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Relationship between daily evaporation of class A tank and climate elements at the Ichuña meteorological station in Moquegua Perú

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---***ABSTRACT***---
Evaporation is a very important stage of the hydrological cycle, its precise determination allows correctly sizing reservoir capacity in water storage dams in high altitude areas and determining potential and reference evapotranspiration for crop water needs and demand. The research was carried out at the Ichuña meteorological station in the Moquegua region in Peru. The general objective was to determine the relationship between daily evaporation and climate elements, as well as calibrate and validate the relationship within a modeling process. Meteorological variables were used such as extraterrestrial radiation, temperature, cloud cover, hours of sunshine, relative humidity, wind speed, water density, evaporation and combinations of these at a monthly level. Missing data was completed with information from neighboring weather stations. The modeling methodology considers a calibration and validation period. For calibration, normality was analyzed and ordinary least squares estimation was used. Validation was performed by comparing calculated and observed values. Most of the meteorological variables do not have normality, which is why they were transformed. By using the regression tool of best subsets and step-by-step regression, the variables most related to evaporation were obtained. There are no heteroscedasticity problems according to the White test and the statistically significant variables ($p<0.05$) are: mean maximum temperature, current vapor pressure, extraterrestrial radiation, saturation vapor pressure, transformed mean temperature and mean temperature of the minimums. The transformed extraterrestrial radiation is not statistically significant. The determination coefficient (r^2) achieved is 0.7923.

KEYWORDS;- *Relationship, model, daily evaporation, class a tank, climate elements, weather station*

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I. INTRODUCTION

Regarding models, in hydrological engineering, there are four types of mathematical models: (1) Deterministic, (2) Probabilistic, (3) Conceptual and (4) Parametric. A conceptual model is a simplified representation of the physical process, obtained by spatial and temporal variations, aggregated, and described in terms of either ordinary differential equations or algebraic equations. A parametric model represents hydrological processes through algebraic equations; it contains key parameters to be determined empirically (Ponce, 1989).

The deterministic model does not consider randomness; a given input always produces the same output. Deterministic models make forecasts. For example a deterministic model for determining daily evaporation in a certain place (Chow et al., 1988).

Stochastic models are models of random or probabilistic variables that do not have a fixed value at a particular point in space and time, but are described through probability distributions. These models make predictions. For example, the rain that will fall tomorrow in a particular location cannot be predicted accurately (Chow et al., 1988).

Like any cycle, the hydrological cycle has neither beginning nor end, and its description can begin at any point. Water that is on or very close to the Earth's surface evaporates under the effect of solar radiation and wind. The water vapor, thus formed, rises and is transported through the atmosphere in the form of clouds until it condenses and falls to the earth in the form of precipitation. During its journey to the earth's surface, precipitated water can evaporate again or be intercepted by plants or buildings, then flows over the surface into streams or infiltrates. The intercepted water and a part of the infiltrated water and that which runs along the surface evaporate again. Of the precipitation that reaches streams, some infiltrates and some reaches the oceans and other large bodies of water, such as dams and lakes. Of the infiltrated water, a part is absorbed by plants and is subsequently transpired, almost entirely, into the atmosphere and another part flows under the surface of the earth towards currents, the sea or other bodies of water, or towards areas deep in the soil (percolation) to be stored as groundwater and then emerge in springs, rivers or the sea (Aparicio, 2010).

In the design projects of structures and works intended for the control and storage of water, a hydrological problem always arises, which is the determination of variables and parameters on which the dimensions of the structures depend. Hydrology provides a wide variety of methods based on various principles, within which the most appropriate must be chosen according to the particular circumstances, depending on the availability of appropriate hydrometeorological data (Mejía, 2001).

Evaporation is an important part of the hydrological cycle. On Earth, water exists in a space called the hydrosphere, which extends from about fifteen kilometers high in the atmosphere to a kilometer below the lithosphere, or Earth's crust. Water circulates in the hydrosphere through a labyrinth of paths that constitute the hydrological cycle (Chow et al., 1988). Evaporation depends on several factors mainly related to solar radiation, temperature, wind speed, relative humidity and even atmospheric pressure.

Climate depends on a large number of factors that interact in a complex way. Unlike the traditional concept of climate, as the average of some variable, today it is thought of as a changing state of the atmosphere, through its interactions with the sea and the continent, on various scales of time and space (Magaña , 2004).

According to the IPCC (Intergovernmental Panel on Climate Change), based on scientific evidence, the main effects of climate change are an increase in the global average temperature of air and oceans, melting of ice and snow formations, and an increase in sea levels on average (Rodríguez-Becerra & Mance, 2009).

According to the IPCC, in the period from 1906 to 2005 the planet's temperature increased 0.74 °C. Also, the IPCC in its 2007 report foresees an increase between 1.1°C and 6.4°C for the period from 2089 to 2099 compared to the year 2000. In 2009, projections were presented where an increase of 4°C is expected before 2055 if it continues current conditions (Rodríguez-Becerra & Mance, 2009).

The disappearance of Andean glaciers would affect the water supply, the increase in water scarcity and increased risk of flooding are also effects of climate change on the water regime (Rodríguez-Becerra & Mance, 2009). The change in rainfall patterns is another effect, decreasing in some places and increasing in others.

Climate Change has been evident in the Andean subregion for more than three decades with an increase in temperature in the region of 0.34°C, which has intensified the trend of melting glaciers in Bolivia, Peru, Colombia and Ecuador, where their future disappearance compromises the availability of water and energy generation (Amat & León, 2008).

Furthermore, the rise in temperature and changes in precipitation, associated with climate change, affect productivity and land degradation processes by increasing, for example, aridity, the number of dry months (ratio between precipitation and evapotranspiration), the concentration of precipitation and, therefore, its intensity (ECLAC, 2010).

One of the variables on which evaporation depends, especially in aerodynamic methods, is atmospheric pressure. To calculate atmospheric pressure, a simplification of ideal gases can be used, at a standard atmospheric temperature of 20 °C (Allen et al., 1998).

The importance of determining the evaporation of a class A tank is that, among other uses, it can be used to calculate the current evapotranspiration for the purposes of designing irrigation systems and irrigation programming (Peña Q. et al., 2005). Accurate estimation of evaporation is also necessary for water balances in new reservoirs and in the operation of existing reservoirs (Martínez Álvarez et al., 2005). The daily time scale has been generally used by many studies (Peña Q. et al., 2005); they carried out an evaluation of the relationship between climate elements and evaporation.

The measurement of evaporation is currently carried out with sensors; there is a proposal for two new sensors for the ArduDrop electronic device, for the study of soil humidity and its relationship with environmental parameters. These sensors are a rocker rain gauge and a small evaporation tanks (de Pablo-Hernández & de Pablo-S, 2013).

Evaporation has also been used to estimate potential evapotranspiration (Flores-Quispe, 2013) and also to estimate the evapotranspiration of the reference crop (Allen et al., 1998), because the class A tank integrates the combined effect of all the variables meteorological or weather elements. Several investigations have considered that evapotranspiration can be well estimated from evaporation (Flores-Quispe et al., 2015). Even for the conditions of the Peruvian Andes, evaporation is a good predictor of evapotranspiration (Flores-Quispe et al., 2021).

The fundamental problem observed in the upper part of the Moquegua region is the lack of locally calibrated models to predict water evaporation based on meteorological elements. That is why it is necessary to propose regional models for evaporation, so that it can be estimated with greater precision for each place within the Moquegua region.

This aspect is related to the efficient use of water because it is considered a scarce resource and an important factor in the economic and social development of the communities in the basin, with a greater impact on agricultural, livestock and urban activities in the area under study.

The correct selection of a method to predict evaporation constitutes an essential contribution of engineering studies, for the adequate sizing of water storage reservoirs. For this, it is important to have a very broad technical criterion in the hydrological study. It is necessary to have information from evaporation series with a longer record length; this will allow us to interpret the hydrological behavior, with the purpose of predicting evaporation for the appropriate design of hydraulic storage structures.

The fundamental reason for this research is to study the relationship between daily evaporation and climate elements at the Ichuña meteorological station in Moquegua Perú. The usefulness of the results is that the relationship obtained will serve to estimate the daily evaporation in Ichuña within the Moquegua region. This is very useful for design calculations for storage structures such as reservoirs or reservoirs, which occur in many parts within the basin. It will also serve to propose actions to reduce evaporation, which is the loss of water to the atmosphere, and also to make water use more efficient.

The general objective was to determine the relationship between daily evaporation and climate elements at the Ichuña meteorological station in Moquegua Peru. The specific objectives were: (a) Determine the relationship between daily evaporation and energy balance and aerodynamic terms at the Ichuña meteorological station in the Moquegua region, (b) Calibrate and validate the relationship between daily evaporation and climate elements at the Ichuña meteorological station in the Moquegua region within a modeling process for prediction and forecasting purposes.

II. MATERIALS AND METHODS

The Ichuña meteorological station is located in the Moquegua region in the south of the Republic of Perú. The geographical coordinates of the Moquegua region are between 15°17' and 17°23' south latitude. The city of Moquegua is the capital of the department, at 1410 meters above sea level. The Moquegua region is located in the southern part of Peruvian territory, limited to the north by the Arequipa region, to the east by the Puno region, to the south by the Tacna region and to the west by the Pacific Ocean (INEI, 2000).). The Moquegua region, politically, encompasses the following provinces of Ilo, Mariscal Nieto and Sánchez Cerro.

Hydrographically, the Ichuña station is located in the upper part of the Tambo River basin; this basin includes the provinces of Sánchez Cerro and Mariscal Nieto in the Moquegua region; the province of Islay, and part of the provinces of Arequipa (Arequipa), Puno and San Román (Puno). Furthermore, this basin has a total area of 12,744 km2, of which 8,149 km2 correspond to the humid basin (64%), above 3,900 altitude above sea level. (IRH, 2003).

The following figure 1 shows the location of the Moquegua region and the Ichuña meteorological station.

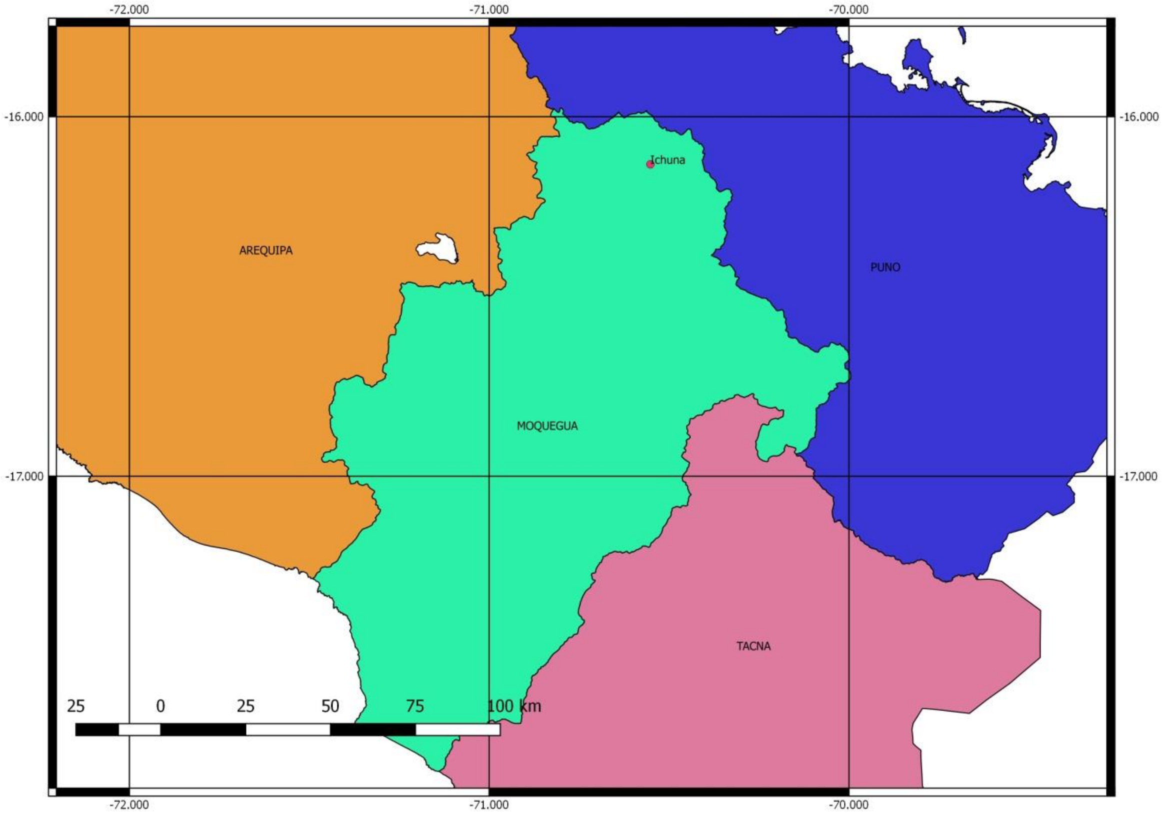

Figure 1. Location of the Moquegua region and the Ichuña station (geographical coordinates).

In the Moquegua region, four geomorphological regions are identified: Coast, High Andean Zone, Lower Andean Zone and Meso-Andean Zone. The Ichuña meteorological station is located in the meso-Andean zone. The Moquegua region is characterized by presenting variable thermal conditions, warm in the lower sectors and cold in the Andean highlands, where some peaks with permanent snow are observed. For climate analysis in the entire Moquegua region there is information from 18 meteorological stations. This network is operated by the National Meteorology and Hydrology Service (SENAMHI) and by Southern Perú Limited SPL.

Within the basins of the Moquegua and Tambo rivers, based on the Köppen criteria, it has been possible to differentiate three types of climate: Very dry semi-warm climate (desert or subtropical arid), sub-humid temperate climate (Steppe and low inter-Andean valleys) and cold or boreal climate (Mesoandean Valleys).

The Ichuña meteorological station is located in an area of Cold or Boreal Climate (Meso-Andean Valleys); this climatic type extends between 3000 and 4000 meters above sea level. It is characterized by its average annual rainfall of 300 mm and its annual temperatures of 12° C; it includes the Mesoandean valleys typical of the central and southern sectors of the Peruvian Andes, it has rainy summers and dry winters with frosts.

The Andean sector, characterized by this type of climate, constitutes the traditional center of dry land mountain agriculture, based on crops represented by small grain cereals, such as wheat, oats, barley and rye; in addition to tuberous and edible legumes, such as oca, mashua and broad bean. In the higher elevation sectors, natural pastures appear. The study area is considered within the biogeographic province called “Subtropical Puna”.

The interesting geographical configuration of the Moquegua region is grouped taking into account: the inclination and general orientation of the department, which is predominantly east-west, with those in the east being the places with the highest altitude. Likewise, the order of the slope and the direction of water drainage have been considered. All these factors have served to identify the following large groups: Andean relief zone, desert zone and coastal zone. The Ichuña meteorological station is located in the Andean relief area.

The geological formations that constitute these basins in the Moquegua region extend from the Triassic to the recent Quaternary. In the study area, four geomorphological regions are identified: Coast, High Andean Zone, Lower Andean Zone and Meso-Andean Zone. The Ichuña meteorological station is located in the meso-Andean zone.

The cartographic information used for the research consisted of:

- National charts in conventional and digital format, of aerial photographic restorations of photos that have been taken between the years of 1955 to 1963 and restored in the years of 1968 to 1971, by the National Geographic Institute (IGN) at the scale 1:100,000.

- Cartographic and complementary thematic information found in the different studies carried out.

In all maps, the digital format of the base plan used is in the UTM WGS84 coordinate system, projected for the respective geographic area where the area under study is located.

The meteorological information recorded within the scope of the region under study is mostly recorded by the National Meteorology and Hydrology Service (SENAMHI). The Ichuña meteorological station located in the study area is located at an altitude of 3800 meters above sea level, at a west longitude of 70°33'7.5" and at south latitude of 16°7'57.4" obtained from the National Weather and Hydrology Service (SENAMHI) Web page in the historical data section.

The record length of the meteorological variables used in this study is from the years 2002 to 2009 and these variables are: Mean maximum temperature (°C), Mean minimum temperature (°C), Cloudiness (octaves), mean humidity relative (%), Wind speed (m/s) and daily evaporation (mm/day).

To manage geographic information, the free software QGIS 2.0 has been used.

Investigation methodology

The research variables are the following:

- Dependent variable: Y = daily evaporation (mm/day).

- Independent variables: X1 = mean temperature (°C), X2 = hours of sunshine (hours per month), X3 = wind speed (m/s), X4 = mean relative humidity (%).

The method used in this research work is detailed in the following points:

- Search for bibliographic information related to the topic.
- Compilation of evaporation information and climate elements.
- Completion of missing data with information from neighboring weather stations.
- Exploratory data analysis of evaporation records and climate elements.
- Analysis of descriptive statistics, normality assessment and graphic representation.
- Box-Cox transformation of data for normalization.
- Determination of the relationship between evaporation and climate elements, using multiple linear regression.
- Detection of heteroscedasticity using White's test.
- The determination followed a mathematical modeling procedure for which the observed data records were divided into two calibration and validation periods. The calibration period is from 2002 to 2006 and the validation period is from 2007 to 2009.

Statistical methods

Multiple linear regression were used. In the most general case of multiple regression, there are two or more independent variables (Cole, 2002):

$$\hat{Y} = b_0 + b_1X_1 + b_2X_2 + \cdots$$

Estimating the coefficients of a multiple regression is a rather complicated and laborious calculation, which requires the use of specialized computer programs. However, the interpretation of the coefficients is similar to the case of simple regression: the coefficient of each independent variable measures the separate effect that this variable has on the dependent variable. The coefficient of determination, on the other hand, measures the percentage of the total variation in Y that is explained by the joint variation of the independent variables (Cole, 2002).

The multiple regression analysis has an equation with two additional independent variables (Robles, 2009):

$$Y = a_1 + b_1x_1 + b_2x_2$$

It can be extended for any number "m" of independent variables (Robles, 2009):

$$Y = a_1 + b_1x_1 + b_2x_2 + b_3x_3 + \cdots + b_mx_m$$

In order to solve and obtain a1, b1 and b2 in a multiple regression equation, the calculation is very tedious because you have to deal with 3 equations that are generated by the least squares method (Robles, 2009):

$$\sum y = na + b_1\sum x_1 + b_2\sum x_2$$

$$\sum x_1y = a\sum x_1 + b_1\sum x_1^2 + b_2\sum x_1x_2$$

$$\sum x_2 y = a \sum x_2 + b_1 \sum x_1 x_2 + b_2 \sum x_2^2$$

In order to solve, can be used computer programs such as AD+, SPSS and Minitab and Excel (Robles, 2009).

The standard error of multiple regression (Sxy) is a measure of dispersion. The estimate becomes more precise as the degree of dispersion around the regression plane becomes smaller (Robles, 2009).

To measure it, the formula is used:

$$S_{xy} = \sqrt{\frac{\sum\left(Y - \hat{Y}\right)^2}{n - m - 1}}$$

Where: Y = Values observed in the sample, Yˆ= Values estimated from the regression equation, n = Number of data, m = Number of independent variables (Robles, 2009).

The multiple determination coefficients (r^2) measure the percentage rate of changes in Y that can be explained by x1, x2 and x3 simultaneously. This coefficient can be obtained with the regression sum of squares (SCregresión) and the total sum of squares (SCtotal) (Robles, 2009).

$$r^2 = \frac{SC_{regresión}}{SC_{total}}$$

III. RESULT VIEW

The Ichuña meteorological station has missing data, which is why, the data on: mean maximum temperature and mean minimum temperature were completed. For this process, data from the neighboring meteorological stations of Lampa, Laraqueri and Santa Lucía and a multiple linear regression equation were used. The regression equation to complete the mean maximum temperature is the following

$$Tmax_{ichuña} = 1.119 + 0.593Tmax_{laraqueri} + 0.37Tmax_{lampa} + 0.16Tmax_{santa\ lucia}$$

Where: Tminichuña= minimum temperature (°C) of the Ichuña station, Tminlampa= minimum temperature (°C) of the Lampa station, Tminlaraqueri= minimum temperature (°C) of the Laraqueri station. This regression equation presents r^2 = 88.55%.

A graphical analysis of jumps was carried out on the meteorological data used from the Ichuña meteorological station, which are: mean maximum temperature, mean minimum temperature, daily evaporation. The following figure 2 shows the variation of daily evaporation.

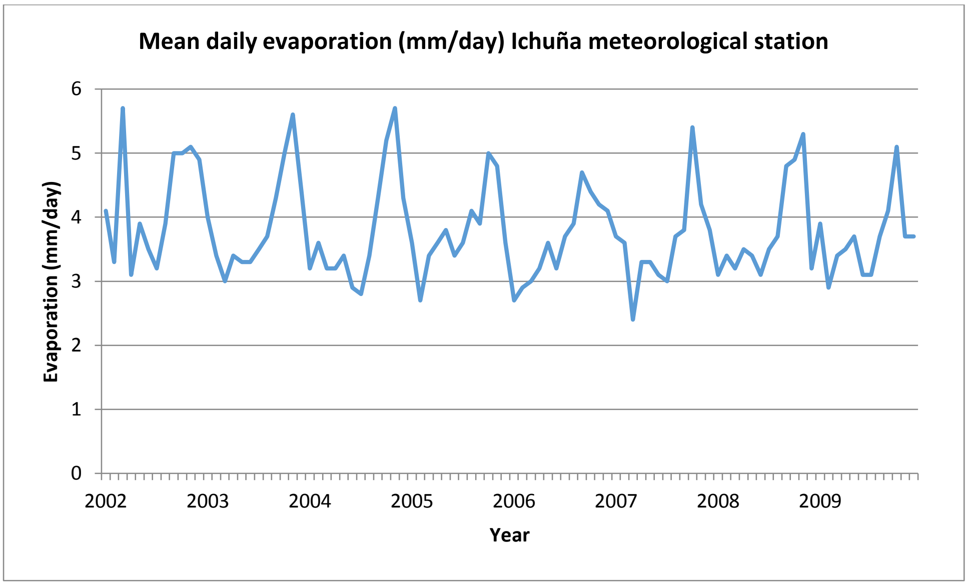

Figure 2. Mean daily evaporation of the Ichuña station

An exploratory data analysis was carried out in which a graphic summary was obtained with histogram and normal curve, box plot and confidence intervals, and a summary of descriptive statistics with Anderson-Darling normality test and confidence intervals for the mean, median and standard deviation. The variables analyzed: mean maximum temperature, mean minimum temperature, mean temperature, cloudiness, extraterrestrial radiation, and latent heat of vaporization, density of water, saturation vapor pressure, relative humidity, current vapor pressure, wind speed, daily evaporation. The following figure 3 shows the statistical and graphic summary of the daily evaporation at the Ichuña station.

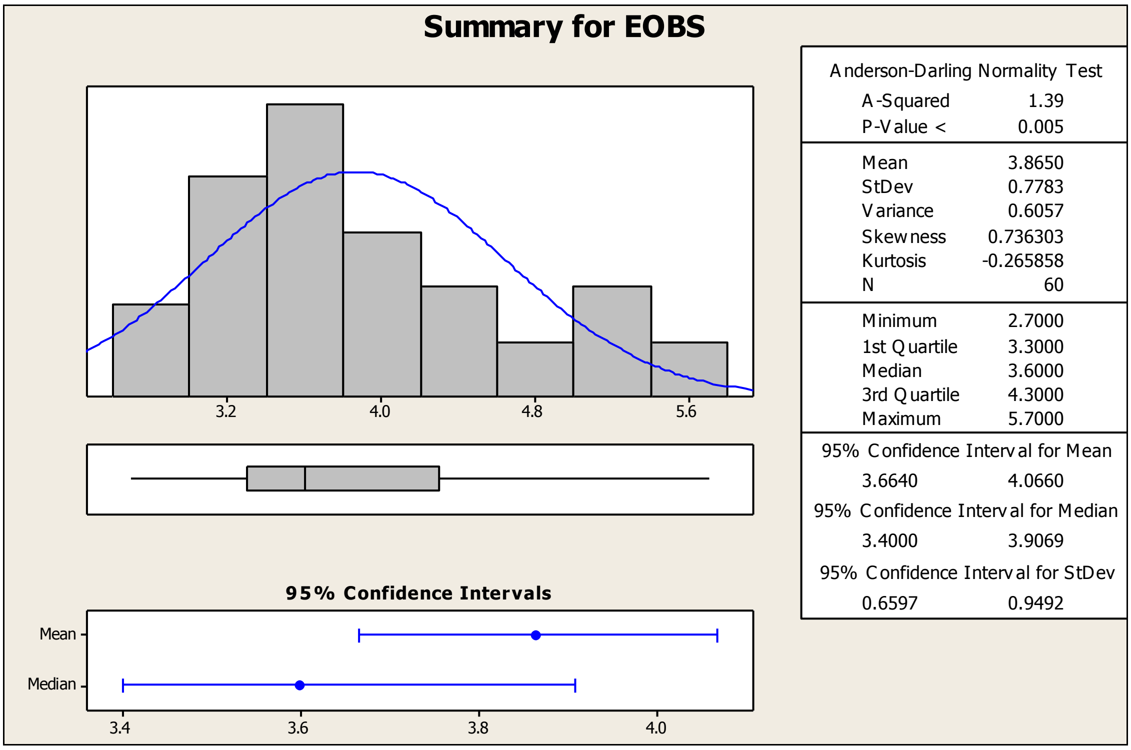

Figure 3. Statistical summary and graph of the mean daily evaporation of the Ichuña station

According to the Anderson-Darling normality test, since the probability is less than 0.05 (significance level), then the null hypothesis that the data is normal is rejected. According to the box plot, there are no outliers. Table 1 shows the summary of the exploratory data analysis.

Table 1. Summary of exploratory data analysis

Variable	Normal	Existence of outliers
Mean maximum temperature	Accepted	No
Mean minimum temperature	Accepted	No
Medium temperature	Rejected	No
Cloudiness	Rejected	No
Extraterrestrial radiation	Rejected	No
Latent heat of vaporization	Rejected	No
Water density	Rejected	No
Saturation vapor pressure	Rejected	No
Relative humidity	Rejected	Si
Current vapor pressure	Rejected	No
Wind speed	Accepted	No
daily evaporation	Rejected	No

The Box-Cox transformation of variables that do not comply with normality was carried out. This process was carried out with the following variables: mean temperature, cloudiness, extraterrestrial radiation, latent heat of vaporization, water density, saturation vapor pressure, relative humidity, current vapor pressure, daily evaporation. The following figure 4 presents the transformation of the measured or observed evaporation and figure 5 shows the graphical normality test after the transformation.

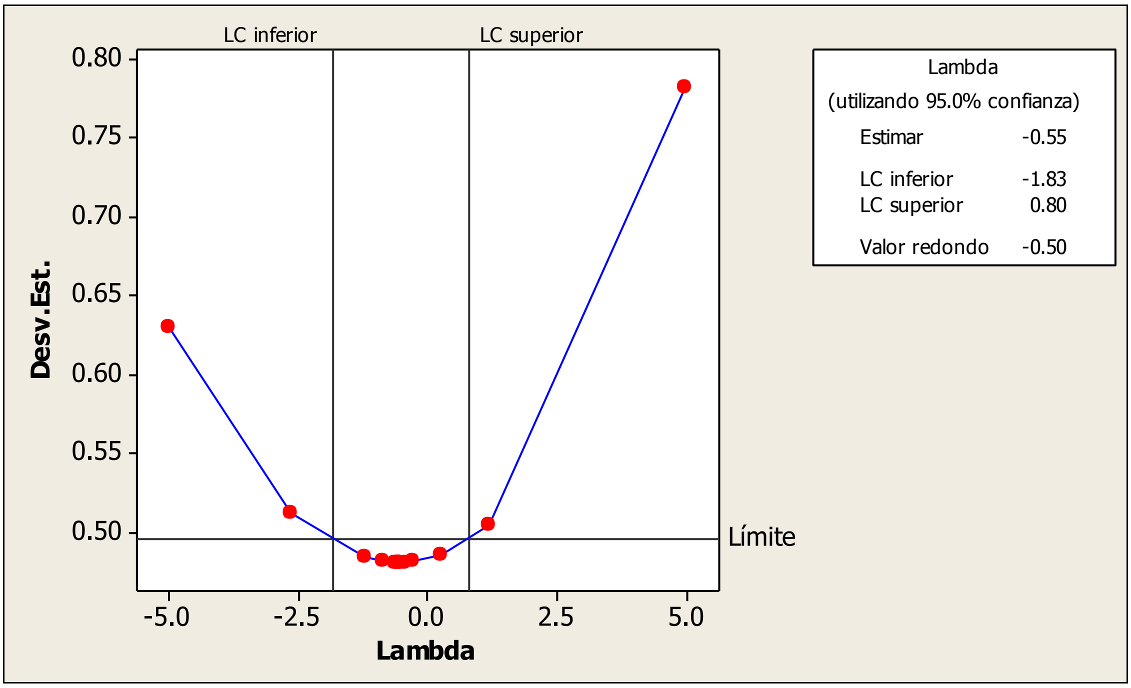

Figure 4. Box-Cox plot to transform the evaporation of the Ichuña station

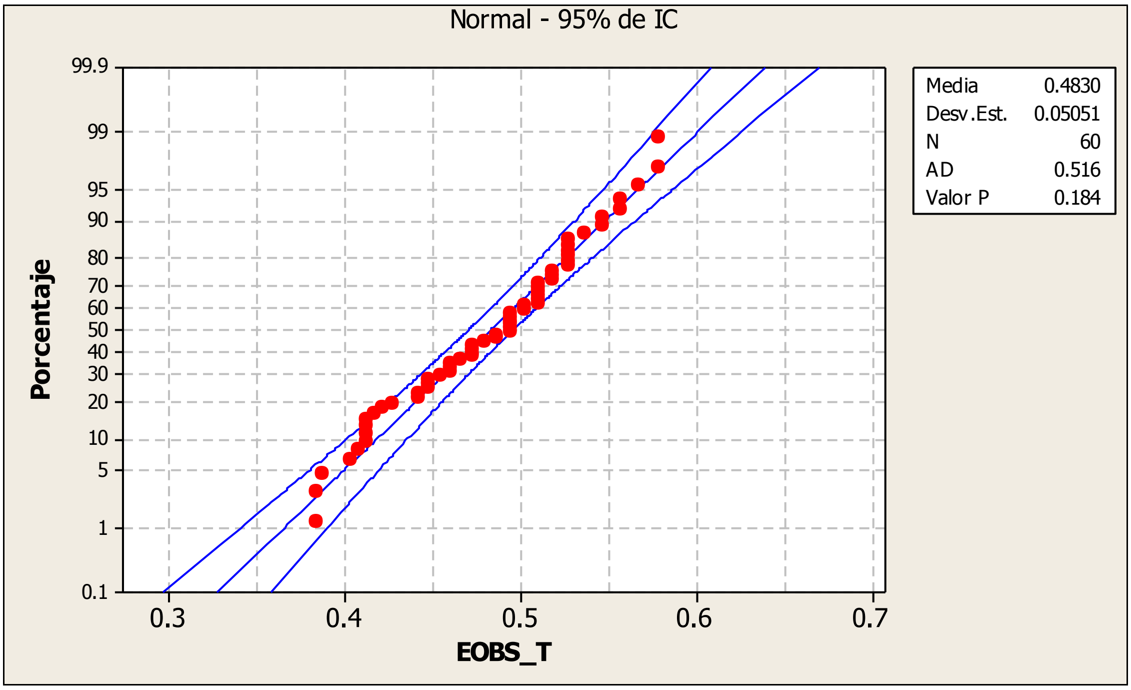

Figure 5. Probability plot of evaporation after transformation

The transformed observed evaporation is normal, according to the Anderson Darling test. The following table 2 presents the summary of the transformation of variables.

Table 2. Summary of variable transformation

Variable	Transformation exponent	Result
Medium temperature	1.43	Not normal after transformation
Cloudiness	0.92	Not normal after transformation
Extraterrestrial radiation	2.86	Not normal after transformation
Latent heat of vaporization	-5	Not normal after transformation
Water density	-5	Not normal after transformation
Saturation vapor pressure	0.95	Not normal after transformation
Relative humidity	3.5	Not normal after transformation
Current vapor pressure	0.77	Not normal after transformation
Measured or observed evaporation	-0.55	Normal after transformation

Model Calibration

Parameters were estimated using transformed and untransformed variables in an estimation process using the ordinary least squares method. Variables were chosen using Minitab 16 statistical software with the best subsets regression tool. Subsequently, for practical purposes, the selection of variables was carried out to generate a linear regression model, using the step-by-step regression tool. According to step-by-step regression, the appropriate model has the following variables:

- Dependent variable: observed daily evaporation (EOBS_T)
- Independent variables: mean maximum temperature (TMAX), current vapor pressure (EA), extraterrestrial radiation (RA), transformed extraterrestrial radiation (RA_T), saturation vapor pressure (ES), transformed mean temperature (TMED_T) and mean minimum temperature (TMIN).

The estimation of multiple linear regression parameters was carried out by the ordinary least squares method using the Eviews 5 software. The following table 3 shows the results of parameter estimation by ordinary least squares in Eviews 5.

Table 3. Ordinary least squares regression results.

Dependent Variable: EOBS_T				
Method: Least Squares				
Date: 03/21/22 Time: 15:59				
Sample (adjusted): 1 59				
Included observations: 59 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	10.92053	2.857896	3.821178	0.0004
TMAX	-0.236360	0.079714	-2.965096	0.0046
EA	0.000342	5.05E-05	6.768720	0.0000
RA	-0.046816	0.021006	-2.228654	0.0303
RA_T	8.66E-05	5.21E-05	1.663563	0.1023
ES	-0.013346	0.003773	-3.537491	0.0009
TMED_T	0.401808	0.121270	3.313344	0.0017
TMIN	-0.221744	0.079524	-2.788377	0.0074
R-squared	0.792269	Mean dependent var		0.483428
Adjusted R-squared	0.763757	S.D. dependent var		0.050858
S.E. of regression	0.024719	Akaike info criterion		-4.436985
Sum squared resid	0.031163	Schwarz criterion		-4.155285
Log likelihood	138.8911	Durbin-Watson stat		1.902351

White's heteroscedasticity test was also carried out without cross terms, the results are shown in the following table 4.

Table 4. Results of White's heteroskedasticity test without crossed terms.

White Heteroskedasticity Test:				
F-statistic	1.239266	Probability		0.284865
Obs*R-squared	15.55408	Probability		0.274050
Test Equation:				
Dependent Variable: RESID^2				
Method: Least Squares				
Date: 03/21/22 Time: 16:00				
Sample (adjusted): 1 59				
Included observations: 59 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.933223	1.584983	-0.588790	0.5589
TMAX	0.001097	0.003425	0.320146	0.7503
TMAX^2	-4.15E-05	9.24E-05	-0.449194	0.6554
EA	2.57E-05	2.99E-05	0.859537	0.3946
EA^2	-1.30E-08	1.41E-08	-0.925303	0.3597
RA	0.061150	0.165346	0.369832	0.7132
RA^2	-0.006667	0.016591	-0.401858	0.6897
RA_T	0.000368	0.000851	0.432638	0.6673
RA_T^2	-1.12E-08	2.07E-08	-0.540180	0.5917
ES	0.001144	0.002849	0.401699	0.6898
ES^2	-1.36E-07	4.53E-07	-0.300148	0.7654
TMED_T	-0.019189	0.044548	-0.430741	0.6687
TMED_T^2	3.36E-05	0.000139	0.241205	0.8105
TMIN^2	-3.96E-05	4.52E-05	-0.876459	0.3854
R-squared	0.263628	Mean dependent var		0.000528
Adjusted R-squared	0.050899	S.D. dependent var		0.001284
S.E. of regression	0.001251	Akaike info criterion		-10.32579
Sum squared resid	7.04E-05	Schwarz criterion		-9.832815
Log likelihood	318.6108	F-statistic		1.239266
Durbin-Watson stat	2.434993	Prob(F-statistic)		0.284865

In White's test, the null hypothesis of the existence of homoscedasticity shows that the hypothesis of homoscedasticity is accepted at the 0.05 level of significance, because the probability obtained is greater than the level of significance. Therefore, it is not necessary to correct heteroscedasticity that does not exist, rather homoscedasticity exists.

Then the regression model has the following form.

$$EOBS_T = f(c(1), TMAX, EA, RA, RA_T, ES, TMED_T, TMIN)$$

Where c(1) is an intercept.

The explicitly obtained regression model has the following multiple linear regression equation.

$$EOBS_T = 10.92053 - 0.236360\mathrm{TMAX} + 0.000342\mathrm{EA} - 0.046816\mathrm{RA} + (8.66\mathrm{E}-05)\mathrm{RA_T} - 0.013346\mathrm{ES} + 0.401808\mathrm{TMED\_T} - 0.221744\mathrm{TMIN}$$

Where the transformed variables are

$$EOBS_T = EOBS^{-0.55}$$

$$RA_T = RA^{2.86}$$

$$TMED_T = TMED^{1.43}$$

Where EOBS = observed evaporation (mm/day), TMAX = mean maximum temperature (°C), EA = current vapor pressure (Pa), RA = extraterrestrial radiation (mm/day), ES = saturation vapor pressure (Pa), TMED = mean temperature (°C), TMIN = mean minimum temperature (°C).

Model validation

For the validation period, the evaporation calculated with the model was determined and compared with the observed evaporation, as shown in the following figure 6.

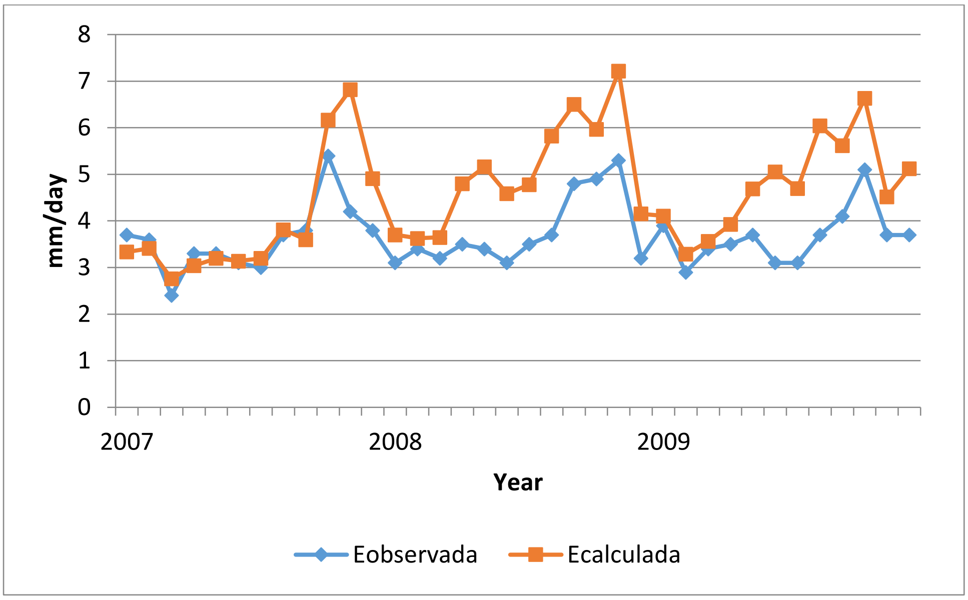

Figure 6. Comparison between observed and model-calculated evaporation

It was also compared to a scatter plot, as shown in Figure 7 below.

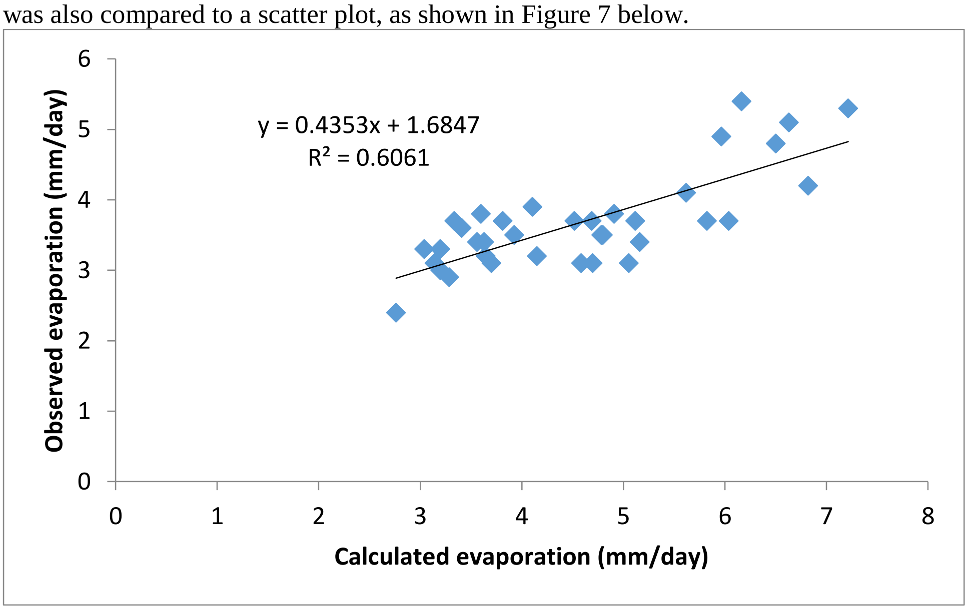

Figure 7. Scatter plot to compare observed and calculated evaporation

For the purposes of using the model, the following linear model should be used.

$$Eobs = 0.4353Ecal + 1.6847$$

Where: Eobs = observed evaporation (mm/day), Ecal = evaporation calculated with the relationship (mm/day). This linear model presents a value of $R^2 = 0.6061$.

DISCUSSION

The relationship obtained shows that the most significant variables are: the mean maximum temperature, current vapor pressure, extraterrestrial radiation, saturation vapor pressure, mean temperature and mean minimum temperature. This result agrees with that obtained by other researchers who used hybrid adaptive Neuro-Fuzzy inference systems with meta-heuristic algorithms (Adnan Ikram et al., 2022), like them, in the present research the maximum temperature is one of the variables of greatest influence on evaporation. The performance of the model in the validation stage was evaluated with the coefficient of determination r^2; as also done by other researchers (Adnan Ikram et al., 2022).

Other researchers have evaluated the water losses due to wind and evaporation generated by the sprinkler irrigation method. In order to evaluate these losses, empirical mathematical models and data mining algorithms have been used. For this, input variables have been used such as working pressure of the sprinkler, vapor pressure deficit, air temperature, wind speed, sprinkler nozzle diameter and relative air humidity (Al-Dosary et al., 2023). Likewise, in our research we have used variables that allow us to predict evaporation such as vapor pressure deficit, air temperature, wind speed and relative humidity; However, in the final relationship the influence of wind and relative humidity is not significant, but at the beginning of the selection of variables they were taken into account, this also indicates that wind and relative humidity do not have a significant influence on evaporation in Ichuña conditions. Spraying water droplets into the air creates different conditions for evaporation than those present in a class A tank where the water is at rest.

Likewise, other researchers have used algorithms and optimization tools to find optimal parameters and have also used the τ-Kendall correlation coefficient to determine the combination of input meteorological variables, and have also used evaluation metrics for the performance of different models (Fu & Li, 2023) that are similar to the coefficient of determination r^2 that we have used in the validation of the model. These authors found that the optimal input meteorological parameters to the models were: the mean monthly temperature, the minimum and maximum air temperature, therefore they recommend using their model with limited meteorological information (Fu & Li, 2023). This reality is also common in the conditions of the Peruvian Andes where there is limited meteorological information. The model that we obtained also allows us to estimate evaporation with information that is more available such as maximum, mean and minimum temperatures, current vapor pressure and saturation that can be obtained with relative humidity, extraterrestrial radiation that simply depends on geographical position. The use of algorithms can be complicated for practical purposes, which is why our relationship is easier to use.

IV. CONCLUSION

The determination of the relationship between daily evaporation and elements of the climate was carried out at the Ichuña meteorological station in Moquegua Peru, the relationship is linear with the meteorological elements considered as independent variables: mean maximum temperature (°C), pressure current vapor pressure (Pa), extraterrestrial radiation (mm/day), saturation vapor pressure (Pa), mean temperature (°C) and mean minimum temperature (°C). In the relationship, the variables that have been transformed to normalize them are: daily evaporation (mm/day), extraterrestrial radiation (mm/day) and mean temperature (°C).

In the calibration of the relationship between daily evaporation and climate elements at the Ichuña meteorological station in the Moquegua region, the ordinary least squares estimation process is sufficient as it does not present problems of heteroscedasticity of the model and the variables that have statistically significant coefficients at the significance level of 0.05 ($p<0.05$) are: mean maximum temperature, current vapor pressure, extraterrestrial radiation, saturation vapor pressure, transformed mean temperature and mean minimum temperature. The transformed extraterrestrial radiation is not statistically significant. The value of the coefficient of determination (r^2) achieved is 0.7923, therefore more than 79% of the variation in daily evaporation is explained by the independent variables.

In the validation of the relationship between daily evaporation and climate elements at the Ichuña meteorological station in the Moquegua region, the comparison graph shows that the relationship obtained slightly overestimates the evaporation in this validation period and also in this period the diagram Dispersion between evaporation observed and calculated with the model shows a good correspondence with a coefficient of determination value (r^2) of 0.6061 and a correlation coefficient of 0.7785, so the relationship represents a good agreement between observed and calculated values.

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