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Research Article

Estimation of the Water Balance in the Vinces River Watershed Office Automation and Geomatic Tools

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ABSTRACT

The Vinces River basin, located in Ecuador, faces significant challenges in its water management due to anthropogenic pressures and climate change. This study estimates the water balance of the basin using office automation (PETP and InnerSoft ISBH) and geomatics (QGIS) tools, to evaluate water dynamics, identify patterns of water deficit and surplus, and propose sustainable management strategies. Using the

Thornthwaite method, an average potential evapotranspiration of 1,307.63 mm/year and an annual excess water balance of 1,322.97 mm/year were determined. In addition, the spatial analysis made it possible to map vulnerable areas and establish conservation priorities. The results show that the basin can generate approximately 6,240.37 Hm^3/year, with an irrigation potential of 422,927.73 ha/year, which represents an opportunity to optimize water use in agricultural activities. The tools used proved essential for integrating climate and spatial data, providing a solid foundation for water planning and decision-making. This approach contributes to the sustainability of water resources, aligning with Sustainable Development Goal 6, promoting equitable and resilient water management in the region.

Keywords: Water balance, water management, geomatics, office automation, basin.

INTRODUCTION

Water resource management is a fundamental challenge in a global context characterized by climate change, population growth, and the expansion of the agricultural frontier (Touge et al., 2024). Watersheds, as territorial management units, play a crucial role in the collection, storage and distribution of water, ensuring ecological balance and the sustenance of economic activities (Tebeje et al., 2024). The Vinces River basin, located in Ecuador and with an approximate area of 4,620 km^2, is a significant example due to its contribution to regional development in the provinces of Cotopaxi, Los Ríos and Guayas. However, unsustainable management and anthropogenic pressure pose direct threats to its water and ecological balance (Tavosi et al., 2024).

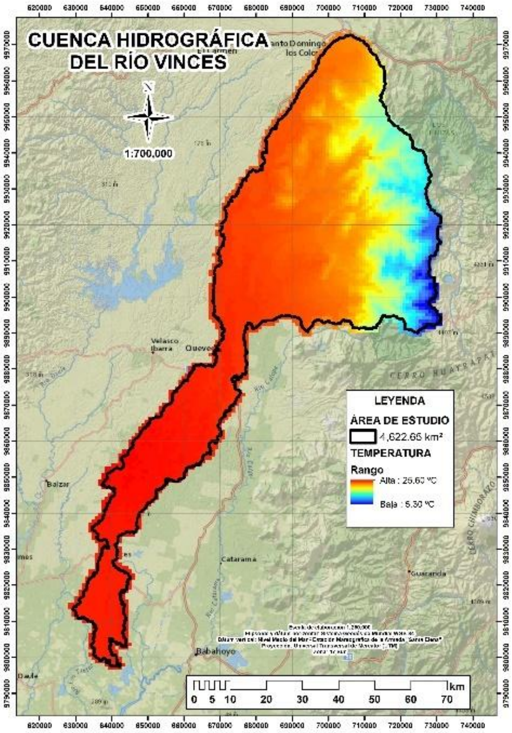
In this context, estimating the water balance of the Vinces River basin using office and geomatic tools is presented as an innovative and efficient strategy (Santos et al., 2024). The water balance is a fundamental tool for assessing the availability, distribution, and quality of water, making it possible to identify surpluses and deficits that affect both ecosystems and human activities (Campodonico et al., 2024). The use of office automation tools, such as hydrological analysis software, and geomatics, such as Geographic Information Systems (GIS), facilitates the integration and analysis of spatial and temporal data, improving the understanding of river dynamics and their interactions with climatic and anthropic factors (Pachac-Huerta et al., 2024).

The application of these tools allows a comprehensive characterization of the basin, covering geomorphological, hydroclimatological and erosion risk aspects (Richards et al., 2018). In addition, it contributes to the design of sustainable strategies for water resource management, aligned with the Sustainable Development Goals (SDGs), particularly SDG 6, which seeks to ensure the availability and sustainable management of water for all (Hughes et al., 2007). In Ecuador, the implementation of these approaches remains limited, despite the relevance of water resources for the country's socioeconomic development.

This research seeks to address this gap through the analysis of the water balance in the Vinces River basin, using office and geomatic tools to generate a database that allows proposing guidelines for its integrated management. This approach will not only contribute to the sustainability of water resources in the region, but also to the reduction of conflicts arising from their use and exploitation, promoting equitable and sustainable development for present and future generations (Tebeje et al., 2024).

METHODOLOGY

The methodology applied in this research has as its main objective to estimate the water balance in the Vinces River basin, using office and geomatic tools to characterize fluvial dynamics and generate key information for the sustainable management of water resources. A quantitative approach was adopted, employing hydrological models and spatial analysis techniques that integrate climate, geomorphological, and land-use data (Figures 1 and 2).



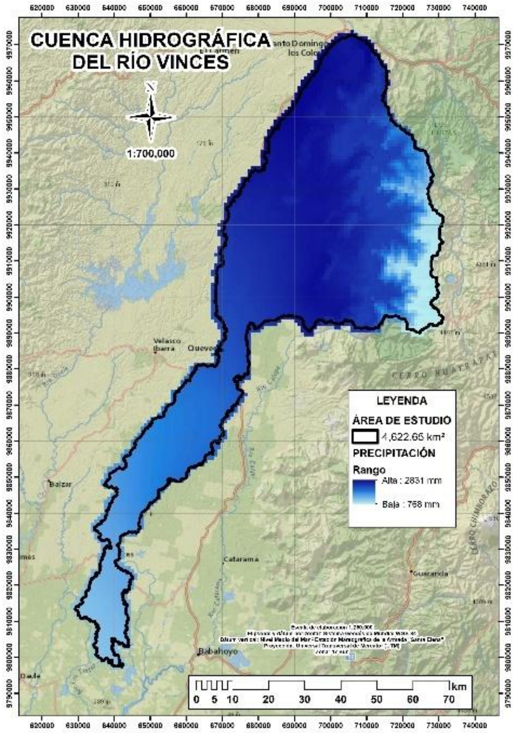


Figure 1. Average temperature of the area

Figure 2. Average rainfall in the area

Procedures and Tools (Ismayilova & Ratkovich, 2024):

- Compilation of Climatic and Hydrological Data: The meteorological information used was obtained and tabulated from the yearbooks of the National Institute of Meteorology and Hydrology (INAMHI).
- Calculation of Potential Evapotranspiration (ETP): The PETP software developed by Gutierrez-Ninahuaman & Gonzalez-Herrera (2021) was used to estimate potential evapotranspiration using the Thornthwaite method (https://bit.ly/35oQkq4).
- Water Balance Estimation: The InnerSoft ISBH (http://isbh.itspanish.org/es/ISBH_es.zip) program was used to calculate the water balance and categorize the climate of the study site according to the Thornthwaite method (Tu et al., 2024).
- Hydroclimatic Analysis with HYDROGNOMON: In addition, climate data were processed to calculate water indices and perform cross-validations of the processed information.
- Spatial Analysis with QGIS: Thematic maps were generated to visualize the spatial distribution of climatic variables and the morphology of the basin (Figure 1, 2). The Digital Elevation Model (DEM) was used to calculate slopes, catchment areas, and drainage networks, allowing the impact of geomorphology on water behavior to be evaluated (Wu et al., 2024).

Validation of Results: The results obtained were validated by comparison with historical data and previous studies carried out in similar basins. This process ensured the reliability of the analyses and their application in decision-making (Kardhana et al., 2024).

Impact on Decision-Making: The information generated directly contributes to designing strategies to optimize the use of water in agricultural activities, mitigating the impact of droughts and excess water; Identify vulnerable areas to implement soil and water conservation practices; Propose integrated management plans that guarantee the sustainability of water resources in the Vinces River basin, aligned with the Sustainable Development Goals "SDGs" (García-Andrade et al., 2024).

RESULT AND DISCUSSION

According to the result obtained for the Vinces River basin, the potential evapotranspiration by Thornthwaite is estimated at 1,307.63 mm/year, obtained from the mean between 1,392.98 mm/year of station M0006 (Table 1) and 1,222.27 mm/year of station M0124 (Table 2).

Table 1. Potential evapotranspiration from station M0006

Month	d (Days)	Tm (°C)	i	ETo' (mm)	N (Hours)	ETo (mm)	ETo (mm/day)
January	31	25.45	11.748	118.454	12.144	123.87	4.00
February	28	25.69	11.916	122.152	12.144	115.37	4.12
March	31	26.24	12.305	130.927	12.100	136.42	4.40
April	30	26.2	12.276	130.275	12.078	131.12	4.37
May	31	25.72	11.937	122.620	12.056	127.30	4.11
June	30	24.48	11.077	104.299	12.035	104.60	3.49
July	31	23.86	10.655	95.894	12.035	99.38	3.21
August	31	23.77	10.594	94.715	12.056	98.33	3.17
September	30	24.52	11.104	104.858	12.078	105.54	3.52
October	31	24.73	11.249	107.828	12.122	112.55	3.63
November	30	25.1	11.504	113.202	12.144	114.56	3.82
December	31	25.44	11.741	118.302	12.165	123.93	4.00
S			138.108			1,392.98	

3,275 being its exponent a.

Table 2. Potential evapotranspiration from station M0124

My	d (Days)	Tm (°C)	i	ETo' (mm)	N (Hours)	ETo (mm)	ETo (mm/day)
January	31	24.13	10.838	103.239	12.138	107.91	3.48
February	28	24.58	11.146	108.974	12.138	102.88	3.67
March	31	25.03	11.456	114.914	12.100	119.73	3.86
April	30	25.09	11.497	115.722	12.081	116.50	3.88
May	31	24.56	11.132	108.714	12.062	112.92	3.64
June	30	23.42	10.359	94.601	12.043	94.94	3.16
July	31	22.92	10.026	88.813	12.043	92.10	2.97
August	31	22.86	9.986	88.134	12.062	91.54	2.95
September	30	22.99	10.072	89.609	12.081	90.21	3.01
October	31	23.08	10.132	90.639	12.119	94.59	3.05

November	30	23.32	10.292	93.424	12.138	94.50	3.15
December	31	23.85	10.648	99.773	12.157	104.45	3.37
S			127.584			1,222.27	

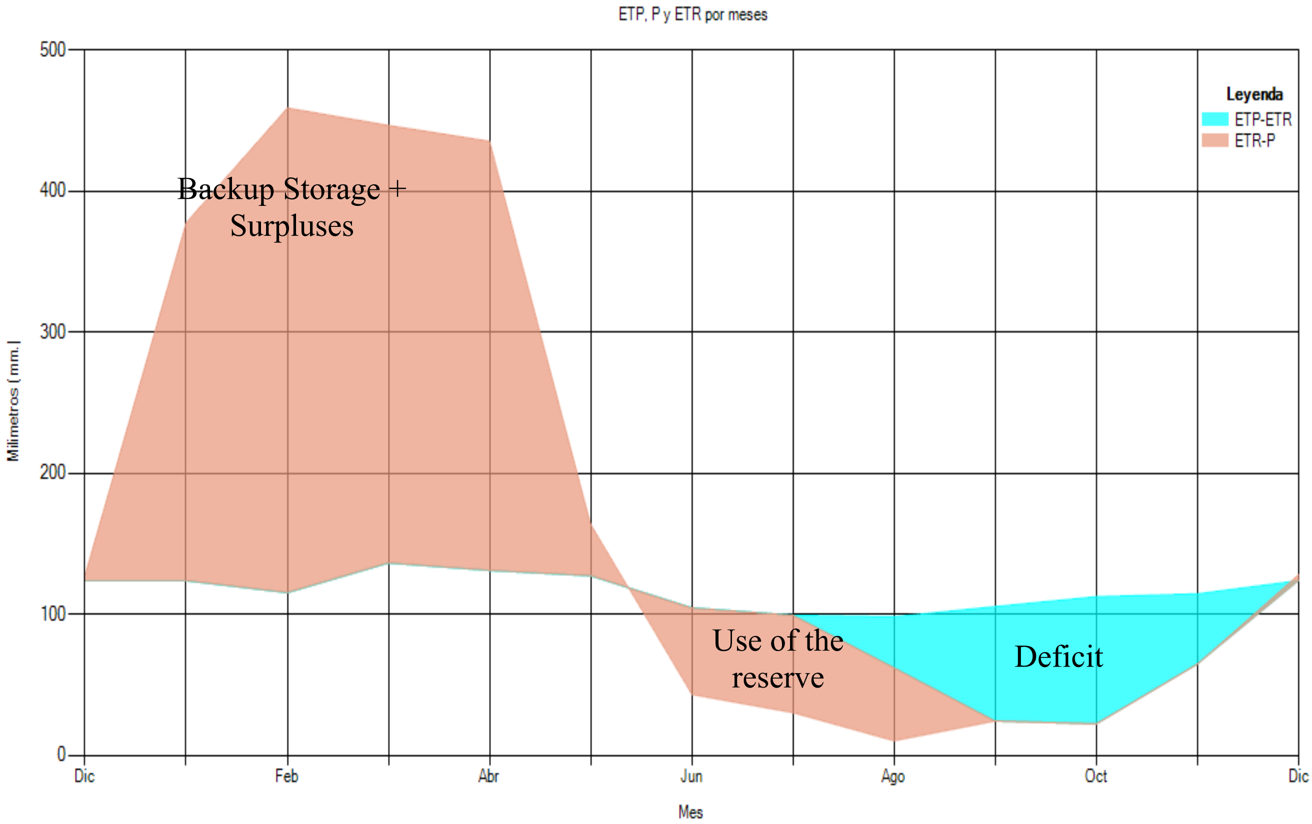
Being 2,926 its exponent a.

And with the data of potential evapotranspiration, a surplus of the water balance according to Thornthwaite of 1,322.97 mm/year is estimated, obtained from the mean between 1,070.89 mm/year of the M0006 station (Table 3 and Figure 3) and 1,575.04 mm/year of the M0124 station (Table 4 and Figure 4).

Table 3. *Water balance of the M0006 station*

M0006	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Total
Precipitation	128.15	377.86	459.11	446.77	435.51	164.00	43.11	30.25	10.28	24.33	22.32	64.78	2,206.47
ETP	123.93	123.87	115.37	136.42	131.12	127.30	104.60	99.38	98.33	105.54	112.55	114.56	1,392.97
P - ETP	4.22	253.99	343.74	310.35	304.39	36.70	-61.49	-69.13	-88.05	-81.21	-90.23	-49.78	813.50
My	moist	moist	moist	moist	moist	moist	dry	dry	dry	dry	dry	dry	
Reservation	4.22	182.50	182.50	182.50	182.50	182.50	121.01	51.88	0.00	0.00	0.00	0.00	1,089.61
Variation	4.22	178.28	0.00	0.00	0.00	0.00	-61.49	-69.13	-51.88	0.00	0.00	0.00	0.00
ETR	123.93	123.87	115.37	136.42	131.12	127.30	104.60	99.38	62.16	24.33	22.32	64.78	1,135.58
Excess	0.00	75.71	343.74	310.35	304.39	36.70	0.00	0.00	0.00	0.00	0.00	0.00	1,070.89
Deficit	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-36.17	-81.21	-90.23	-49.78	-257.39

Figure 3 Water balance of station M0006



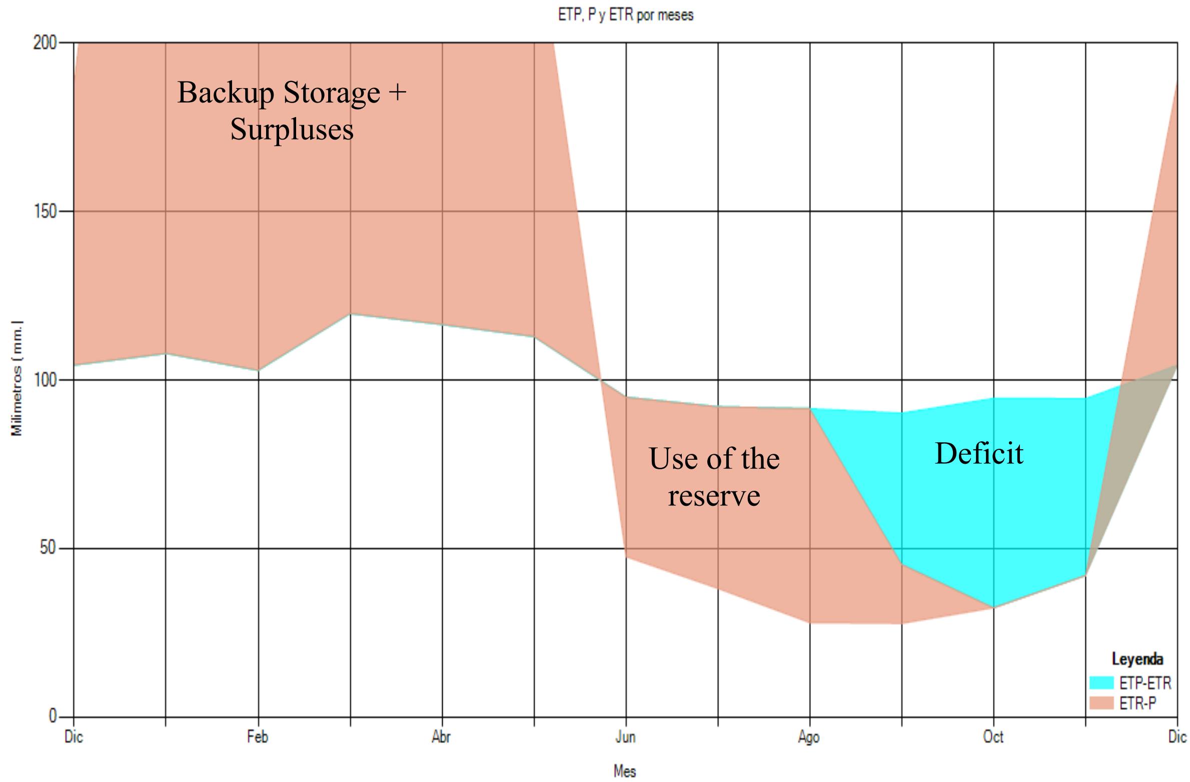
The Aridity Index (Ia) "18.478", indicates that it is very wet; the Moisture Index (Ih) "76.878" and the Thornthwaite Moisture Index (Im) of "65.792", as the Thornthwaite Climate Classification "B3", indicate that the study area is wet; and the Climatic Subdivision "s" / "w" indicates a moderate surplus of water in the rainy and dry seasons (Li et al., 2024).

Table 4. Water balance of the M0124 station

M0124	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Total
Precipitation	418.59	513.01	548.51	512.42	240.40	47.56	38.11	27.97	27.73	32.39	41.97	189.00	2,637.65
ETP	107.91	102.88	119.73	116.50	112.92	94.94	92.10	91.54	90.21	94.59	94.50	104.45	1,222.27
P - ETP	310.68	410.13	428.78	395.92	127.48	-47.39	-54.00	-63.57	-62.49	-62.21	-52.53	84.55	1,415.38
My	moist	moist	moist	moist	moist	dry	dry	dry	dry	dry	dry	moist	
Reservation	84.55	182.50	182.50	182.50	182.50	182.50	135.12	81.13	17.56	0.00	0.00	0.00	1,230.86
Variation	84.55	97.95	0.00	0.00	0.00	0.00	-47.38	-53.99	-63.57	-17.56	0.00	0.00	0.00

ETR	104.45	107.91	102.88	119.73	116.50	112.92	94.94	92.10	91.54	45.29	32.39	41.97	1,062.62
Excess	0.00	212.73	410.13	428.78	395.92	127.48	0.00	0.00	0.00	0.00	0.00	0.00	1,575.04
Deficit	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-44.92	-62.20	-52.53	-159.65

Figure 4. Water balance of the M0124 station



The Aridity Index (Ia) "13.062", the Humidity Index (Ih) "128.862"; the Thornthwaite Moisture Index (Im) "121.025" and the Thornthwaite Climate Classification "A", indicate that the study area is super humid; and the Climate Subdivision "s" / "w" indicates a moderate surplus of water in the rainy and dry seasons (Li et al., 2024).

Interpretation of the Water Balance graphs: P curve on ETR indicates STORAGE in reserve + Surpluses; ETR curve over P indicates USE OF THE RESERVE of the land; Curves between ETP and ETR indicate DEFICIT. Its results coincide with the comparison between P and ETo (Figure 5 and Figure 6).

Figure 5. Comparison of the P with the ETo at station M0006

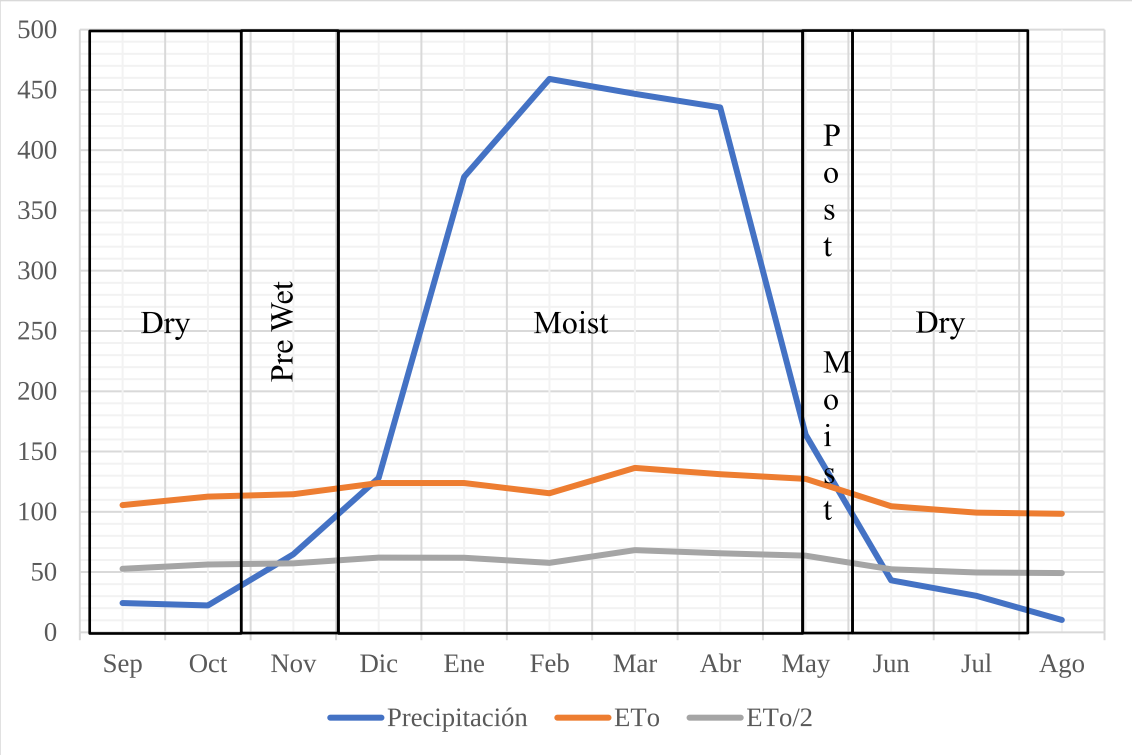
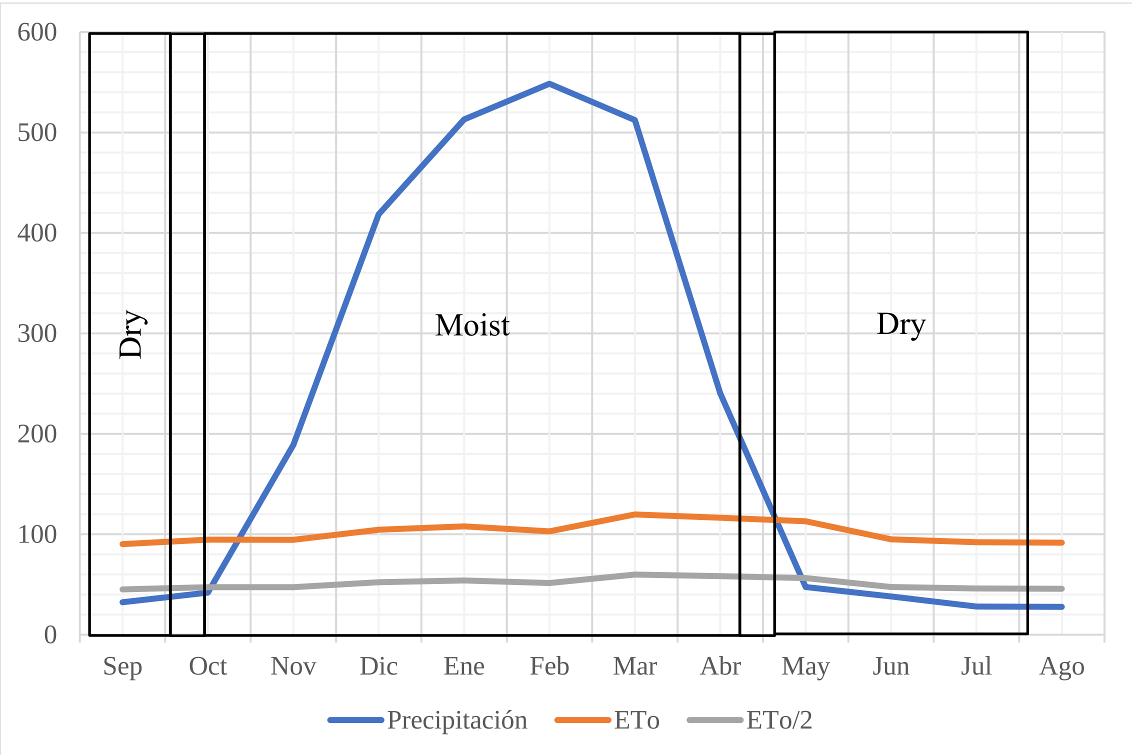


Figure 6. Comparison of the P with the ETo at station M0124



The B3 code in the Thornthwaite climate classification refers to a specific subclass of the climate. In this case, B3 indicates a moderate water deficiency in both the rainy and dry seasons. This means that the region experiences an insufficient amount of precipitation in both seasons, which can have an impact on the water supply available for living things and agriculture (Jirjees, 2024).

In addition, the climatic subdivision "s" indicates a moderate deficiency of water in the dry season, which implies that water availability is limited during the warmest months of the year. The subdivision "w" indicates a moderate water deficiency in the rainy season, suggesting that there is also a moderate lack of water during the season (Choudhary et al., 2023).

These classifications provide useful information for understanding climatic conditions and water availability patterns in a given region. They are important tools for climate studies and planning of water-dependent activities, such as agriculture and water management (Bañares et al., 2024).

With the results obtained from the mean water balance of the basin according to Thornthwaite [(1,070.89 + 1,575.04) / (2)] which is 1,322.97 mm/year → 0.0132297 Hm^3/ha/year, and with the data of the basin area 4,716.94 km^2 → 471,694.00 ha, it can be estimated that the Vinces river basin can generate approximately 6,240.37 Hm^3/year, being able to make consumptive use of 50% of the water "3,120.19 Hm^3/year" (because 10% ecological flow and 40% non-consumptive use are discounted). And considering a representative crop of the area, with a water requirement of 0.0074 Hm^3/ha/year [(ETc = 3.82 mm x 1.05) → (4.01 x 10) → (40.10 m^3/ha/day x 184 dry season) = 7,377.60 m^3/ha/year]. A priori, 422,927.73 ha/year (3,120.19 / 0.0074) → 4,229.28 km^2 could be irrigated. And according to statistics from the Ministry of Agriculture and Livestock (MAG), approximately 1200 hectares are currently irrigated in the area of direct influence, which would mean 0.28%.

The results obtained from the hydroclimatic analysis in the Vinces river basin showed seasonal patterns of water surplus and deficit, determined by the Thornthwaite method and the application of tools such as PETP and InnerSoft ISBH. He agrees with Kim et al. (2023) who mention that these tools made it possible not only to calculate potential evapotranspiration and water balance, but also to categorize the local climate, providing a clear framework for the assessment of water availability.

The use of QGIS and spatial analysis based on DEM data facilitated the generation of thematic maps highlighting areas vulnerable to water deficit and priority areas for conservation. According to El Boute et al. (2024), these findings are supported by climate data processing in HYDROGNOMON, underscore the relevance of integrating advanced technologies for continuous monitoring and evidence-based decision-making.

The application of these methodologies also highlights the importance of sustainable water management in the region, especially considering the impact of intensive agricultural activities. Wang et al. (2024) also mention that by identifying risk areas and categorizing local climates, a solid basis is offered to develop adaptive strategies in the face of climate change, promoting water security and sustainable development.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions:

- The hydroclimatic analysis carried out in the Vinces River basin showed seasonal patterns of water surplus and deficit, highlighting the importance of adaptive strategies to guarantee sustainable management of water resources.
- The technological tools employed, such as PETP, InnerSoft ISBH and QGIS, proved to be instrumental in integrating and analysing climate and spatial data, providing a robust basis for water balance assessment.
- The thematic maps generated identified priority areas for water conservation and management, promoting evidence-based management in contexts of water vulnerability.
- The implementation of advanced technologies in the monitoring of water resources constitutes a replicable model for other watersheds in Ecuador and similar regions.

Recommendations:

- Establish continuous monitoring systems in the Vinces River basin, using technological tools to improve data collection and analysis.
- Design training programs aimed at local communities on the use of GIS tools and hydrological analysis, encouraging their active participation in water management.
- Propose policies that prioritize the conservation of vulnerable areas and promote integrated water resources management, aligning with the Sustainable Development Goals.
- Replicate the methodology in other basins of the country to contribute to the strengthening of water resilience and sustainable development.
- To promote interdisciplinary research that integrates socioeconomic, climatic and ecological aspects, expanding the scope of hydrological studies in the Ecuadorian context.

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