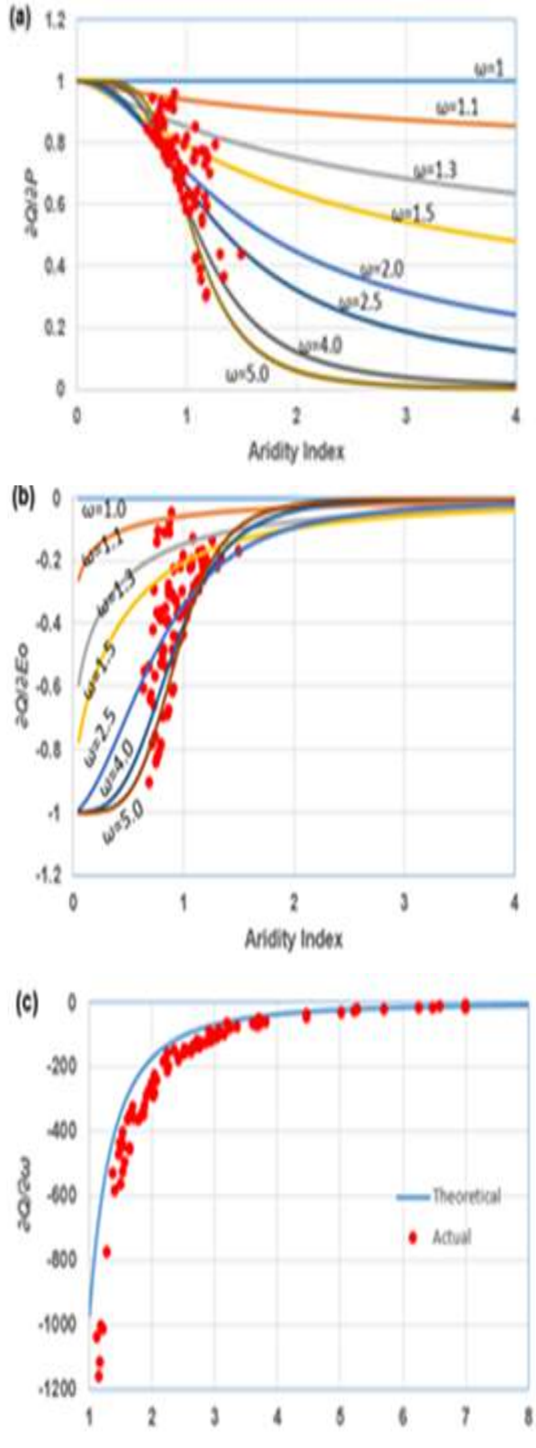


Fig 4a Relationships of the elastic coefficient of precipitation, Fig 4b. Potential evapotranspiration, and Fig 4c. watershed characteristics with the Aridity Index and underlying surface parameters

characteristics change induced a wide range of increasing and decreasing mean annual streamflow shifts. In 52 (54.7%) of the watersheds, variation in watershed characteristics contributed to a decrease in streamflow.

Compared to watershed characteristics changes, climate variation tends to contribute towards increased streamflow.

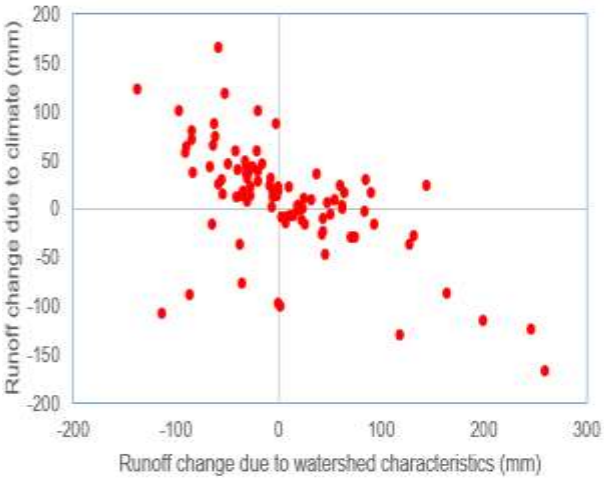
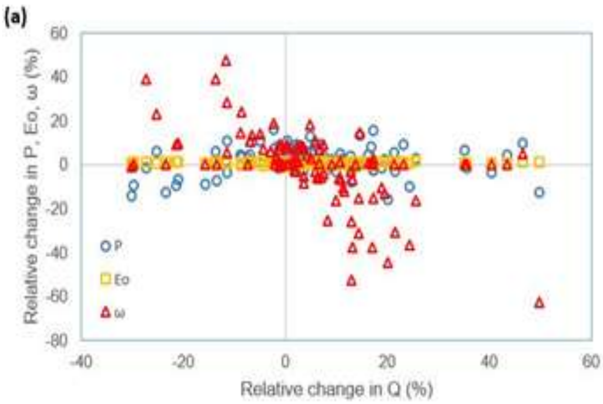


Fig 5. Climate-induced vs. Watershed characteristics-induced streamflow changes for the 95 watersheds in the UBNRB



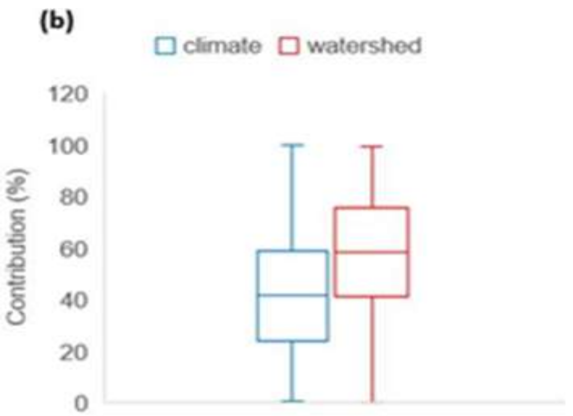


Fig 6a. Relative runoff change due to precipitation, potential evapotranspiration, and watershed characteristics coefficient, and Fig 6b. Box plot showing the relative contribution of climate and related factors

Climate contributed to increased streamflow in 63 (66.3%) watersheds. The relative change in climate and watershed characteristics as well as streamflow, is given in Figure 6. Potential evapotranspiration exhibits the least fluctuation over the years, with 95% of the watersheds exhibiting a very low variation ranging between 0.1% and 1.5% (Figure 6 (a)). Precipitation in all the watersheds varied between -20% and 20%, with 66.3% receiving increased precipitation. Conversely, the watershed characteristics coefficient varied considerably over the study period, with nearly 54% of the watersheds exhibiting a decrease in ω between the base and change periods. The overall contribution of watershed characteristics change to runoff variation is larger than the contribution due to climate variation (Figure 6(b)). This indicates that the majority of watersheds in the UBNRB experience streamflow changes primarily due to alterations within the catchments.

4. CONCLUSION

In this study, the Budyko framework and elasticity method were applied to quantify the relative contributions of climate and watershed characteristics to streamflow changes in 95 watersheds within the Upper Blue Nile River Basin (UBNRB). The findings reveal several key conclusions. First, precipitation exhibited moderate fluctuations over the study period (1983-2018) with a discernible increasing trend, while the watershed characteristics coefficient (ω) showed an overall decrease. Second, approximately 81% of UBNRB watersheds had aridity index values ranging between 0.6 and 1.1, indicating humid conditions. Third, streamflow in the UBNRB appeared to be more influenced by changes in watershed characteristics than by variations in climate. Lastly, the Eastern and Southern source regions, alongside the Northwestern lowlands of the basin, were notably impacted by climate and watershed alterations, underscoring the necessity for enhanced water resource management strategies in these areas.

REFERENCES

[1] X.Lv, S.Liu, S.Li N.Ni, T.Qin, and Q.Zhang,, “Quantitative estimation on contribution of climate changes and watershed characteristic changes to decreasing streamflow in a typical basin of yellow river”, Front. Earth Sci. vol.9, p.752425, 2021. doi:10.3389/feart.2021.752425.1

[2] P.C.D.Milly, J.Betancourt, M.Falkenmark, R.M. Hirsch, Z.W. Kundzewicz, Z.W, D.P Lettenmaier, and R.J. Stouffer, “Stationarity Is dead: Whither water management?”, Science , vol. 319, pp.573–574, 2008. doi:10.1126/science.1151915

[3] T.P.Barnett, D.W.Pierce, H.G.Hidalgo, C.Bonfils, B.D.Santer, T.Das, G.Bala, A.W.Wood, T.Nozawa and A.A.Mirin, “Human-induced changes in the Hydrology of the Western United States”, Science , vol. 319, pp.1080–1083, 2008. doi:10.1126/science.1152538.

[4] M.L.Roderick and G.D.Farquhar, “A simple framework for relating variations in runoff to variations in climatic conditions and catchment properties”,Water Resources Research, vol.47, 2010WR009826, 2011. doi:10.1029/2010WR009826.

[5] R.J.Donohue, M.L.Roderick and T.R.McVicar, “Assessing the differences in sensitivities of runoff to changes in climatic conditions across a large basin”. Journal of Hydrology, vol.406, pp.234–244, 2011. doi:10.1016/j.jhydrol.2011.07.003.

[6] H.Yang, D.Yang and Q.Hu, “An error analysis of the budyko hypothesis for assessing the contribution of climate change to runoff”, Water Resources Research, vol. 50, pp.9620–9629, 2014. doi:10.1002/2014WR015451.

[7] M.I.Budyko, “Climate and life”, International geophysics series, Academic Press, New York, 1974. ISBN 978-0-12-139450-9.

[8] E.Hasan, A.Tarhule, P.E.Kirstetter, R.Clark, and Y.Hong, “Runoff sensitivity to climate change in the Nile River basin”, Journal of Hydrology , vol. 561, pp.312–321, 2018. doi:10.1016/j.jhydrol.2018.04.004.

[9] A.M.Carmona, M.Renner, A.Kleidon and G.Poveda, “Uncertainty of runoff sensitivity to climate change in the Amazon River basin”, Annals of the New York Academy of Sciences, no.1504, pp. 76–94, 2021. doi:10.1111/nyas.14515.

[10] B.P.Fu, “On the calculation of the evaporation from land surface”, Chinese Journal of Atmospheric Sciences, vol.5, pp..23–31, 1981.

[11] L.Zhang, K.Hickel, W.R.Dawes, F.H.S.Chiew, A.W.Western and P.R.Briggs, “A rational function approach for estimating mean annual evapotranspiration”, Water Resources Research, vol.40, p.2003WR002710,2004.doi:10.1029/2003WR002710.

[12] S.Tekleab, S.Uhlenbrook, Y.Mohamed, H.H.G. Savenije, M.Temesgen and J.Wenninger, “Water balance modeling of upper Blue Nile catchments using a top-down approach”, Hydrol. Earth Syst. Sci., vol.15, pp.2179–2193, 2011. doi:10.5194/hess-15-2179-2011.

[13] D.Conway, “From headwater tributaries to international river: Observing and adapting to climate variability and change in the nile basin. global environmental change”, vol.15, pp.99–114, 2005. doi:10.1016/j.gloenvcha.2005.01.003.

[14] K.Burrows, P.Kinney, “Exploring the climate change, migration and conflict Nexus”, IJERPH vol.13, p.443, 2016.doi:10.3390/ijerph13040443.

[15] S.Asseng, A.M.S.Kheir, B.T.Kassie, G.Hoogenboom, A.I.N.Abdelaal D.Z.Haman, and A.C.Ruane, “Can Egypt become self-sufficient in wheat? Environ”, Res. Lett., vol.13, p.094012, 2018. doi:10.1088/1748-9326/aada50.

[16] A.N.Pettitt, “A non-parametric approach to the change-point problem”, Applied Statistics, vol.28, no.126, 1979.doi:10.2307/2346729.

[17] G.Gan, Y.Liu and G.Sun, “understanding interactions among climate, water, and vegetation with the Budyko framework”, Earth-Science Reviews, no.212, p.103451, 2021. doi:10.1016/j.earscirev.2020.103451.

[18] G.Sposito, “Understanding the Budyko equation”, Water, vol.9, p.236, 2017. doi:10.3390/w9040236.

[19] D.Li, M.Pan, Z.Cong, L.Zhang and E.Wood, “Vegetation control on water and energy balance within the Budyko framework”, Water Resources Research, vol.49, pp.969–976, 2013. doi:10.1002/wrcr.20107.

[20] S.Han, H. Hu, D.Yang and Q.Liu, “irrigation impact on annual water balance of the oases in tarim basin, Northwest China”, Hydrological Processes, vol. 25, pp.167–174, 2011.doi:10.1002/hyp.7830.

[21] X.Chen,, N.Alimohammadi and D.Wang, “Modeling interannual variability of seasonal evaporation and storage change based on the extended Budyko framework”, Water Resource, vol.49, pp.6067–6078, 2013. doi:10.1002/wrcr.20493.

[22] H.Yang, D.Yang, Z.Lei and F.Sun, “New analytical derivation of the mean annual water-energy balance equation”, Water Resources Research, vol.44,2007WR006135,2008. doi:10.1029/2007WR006135.

[23] Choudhury and J.Bhaskar, “Evaluation of an empirical equation for annual evaporation using field observations and results from a biophysical model”, Journal of Hydrology, no.216, pp.99–110, 1999. doi:10.1016/S0022-1694(98)00293-5

[24] L.Zhang, W.R. Dawes and G.R.Walker, “Response of mean annual evapotranspiration to vegetation changes at catchment scale”, Water Resources Research, vol.37, pp.701–708, 2001. doi:10.1029/2000WR900325.

[25] R.J.Donohue, M.L.Roderick and T.R.McVicar, “On the importance of including vegetation dynamics in Budyko’s hydrological model”, Hydrol. Earth Syst. Sci. 2007, vol.11, pp.983–995, 2007 .doi:10.5194/hess-11-983-2007.

[26] A.Porporato, E.Daly and I.Rodriguez-Iturbe,“ Soil water balance and ecosystem response to climate change”,The American Naturalist,no.164, pp.625–632, 2004. doi:10.1086/424970.

[27] S.Huang, J.Chang, Q.Huang, Y.Chen and G.Leng, “Quantifying the relative contribution of climate and human impacts on runoff change based on the Budyko hypothesis and SVM model”, Water Resour Manage, no.30, pp.2377–2390, 2016. doi:10.1007/s11269-016-1286-x

[28] P.E.Todhunter, C.C.Jackson and T.H.Mahmood, “Streamflow partitioning using the Budyko framework in a northern glaciated watershed under drought to deluge conditions”, Journal of Hydrology, no.591, p. 125569, 2020. doi:10.1016/j.jhydrol.2020.125569.

[29] Y.Jia, G.Ni, Y.Kawahara and T.Suetsugi, “Development of WEP model and its application to an urban watershed”, Hydrological Processes, no.15, pp.2175–2194, 2008. doi:10.1002/hyp.275.

[30] Y.Jia, G.Ni, J.Yoshitani, Y. Kawahara and T.Kinouchi, “Coupling simulation of water and energy budgets and analysis of urban development impact”, J. Hydrol. Eng., vol.7, pp.302–311, 2002. doi:10.1061/(ASCE)1084-0699(2002)7:4(302).

[31] H.V.Gupta, S.Sorooshian and P.O.Yapo, “Status of automatic calibration for hydrologic models: comparison with multilevel expert calibration”, J. Hydrol. Eng., vol.4, pp.135–143, 1999. doi:10.1061/(ASCE)1084-0699(1999)4:2(135).

[32] D.N.Moriasi, J.G.Arnold, R.LVan Liew; R.L. Bingner, R.D.Harmel and T.L.Veith, “Model evaluation guidelines for systematic quantification of

accuracy in watershed simulations", Transactions of the ASABE, no.50, pp.885–900, 2007. doi:10.13031/2013.23153.

[33] T.G.Gebremicael, Y.A.Mohamed, G.D.Betrie, P.Van Der Zaag and E.Teferi, "Trend analysis of runoff and sediment fluxes in the upper Blue Nile basin: A combined analysis of statistical tests, physically-based models and Landuse maps", Journal of Hydrology, no.482, pp.57–68, 2013. doi:10.1016/j.jhydrol.2012.12.023.

[34] Z.K.Tesemma, Y.A.Mohamed, T.S.Steenhuis, "Trends in rainfall and runoff in the blue nile basin: 1964–2003", Hydrological Processes 2010, no.24, pp.3747–3758, 2010. doi:10.1002/hyp.7893.