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Temporary Variability of Rain in Pedregal Gorge due to the Effects of Climate Change, Lima – Perú

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Abstract

The climate is an essential factor in the sustainable and economic development of a country; its study helps to classify the different types of environments to better plan economic and productive activities. The objective of this study is to analyze the information of precipitation in Pedregal Ravine between the years 1980 and 2017 and to determine its behavior and temporal variability. Between January and March 2017, heavy rains occurred on the northern and central coast of Peru, which caused flooding and debris flow that affected the departments of Tumbes, Piura, Lambayeque, La Libertad, and Lima. This event has been described in Peru as "Coastal Child," and according to INDECI reports, it caused the death of 100 people. There are no precipitation stations in Pedregal Ravine, but the Chosica and Santa Eulalia stations were used as a reference, which is located 3 km from the study zone. The Matucana and Carampoma stations located in the upper part were also analyzed in order to better understand the spatial behavior of precipitation in the entire basin. Two statistical tests have been used to detect changes in the precipitation time series: Mann Kendall and Student's T. The results of these tests indicate that there is a change in the behavior of precipitation in Pedregal Ravine between the period of 1980 and 2017; this change is a tendency to increase rainfall.

Keywords; *variability, climate, sustainable development, flooding, debris flows.*

I. INTRODUCTION

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) concludes that the earth's climate is warming. This conclusion is based on changes observed around the world, such as the average increase in the earth's surface temperature, sea-level rise, and changes in precipitation trends.

Mentions in its report that between 1998-2017 countries hit by natural disasters reported direct economic losses of $2908 billion of which climate type disasters were 2245 billion or 77% of the total while between 1978-1997 disasters by climate type were $895 billion [1].

The 1998 floods in the Yangtze River in southern China and the Nenjiang-Songhuajiang Valley in northern China caused $36 billion in economic losses and more than 3000 lives.

In their research on the analysis of precipitation trends in Mexico [2] for the period 1920-2004 mention that they used the Mann-Kendall test to detect the seasonal pattern of precipitation, they found significant changes in precipitation trends especially during summer, and rain increases more in arid and semi-arid regions than in the humid areas.

Performed a trend analysis for monthly rainfall and temperature series in the Rio Grande [3] basin in

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Antioquia Colombia using parametric and non-parametric statistical tests with a 95% confidence level and found that there is increasing and decreasing rainfall trends distributed throughout the pool with a statistical significance of 38% at the stations used.

Conducted the trend analysis of annual rainfall for the period 1964-2011 in the Pastaza River basin in Ecuador [3], using 23 INAMHI stations, three statistical tests to establish data homogeneity: Student’s t, Cramer and Helmert. He applied Spearman's statistical analysis to develop the temporal trend and determine that 30.4% of the stations present positive temporal trends, 26.1% negative, and 43.5% show no direction during the period 1964-2011.

Precipitation in Peru starts in December and generally reaches its highest values between February and March. These precipitations generate runoff and cause the activation of streams, originating the increase in the flow of the Rimacriver. The area where landslide occurs in the Rimac river basin is very well-identified; they arise from the confluence of Santa Eulalia and San Mateo rivers through the Chaclacayo and Ate districts to the mouth of Huaycolororiver.

In Pedregal Ravine, the largest landslide event that affected this area occurred on March 9, 1987, due to heavy rains that generated tons of mud and stones that fell on the homes of residents of the young town San Antonio de Pedregal and San Miguel Housing Association, causing 100 deaths and leaving thousands of people homeless [4]

In the Rímac basin, some changes have been observed: the increased temperature, changes in the intensity and duration of precipitation, among others. Likewise, an increase in the frequency of occurrence and severity of landslides has been observed in recent years in the Rimac river basin; a landslide of importance has occurred in the years 1987, 2012, 2015, and 2017.

II. MATERIAL AND METHODS

2.1. Study area

The study zone is the Pedregal Ravine, which has an area of approximately 10.3 km2 in the district of Lurigancho-Chosica.

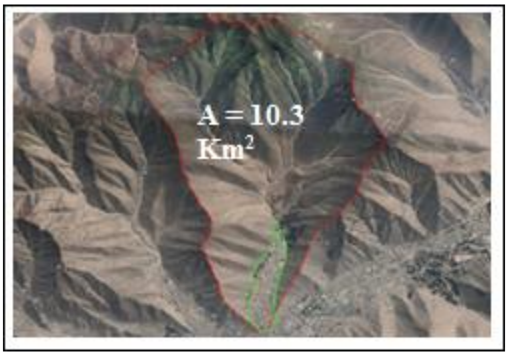

Figure 1.Delimitation of Pedregal Ravine.

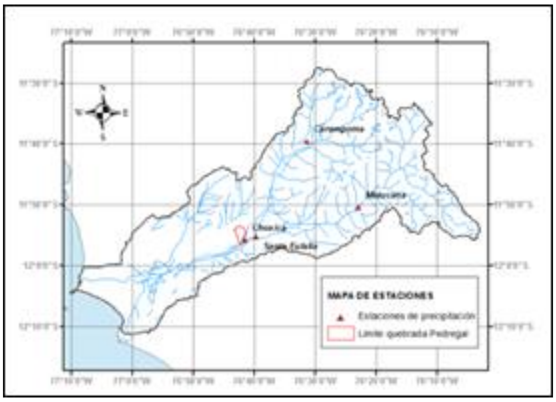

Figure 2. Location of precipitation stations

2.2. Description of the study area

Pedregal Ravine is one of the tributaries to the Rímacriver; on the right bank, it borders the La Libertad and Nicolás de Piérola Ravine.

The stream has steep slopes (38.68% between 60 and 100%, and 11% with hills above 100%). Its average longitudinal profile is 28% [5].

The coordinates of the precipitation stations used in this study are shown below:

Station	Altitude	Latitude	Longitude
Chosica	867	11º 55' 47.48"	76º 41' 23.09"
Santa Eulalia	970	11º 55' 12"	76º 39' 59.9"

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The Chosica and Santa Eulalia stations are located in the middle basin of the Rímac River.

Station	Altitude	Latitude	Longitude
Matucana	2417	11º 50' 20.86"	76º 22' 40.9"
Carampoma	3424	11º 39' 18.1"	76º 30' 54.49"

The Matucana and Carampoma stations are located in the upper part of the Rimac River basin.

2.3. Weather

Pedregal Ravine has a dry climate with significant rainfall between January and March. The average rain according to Chosica and Santa Eulalia stations fluctuates between 0 mm in July and 10 mm in February, the maximum rainfall values occur between January and March with an average cost of 50 mm/month. The average temperature in Pedregal Ravine, according to La Cantuta station, fluctuates between 15.8° C in July to 22° C in February.

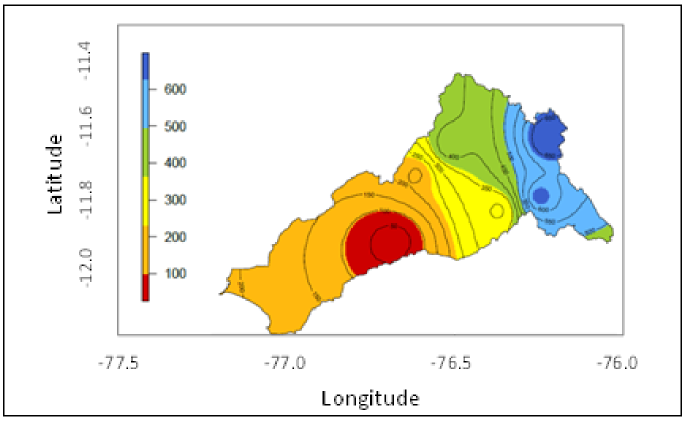

Figure 3. Mean annual rainfall in the Rimac basin

2.4. Statistical Analysis

Two types of statistical tests have been used to determine if there are trends in the precipitation time series: the Mann Kendall Test and Student's T-test.

The Chosica and Santa Eulalia stations have been evaluated for the middle basin of the Rímac, while the Matucana and Carampoma stations have been assessed for the upper basin.

Mann Kendall Test

This method tests whether there is a trend in the time series of the data. It is a non-parametric test. The n time series values (X1, X2, X3, ...,Xn) are replaced by their relative rankings (R1, R2, R3, ..., Rn) (starting at 1 for the lowest to n) using formula 1. The statistical test S is:

$$S = \sum_{i=1}^{n-1} \left[\sum_{j=i+1}^{n} \mathrm{sgn}(R_i - R_j) \right] \quad (1)$$

Where: sgn(x) = 1 For x > 0

sgn(x) = 0 For x = 0

sgn(x) = -1 For x < 0

If the null hypothesis Ho is true, then S is approximately normally distributed with

$\mu = 0$ and $\sigma = n (n – 1) (2n + 5) / 18$

The z-statistic is, therefore (critical statistical value of the test for various levels of significance that can be obtained from normal probability tables):

z = | S | / σ0.5 (A positive value of S indicates that there are an increasing trend and vice versa)

Mann Kendall's test is one of the most widely used tests for analyzing trends in time series (Zhang et al., 2006).

Student's T-test

This method tests whether the averages in 2 different periods are different. The test assumes that the data are normally distributed. In this test, t is the critical value for various levels of significance which can be obtained from the Student's t statistics tables, x and y are the means of the first and second periods respectively, and m and n are the numbers of observations in the first and second periods respectively. S is the sample standard deviation (the total views of m and n).

For the calculation of statistical trend tests with significance levels of 0.01, 0.05, and 0.1, TREND software was used; for significance levels greater

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than 0.1, XLSTAT statistical with formula 2, software for Excel was used.

$$t = \frac{(\bar{x} - \bar{y})}{s\sqrt{\frac{1}{n} + \frac{1}{m}}} \quad (2)$$

III. RESULTS

The Chosica station began recording in 1989; for this reason, it had to be completed (between 1980 and 1988) with data from the Santa Eulalia station. It was found a good correlation (0.859) between these two stations.

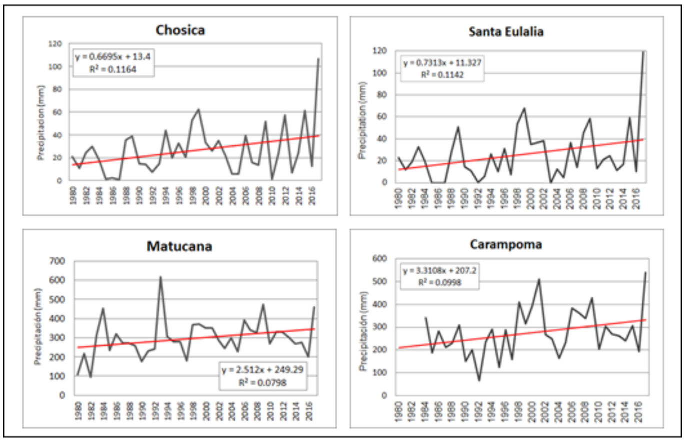

Figure 4.Annual rainfall time series at the four stations used in this study.

Apparently, it can be observed that there is a tendency to increase precipitation in the four stations used in this study (see Fig. 4).

Ta**ble 1. Summary table of statistical tests with TREND software**

	Statistical Test	Critical Values (Statistical table)			Results
CHOSICA		**a=0.1**	**a=0.05**	**a=0.01**	
Mann-Kendall	0.469	1.645	1.96	2.576	NS
Student's t	-0.77	1.701	2.048	2.763	NS
SANTA EULALIA		**a=0.1**	**a=0.05**	**a=0.01**	
Mann-Kendall	1.848	1.645	1.96	2.576	S (0.1)
Student's t	-1.765	1.688	2.027	2.718	S (0.1)
MATUCANA		**a=0.1**	**a=0.05**	**a=0.01**	
Mann-Kendall	1.835	1.645	1.96	2.576	S (0.1)
Student's t	-1.444	1.688	2.027	2.718	NS
CARAMPOMA		**a=0.1**	**a=0.05**	**a=0.01**	
Mann-Kendall	3.224	1.645	1.96	2.576	S (0.01)
Student's t	-3.626	1.692	2.034	2.732	S (0.01)

Table 2. Mann Kendall's test result for Chosica station

Mann Kendall trend test / Bilateral test (Precipitation):

Kendall's Tau	0.172
S	121
Var(S)	6327
p-value	0.128
alfa	0.13

Table 2. Descriptive statistic

Descriptive Statistics

Variable	Observations	Minimum Value	Maximum Value	Average	Standard Deviation
Precipitation	38	0.84	106.5	26.457	21.806

Table 2 shows that 38 mean annual precipitation values (1980-2017) were used in Mann Kendall's test, with a significance level (alpha) of 13%. The following hypothesis was made: Ho: There is no trend in the precipitation series and Ha: There is a trend in the precipitation series.

The calculated p-value is less than the significance level of 13%; therefore, the null hypothesis Ho should be rejected, and the alternative hypothesis Ha should be accepted, i.e., the Chosica station does show an increase in the precipitation trend for a significance level of 13%.

Table 3. Relationship between the altitude of the station and the level of significance

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STATION	ALTITUDE	ALFA (α)
Carampoma	3424	1%
Matucana	2417	10%
Santa Eulalia	970	10%
Chosica	867	13%

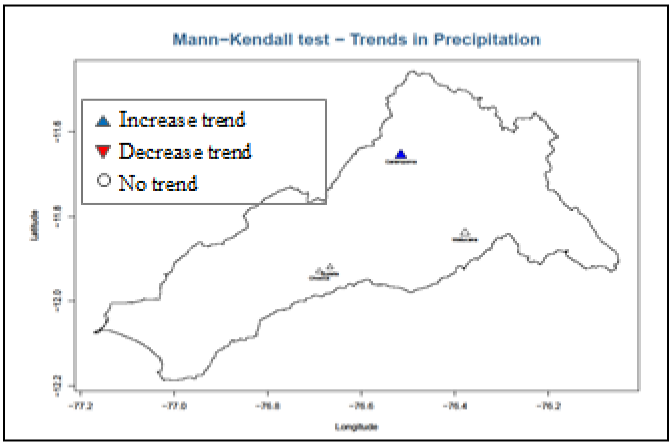

Figure 5. Trends for 1% significance level

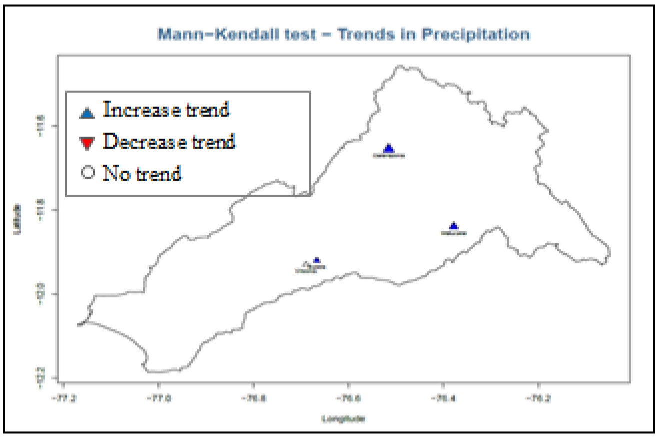

Figure 6. Trends for 10% significance level

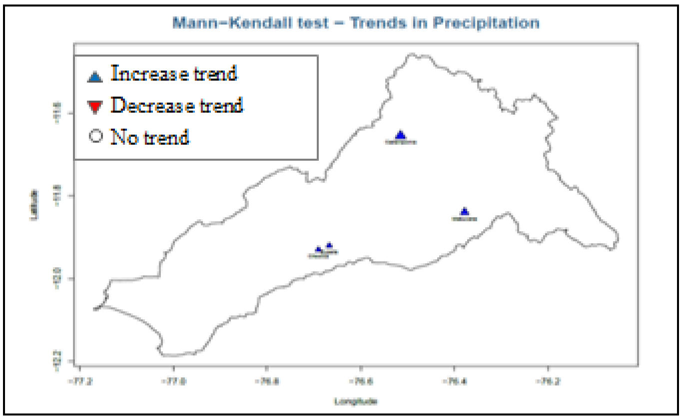

Figure 7. Trends for 13% significance level

IV. DISCUSSION

In table 1, it can be seen fig.5, that trend analysis using Mann Kendall's test indicates that for a significance level of 1%, the Carampoma station already shows an increase in the trend of mean annual precipitation. Then, for a significance level of 10%, Matucana and Santa Eulalia stations show increasing trends in rainfall as the show fig. 6. For the significance levels that TREND software has (1%, 5%, and 10%) as the show fig. 7, Chosica station does not show tendencies in the increase of precipitation, for this reason, XLSTAT software was used, and it was obtained that Chosica station shows an increase in the trend of rainfall for a significance level of 13% [6].

Likewise, the trend analysis applied to the Chosica, Santa Eulalia, Matucana and Carampoma stations indicates, according to the t Student test, that the averages of the two periods (1980-1998 and 1999-2017) at Santa Eulalia station are significantly different at 90%; similarly, the standards of the periods at Carampoma station between 1980-1998 and 1999-2017 are significantly different at 99%.

According to Mann Kendall's statistical test, Chosica station did not show a significant tendency to increase precipitation of a substantial level of 10%, but it did for 13%.

In table 3 it can be observed that there is a very marked relationship between the altitude of the precipitation station and the significance level (α), this can be understood in the following way, first, we must say that no hypothesis test is 100% true since the analysis is based on probabilities; therefore we can say that for the Chosica station there is a 13% probability that the Mann Kendall test is not correct, but there is an 87% probability that it is accurate, similarly for the Matucana and Santa Eulalia stations we can say that there is a 10% probability that the Mann Kendall test is not correct, but there is a 90% probability that it is accurate.

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According to Mann Kendall and Student's T statistical tests, the Carampoma station is the one that shows significant changes in precipitation increase for a 1% significance level, that is, there is a 99% probability that the precipitation has increased in the 1980-2017 period.

The analysis of consecutive precipitation days for each station and each year starting from 1980 to 2017 was also carried out [7]. In the case of the Chosica station, period one considered was 1989-2003 and period two from 2004-2017 for the other stations the period one found was 1980-1998 and period two from 1999-2017. This analysis consisted of adding up all daily values of consecutive precipitation, the cost for a given year is assigned to the maximum accumulated precipitation value; thus, the following results were obtained:

Table 4. Summary table of mean and maximum accumulated precipitation by periods

	Mean		Maximum	
	Period 1	Period 2	Period 1	Period 2
Chosica	7.28	13.03	30.70	41.70
Santa Eulalia	8.76	14.89	32.90	49.70

	Mean		Maximum	
	Period 1	Period 2	Period 1	Period 2
Matucana	66.84	64.66	223.90	151.90
Carampoma	62.27	114.07	132.70	234.50

Table 4 shows that the accumulated daily precipitation in period two concerning period 1 in Chosica, Santa Eulalia, and Carampoma stations is higher; only in the case of the Matucana station, the accumulated daily precipitation maintains similar values in both periods [8].

In conclusion, and after analyzing the annual time series, we can say that there is a positive or increasing trend in precipitation in the four stations evaluated: Carampoma, Matucana, Santa Eulalia, and Chosica for the period considered from 1980 to 2017 [9].

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