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Microbasin Hydrological Modeling Located in a High Andean Zone for Monthly Flows Estimation, Using GR2M, Temez and Lutz Scholtz Models

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Abstract*– In Peruvian remote areas, hydrometric stations records are limited. This limitation delays study of water resource management in high Andean zone of central-southern Peru. Therefore, in this work, hydrological modeling is carried out in Paucarbamba micro-watershed to generate flows from the pluviometric data obtained from the scarce SENAMHI pluviometric stations. These hydrological models are GR2M, Lutz Scholtz and Temez. After results analyzing, Lutz Scholtz model has a satisfactory fit with the following validation coefficients Nash = 1.00, PBIAS = 5.52 and RMSE = 0.05. In conclusion, for generation of monthly mean flows in Paucarbamba microbasin, Lutz Scholtz hydrologic model has better fit according to validation coefficients analysis.

***Keywords*-- hydrologic model, GR2M model, Lutz Scholtz model, Temez model, HEC-H4 software.**

I. Introduction

In Peru, existence of few hydrometric stations and their short records make continu-ous monitoring of monthly average flows difficult [1]. This limitation of knowing historical records of hydrometeorological information such as precipitation, tempera-tures and flow rates makes it difficult to develop adequate studies and hydraulic projects [2]. Estimates of hydrological records involve a series of analysis where the greater the extent, more likely it is to include periods of dry and wet years [3]. There-fore, the application of hydrologic models is one of the solution tools that simplifies this analysis.

Buguña, 2019 [4] faced with the need to know runoff flows of the Bigote River, pro-poses GR2M as a better hydrological model to determine runoff. GR2M obtained an efficiency index of 81 (very good), a correlation coefficient of 0.86 (very good) and a higher modified fit index of 0.87.

Canales et al., 2021 [1] In Peru there are not enough monitoring stations and conse-quently there is scarce hydrometeorological data in the Selva Alta area. Therefore, a modeling of hydrological balance in a sub-basin in high jungle based on the PISCO satellite product and Temez, GR2M and Lutz Scholtz methodologies is pro- posed. GR2M model gave better results, with the following validation coefficients: Nash = 0.70, PBIAS = 2.31, R2 = 0.69 and KGE = 0.74.

In this research its proposed to estimate mean flows in Paucarbamba microbasin, using and comparing the GR2M, Temez and Lutz Scholtz models for a 3-year period. To estimate values, models were calibrated with existing data from the area. Likewise, this research focuses on determining hydrological model that best fits the determination of flows generated in micro-watershed of the Peruvian high Andean zone in absence of flow records. For this purpose, Nash, PBIAS and RMSE coefficients were used to evaluate the model fits.

II. Hydrological models

A. GR2M model

GR2M is a model that simulates monthly mean flows, converts precipitation of a watershed into runoff by running two functions. Which are: production function and a transfer function. [5]

Equations used by this model are divided into the Production and Transfer function, which are detailed below:

1) Production function

$$S_1 = \frac{s+X_1\varphi}{1+\frac{s}{X_1}\varphi} \tag{1}$$

$$P_1 = P + S - S_1 \tag{2}$$

$$S_2 = \frac{s_1(1-\psi)}{1+(1-\frac{S}{X_1})\psi} \tag{3}$$

$$S_1 = \frac{S_2}{(1+(\frac{S_2}{X_1})^{\wedge}3)^{\frac{1}{3}}} \tag{4}$$

$$P_2 = S_2 - S \tag{5}$$

P: Monthly total precipitation (mm/month)
S: Soil reservoir storage (mm)
S_1: Volume of the new soil reservoir (mm)
S_2: Volume of new soil reservoir in second instance (mm)
P_1: Surface runoff (mm)
P_2: Percolation depth (mm)
X_1: Maximum capacity of the soil reservoir (mm)
E: Potential evapotranspiration

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φ: Tanh (P/X_1)
ψ: Tanh (E/X_1)

2) Transfer Function

$$P_3 = P_1 + P_2 \quad (6)$$
$$R_1 = R + P_3 \quad (7)$$
$$R_2 = X_2 R\ (mm) \quad (8)$$
$$Q = \frac{{R_2}^2}{R_2+60} \quad (9)$$

P_3: Effective precipitation (mm)
R: Initial gravity water reservoir storage (mm)
R_1: New gravity water reservoir storage volume (mm)
X_2: Coefficient of subway exchanges (dimensionless)
R_2: New volume (mm)
Q: Average monthly flow (mm)

B. Temez Model

Hydrological simulation model Temez simulates monthly mean flows in any hydrographic basin. The model performs moisture balances on hydrographic processes such as: ascension of atmospheric water vapor, rainfall production, runoff generation and aquifers discharge to rivers. [5].

Equations used to estimate monthly mean flows:

1) Surface contribution

$$T_i = \frac{(P_i - P_0)^2}{P_i - \delta_t - 2P_0} \quad (10)$$
$$I_i = I_{max} * \frac{T_i}{T_i + I_{max}} \quad (11)$$
$$Q_s = T_i - I_i \quad (12)$$

P_0: Runoff threshold (mm)
P_i: Precipitation month “i” (mm)
T_i: Surplus month “i” (mm)
$H_{máx}$: Maximum humidity parameter (mm/month)
H_{i-1}: Antecedent humidity month “i-1” (mm)
PET: Potential Evapotranspiration (mm)
$I_{máx}$: Maximum infiltration parameter (mm/month)
Q_s: Surface runoff (m^3/s)

2) Subsurface supply (Qg)

$$V_i = V_{i-1} - V_i - 1 * e^{-\alpha*\Delta t} * R_i * \left(\frac{1-e^{-\alpha*\Delta t}}{\alpha}\right) \quad (13)$$
$$Q_g = V_{i-1} - V_i * R_i \quad (14)$$

V_{i-1}: Antecedent volume month “i-1”
Q_g: Aquifer discharge (m^3/s)

3) Total, discharge (Qt)

$$Q_t = Q_g + Q_s \quad (15)$$

C. Lutz Scholtz Model

The model consists of two types of structure: a deterministic structure for calculation of monthly mean flows; and a stochastic structure for extended flow series generation. This model was developed in 1979 for watersheds in Peruvian high- lands, within the framework of Germany Republic Technical Cooperation (CTRA) through the Meris II plan. [6].

1) Water balance

$$CM_i = P_i - D_i + G_i - A_i \quad (16)$$

CM_i: Monthly flow (mm/month)
P_i: Precipitation of month “i” (mm)
G_i: Monthly retention (mm/month)
A_i: Effective monthly rainfall supply deficit (mm/month)
D_i: Runoff deficit for month "i" (mm/month)

2) Effective precipitation

$$PE = a_0 + a_1 \times P + a_2 \times P^2 + a_3 \times P^3 + a_4 \times P^4 + a_5 \times P^5 \quad (17)$$

The values of $a_0, a_1, a_2, a_3, a_4\ y\ a_5$ values are shown in Table I.

TABLE I
GR2M parameters

Calculation coefficient according to			
Coefficient	Curve I	Curve II	Curve III
$\boldsymbol{a_0}$	-0.047000	-0.106500	-0.417700
$\boldsymbol{a_1}$	0.009400	0.147700	0.379500
$\boldsymbol{a_2}$	-0.000500	-0.002900	-0.010100
$\boldsymbol{a_3}$	0.000020	0.000050	0.000200
$\boldsymbol{a_4}$	-5.00E-08	-2.00E-07	-9.00E-07
$\boldsymbol{a_5}$	2.00E-10	2.00E-10	1.00E-09

Nota 1 Adapted from "Generación de caudales mensuales en la sierra peruana" MERISS II, 1980.

3) Exhaustion coefficient

$$a = f\ (\ln AR) \quad (18)$$

a: Depletion rate per day
AR: Area of the basin (km^2)

4) Retention

$$\frac{G_i}{Rmo} = b_i \sum_{i=1}^{m} b_i \quad (19)$$
$$b_i = e^{-a*t} \quad (20)$$

bi: Ratio between current flow rate and previous month (retention coefficient)
$b_i \sum_{i=1}^{m} b_i$: Sum of the ratio between the flow rate of month "i" and the initial flow rate (retention coefficient).

5) Retention supply

$$A_i = a_i \times Ryr/100 \quad (21)$$

ai: Supply coefficient (%)
Ai: Shortfall of effective monthly rainfall supply (mm/month)
Ryr: Retention in the basin (mm/year)

6) Average monthly flow rate

$$CM_i = PE_i + G_i - A_i \quad (22)$$

7) Generation of monthly flow rates for extended periods of time

$$Q_t = B1 + B2 * Q_{t-1} + B3 * PE_t + z * s * (1 - r^2)^{1/2} \quad (23)$$

Q_t: month "t" flow
$B1$: Constant factor (basic flow)
Q_{t-1}: Previous month's flow rate
PE_t: Effective precipitation for month "t"

III. Study Area Data

A. Study area

The study area is the Paucarbamba micro-watershed located in the high Andean zone of Peru in the department of Huancavelica, province of Churcampa, district of Paucarbamba, with an area of 11, 689 km2 and at an altitude of 3250 above Peruvian sea level (see Fig. 1).

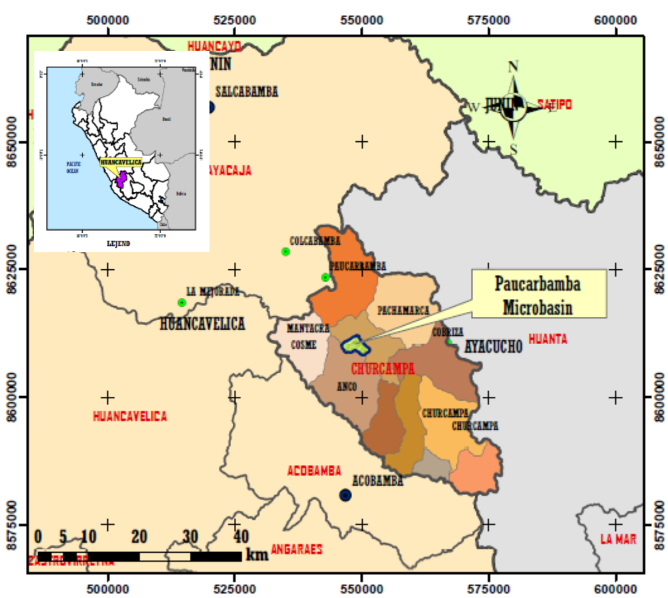

Fig. 1 Paucarbamba microbasin delimitation generated in Arc Gis software.

B. Precipitation data

The closest meteorological station to the micro-watershed is the Paucarbamba station, however, this station only has precipitation data as of 2017.

This limitation of historical data prevents us from conducting hydrological studies in the Paucarbamba micro-watershed, since for a better consistency analysis, data from the last 30 years are required.

For our study, two closer stations, Colcabamba and Acobamba, were chosen for analysis and data completion (see Fig. 1). Likewise, the HEC-H4 software was used for data completion from 1964 to 2021.

The precipitation data from the aforementioned stations were obtained from the SENAMHI platform, which is the National Meteorological and Hydrological Service of Peru, whose purpose is to generate and provide meteorological, hydrological, agrometeorological and environmental information and knowledge.

From the above, it was appreciated that the Paucarbamba station presents records from the year 2017 and the Acobamba station presents a historical record from the year 1964 to the present, which has historical information of more than 50 years and will be used as a basis for generating precipitation data from the Paucarbamba station from the year 1964 to the present.

IV. Methodology

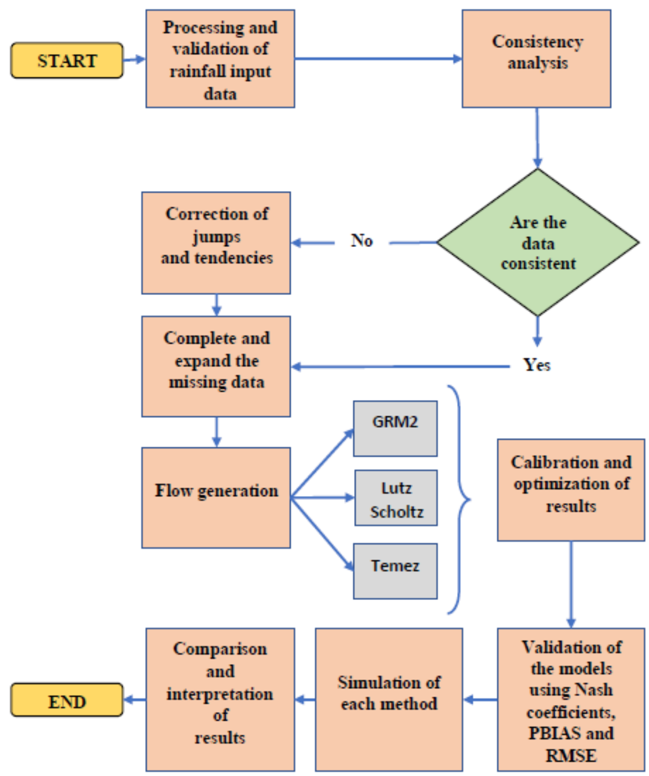

Fig. 2 Methodology Flow chart

A. Input data processing and validation

For precipitation data validation, it is verified that information obtained is constant and complete. Paucarbamba station only presents precipitation data since 2017, which was completed with the HEC-H4 software from 1991 to 2017 using precipitation data from Acobamba station as a base.

Likewise, with values obtained and taking into account altitude, rainfall, record period and topographic characteristics, a consistency analysis was performed, where Double mass obtained showed no breaks, indicating that records are consistent, as shown in Fig. 3.

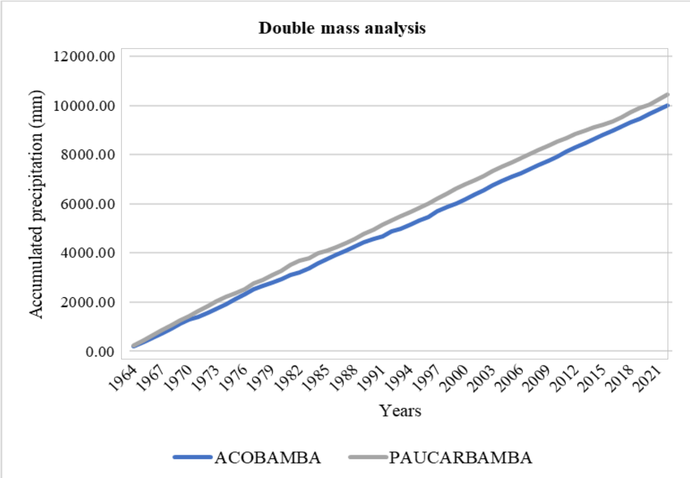

Fig. 3 Double mass analysis – Acobamba and Paucarbamba stations

CROPWAT software was used to obtain potential evapotranspiration, since it only uses maximum and minimum temperature data for potential evapo- transpiration calculation. Temperature data were extracted from SENAMHI platform and completed with HEC-H4 software.

B. Flow generation

To determine monthly mean flows, were needed input precipitation and potential evapotranspiration data. GR2M, Lutz Scholtz and Temez formulations were then used, which also require some parameters and initial microbasin data that vary according to the model.

C. Calibration and validation of hydrological models

For the calibration of the models, flows from district municipality of Paucarbamba archive were used ("Hydrological study of Sallccabamba"), which conducted a last 3-year study (2016-2018) and the study area of the file is close to our study area. In addition, they share same altitude and geography, however, area of this study is 0.91 km2, which is a much smaller in comparison area under study (11. 689 km2). Therefore, flow transposition method was used. After transposition, these transposed flows were compared in the 3 models based on Nash, PBIAS and RMSE coefficients. With these values, it was determined that Lutz Scholtz model best fits real data to generate flows of high Andean microbasin.

Likewise, for validation purposes, flows were generated with Lutz Scholtz model for the years 2016 to 2018 and results obtained were analyzed using Nash coefficients, BIAS and RMSE.

D. Calidation and calibration coefficient: Nash, PBIAS and RMSE

Calibration and validation was estimated with use of initial simulated and observed flow data. With these values, formulas corresponding to each coefficient were applied. Likewise, Excel SOLVER command was applied to obtain maxi mum coefficients. Ranges shown in Table II indicate a level of adjustment of simulated data in relation to observed data. Validity of results obtained is determined by values obtained for PBIAS, Nash and RMSE coefficients, which present ranges of values that are in very good, good and satisfactory.

It can be defined that PBIAS measures the average trend of the simulated data with respect to its observed data, while Nash measures the quantification of the variability of the observed data explained by the simulated data. Finally, RMSE allows us to quantify the magnitude of the deviation of the simulated values with respect to the observed values. [3]

TABLE II
Values of PBIAS, Nash and RMSE

PBIAS	Nash	RMSE	Model Interpretation
PBIAS< ± 10	0.75≤Nash≤1.00	0.00<RMSE≤0.5	Very Good
± 10≤PBIAS<± 15	0.65≤Nash≤0.75	0.50<RMSE≤0.6	Good
± 15≤PBIAS<± 25	0.50≤Nash≤0.65	0.6<RMSE≤0.7	Satisfactory
PBIAS≥ ± 25	0.50≤Nash	RMSE>0.7	Unsatisfactory

V. RESULTS

A. Microbasin Delimitation

Paucarbamba microbasin has been delimited with ArcGIS software, it was determined an area of 11,689 km2 and a perimeter of 16.197 km. (Fig 1).

B. Precipitation data

After completing Paucarbamba station data, graphical analysis and double mass analysis were performed, where the three stations have a similar consistency over last thirty years, from 1991 to 2022. Fig. 4 shows the records obtained from Paucarbamba station.

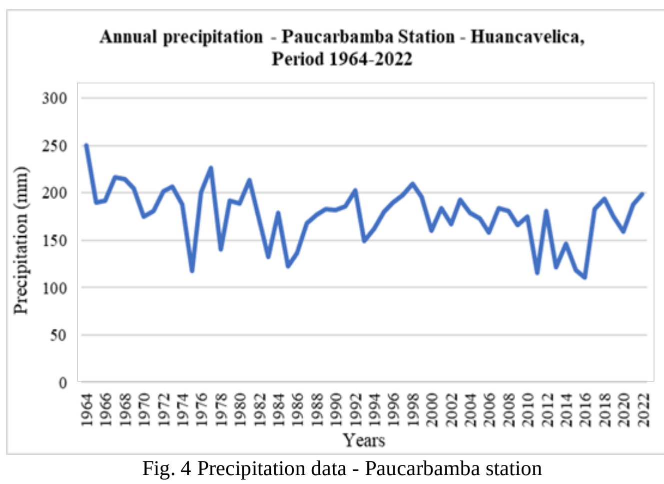

Fig. 4 Precipitation data - Paucarbamba station

C. Hydrological models Calibration

In Fig. 5, hydrographs generated from models such as GR2M, Lutz Scholtz and Temez with actual flows (Qreal) of

Paucarbamba station between periods 2016 and 2018 are shown.

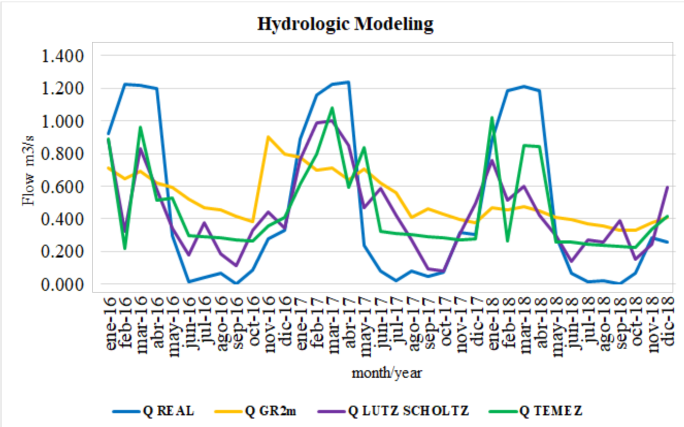

Fig. 5. Comparison of observed and simulated flow (January 2016 – December 2018).

1) GR2M model

From calibration, parameters were obtained for this model, which are shown in Table III.

TABLE III
GR2M parameters

MODEL PARAMETERS	
Maximum storage capacity of floor tank (mm)	110.62
Subsurface exchange coefficient	1.03

According to Fig. 5, it is observed that GR2M model only presents a signifi-cant peak in November 2016. As a result, following validation coe- fficients were obtained: Nash = 0.99, PBIAS = -11.83, RMSE = 0.10.

2) Lutz Scholtz model

For model development, initial values were established, which are shown in Table IV.

TABLE IV
Lutz Scholtz Model Parameters

INITIAL VALUES	
Average annual precipitation	182.25 mm
Exhaustion coefficient	0.01
Runoff coefficient	0.8

According to Fig. 5, it is observed Lutz Scholtz model there is only one signif-icant peak between February and March 2016. In addition, there are two significant drops in September 2016 and September and October 2017. As a result, following validation coefficients were obtained: Nash = 1.00, PBIAS = 5.52, RMSE = 0.05.

3) Temez model

From calculations performed, main parameters of model were obtained, which are shown in Table V.

TABLE V
Temez model parameters

MODEL PARAMETERS	
Aquifer recession coefficient (l/s)	16.17
Maximum infiltration capacity (mm)	25.43
Maximum soil humidity (mm)	70
Excess parameter	0.25

According to Fig. 5, it is observed in Temez model there are three significant peaks in March 2016, March 2017, and January 2018. In addition, there are two significant drops in February 2016 and October 2018. As a result, fol-lowing results were obtained in validation coefficients: Nash = 1.00, PBIAS = 2.12, RMSE = 0.02.

D. Validation of the hydrological model

For validation, observed flows were compared with those simulated by Lutz Scholtz model, which shows that hydrograph obtained from validation of hydrological model in Paucarbamba microbasin has a certain similarity with observed data. This similari-ty can be visualized in detail in Fig. 6.

According to calibration coefficients analysis, best fitting model is Lutz Scholtz: Nash = 1.00 (very good), PBIAS = 5.52 (very good) and RMSE = 0.05 (very good).

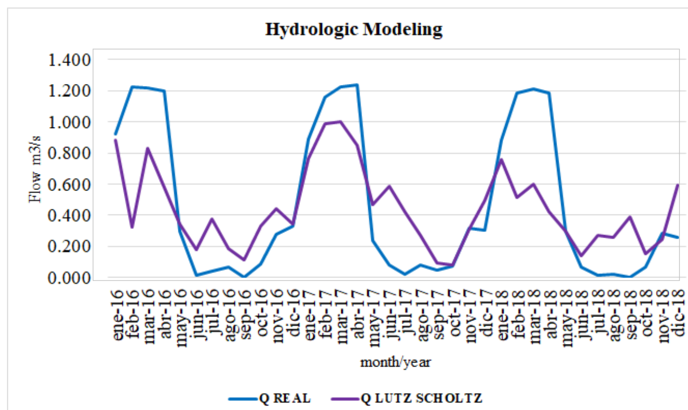

Fig. 6. Observed and simulated flow Hydrograph by the Lutz Scholtz model of Paucarbamba microbasin (January 2016 - December 2018).

VI. Analysis of Results

Table VI shows coefficients summary obtained in calibration and validation of each hydrological method. GR2M model presents very good, good and very good values for NASH, PBIAS and RMSE coefficients, respectively. Lutz Scholtz model presents very good values for all coefficients, as well as for Temez method (both models with very good values), with the difference that in Nash coefficient they have values of 1.00 and 0.99, respectively.

The model with the best values was Lutz Scholtz because its Nash coefficient value is equal to 1.00.

A summary of the 2016-2018 calibration coefficients is shown below in Table VI.

TABLE VI
Calibration coefficients

Coefficient	GR2M	Model Interpretatión	Lutz Scholtz	Model Interpretatión	Temez	Model Interpretatión
Nash	0.99	(Very Good)	1	(Very Good)	0.99	(Very Good)
PBIAS	-11.83	(Good)	5.52	(Very Good)	2.12	(Very Good)
RMSE	0.1	(Very Good)	0.05	(Very Good)	0.02	(Very Good)

VII. CONCLUSIONS

In relation to calibration coefficients obtained from PBIAS, the Temez and Lutz Scholtz models have a very good fit; however, Lutz Scholtz has been validated for its accuracy and predictive capacity, since they show acceptable errors or limits. There- fore, Lutz Scholtz has a satisfactory fit for flow generation in the Paucarbamba mi-crobasin of high Andean zone. Similarly, it was observed that all hydrological models obtained a satisfactory fit for the Nash coefficient in the validation.

GR2M model presents an unsatisfactory fit in RMSE validation coefficient, but a satisfactory fit with other coefficients. Therefore, GR2M hydrologic model is not recommended for generation of mean flows in Peruvian high Andean zones.

GR2M model has limitations because it has few input parameters, which increase uncertainty and cause accuracy to be reduced y Temez model tends to underesti-mate flows in initial periods and overestimate in final periods. These make simulation not inappropriate.

REFERENCES

[1] Traverso, K., Mamani, J., Alfaro, R. Generation of monthly average flow rates from hydrological characteristics in the Huancane river basin (2019) E-proceedings of the 38th IAHR WorCongress https://doi.org/10.3850/38WC092019-1617.

[2] Buguña, N. Aplicación de Modelos Hidrologicos para la estimación de caudales mensuales en la subcuenca del Río Bigote (2019). https://pirhua.udep.edu.pe/bitstream/handle/11042/4016/MAS_ICIH_1901.pdf?sequence=4&isAllowed=y.

[3] Llauca H., Lavado W., Montesinos C., Santini W., Rau P. (2021). PISCO_HyM_GR2M: A Model of Monthly Water Balance in Peru (1981–2020). Water. 13(1048). 1- 19. 1048. https://doi.org/10.3390/w13081048

[4] Oñate F., Bosque J. Sastre A. Ponce M. (2016). Calibration, validation and evaluation of a lumped hydrologic model in a mountain area in Southern Ecuador. Agrociencia. 50(8). 945-963. https://www.scielo.org.mx/scielo.php?script=sci_abstract&pid=S1405-31952016000800945&lng=es&nrm=iso&tlng=en

[5] Canales, J., Gonzales, F. Hydrological modeling of High Jungle area sub-basin, using the GR2M, Temez and Lutz Scholtz models (2022) Congreso Internacional de Innovación y Tendencias en Ingenieria (CONIITI) https://DOI: 10.1109/CONIITI53815.2021.9619714

[6] Gamarra, H. (2018). "Aplicación del modelo hidrológico Lutz Scholz para determinar caudales medios mensuales en la sub cuenca del rio Quiroz". Universidad Nacional de Piura.