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GENERATION OF MONTHLY FLOW IN THE LURIN RIVER BASIN UP THE MANCHAY HYDROMETRIC STATION USING THE GR2M MODEL

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ABSTRACT:
This research focuses on the Lurín River basin, specifically up to the Manchay Hydrometric Station, with the objective of estimating monthly flow series spanning 34 years. The GR2M model was employed to achieve this goal. Temperature data was sourced from the ERA5 dataset, managed by the European Space Agency's Copernicus Satellite, while precipitation information was derived from the RAIN4PE gridded product. Access to these datasets was facilitated through the Google Earth Engine (GEE) platform. Additionally, daily flow records from the Manchay Hydrometric Station, covering the period from January 1981 to February 1984, were obtained from the National Water Authority (ANA) and subsequently converted into monthly averages. The calibration and validation of the model were based on these processed data. To evaluate the model's performance, efficiency criteria such as the Nash-Sutcliffe coefficient and the coefficient of determination (R^2) were utilized.
KEYWORDS: ERA5, GEE, GR2M, Lurín River Basin, RAIN4PE.

1) INTRODUCTION:

Current investments in water supply infrastructure and agricultural irrigation projects remain unexecuted due to the absence of hydrometric studies, which stems from the lack of updated records. One such case is the Lurín River basin. Despite efforts by the National Water Authority (ANA) and the National Meteorology and Hydrology Service (SENAMHI) to measure daily hydrometric data across multiple basins in Peru, significant gaps persist in three out of the four hydrometric stations in the Lurín River basin, with records missing since 1984.

1.1. Research Objective

This study aims to generate monthly flow series based on precipitation data from the RAIN4PE dataset and temperature records from the ERA5 satellite dataset. The objective is to create a reliable database that can serve as a foundation for future hydrological studies, hydraulic assessments, and agricultural irrigation projects in the affected areas.

1.2. Theorical Framework

1.2.1. Study Area Location

The Lurín River basin is part of Peru's Pacific watershed, originating in the Andes Mountains and flowing toward the Pacific Ocean. The basin encompasses the districts of Antioquía, Cieneguilla, Pachacámac, and San Damián, all situated within the Lima region. The geographical coordinates defining the study area are between -76.75 and -76.15 longitude, and -12.32 and -11.80 latitude. The Manchay Hydrometric Station is positioned at -76.85 longitude and -12.16 latitude. [1].

1.2.2. Basin Morphology

Covering an area of 1,633.81 km², the Lurín River extends approximately 159.08 km. The basin exhibits significant variation in elevation, ranging from 5,300 meters above sea level (m.a.s.l.) in the upper reaches to 29.88 m.a.s.l. in the lower sections. [2].

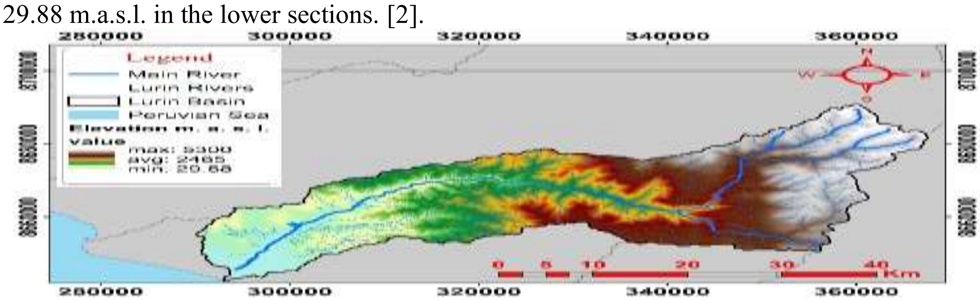

Fig. 1 Distribution of altitudes of the Lurin River Basin. Source: Authors.

1.2.3. Geographic Information Systems (GIS)

GIS platforms, such as ArcGIS, play a vital role in the management, analysis, and visualization of geospatial data. This study employed ArcGIS to delineate the basin boundaries and process hydrological data [3]. Figure 2 shows the delimitation made in the software.

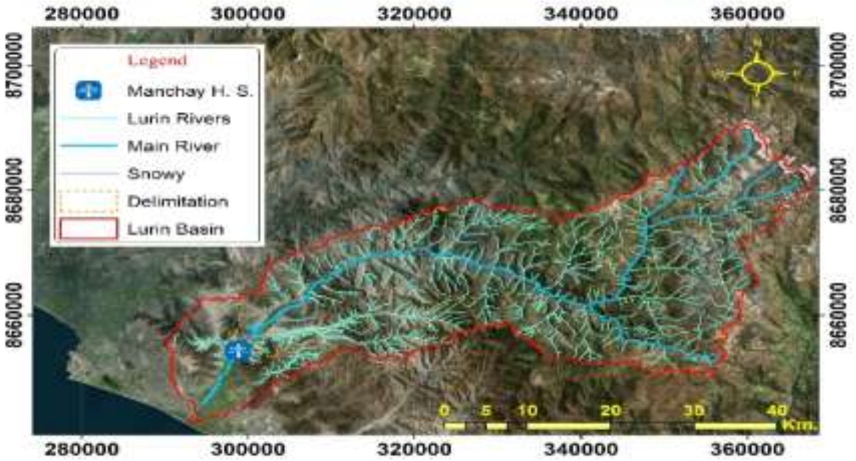

Fig. 2 Delimitation of the basin Lurin River to the Manchay hydrological station. Source: Authors.

1.2.4. National Geographic Institute (IGN)

The IGN is the institution in charge of the elaboration of cartography in Peru. To define the boundaries of the basin, national maps at a scale of 1:100000 were used, stored in shapefile format. These cards are: 24-J, 24-K, 25-J and 25-K.

1.2.5. Google Earth Engine (GEE)

Meteorological variables, including precipitation and temperature, were extracted using GEE, a cloud-based geospatial analysis tool. JavaScript and Python scripts were developed to retrieve and process the necessary climate datasets. To access information from these climatic data it is necessary to create codes in Java programming language (Script) and Python, so the codes provided by Mg. Sc. Abel Carmona Arteaga were used:

1.2.6. Code for grilled product RAIN4PE

The creation of the code belongs to Fernández, C.; Vega, F.; Washing, W.; Santini, W.; Bronstert, A. Consequently, the modification of the code for this research was carried out by Mg. Sc. Abel Carmona Arteaga.
The creation of this grilled product code RAIN4PE belongs to (Fernández-Palomino et al., 2021) [4].
The code created for this purpose is described below:

```
rain4pe: High-resolution gridded precipitation dataset for Peruvian and Ecuadorian basins (1981-2015)
Image properties
-'system:time_start' (Unix time)
Spatial resolution: 0.1° (or roughly 10km x 10km)
Google Earth Engine assets.
-rain4pe monthly: "users/csaybar/rainpe/monthly"
-rain4pe daily: "users/csaybar/rainpe/monthly" & "users/ryali93/rainpe/monthly"
-rain4pe monthly climatology: "users/csaybar/rainpe/monthly_clim"
-rain4pe annual mean: "users/csaybar/rainpe/annual"
1. Global parameters
var ROI = ee. FeatureCollection('projects/ee-angelgabrielochantesanchez/assets/Cuenca_Manchay');
var start_date = "1981-01-01";
var end_date = "2015-12-31";
2. Function to calculate spatial average
var ppreducer = function(rain4pe) {
var params = {collection: ROI, reducer: ee. Reducer.mean(), scale: 5000};
var image_value = rain4pe.reduceRegions(params).first().get('mean');
var image_date = rain4pe.get('system:time_start');
var ft = ee. Feature(null, {'system:time_start': image_date,
'Date': US Date(image_date).format('Y-M-d'), 'value': image_value});turn ft;};
3. Create a time series chart
var rain4pe_daily_data = ee. ImageCollection("projects/sat-io/open-datasets/rainpe/daily")
var rain4pe_data = rain4pe_daily_data.filterDate(start_date, end_date).map(ppreducer);
var graph = ui. Chart.feature.byFeature(
rain4pe_daily_data.filterDate("1981-06-01", "1983-06-01").map(ppreducer),'system:time_start','value');
print(graph.setChartType("ColumnChart").setOptions({vAxis: {title: 'PP (mm/day)'},hAxis: {title: 'date'}}));
4. Export results
Export.table.toDrive({collection: rain4pe_data,selectors: 'date, value',description: "rain4pe-daily data", fileNamePrefix:"rain4pe_ts"})
```

5. Show a specific day
var daily_rain = EE. Image("users/ryali93/rainpe/daily/1998_01_25")
var palette = ['000096','0064ff', '00b4ff', '33db80', '9beb4a','ffeb00', 'ffb300', 'ff6400', 'eb1e00', 'af0000'];
Map.addLayer(daily_rain, {min:0, max:80, palette: palette})
Map.centerObject(ROI);
Map.addLayer(ROI)

1.2.7. Code for ERA5

The creator of the Google Earth Engine code for data extraction of the ERA5 project is Mg. Sc. Abel Carmona Arteaga [5].

Define periods
var param = {
T1:'1984-03-01',
T0:'1980-01-01',
}
Basin analyzed in Shapefile format
var Station = ee. FeatureCollection("users/ppingog27/sub_cuenca_manchay")
var Station = geometry
Collect data and filter by total dates
var Precipitation = ee. ImageCollection('ECMWF/ERA5/DAILY');
var Precipitation = ee. ImageCollection('UCSB-CHG/CHIRPS/DAILY')
Wind data collections for all years, one value per hour
This is where you can change the dates
var collection01 = ee. ImageCollection(Precipitation.filterDate(param. T0, param. T1));
Trim to the specified region
var clipped01 = collection01.mean().clip(Station)
Graphics//
Long-term time series.
var TS1 = ui. Chart.image.seriesByRegion({
imageCollection: collection01,
regions: Station,
Reducer: USA Reducer.mean(),
Change data source//
To use Copernicus average air temperature at 2m in Kelvin
band:'mean_2m_air_temperature',
scale: 5000,
xProperty: 'system:time_start',
seriesProperty: 'Subbasin'})
.setOptions({
title: 'Average precipitation in a basin P(meters) at daily pace',
hAxis: {title: 'Time interval in days'},
vAxis: {title: 'P (meters)'}}
)
;
print(TS1);
Map.addLayer(Station,{palette: 'blue'}, 'basin')teaga [5].

Emphasize that precipitation is obtained in mm and temperature in Kelvin, which had to be converted to Celsius.

1.2.8. National Water Authority (ANA)

It is the governing body and the highest technical-regulatory authority of the National Water Resources Management System [6].

1.2.9 Grilled Product RAIN4PE

It is a novel dataset and gridded precipitation product for Peru and Ecuador, benefiting from the maximum available in situ observations, elevation data and supplementing with flow data to correct for rainfall underestimation [4]. Figure 3 shows the hydrological calibration and adjustment of data sets of (P) using current flow (Q) and in turn also shows the hydrological evaluation.

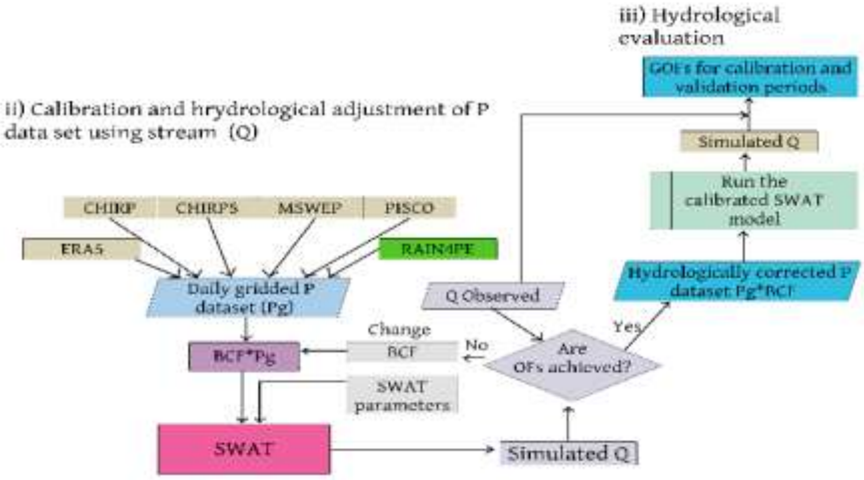

Fig. 3 Schematic framework of the RAIN4PE product (Fernández et al., 2022)

1.2.10. ERA5

It provides atmospheric information of global coverage that is generated by hours and days, which gives an estimate of the atmospheric state updated and improved [7].

1.2.11. Model GR2M

GR2M is a conceptual rainfall-runoff model designed for monthly time-step hydrological simulations. This model was selected due to its reliability in estimating flow based on precipitation and evaporation inputs. Calibration of the model was performed using the Nash-Sutcliffe efficiency coefficient as an optimization criterion.[8].

1.2.12. Coefficient of determination R^2

IMeasures the linear correlation between observed and simulated flows.

Table 1 Reference values for the coefficient of determination

R^2 range	Model Quality Category
0.99≤R2< 1.00	Excellent
0.95≤R2< 0.99	Very good
0.90≤R2< 0.95	Well
0.85≤R2< 0.90	Pretty good
0.80≤R2< 0.85	Average
0.70≤R2< 0.80	Satisfactory
R2< 0.70	Insufficient

1.2.13. Nash Sutcliffe coefficient

It is one of the most used criteria in Hydrology. It is defined as:

$$E = \frac{\sum_{i=1}^{n}(Qsim,i - Qi)^2}{\sum_{i=1}^{n}(Qi - \bar{Q})^2}$$

Where:

$Q_{sim,i}$: Simulated flows in m^3/s

Q_i : Observed flows in m^3/s

$\bar{Q}$: Average observed flows in m^3/s

And it measures when the simulation explains the variability of the observations. If the simulation is perfect, E=1; If we tried to fit the observations with the average value, then E=0 [9]. Table 2 shows the reference values of the Nash Sutcliffe criterion.

Table 2 Reference values for the nash-sutcliffe efficiency criterion.

And	Adjustment
< 0.2	Insufficient
0.2 – 0.4	Satisfactory
0.4 – 0.6	Well
0.6 – 0.8	Very good
> 0.8	Excellent

2) METHODOLOGY:

The selection of the study basin was based on the availability of at least three consecutive years of hydrometric data. The delineation of the basin was carried out using ArcGIS following a structured workflow. Data extraction from GEE was performed using predefined scripts to obtain ERA5 temperature and RAIN4PE precipitation data. Following this reasoning, we require the polygon of the basin, for this we will follow the steps shown in Figure 4.

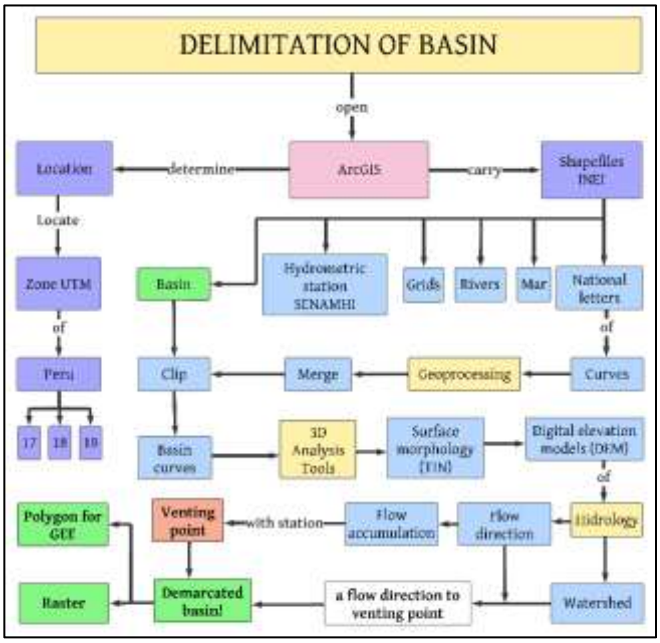

Fig. 4 Flowchart showing the steps to delimit the basin in ArcGIS software. Source: Authors.

Finally, we perform the data extraction in Google Earth Engine by executing the codes for temperature (ERA5) and prefixations (RAIN4PE), as shown in Figure 5.

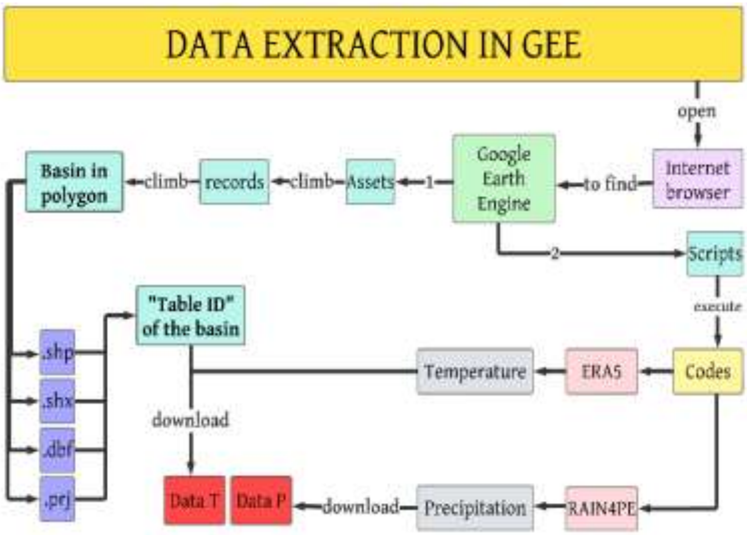

Fig. 5 Flowchart indicating the steps for data extraction in GEE. Source: Authors.

3) RESULTS:

To develop the GR2M model, the Spreadsheet prepared by Charles Perrin and Vazken Andréassian [8] was used, the version here is the one presented by Mouelhi (2003) and Mouelhi et al. (2006), which presents a spreadsheet that is used to perform flow simulations in monthly time steps, making an improvement of a global model of precipitation and runoff through a comparative approach [10].
Mouelhi towards a coherent chain of global conceptual models of rainfall flow with multiannual, annual, monthly and daily temporal steps. In addition, the values of the parameters X1, X2, of the model can be optimized using the "Solver" function.

3.1 Model Calibration

Calibration was conducted using hydrometric records from the ANA Observatory, covering a total area of 1,449.32 km² and a timeframe from January 1981 to July 1982. The Nash-Sutcliffe efficiency coefficient obtained for this phase was 97.4%, indicating an excellent model fit.

Table 3 Hydrometric data used in the calibration process

Efficiency criteria (%)	
Nash(Q)	97.4
Nash (VQ)	97.2
Nash(ln(Q))	97.6
Bilan	97.9

Table 4 shows the parameters of the GR2M model.

Table 4 GR2M model parameters in the calibration process

Parameters	**Transf**	**Current.**
X1: Res. Output (mm)	4.61	100.96
X2: Interchange parameter (mm)	0.76	0.76

Table 5 shows the initial filling values.

Table 5 Initial values for the Lurin river basin in calibration process

Initial values	
Initial fill level S0 (max: x1 mm)	50.48
Initial fill level R0 (max: 60 mm)	30

Table 6 shows the hydrometric data used in the calibration process.

Table 6 Hydrometric data used in the calibration process

Hydrometric Data	
Average observed precipitation (mm/month)	23.8
Average observed ETPs (mm/month)	2.1
Average flow rates observed (mm/month)	14.0
Average of the roots of the observed flows	3.3
Average of observed logarithmic flows	2.2

At the end of the calibration process of the GR2M model, the adjustment parameters were obtained, the data extracted from the ANA Observatory and the monthly flows estimated by the GR2M model were compared. Figure 6 shows the comparison of the measured flows with the simulated ones and that in February 1982 they presented high flows.

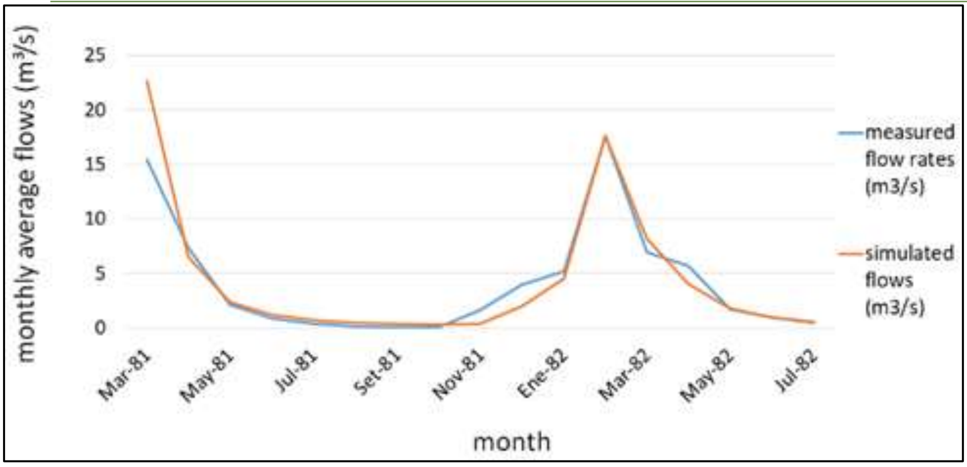

Fig. 6 Comparison of monthly measured flows (ANA) and generated flows (GR2M) for the Lurin River Basin in the calibration process between 01/01/1981 to 31/07/1982

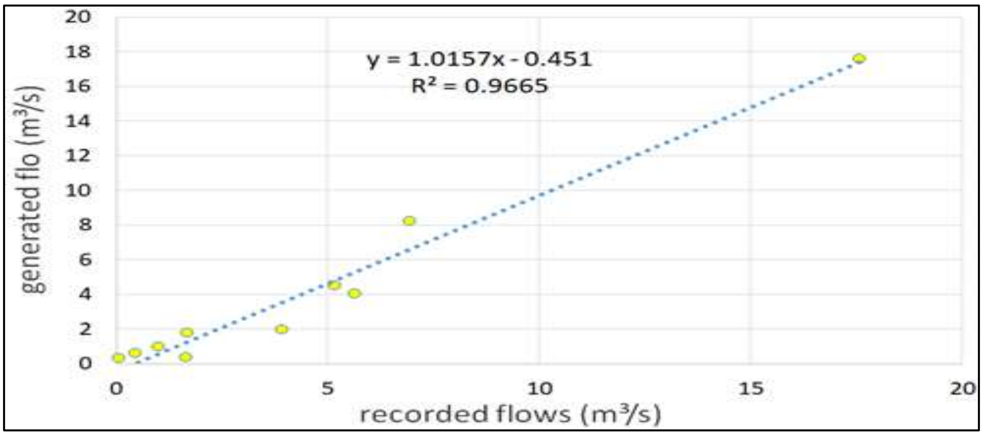

Fig. 7 Correlation of R2 between measured daily flow rates (ANA) and generated flow rates (GR2M) for the calibration period.

Considering a linear trend line, a coefficient of determination (R2) equal to 0.9665 is obtained.

3.2. Model Validation

Validation was performed using an extended dataset from January 1981 to February 1984, confirming the consistency of the model's predictions. The Nash-Sutcliffe efficiency coefficient for this phase was 92.8%, further supporting the model's reliability.

Table 7 Efficiency criteria (%) obtained in the validation process hydrometric

Efficiency criteria (%)	
Nash(Q)	92.8
Nash (VQ)	85.9
Nash(ln(Q))	73.3
Bilan	98.5

Table 8 shows the parameters of the GR2M method calculated for the Lurin River Basin.

Table 8 Hydrometric parameters employed during the validation process

Parameters	**Transf**	**Current.**
X1: Res. Output (mm)	5.24	188.99
X2: Interchange parameter (mm)	0.79	0.79

Table 9 presents the initial values for validation.
Table 9 Initial values for the Lurin river basin in validation

Initial values	
Initial fill level S0 (max: x1 mm)	94.49
Initial fill level R0 (max: 60 mm)	30

In addition, Table 10 shows the hydrometric values obtained using the calibration model of the Lurin River Basin.
Table 10 Hydrometric data employed during the validation process

Hydrometric Data	
Average observed precipitation (mm/day)	23.55
Average ETP observed (mm/day)	2.24
Observed average flow rates (mm/day)	11.77
Average of the roots of the observed flows	2.78
Average logarithm of observed flows	1.62

Figure 8 shows the comparison between the measured daily flows (ANA) and generated flows (GR2M) for the Lurin River Basin from 01/01/1981 to 29/02/2015.

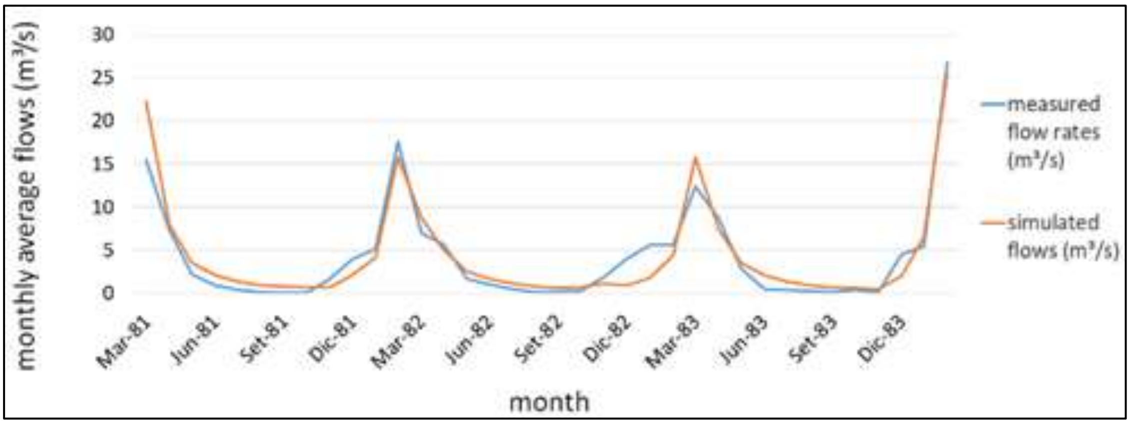

Fig. 8 Comparison of observed daily flows (ANA) and simulated flows (GR2M) for the Lurin River Basin during the validation period from 01/01/19 to 31/12/1984.

Figure 9 shows the comparisons of estimated and measured flows. Considering a linear trend line, a coefficient of determination (R2) equal to 0.9109 is obtained.

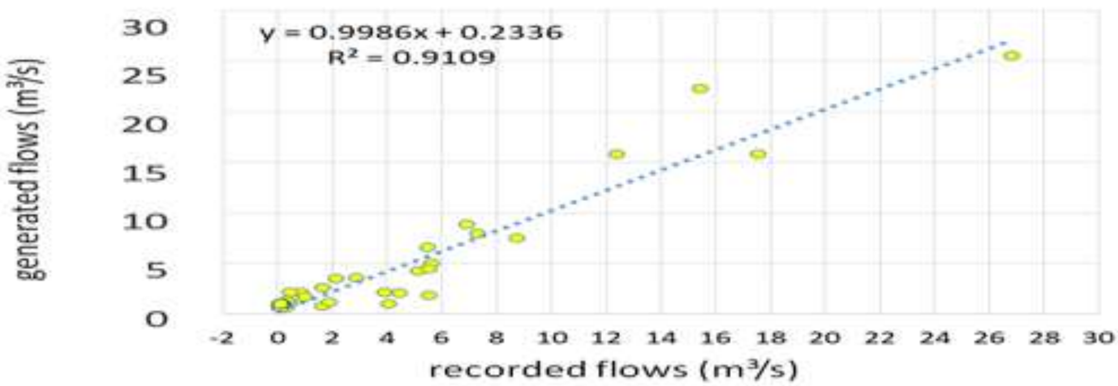

Fig. 9 Correlation of R2 Comparison of measured daily flows (ANA) and generated flows (RAIN4PE-ERA5) for the Lurin Basin in the validation process between 01/01/1981 to 29/02/1984.

3.3 Flow Series Extension

Following the successful calibration and validation, the GR2M model was applied to generate monthly flow estimates for the period spanning January 1981 to December 2015. The comparison between measured and simulated flows demonstrated a strong correlation, reinforcing the validity of the generated data..

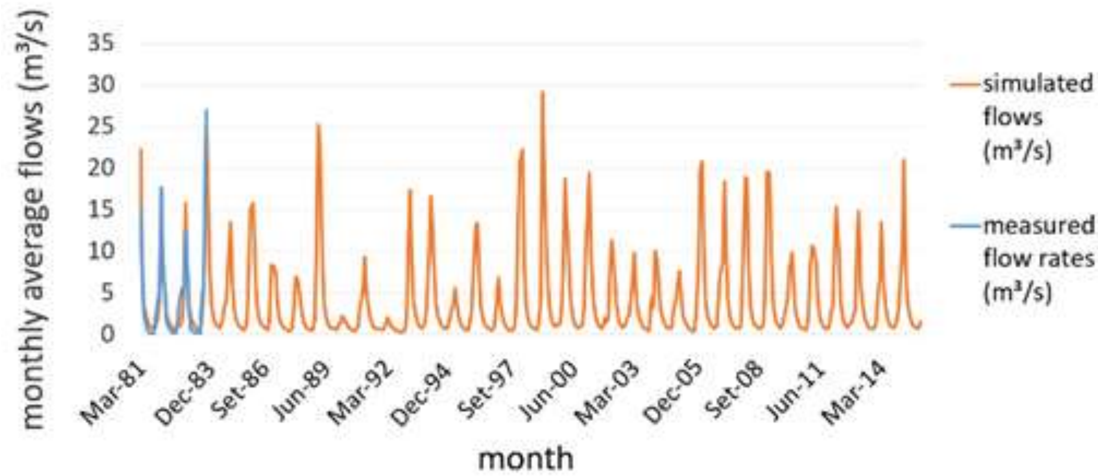

Fig. 10. Daily assessment of observed flows (ANA) and simulated flows (GR2M) for the Lurin River Basin over the period from 01/01/1981 to 31/12/2015.

The flows measured by the ANA Observatory were used together with information from the grid climate records of precipitation, temperature obtained from RAIN4PE and ERA5 respectively from the Google Earth Engine platform. Figure 10 shows the adjustment between the flows generated and measured, in turn the generated years of extension to date of 29/02/2015.

4) CONCLUSIONS:

The results of this study confirm that the GR2M model effectively simulates monthly flow variations in the Lurín River basin. The high Nash-Sutcliffe efficiency values obtained during both calibration (97.4%) and validation (92.8%) indicate that the model was successfully calibrated and can be used for future hydrological studies. The generated flow series can contribute to the planning and execution of hydraulic and agricultural irrigation projects in the study area.

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