Civil Engineering and Architecture 11(3): 1137-1145, 2023 http://www.hrpub.org
DOI: 10.13189/cea.2023.110303

Hydrological Modeling for Daily Step Flood Forecasts with a Semi Distributed Approach Using the GR4J Model - Camaná River Basin – Arequipa

Alvarado Mendoza Carlos[1], Pérez Campomanes Giovene[1,*], Pérez Campomanes María[2]

[1]Faculty of Engineering, Continental University, Huancayo, Peru
[2]Faculty of Engineering, Universidad Cesar Vallejo –Chimbote, Peru

Received September 8, 2022; Revised January 23, 2023; Accepted February 15, 2023

Cite This Paper in the Following Citation Styles

(a): *[1] Alvarado Mendoza Carlos, Pérez Campomanes Giovene, Pérez Campomanes María , "Hydrological Modeling for Daily Step Flood Forecasts with a Semi Distributed Approach Using the GR4J Model - Camaná River Basin - Arequipa," Civil Engineering and Architecture, Vol. 11, No. 3, pp. 1137 - 1145, 2023. DOI: 10.13189/cea.2023.110303.*

(b): *Alvarado Mendoza Carlos, Pérez Campomanes Giovene, Pérez Campomanes María (2023). Hydrological Modeling for Daily Step Flood Forecasts with a Semi Distributed Approach Using the GR4J Model - Camaná River Basin - Arequipa. Civil Engineering and Architecture, 11(3), 1137 - 1145. DOI: 10.13189/cea.2023.110303.*

Abstract The purpose of this research is to implement a precipitation-runoff model (GR4J) at a daily rate in the Camaná River Basin, from a semidistributed perspective (RS-MINERVE platform), adequately representing the average daily flows in periods of flooding [1]. According to the author, in this way an alternative is sought for the forecast of flows of maximum floods that will allow the issuance of early warnings in the event of the probable occurrence of extreme events, taking into account the thresholds or alert levels that are currently used in the river basin Camana [1]. For the implementation of the Simulation, the RS-Minerve platform was used, with the data between 1964 and 2014. It began in two stages: Calibration (1964-1983) and Validation (2008-2014) for the Hydrometric Stations of Pte., Pendant Sibayo, Pallca Huaruro and Huatiapa [1]. The modeling of the Precipitation - runoff process in the Camaná River Basin was modified, as well as being able to forecast the flows of maxima avenues in the presence of climate change and at a daily rate, using the GR4J Model and the historical information for the Calibration and Validation stages.

Keywords GR4J, RS-Minerve, Nash, River Camana, Arequipa

1. Introduction

The GR4J model that effectively represents the series of daily flows in the Guali River basin (Colombia) [16], these validated results (observed vs simulated flows) have a good response to the mean, and that vary according to the passage of time used [5]. Combinations between CUTOFF and Qm are a conservative and efficient method to successfully complete the lack of data in a series of flows [3]. They are the hydrological models that deliver good results for a good management of water resources [13].

Updates to the GR4J models were investigated by evaluating the advantages and disadvantages of the components of the rain-runoff models used in the five basins and for four 10-year periods of data with different climatic characteristics [9]. In the future this process will allow users to easily obtain simulated data from numerous models that were developed to help make decisions about the effects of human activities on the environment [4]. This database uses the combination of a rain-runoff model and residual analysis using GAMM to identify the effects of land use change on current flow [8].

Studies reveal that the simulated flows overestimate the flows observed during the low-water period, from November to May with a probability between 0 to 70% and underestimate during the periods of high water with Nash from 70 to 95%, which can be attributed to the effect of the total amount of rainfall in June, July, August, September and October on the study area [8]. It is possible to predict water availability through the uses of different regression equations. In themselves, these researchers conclude that, in the countries of South America, simulation models have been developed, although these are not articulated with the needs of the populations [14,15]. Farmers' knowledge coupled with the actual data analysis may concertedly give a clearer understanding of climate change–related instability and patterns in weather variables, which is critically important for planning and implementing appropriate adaptation measures in their farming against climate change in the Kashmir Valley [17]. The results showed a decreasing volumetric water availability from all generated climate data and scenarios, identified by comparing the discharge normal distribution of the historical and future data periods [10]. CHIRPS proved to be an effective alternative tool for deriving spatio-temporal trends of drought using two important hydrometeorological indices, viz., Rainfall Anomaly Index (RAI) and Standardized Precipitation Index (SPI). It may thus point to the fact that the basin could be prone to high precipitation possibly due to climatic anomalies [18].

Thanks to the ease of calibration, we conclude that the GR4J model represents a good alternative to model the Chillón river basin and its use is recommended [2]. The objective of this research is to carry out hydrological modeling with a semi-distributed approach with the GR4J model in the Camaná River Basin, for daily avenue forecasts.

2. Materials and Methods

The present research was divided into three phases which contain the different activities that will fulfill the main objective. In the First Phase: Trends, regionalization, and completion of Hydrometeorological data were collected and analyzed.

The Digital Elevation model was elaborated with Cartographic data, the delimitation of basins and Sub-basins with Shape files of the National Water Authority - ANA and delimitation of the area to be worked [1].

In the Second Phase:

The Hydrological scheme of the Camaná River basin was elaborated within the RS MINERVE Platform, the scope of the GR4J application is rainfall-runoff modeling with few parameters for ungauged catchments. It is a 4-parameter rainfall-runoff model at a daily time pacing that can be used for regional studies. The GR4J model was initially applied to catchments up to 4,000 km^2 in area, but was later used globally for larger catchments (up to 40,000 km^2), in a semi-distributed form, dividing the catchment into homogeneous sub-catchments. Using the GR4J Model, entering the hydrometeorological, geomorphological data, the Hydrological Response Units (URH), virtual stations, river confluences, source, comparator between the observed versus simulated flows. The Objective Function (OF) was determined [1].

The accuracy in the simulation of the flows, produced in the Hydrological Model, is calculated by performing the difference between the Simulated Flow and the Observed Flow. During the Calibration process a set of indicators are used to optimize the model by comparing the response value of the Hydrological Model and the Simulated Flow with Observed Flow, which allows us to evaluate the robustness of the calibrated Model in different periods within the basin. With the efficiency indicators, an analysis is made of each one of them, as indicated below:

- The Nash-Sutcliffe Coefficient (NSE).
- The Coefficient for logarithm values (Nash-ln).
- The Pearson correlation coefficient (Pearson).
- The Kling-Gupta Coefficient (KGE).
- The Bias Score Coefficient (BS).
- The Relative Root Mean Square Error Coefficient (RRMSE).
- The Relative Volume Bias Coefficient (RVB).
- Coefficient Normalised Peak Error (NPE) [1].

The Calibration period (01/01/1964 to 31/08/1983 > 19 years = 7269 days) and the Validation period (01/09/2008 to 31/12/2014 -> 6 years = 2284 days) were defined.

The run of the Hydrological Model and Coupled submodels and use of the Expert Module were carried out where optimization algorithms were used [1].

In the Third Phase:

Calculation of the efficiency of calibration and validation models by sub-basins through the analysis of efficiency indicators.

3. Results

After concluding the calculations, the following results were obtained:

Table 1. Comparison of Efficiency Indicators and Objective Function in the Validation Stage of the GR4J Model – Camaná Basin [1]

Zone	Hydrometric station	CALIBRATION				VALIDATION			
		NSE	Adjustment	F0	Adjustment	NSE	Adjustment	F0	Adjustment
A - B	Puente Colgante Sibayo	0.8	Very Good	0.47	Regular	0.7	Very Good	0.41	Acceptable
E – F	Pallca - Huaruro	0.9	Excellent	0.60	Acceptable	0.89	Excellent	0.65	Good
C, D, G, H, I	Huatiapa	0.9	Excellent	0.54	Acceptable	0.88	Excellent	0.61	Good

Source: [1]

According to Table 1, for zones (A-B) we obtain a Very Good rating, and for the case of Zones (E - F) and (C, D, G, H and I), we have the Excellent rating

Table 2. Behavior of Average, Maxima and Minima Monthly Flows in the Hydrometric Stations of the Camaná Basin

Hydrometric Station:	Qmed(m^3/s)	Qmax-Abs(m^3/s)	Qmin_abs(m^3/s)
Huatiapa	82.497	2400	2.8
Negropampa	57.184	650	2.523
Pallca-Huaruro	16.647	150	2.122
Puente colgante Sibayo	30.874	941.986	0.855

Source: [1]

According to Table 2, the maxima absolute flows were obtained in Huatiapa (2400 m3/s) and the minima was obtained in Pallca-Huaruro (150 m^3/s).

Table 3. Model GR4J – Cuenca del Camaná

Model	Sub-basins	Hydraulic Structure	Hydrological Station	Calibration	Validation
GR4J	7	Presa Condoroma	Puente. Colgante Sibayo	NSE = 0.77	NSE = 0.70
		Bocatoma Tuti	Palca Huaruro	NSE = 0.86	NSE = 0.89
			Huatiapa	NSE = 0.86	NSE = 0.88

Source: [1]

According to Table 3, and During the process of Hydrological Modeling in the different Hydrometric Stations, Calibration and Validation stages, the values of the parameters X1, X2, X3 and X4 were obtained

Table 4. Result of the Parameters Obtained by Zones with the GR4J Model, Camaná Basin

Model	Parameters	Unit	Pte. Colgante Sibayo / Zone		Pallca - Huaruro/Zone		Huatiapa/Zone				
			A	B	E	F	C	D	G	H	I
GRJ4	X1	mm	0.11	0.02	5.60	0.85	17.42	1199.96	151.60	154.50	18.70
	X2	mm	0.00	0.01	0.00	4.18	1.47	7.00	1.47	6.03	1.51
	X3	mm	0.02	0.13	423.02	17.89	191.31	779.99	488.52	68.47	136.13
	X4	day	2.29	3.50	2.10	2.16	3.00	3.38	2.59	2.00	3.75

From where:

X1 = Maxima capacity of the production reservoir in mm.

X2 = Groundwater exchange coefficient in mm (Parameter representing the maxima storage capacity of the soil).

X3 = Maxima Transit Reservoir Capacity in mm (the storage capacity of the non-linear reservoir is another parameter

X3(mm))

X4 = Time Base of the Unit Hydrograph by day (The time base of both unit hydrographs is represented by a single parameter X4) (see attached picture).

According to [1], in this stage the efficiency indicators and the result of the FO in Pte. Colgante Sibayo, Pallca - Huaruro and Huatiapa are analyzed, using the relationship indicated: OF = 0.4*Nash + 0.3*Nashln + 0.1*Pearson - ABS (0.2*RRMSE) [1].

Table 5. Calibration Process, Model GR4J Zone A-B, Hydrometric Control Station at Pte. Colgante Sibayo (Algorithm SCE-UA)

Zone	Parameters	Zone	Parameters	Indicators	Indicators
A	X1 = 0.1090	B	X1 = 0.0155	Nash = 0.76677	Nash-ln = 0.7018
A	X2 = -0.0007	B	X2 = 0.007	Pearson = 0.889	KGE= 0.72253
A	X3 = 0.024	B	X3 = 0.1337	BS = 0.9998	RRMSE = 0.7044
A	X4 = 2.285	B	X4 = 3.4992	RVB=-0.0138	NPE= -0.1745

FO = 0.4*Nash + 0.3*Nash-ln + 0.1*Pearson - ABS(0.2*RRMSE) = 0.465257575872229

Maxima possible OF value = 0.8

According to Table 5:

- The Nash-Sutcliffe Coefficient (NSE).
- The Coefficient for log values (Nash-ln).
- The Pearson correlation coefficient (Pearson).
- The Kling-Gupta Coefficient (KGE').
- The Bias Score Coefficient (BS).
- The Relative Root Mean Square Error Coefficient (RRMSE).
- The Relative Volume Bias Coefficient (RVB).
- Coefficient Normalised Peak Error (NPE) [1].

Table 6. Calibration Process, Model GR4J, Zone E-F, Pallca - Huaruro Hydrometric Station (Algorithm SCE-UA)

Zone	Parameters	Zone	Parameters	Indicators	Indicators
E	X1 = 5.599	F	X1 = 0.848	Nash = 0.85343	Nash-ln = 0.8717
E	X2 = -0.0003	F	X2 = 4.18	Pearson = 0.92393	KGE= 0.88174
E	X3 = 423.02	F	X3 = 17.895	BS = 0.999	RRMSE = 0.4498
E	X4 = 2.0967	F	X4 = 2.1573	RVB= 0.00022	NPE= 0.0852397

OF = 0.4*Nash + 0.3*Nash-ln + 0.1*Pearson - ABS(0.2*RRMSE) = 0.60530455752458

Maxima possible FO value = 0.8

According to Table 6, it was obtained the calibration process results, with optimal results in the X1 and X2 parameters, both for Nash and Pearson indicators.

Table 7. Calibration Process, Model GR4J Zone C, D, G, H and I, Huatiapa Hydrometric Station (Rosenbrock Algorithm: 2/2 Iteration 2000)

Zone	Parameters	Zone	Parameters	Zone	Parameters	Zone	Parameters	Zone	Parameters
C	X1 = 17.425	D	X1 = 1199.962	G	X1 = 151.599	H	X1 = 154.505	I	X1 =18.696
C	X2 = 1.468	D	X2 = 6.999	G	X2 = 1.47	H	X2 = 6.029	I	X2 = 1.51
C	X3 = 191.308	D	X3 = 779.99	G	X3 = 488.52	H	X3 = 68.472	I	X3 = 136.135
C	X4 = 2.999	D	X4 = 3.37805	G	X4 = 2.593	H	X4 = 1.999	I	X4 = 3.746
	Indicators		Nash = 0.857132		Nash-ln = 0.682		Pearson = 0.926		KGE = 0.907834
	Indicators		BS = 0.99959		RRMSE = 0.4819		RVB = -0.01976		NPE = -0.35064

FO = 0.4*Nash + 0.3*Nash-ln + 0.1*Pearson Correlation Coeff - ABS(0.2*RRMSE) = 0.543536503870042

Máxima possible OF value = 0.8

According to Table 7, by making use of the Expert Module of the RS-Minerve Platform, and the Hydrological Model GR4J at a daily pace, it is observed that converges following the Objective Function formulated, the efficiency indicators, specifically the Nash used to evaluate maxima avenues. It was obtained an NSE = 0.8571 that corresponds to an Excellent Adjustment, and evaluating the Objective function it was obtained OF = 0.5435, (OF 0.50 – 0.69 Acceptable).

Analyzing the Hydrological Modeling in the Hydrological Stations Puente Colgante Sibayo, Pallca Huaruro and Huatiapa in the Calibration and Validation stages. Evaluating the Huatiapa Hydrological Station, the Objective Function: the OF Calibration = 0.544 and the OF Validation = 0.6116 (Good) and for NSE indicator: the NSE Calibration = 0.86, Excellent Fit and the NSE Validation = 0.6116, Source Excellent Fit: [1].

From Table 8, the best results were obtained from the efficiency of the validation of the calibration process of the GR4J model.

Analysis at the Sibayo Suspension Bridge Hydrometric Station:

The Evaluated Series, period: 01/09/1984 until 31/08/1993, the Scatter Plot that compares observed Q vs simulated Q is determined, obtaining the function y = 0.7036X+ 7.2774 and a positive value of R2 = 0.7768 is obtained, close to 1, indicating that the relationship is strong and positive [1].

Analysis at the Pallca - Huaruro Hydrometric Station:

The Evaluated Series, period: 01/10/1963 until 31/08/1978, the Scatter Plot that compares observed Q vs simulated Q is determined, obtaining the function y = 0.8474X + 2.71123 and a positive value of R2 = 0.86, close to 1, is obtained, indicating that the relationship is strong and positive.

Analysis at the Huatiapa Hydrometric Station:

The Evaluated Series, period: 01/09/1997 until 31/12/2014, the Scatter Plot that compares observed Q vs simulated Q is determined, obtaining the function y = 0.8544X + 9.9403 and it obtains a positive value of R2 = 0.86, close to 1, indicating that the relationship is strong and positive.

The analysis of the response of the GR4J Hydrological Model, in the Camaná River Basin, forecasts the flow of Maxima Avenue, and are the indicators that allow us to evaluate the Peak flows (Maxima Avenue), the most representative of the SCE-UA, in each of the areas.

The Objective Function (FO), the resulting value in the various zones and Validation period [1].

Table 8. Result of the Efficiency Indicators in Calibration and Validation stages

Checkpoint/indicator	**Pte. Colgante Sibayo**		**Pallca - Huaruro**		**Huatiapa**	
	Calibration	**Validation**	**Calibration**	**Validation**	**Calibration**	**Validation**
Nash	0.77	0.77	0.85	0.89	0.86	0.88
Nash-ln	0.71	0.71	0.87	0.93	0.68	0.88
Pearson	0.89	0.89	0.92	0.94	0.93	0.94
KGE	0.72	0.72	0.89	0.88	0.91	0.9
BS	1	1	1	1	1	1
RRMSE	0.71	0.71	0.45	0.4	0.48	0.49
RVB	-0.02	-0.02	0	0.04	-0.02	-0.02
NPE	-0.17	-0.17	0.09	-0.03	-0.35	-0.09
OF	0.466	0.414	0.604	0.649	0.544	0.612

According to Table 9, for the Nash-Sutcliffe indicator (NSE), for the Zone (A – B), we have a Very Good rating, and for the case of the Zones (E – F) and (C, D, G, H and I) compared to Table 9, we have the Excellent rating.

In addition, evaluating the previous tables, with the Objective Function (OF), in the zone (A – B), we have the Acceptable rating, and in the case of the Zones (E - F), compared with Tables we have the Good rating and (C, D, G, H and I), we have the Acceptable rating.

Analyzing the NSE value, obtained in the Hydrological Modeling process in the Camaná River Basin, in the Calibration and Validation stages, in the Hydrometric Stations: Siabayo Suspension Bridge, in Calibration Stage NSE = 0.77 and in Validation Stage NSE = 0.70; Palca Huaruro, in Calibration Stage NSE = 0.86 and in Validation Stage NSE = 0.89; Huatiapa, in the Calibration Stage NSE = 0.86 and in the Validation Stage NSE = 0.88, it was observed that in general the values of the NSE in the Calibration Stage were improved in the Validation Stage, allowing the simulated values to approach those observed [1].

From Table 10, it was obtained, during the process of Hydrological Modeling in the different Hydrometric Stations, Calibration and Validation stages, the values of the parameters X1, X2, X3 and X4 were obtained.

The resulting values in Point I are: X1 = 18.69 mm, X2 = 1.51mm, X3 = 136.14 mm and X 4 = 3.75 day.

From Table 11, it was obtained after having carried out the Modeling of Maxima Avenues at a daily pace, with a Semi-distributed approach using the GR4J, in the Camaná River basin, Arequipa-Peru, at the control points, where data on observed average daily flows were obtained, it was possible to obtain the Calibration and Validation of the data simulated by the GR4J model, using the Averages, Maxima and Absolute Minima Monthly data [1].

Table 9. Comparison of Efficiency Indicators and Objective Function in the Validation Stage of the GR4J Model – Camaná Basin

Zone	Hydrological station	Calibration				Validation			
		NSE	Adjustment	F0	Adjustment	NSE	Adjustment	F0	Adjustment
A - B	Puente Colgante Sibayo	0.77	Very good	0.466	Regular	0.7	Very good	0.414	Acceptable
E – F	Pallca - Huaruro	0.85	Excellent	0.604	Acceptable	0.89	Excellent	0.649	Good
C, D, G, H, I	Huatiapa	0.86	Excellent	0.544	Acceptable	0.88	Excellent	0.612	Good

Source: [1]

Table 10. GR4J Model - Camana Basin

Model	Sub-Basin	Hydrologic Structure	Hydrologic Station	Calibration	Validation
GR4J	7	Presa Condoroma	Pte. Colgante Sibayo	NSE = 0.77	NSE = 0.70
		Bocatoma Tuti	Palca Huaruro	NSE = 0.86	NSE = 0.89
			Huatiapa	NSE = 0.86	NSE = 0.88

Table 11. Result of the Parameters Obtained by Zones with the GR4J Model, Camaná Basin

Model	**Parameters**	**Unit**	**Pte. Colgante Sibayo / ZONA**		**Pallca - Huaruro/Zona**		**Huatiapa/Zona**				
			A	B	E	F	C	D	G	H	I
GR4J	X1	mm	0.109	0.0154	5.599	0.8478	17.425	1199.962	151.599	154.505	18.696
	X2	mm	-0.0007	0.00699	-0.0003	4.175	1.468	6.999	1.469	6.0286	1.51
	X3	mm	0.024	0.13374	423.0156	17.895	191.308	779.99	488.517	68.472	136.135
	X4	día	2.285	3.49912	2.096716	2.15725	2.999	3.37805	2.59287	1.999	3.7458

4. Discussion

After having carried out the Maximum Daily Flood Modelling, with a Semi-distributed approach using the GR4J, in the Camaná river basin, Arequipa-Peru, the Calibration and Validation of the data simulated by the GR4J model was achieved, using the Mean, Maximum and Minimum Monthly Absolute data. However, to assess the performance of this hybrid forecasting method, a comparison is made of the relative performances of Bayesian ANN, the GR4J conceptual model and the hybrid streamflow forecasting approach in producing 1 month ahead streamflow forecasts at three critical locations in south-eastern South Australia. These results suggest that the hybrid models developed in this study can take advantage of the complementary strengths of the ANN and GR4J conceptual models [7]. The results of the study indicate that the Génie Rural à 4 paramètres Journalier (GR4J) lumped conceptual model yielded better modeling performance compared to the data-driven models, namely ANN, DNN and RT models.

Moreover, the enhanced version of the GR4J model (i.e. GR6J) also yielded good performance in terms of the recession part [6], and despite the differences in model structure and data used, both models simulated streamflow on a daily time scale with Nash-Sutcliffe coefficients of 0.71-0.82 for the VIC model and 0.63-0.71 for GR4J. Due to the more straightforward structure, parsimonious nature, fewer parameters and reasonable accuracy, the results suggest that a conceptual rainfall-runoff model such as GR4J can be used under insufficient data conditions [11]. Therefore, it must be concluded that the PET formulation has little impact on the results of the GR4J model for these tropical catchments. However, in the context of global changes, particularly the changes that the study area is facing, this result should be taken into account in the analysis of current hydrological processes and the revision of hydrological standards in tropical catchments [8].

5. Conclusions

When performing the analysis in the calibration stage, the Nash- Sutcliffe (NSE) indicator for the Pte. Sibayo Pendant Hydrological Control Stations, obtained the following results: (NSE = 0.77, very good fit), Pallca-Huaruro (NSE = 0.85, Excellent fit) and Huatiapa (NSE = 0.86, Excellent fit), obtaining satisfactory values.

Finally, it was possible to model the Precipitation - runoff process in the Camaná River Basin as well as to be able to Forecast the flows of maxima avenues in the presence of climate change and at a daily pace, using the GR4J Model and historical information for the Calibration and Validation stages.

Acknowledgements

We want to thank Giovani Alfonso Pérez Ramos and Joaquin Davila Morales for the great help in doing the translation of this paper.

REFERENCES

[1] Alvarado, C. (2021). tesis de maestría. Modelación de máximas avenidas a paso diario (1964-2014), con enfoque semidistribuido usando GR4J, en la cuenca del río Camaná, Arequipa-Perú. UNMSM. Lima –Perú.

[2] Astorayme, M., García Hernández, J., Suarez, W., Felipe, O., Hugel, & Molin, W. (2015). Modelización hidrológica con un enfoque semidistribuido en la cuenca del río Chillón, Perú. *Geo atmosferica RPGA*, 109 - 124.

[3] Aybar, C., Fernández, C., Huerta, A., Lavado, W., & Vega, F. (2019). Construction of a high-resolution gridded rainfall dataset for Peru from 1981 to the present day. *Hydrological Sciences Journal*, 1-50.

[4] Bouadi, T., Cordier, M., Moreau, P., Quiniou, R., Salmon-Monviola, J., & Gascuel-Odoux, C. (2016). A data warehouse to explore multidimensional simulated data from a spatially distributed agro-hydrological model to improve catchment nitrogen management. *Environmental Modelling & Software*, 229- 242.

[5] Boudilla, A. (2015). Elaboration of modele hydrometeorologique sous les plateformes athys et gr4j. *elaboration d'un modele hydrometeorologique sous les plateformes athys ET GR4J.*

[6] Cenk Sezen, N. B. (2019). Hydrological modelling of karst catchment using lumped conceptual and data mining models. *Journal of Hydrology*, 98-110.

[7] Greer B. Humphrey, M. S. (2016). A hybrid approach to monthly streamflow forecasting: Integrating hydrological model outputs into a Bayesian artificial neural network,. *Journal of Hydrology*, 623-640.

[8] Japhet Kodja, D., Mahé, G., Amoussou, E., Boko, M., & Paturel, J. (2018). Assessment of the Performance of Rainfall-Runoff Model GR4J to Simulate Streamflow in Ouémé Watershed at Bonou's outlet (West Africa). *Preprints*, 1-18.

[9] JuShin, M., & Kim, C.-S. (2021). Component Combination Test to Investigate Improvement of the IHACRES and GR4J Rainfall–Runoff Models. *Water, 13*, 1-20.

[10] Heryani, N., Kartiwa, B., Sosiawan, H., Rejekiningrum, P., Hari Adi, S., & Apriyana, Y. (2022). Analysis of Climate Change Impacts on Agricultural Water Availability in CimanukWatershed, Indonesia. *Sustainability*(14), 1-20.

[11] Kumari, N. S., Singh Raghuwanshi, N., & Bretreger, D. (2021). Identification of Suitable Hydrological Models for Streamflow Assessment in the Kangsabati River Basin, India, by Using Different Model Selection Scores. *Nat Resour Res, 30*, 4187–4205.

[12] Navas, R., Alonso, J., Gorgoglione, A., & Vervoort, R. (2019). Identifying Climate and Human Impact Trends in Streamflow: A Case Study in Uruguay. *water, 11*(1433), 1-15.

[13] Pechilivanidis, I., Jackson, B., Mcintyre, N., & Wheater, H. (2011). catchment scale hydrological modelling: a review of model types, calibration approaches and uncertainty analysis methods in the context of recent developments in technology and applications. *Global NEST, 13*(3), 193-214.

[14] Perez, G., & Innacone, J. (2021). Effects of Climate Change on the Surface Waters. *IOP Conference Series: Earth and Environmental Science*, 1-8.

[15] Pérez; Innacone. (2020). Impacto del cambio climático en la disponibilidad de las aguas superficiales en sudamerica. *paideia, 10*(1), 173-202.

[16] Rincón Achury, L. (2019). aplicación de los modelos lluvia-escorrentia GR2M y GR4J en la cuenca del rio Guali para la gestión de los recursos hídricos. *aplicación de los modelos lluvia-escorrentia GR2M Y GR4J en la cuenca del rio Guali para la gestión de los recursos hídricos.*

[17] Sheraz, S., Dhekale, B., Jan, R., M, A., Hussain, A., & Aalum Jehangir, I. (2022). Analysis and farmers' perception of climate change in the Kashmir. *Theoretical and Applied Climatology*, 1-15.

[18] Tabassum, F., & Pramod Krishna, A. (2022). Spatio-temporal drought assessment of the Subarnarekha River basin, India, using CHIRPS-derived hydrometeorological indices. *Environ Monit Assess*, 1-18.