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Review Paper

Review of Rainfall-Runoff Modelling in Ethiopia

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Rainfall-Runoff modelling is critical to the understanding of the hydrological process and hydrological models are crucial tools for water resources planning, developments and management in a sustainable approach. Currently, a lot of models developed throughout a world and researchers conducting researches to check the model performances in different areas. The most commonly used and freely available models are Hydrologic Engineering Centre-Hydrologic Modelling System (HEC-HMS), Hydrologiska Byråns Vattenbalansavedlning (HBV) and Soil Water Assessment Tool (SWAT). In this review, a review was done to evaluate rainfall-runoff modelling in Ethiopia. The highest model's performance results using HEC-HMS model coefficient of determination (R^2) value 0.925 and 0.842, and Nash Sutcliffe efficiency (NSE) value 0.884 and 0.746, HBV were in R^2 0.85 and 0.84, and NSE value 0.80 and 0.78, and SWAT model were 0.82 and 0.78, and NSE 0.70 and 0.71 in calibration and validation respectively. The most reputable model was SWAT performed average performance evaluation most studies and HEC-HMS model performed well than other models reviewed during the study. This review will help the researchers, policymakers and management in giving the overview summary of rainfall-runoff modelling

Keywords: *Calibration, HBV, HEC-HMS, SWAT, Validation*

1. Introduction

The most common problem currently was to select an appropriate model for specific research from plenty of models. Hydrological models simulate the hydrological processes within catchments. Simulation of the hydrological process allows us to address the impacts on water resources, management and how to use water resource sustainably [1]. Rainfall-runoff modelling plays a very significant role for purposes of water resources development; inter-basin water transfer and control and management the water resources, and thus do help in decision making, policy formulations, and other benefits [2]. Currently, there are several hydrological models developed to model the rainfall-runoff process for a catchment. Therefore, the main problem often encounters is to select the appropriate hydrologic model for a specific catchment [3]. Nowadays, hydrological models are good for representing hydrological characteristics. Although many studies have been carried out using these basin-scale models to estimate and the most common models used in Ethiopia were such as SWAT, HBV and HEC-HMS models. In different parts of Ethiopia models used model starting before a couple of years, were SWAT model [5] [6] [7] [8] [9] and HEC-HMS were also used by a lot of researchers [10] [11] [12] and the other common model used by most of the researchers were HBV model [13] [14]. However, there were no earlier attempts to review in rainfall-runoff modelling in Ethiopia. Especially by taking common models like SWAT, HBV, HEC-HMS and other models will be discussed in this review. There is a huge gap exists that there is no more understanding and knowledge of the rainfall-runoff modelling particular in Ethiopia. Therefore, the main objective of this review is to review rainfall-runoff modelling in different common hydrological models in Ethiopia.

Review of Rainfall-Runoff Modeling in Ethiopia. The most common and open accessed hydrological models used for rainfall-runoff modelling in Ethiopia were emphasized and discussed under this review. All these models used for modelling of the rainfall-runoff process were very helpful and has been used in different catchments, watersheds and basins of Ethiopia.

2. HEC-HMS Model

The one of the most common models used in Ethiopia were the HEC-HMS model and different researchers applied this model in a different part of Ethiopia and obtain good model performance by model performance during the evaluation of the model.

According to [15] were applied this model in Blue Nile River basin of four watersheds modelled a result was coefficient of determination (R^2) and Nash-Sutcliffe Efficiency (NSE) were 0.73 and 0.71 during calibration and 0.78 and 0.77 during validation, respectively in Gilgel Abay watershed, R^2 and NSE were 0.72 and 0.52 during calibration and 0.76 and 0.56 during validation, respectively in Gumera watershed, R^2 and NSE were 0.77 and 0.52 during calibration and 0.78 and 0.53 during validation, respectively in Ribb watershed and R^2 and NSE were 0.50 and 0.49 during calibration and 0.51 and 0.50 during validation, respectively in Megech watershed. The limitation raised by the researcher in the conclusion section was the model over and a slight underestimate of high flows and this were the common drawbacks of hydrological models. According to [16] were studied using HEC-HMS model and obtain good agreement observed between the gauged and simulated streamflow. The model performance evaluation statics showed that R^2 were 0.83 and 0.74, and NSE were 0.82 and 0.71 in calibration and validation period of modelling respectively. According to [17] were studied with HEC-HMS model in Lake Tana Basin and the model performance evaluated and showed that a good agreement between the observed and simulated runoff during the calibration (R^2=0.925 and NSE=0.884) and validation (R^2=0.842 and NSE=0.746). According to [18] were researched Rainfall-Runoff Modeling using HEC-HMS and SWAT model, the model performances evaluated using the static indices such as for SWAT model R^2 were 0.80 and 0.78, and NSE 0.69 and 0.67 for both calibration and validation respectively. The model performances evaluated using the static indices such as for HEC-HMS model R^2 were 0.88 and 0.87, and NSE 0.75 and 0.73 for both calibration and validation respectively. In general, the simulated streamflow given by the HEC-HMS model is more satisfactory than that provided by the SWAT model. According to [19] were studied in Awash river basin using HEC-HMS model and the model had shown good performance both during calibration and validation with (NSE = 0.855, R^2= 0.867) for calibration and (NSE = 0.739, R^2 = 0.863) for validation respectively. Generally, the researchers recommended that the calibrated parameters to be used for further hydrological investigations in the study area, nearby watersheds, the river basin and this adopted methodology to be used for other ungauged similar catchments around the world. Generally, the result and model performance were acceptable.

3. HBV Model

The next common model used for Rainfall-Runoff modelling in Ethiopia were HBV model. According to [19] were researched two watersheds namely such as Gilgel Abay and Gumara watersheds, the model performance evaluation statics showed that R^2 were 0.84 and 0.85, and NSE were 0.78 and 0.80 in calibration and validation period of modelling respectively for Gilgel Abay watershed and for Gumara watershed the model performance evaluation statics showed that R^2 were 0.79 and 0.87, and NSE were 0.78 and 0.85 in calibration and validation period of modelling respectively. According to [20] were researched two catchments of Lake Ziway watershed such as Meki and Katar catchments. The model performance was evaluated by Nash Sutcliffe efficiency (NSE) were 0.78 and 0.70, and relative volume error (RVE) were -0.80 and 1.96 in Katar catchment and NSE were 0.67 and 0.70, and RVE were -1.63 and 1.27 for Meki catchment in both calibration and validation period respectively. According to [22] were studied Rainfall-Runoff modelling by comparing HBV and SWAT model in the upper Tekeze Basin of Ethiopia. The performance evaluation statics results show that in SWAT model R^2 were 0.82 and 0.72, NSE were 0.73 and 0.72, in HBV light model results are R^2 were 0.714 and 0.71, NSE were 0.707 and 0.71 in both calibration and validation respectively. Moreover, in these above studies that HBV model overestimates the low flow and the peak flow beside SWAT model underpredict the low flow and over predict the peak flow which can be attributed to inadequate representation of the spatial variability of rainfall and poor model responses to high rainfall amount. To summarize the discussion, in most studies discussed HBV model performance was good by using performance evaluation static indices. The template is used to format your paper and style the text. All margins, column widths, line spaces, and text fonts are prescribed; please do not alter them. You may note peculiarities. For example, the head margin in this template measures proportionately more than is customary.

4. SWAT Model

The most common model used in Ethiopia were the SWAT model for Rainfall-Runoff modelling. According to [23] were compared SWAT-CN and SWAT-WB hydrological models and the model performance statistical results were coefficient of determination of 0.71 & 0.77, Nash-Sutcliffe Efficiency of 0.66 & 0.68, for calibration were 0.70 & 0.77, 0.68 & 0.69 respectively for validation, both models indicated the good performance of the model simulation on monthly time step

in SWAT-CN and SWAT-WB models respectively. According to [24] were compared three models such as GRA4J, IHACRES and SWAT in different four watersheds such as Gilgel Abay, Gumera, Megech and Ribb of Upper Blue Nile Basin. In the results section of the study findings in Gilgelabay watershed SWAT model were R^2 were 0.70 and 0.71, NSE were 0.69 and 0.68 was showed the best model, in Gumera watershed IHACRES model were R^2 were 0.79 and 0.80, NSE were 0.79 and 0.78 was showed the best model, in Megech watershed IHACRES model were R^2 were 0.34 and 0.44, NSE were 0.30 and 0.30 was showed the best model and in Ribb GR4J model were R^2 were 0.58 and 0.63, NSE were 0.56 and 0.56 was showed the best model in this watershed in calibration and validation respectively. Moreover, IHACRES model performed well in two watersheds and SWAT model performed well in Gilgelabay watershed. According to [25] were conducted research using SWAT model and obtained model performance was evaluated with R^2 were 0.72 and 0.56, NSE were 0.65 and 0.67, and PBIAS were 6.8 and 8.2 in calibration and validation respectively. According to [26] was studied that Rainfall-Runoff Modeling in the Blue Nile basin. The calibration results revealed the observed data showed a very good agreement with the simulated data with the R^2 and NSE values of 0.90 and 0.84 respectively and validation results of streamflow were acceptable with the R^2 and NSE values of 0.80 and 0.82 respectively.The study in Ziway Lake by SWAT model obtained results of R^2 & NSE were 0.82 & 0.7 during calibration & 0.78 & 0.71 during validation, respectively [27].

5. Conclusion

The most common problem currently was to select an appropriate model for specific research from plenty of models. One of the most common were SWAT, HEC-HMS, HBV and other models used in Ethiopia for Rainfall-Runoff modelling or other hydrological modelling and many researchers use this model due that there was a free tutorial for modelling. In this review that most of the study obtain a SWAT model performance of R2 between 0.70 - 0.90 and 0.56 – 0.80 in calibration and validation respectively and NSE value were between 0.67 – 0.84 and 0.67 – 0.82 in calibration and validation respectively. However, most of the sensitivity analysis were identified by conducting sensitivity analysis using SWAT-CUP. As far as the HEC-HMS model concerned for Rainfall-Runoff modelling. The HEC-HMS model performance of model shows that R^2 between 0.77 - 0.87 and 0.71 – 0.87 in calibration and validation respectively and NSE value were between 0.78 – 0.88 and 0.71 – 0.77 in calibration and validation

respectively. The other most common model in Ethiopia were HBV model were used for hydrological modelling. The model performance was shown in the interval such as in R^2 between 0.71 - 0.87 and 0.71 – 0.79 in calibration and validation respectively and NSE value were between 0.71 – 0.85 and 0.70 – 0.78 in calibration and validation respectively. Moreover, to summarize that rainfall-runoff modelling was a crucial task to understand the rainfall-runoff process and to model this process was a primary task to conduct. Generally, HEC-HMS model was mostly performed very well than other models by depending on performance evaluation statics.

Conflict of interest

The authors declare that they have no conflict of interest

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References

[1] S. M. Tessema, S. G. Setegn, and U. Mortberg, *Watershed Modeling as a Tool for Sustainable Water Resources Management, SWAT Model Application in the Awash River Basin, Ethiopia*. 2015.

[2] V. K. Vidyarthi, A. Jain, and S. Chourasiya, "Modeling rainfall-runoff process using artificial neural network with emphasis on parameter sensitivity," *Model. Earth Syst. Environ.*, vol. 6, no. 4, pp. 2177–2188, 2020, doi: 10.1007/s40808-020-00833-7.

[3] Y. Sajadi Bami, P. Jahangir, S. Hossein, and J. Navid, "Performance Evaluation Of Mike Nam Rainfall-Runoff (R-R) Model In Daily Flow Simulation (Case Study : Gonbad Catchment In Hamedan) " *J. Appl. Eng. Sci.*, vol. 10, no. 1, pp. 1–6, 2020, doi: 10.2478/jaes-2020-0001.

[4] R. Makungo, J. O. Odiyo, J. G. Ndiritu, and B. Mwaka, "Rainfall-runoff modelling approach for ungauged catchments: A case study of Nzhelele River sub-quaternary catchment," *Phys. Chem. Earth*, vol. 35, no. 13–14, pp. 596–607, 2010, doi: 10.1016/j.pce.2010.08.001.

[5] S. G. Setegn, R. Srinivasan, and B. Dargahi, "Hydrological Modelling in the Lake Tana Basin, Ethiopia

Using SWAT Model," *Open Hydrol. J.*, vol. 2, no. 1, pp. 49–62, 2008, doi: 10.2174/1874378100802010049.

[6] Z. M. Easton *et al.*, "A multi basin SWAT model analysis of runoff and sedimentation in the Blue Nile, Ethiopia," *Hydrol. Earth Syst. Sci. Discuss.*, vol. 7, no. 3, pp. 3837–3878, 2010, doi: 10.5194/hessd-7-3837-2010.

[7] S. G. Setegn, B. Dargahi, R. Srinivasan, and A. M. Melesse, "Modeling of sediment yield from anjeni-gauged watershed, Ethiopia using swat model1," *J. Am. Water Resour. Assoc.*, vol. 46, no. 3, pp. 514–526, 2010, doi: 10.1111/j.1752-1688.2010.00431.x.

[8] D. Tibebe and W. Bewket, "Surface runoff and soil erosion estimation using the SWAT model in the Keleta Watershed, Ethiopia," *L. Degrad. Dev.*, vol. 22, no. 6, pp. 551–564, 2011, doi: 10.1002/ldr.1034.

[9] T. Mahtsente, M. M. Assefa, and H. Dereje, "Rainfall-runoff relation and runoff estimation for Holetta River, Awash subbasin, Ethiopia using SWAT model," *Int. J. Water Resour. Environ. Eng.*, vol. 9, no. 5, pp. 102–112, 2017, doi: 10.5897/ijwree2015.0601.

[10] G. Yimer, A. Jonoski, and A. Van Griensven, "Hydrological response of a catchment to climate change, case study on Upper Beles Sub-Basin, Upper Blue Nile, Ethiopia," *Nile Basin Water Eng. Sci. Mag.*, vol. 2, no. January, p. 12, 2009.

[11] M. Seyoum, S. J. van Andel, Y. Xuan, and K. Amare, "Precipitation forecasts for rainfall runoff predictions. A case study in poorly gauged Ribb and Gumara catchments, upper Blue Nile, Ethiopia," *Phys. Chem. Earth*, vol. 61–62, pp. 43–51, 2013, doi: 10.1016/j.pce.2013.05.005.

[12] D. G. Zelelew and S. Langon, "Selection of appropriate loss methods in HEC-HMS model and determination of the derived values of the sensitive parameters for un-gauged catchments in Northern Ethiopia," *Int. J. River Basin Manag.*, vol. 18, no. 1, pp. 127–135, 2020, doi: 10.1080/15715124.2019.1672701.

[13] S. Uhlenbrook, Y. Mohamed, and A. S. Gragne, "Analyzing catchment behavior through catchment modeling in the Gilgel Abay, Upper Blue Nile River Basin, Ethiopia," *Hydrol. Earth Syst. Sci.*, vol. 14, no.

10, pp. 2153–2165, 2010, doi: 10.5194/hess-14-2153-2010.

[14] A. Birhanu, I. Masih, P. van der Zaag, J. Nyssen, and X. Cai, "Impacts of land use and land cover changes on hydrology of the Gumara catchment, Ethiopia," *Phys. Chem. Earth*, vol. 112, no. July 2018, pp. 165–174, 2019, doi: 10.1016/j.pce.2019.01.006.

[15] S. L. Gebre, "Application of the HEC-HMS Model for Runoff Simulation of Upper Blue Nile River Basin," *Hydrol. Curr. Res.*, vol. 06, no. 02, 2015, doi: 10.4172/2157-7587.1000199.

[16] D. G. Zelelew and A. M. Melesse, "Applicability of a spatially semi-distributed hydrological model for watershed scale runoff estimation in Northwest Ethiopia," *Water*, vol. 10, no. 7, pp. 10–12, 2018, doi: 10.3390/w10070923.

[17] B. G. Tassew, M. A. Belete, and K. Miegel, "Application of HEC-HMS Model for Flow Simulation in the Lake Tana Basin: The Case of Gilgel Abay Catchment, Upper Blue Nile Basin, Ethiopia," *Hydrology*, vol. 6, no. 1, 2019, doi: 10.3390/hydrology6010021.

[18] M. A. Aliye, A. O. Aga, T. Tadesse, and P. Yohannes, "Evaluating the Performance of HEC-HMS and SWAT Hydrological Models in Simulating the Rainfall-Runoff Process for Data Scarce Region of Ethiopian Rift Valley Lake Basin," *Open J. Mod. Hydrol.*, vol. 10, no. 04, pp. 105–122, 2020, doi: 10.4236/ojmh.2020.104007.

[19] W. G. Namara, T. A. Damise, and F. G. Tufa, "Rainfall Runoff Modeling Using Hec-Hms: The Case Of Awash Bello Sub-Catchment, Upper Awash Basin, Ethiopia," *Int. J. Environ.*, vol. 1, no. 1, pp. 9–19, 2020.

[20] A. W. Worqlul *et al.*, "Performance of bias corrected MPEG rainfall estimate for rainfall-runoff simulation in the upper Blue Nile Basin, Ethiopia," *J. Hydrol.*, vol. 556, pp. 1182–1191, 2018, doi: 10.1016/j.jhydrol.2017.01.058.

[21] D. W. Goshime, R. Absi, and B. Ledésert, "Evaluation and Bias Correction of CHIRP Rainfall Estimate for Rainfall-Runo ff Simulation over Lake," *Hydrology*, vol. 6, no. 68, pp. 1–22, 2019, [Online]. Available: doi:10.3390/hydrology6030068.

[22] A.A. Temesgen, "Rainfall - Runoff

Modeling: A Comparative Analyses: Semi Distributed HBV Light and SWAT Models in Geba Catchment, Upper Tekeze Basin, Ethiopia," *Am. J. Sci. Eng. Technol.*, vol. 4, no. 2, p. 34, 2019, doi: 10.11648/j.ajset.20190402.12.

[23] T. Tekle and A. Abebe, "Performance Evaluation of SWAT-CN and SWAT-WB Hydrological Models for Estimation of Runoff in the Didessa Watershed, Abbay Basub, Ethiopia," *J. Environ. Earth Sci.*, vol. 6, no. 9, pp. 174–185, 2016.

[24] G. Tegegne, D. K. Park, and Y. O. Kim, "Comparison of hydrological models for the assessment of water resources in a data-scarce region, the Upper Blue Nile River Basin," *J. Hydrol. Reg. Stud.*, vol. 14, no. October 2016, pp. 49–66, 2017, doi: 10.1016/j.ejrh.2017.10.002.

[25] A. Halefom, E. Sisay, T. Worku, D. Khare, M. Dananto, and K. Narayanan, "Precipitation and Runoff Modelling in Megech Watershed, Tana Basin, Amhara Region of Ethiopia," *Am. J. Environ. Eng.*, vol. 8, no. 3, pp. 45–53, 2018, doi: 10.5923/j.ajee.20180803.01.

[26] T. G. Andualem, A. Guadie, G. Belay, I. Ahmad, and M. A. Dar, "Hydrological modeling of upper Ribb watershed, Abbay basin, Ethiopia," *Glob. Nest J.*, vol. 22, no. 2, pp. 158–164, 2020, doi: 10.30955/gnj.003152.