Precipitation Anomalies Characterization in Papalotla River Basin and Their Implications for Territorial Planning

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Abstract: *This paper focuses on calculating the monthly anomaly of precipitation using a straightforward methodology based on average monthly values and drought categorization. The specific case study conducted in this study pertains to the Papalotla River subbasin, which is a part of the Texcoco Lake basin. The research findings reveal that anthropogenic activities, particularly land use change, have had a detrimental impact on the environmental balance of the region. These activities have resulted in several negative consequences such as soil degradation, loss of biodiversity, and environmental pollution. Additionally, the utilization of water resources upstream has led to a reduction in runoff, further exacerbating the environmental challenges faced by the subbasin. Overall, the research highlights the significant disturbances caused by human activities in the Papalotla River subbasin. These disturbances have disrupted the natural area equilibrium, leading to adverse environmental effects.*

Keywords: *Standardized Drought Index, monthly anomaly, Papalotla River, land use*

1. Introduction

Mexico is a country that, due to its geographical characteristics, location, relief and location between two oceans, is impacted by different hydrometeorological phenomena and this increases vulnerability to climate change. Hurricanes, droughts, extreme temperatures and torrential rains have caused serious human losses and high economic and social costs over time. These events limit development opportunities in the short and medium term. These and other consequences of the impacts of climate change have been addressed in various scientific studies and technical papers, which suggest that some of the negative consequences of climate variability are already visible and could worsen over the coming decades. Likewise, the aggregate impact of extreme events, resulting from climate change, can intensify other environmental and social problems, such as land use change, the shape and structure of urban settlements, production processes or the state of ecosystems [1]. As for precipitation, changes in rainfall distribution patterns are observed.
Climate change scenarios present a high level of uncertainty, since in some cases a slight increase is projected in some regions, but in general a decrease in precipitation is appreciated. precipitation anomaly is the main indicator of the behavior of precipitation in a certain period and a certain place, it is a parameter that measures the deviation in percentage of the precipitation of a given period in relation to the historical average value of a period and indicates how far away the rainfall recorded, either below or above what is assumed to be the average or normal value; this indicator is important for assessing weather responses [1]. Droughts, storms and floods, all water-related phenomena, dominate the list of catastrophes of the last 50 years, both in terms of human and economic losses, according to a comprehensive analysis [2] (World Meteorological Organization, 2012).
Desertification is strongly linked to poverty and migration, since unproductive land causes scarcity and migration. In absolute terms, the population below the poverty line increased from 15.9 million to 17.0 million people in the period 2008-2010 and it is estimated that between 300,000 and 400,000 people are displaced each year, leaving behind unproductive land. The international community, including Mexico, has long recognized that land degradation and desertification is a multidimensional economic, social, and environmental problem of concern to more than 167

countries in all regions of the world, affecting some two billion inhabitants and a quarter of the planet's land surface [3]. Desertification risks arise when human interventions modify the natural balance beyond its limits of resistance. Historically, in dry regions, man has often developed social, cultural and economic systems that have allowed him to regulate pressure on basic natural resources (soil, water and vegetation), depending on the availability of those resources. In this way it has achieved a sustainable exploitation in the regime of rainfall variability of the region; the threat that hangs over these environments is, therefore, potential and degradation only appears after the rupture of the balance [4]. This paper presents a methodology with which it is intended to calculate the monthly anomaly of precipitation in a simple way from average monthly values and drought categorization having as a case study the Papalotla River subbasin which is part of the Texcoco Lake basin.

2. Methodology

The Valley of Mexico is closed basin as shown in Figure 1, without natural outlets for rainwater runoff and where there are convective storms of high intensity and short duration, which cause serious problems for the evacuation and control of its waters. In addition to this, the Mexico City metropolitan area (ZMCDMX) has grown in a disorderly manner, and snowing hillsides and old areas, coupled with this the ZMCDMX which is the most populated in the country, with more than 22 million people settled in an area of the order of 7,000 square kilometers, which include Mexico City in whole and in part in the states of Mexico, Hidalgo, Tlaxcala and Puebla.

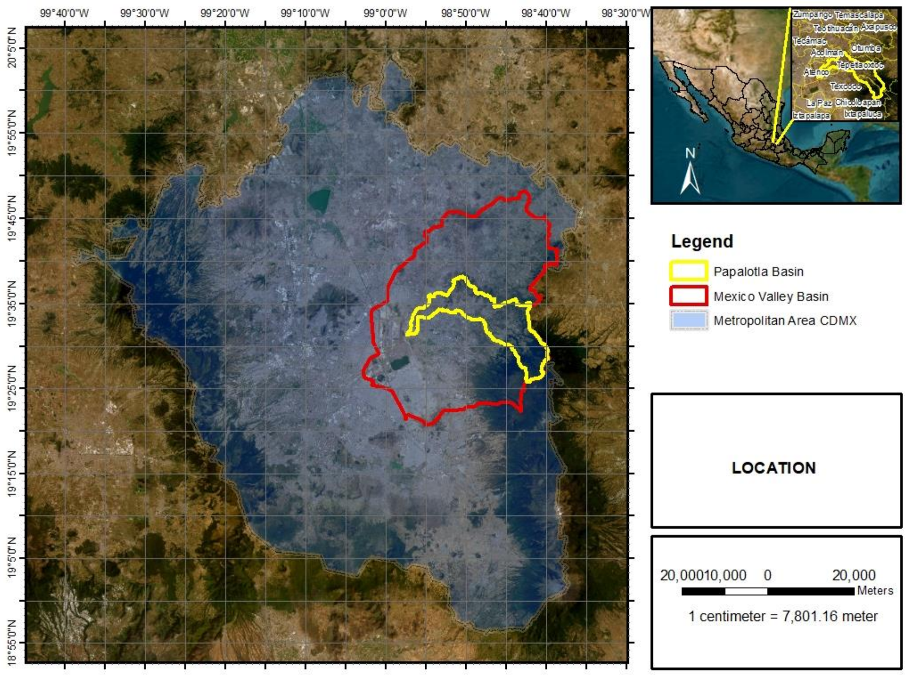


Fig. 1. Location of the Papalotla River Basin

The great difference in unevenness between ravines and subsidence allows runoff to descend unexpectedly, carrying garbage, mud and stones to the drainage systems and silting them. While, in the latter, they are characterized by differential subsidence of land, mainly due to the overexploitation of aquifers. These subsidence’s cause slopes and dislocations of drainage networks, causing flooding and waterlogging [5]. Papalotla River basin which will be taken as a study area is located east of the State of Mexico. Its source is located in the Sierra Nevada. It runs through the municipalities of Tepetlaoxtoc, Papalotla, Chiautla, Tezoyuca and Atenco, to finally flow into Texcoco Lake. This river is part of Valley of Mexico basin and like other rivers that make it up presents a high degree of pollution due to the discharge of wastewater, both domestic and the paper and livestock industry since 1985.

As established by the World Meteorological Organization, the Climatological Normal, or normal value, is used to define and compare climate and is generally represented by the average value of a continuous series of measurements of a climatological variable (precipitation, temperature, wind, etc.) over a period of at least 30 years. The difference between the recorded value of the variable and its normal value is known as an anomaly. In general terms, the hydrometeorological data contain both a temporal and spatial structure, therefore, the statistical methodologies used in their analysis should consider this type of structures [6]. It is very important to remember that, of all meteorological parameters, precipitation is one of the most spatial-temporal variability. This fact makes it difficult to determine an interval within which the anomalies that occur most frequently can be grouped, to consider them as common alterations and, therefore, as normal values. We will call this range or interval hereinafter, the Threshold of Normality. The anomalies, in the case of precipitation, are calculated as the quotient between the total recorded in a particular month and its multiannual average value and is expressed as a percentage, so that 100% indicates that a volume of water exactly equal to its historical average was recorded. That both the data move away from 100% up or down, indicates the degree of alteration by excess or default, respectively [7]. There are two very important aspects in the representation of precipitation anomalies on which this proposal of categorization of drought using the standardization of precipitation anomaly is based. Reflecting the situation of the event in relation to the series of past data is as important as the phenomenon itself and converts the numeric value into an index that categorizes the event and it is easily understood. The standardized anomaly is calculated according to the procedure used by Ogallo [2], where:

$$Z_{ij} = \frac{x_{ij} - x_j}{S_j} \quad (1)$$

Where:
Xij is the cumulative total of the analysis period of station j in year i and xj, Sj are the mean and standard deviation of that period, respectively.
Under this premise it is proposed that for the calculation of the proposed anomaly will be monthly by weather station to which the following equation is proposed:

$$Anomaly = \frac{xi - So_i}{So} \quad (2)$$

Where xi is the mean of the value of month i over the period, So_i is the standard deviation of the mean of month i and So is the average deviation of all months.
The standardized drought indices (SI) evaluate the difference between the values of the analyzed variable and the condition considered "normal" in a normalized sample. Thus, the numerical values of the SI index represent anomalies of the variable of interest with respect to the mean [8]. In this work it is proposed that from the results obtained it is categorized according to the range indicated in Table 1 since this allows converting the numerical value into an index that categorizes the event, and this is easily understood.

Table 1: Standardized Drought Index (SI) scale

Value	Category
More than 2	extremely rainy
Between 1.5 and 2	rainy
Between 1 and 1.5	slightly rainy
Between 0.5 and 1	Normal
Between 0 and 0.5	Normal
Between -0.5 and -1	slightly dry
Between -1.5 and -2	dry
Below than -2	extremely dry

Application of the methodology to the Papalotla river basin

Study area is part of the well-known Federal Zone of Texcoco Lake and adjacent lands that are located east of the State of Mexico. In Texcoco Lake nine rivers converge in natural conditions; five in its northern portion (San Juan Teotihuacán, Papalotla, Xalapango, Coxcacoaco, Texcoco) two in the central zone (Chapingo and San Bernardino) and two in the southern portion (Santa Monica and Coatepec). In addition, in the lower zone, through the General del Valle drain, the waters from the Ameca, La Compañía and San Francisco rivers converge. The former lake of Texcoco is fed by the rivers Churubusco, La Compañía, Los Remedios, San Juan Teotihuacán and Papalotla, and reaching the federal zone by two arms, the Santa Rosa and San Bartola, Xalapango, Coxcacoaco, Texcoco (which currently functions as drainage and sanitary drainage of the metropolitan area of Texcoco), San Bernardino, Chapingo, Coatepec and Santa Monica.
Papalotla River basin (Figure 2) is formed by the union of two slopes which join each other in the lower part of the basin, one that collects the runoff from mountainous areas located in the center of the municipality of Tepetlaoxtoc, and another that comes from the mountainous area near the town of Santa Inés (upper part of the basin). The approximate extension of the northern branch is 17.2 km. Papalotla River crosses the municipalities of Papalotla, San Andrés Chiautla, Tezoyuca and Atenco until it reaches the former Texcoco Lake. It has an average annual contribution of 6.42 million cubic meters.

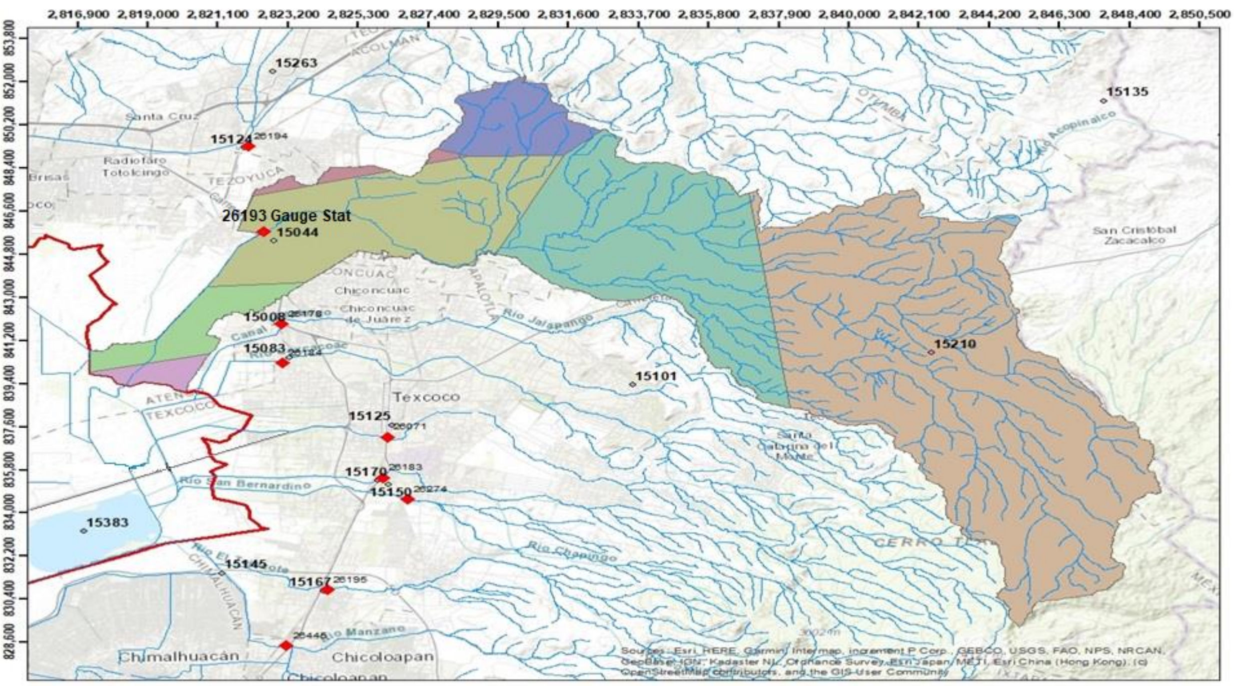
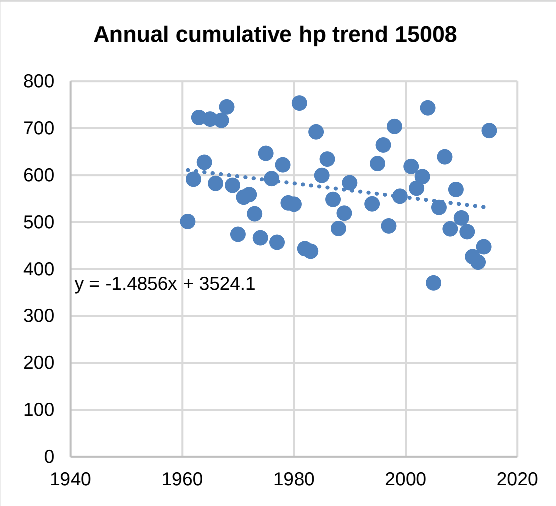
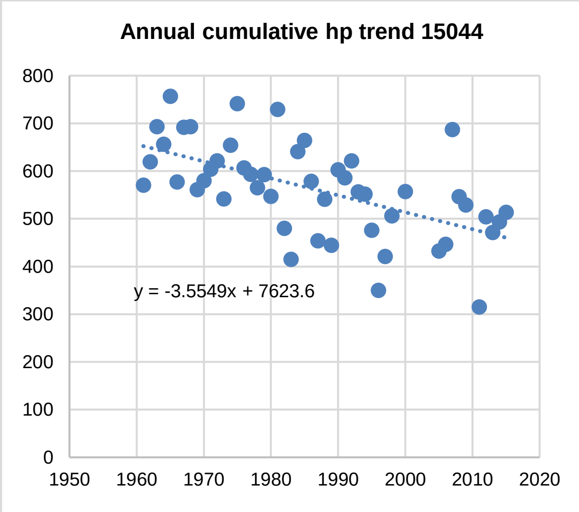


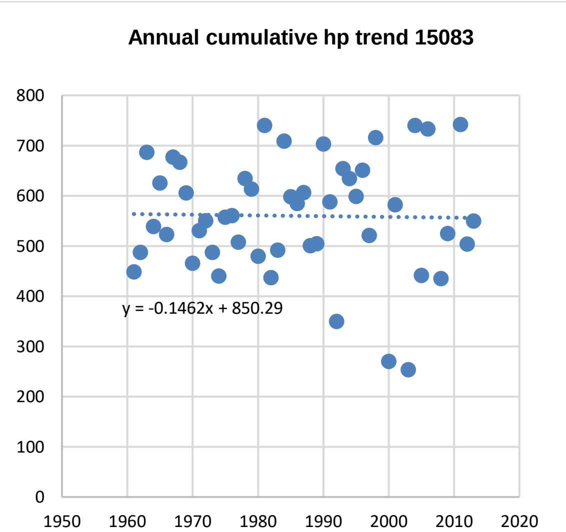
Fig. 2. Papalotla River Basin

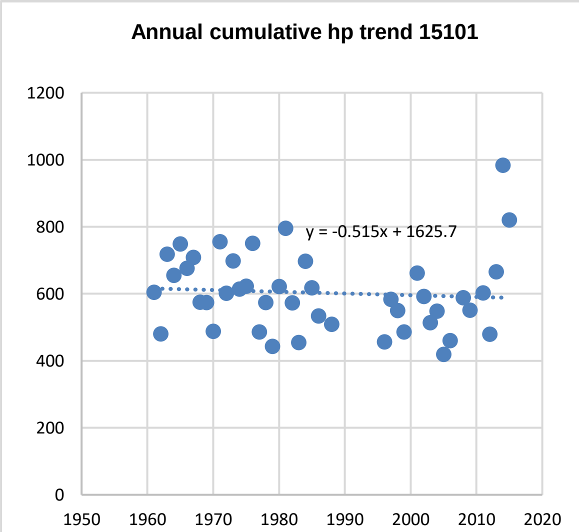
3. Results

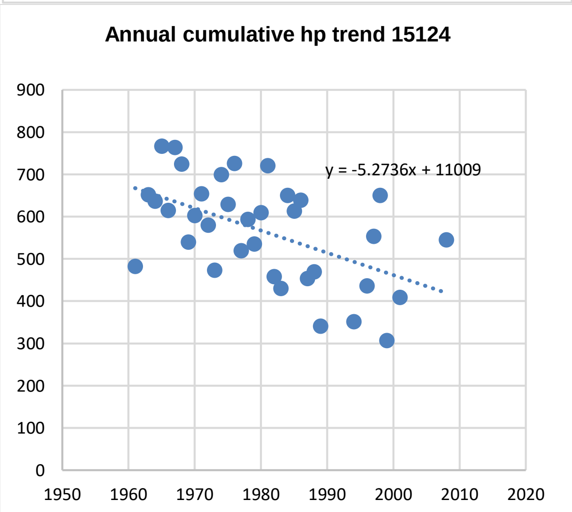
Based on the climatological data of the Clicom Database, the analysis of accumulated precipitation annual trends records for each of the climatological stations were carried out, which are observed below (Figure 3).

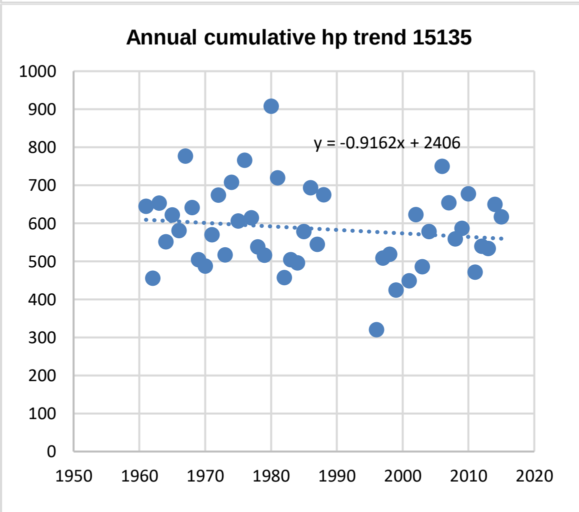

Annual cumulative hp trend 15008
800
700
600
500
400
300
200
100
0
1940
1960
1980
2000
2020
y = -1.4856x + 3524.1

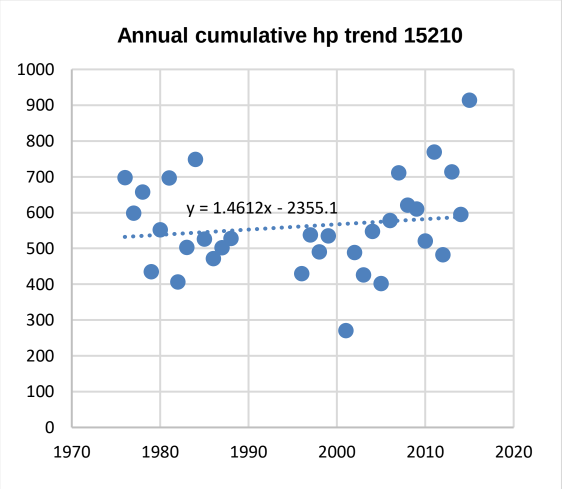

Annual cumulative hp trend 15044
800
700
600
500
400
300
200
100
0
1950
1960
1970
1980
1990
2000
2010
2020
y = -3.5549x + 7623.6


Annual cumulative hp trend 15083
800
700
600
500
400
300
200
100
0
1950
1960
1970
1980
1990
2000
2010
2020
y = -0.1462x + 850.29


Annual cumulative hp trend 15101
1200
1000
800
600
400
200
0
1950
1960
1970
1980
1990
2000
2010
2020
y = -0.515x + 1625.7


Annual cumulative hp trend 15124
900
800
700
600
500
400
300
200
100
0
1950
1960
1970
1980
1990
2000
2010
2020
y = -5.2736x + 11009


Annual cumulative hp trend 15135
1000
900
800
700
600
500
400
300
200
100
0
1950
1960
1970
1980
1990
2000
2010
2020
y = -0.9162x + 2406



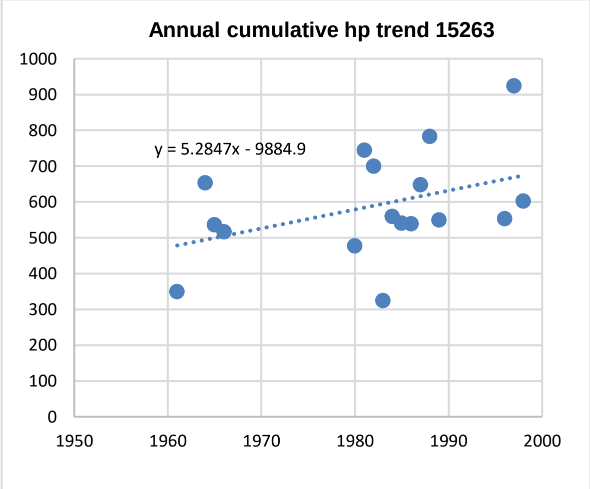


Fig. 3. Annual cumulative hp trend for 15263, 15210, 15135, 15124, 15101, 15083, 15044 and 15008 climatologic Stations

From figure 3 it can be seen that station 15008 shows a downward trend with 26 records above the average of 571.41 and 26 below average. The station has a record of 370 mm per year for 2005. Station 15044 presents a downward trend with an average annual cumulative of 562.98 mm registering 30 data above the average and 20 below the average. The minimum registration was presented in 2011 with 315 mm accumulated annually. Station 15083 presents a very slight downward trend with an average of 559.95 mm accumulated per year being 24 records above the average and 25 below the average with 253.1 mm accumulated in the year 2000.
The station 15101 presents a slight downward trend with 602.83 mm accumulated per year having registered 19 data above the average and 25 below the average, all years accumulated records greater than 400 mm being the lowest in 2005 with 419 mm. The station 15124 presents a marked downward trend with an accumulated annual average of rainfall of 566.28mm with 19 records above the average and 16 below the average the lowest recorded value of accumulated rain was the year of 1999 with 306.5 mm.
Station 15135 presents a downward trend with 21 records above the average that is 585.73 and 25 below the average the lowest value recorded was 320 mm accumulated in 1996. The station 15210 presents a tendency to the high with 26 records above the average that is 561.59mm and 6 below the average the lowest value recorded was 270.6 mm in 2001 it is worth mentioning that this station is the one that occupies more than half of the area of influence of the entire basin, according to the Thiessen polygons shown in Figure 2.
Station 15263 presents a trend to the high with 7 records above the average that is 588.84mm and 10 below the average the lowest value recorded was 324 mm in 1983. Stations 15008, 15044, 15083, 15101, 15124 and 15135 show a downward trend only station 15210 and 15263 have a trend to high.
According to the calculation made using the methodology described above in Table 2, the calculation of the monthly precipitation anomalies for each of the 8 climatological stations is presented.

Table 2: Monthly precipitation anomalies. Climatological Papalotla River basin

Months	15008	15044	15083	15101	15124	15135	15210	15263
January	-0.301	-0.319	-0.267	-0.022	-0.014	-0.014	-0.016	-0.012
February	-0.382	-0.143	-0.164	-0.009	-0.005	-0.013	-0.035	-0.014
March	-0.197	-0.123	-0.183	-0.017	-0.012	-0.011	-0.018	-0.015
April	0.218	0.139	0.298	0.003	-0.006	-0.016	0.003	-0.011
May	0.893	0.581	0.855	0.007	-0.006	0.009	0.013	-0.034
June	2.457	1.886	2.512	0.071	0.036	0.019	0.047	-0.025

Months	15008	15044	15083	15101	15124	15135	15210	15263
July	3.616	2.394	3.235	0.073	0.052	0.013	0.030	-0.037
August	3.152	2.373	2.631	0.053	0.050	-0.002	0.053	-0.014
September	1.706	1.404	1.302	0.051	0.026	-0.001	0.022	-0.047
October	0.814	0.272	0.468	0.016	-0.001	-0.009	0.008	-0.035
November	-0.277	-0.263	-0.143	-0.009	-0.016	-0.020	-0.011	-0.019
December	-0.242	-0.280	-0.237	-0.010	-0.007	-0.013	-0.009	-0.015

Likewise, Figure 4 graphically presents the monthly anomalies for the same weather stations.

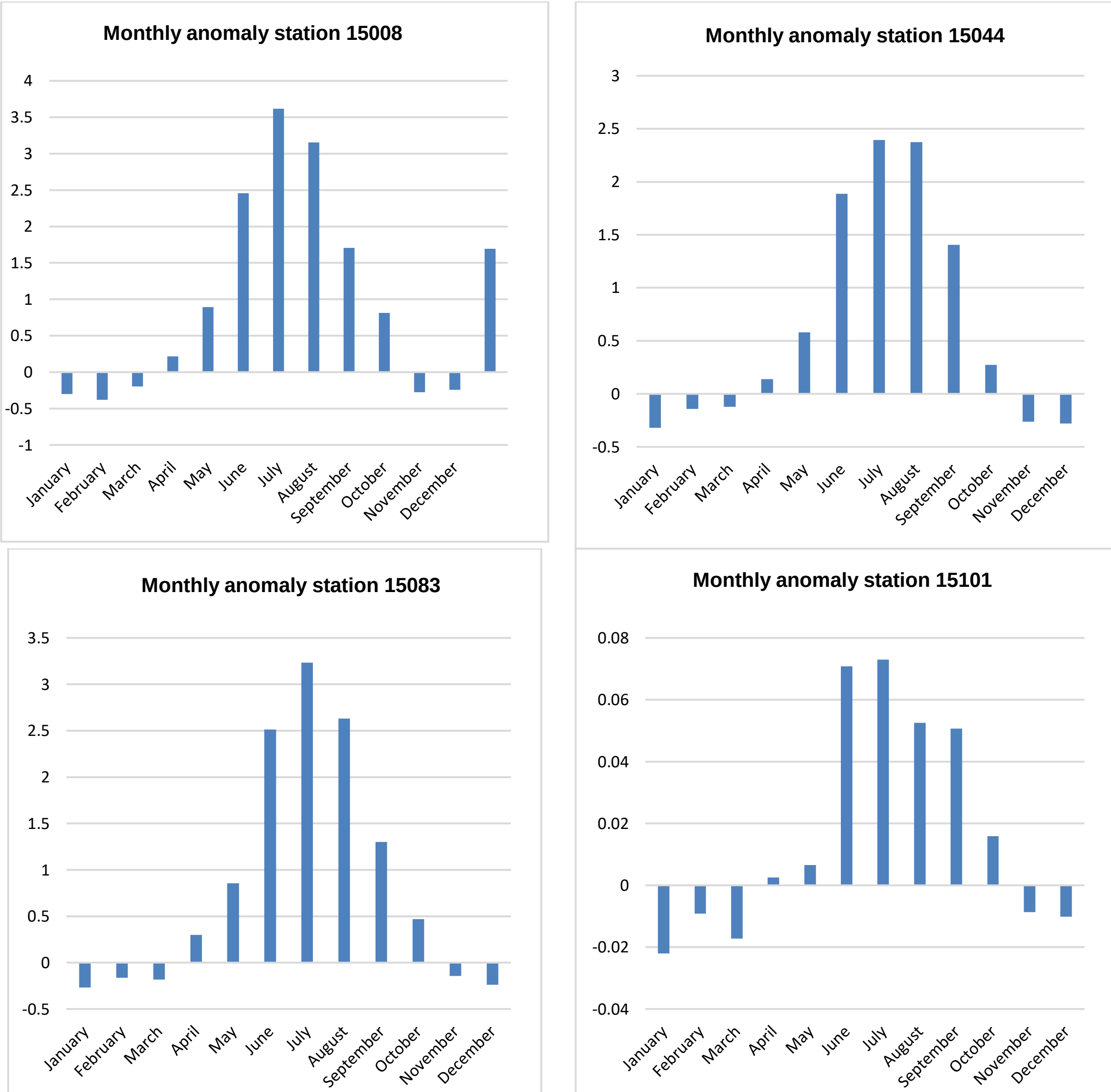


Fig. 4. Monthly anomalies of stations 15263, 15210, 15135, 15124, 15101, 15083, 15044 and 15008

According to the previous categorization it has that for the eight climatological stations of the Papalotla river basin, the slightly dry category is reached in the dry months November to March for seasons 15008 15044, 15083 and 15210 for season 15124 from October to May, for season 15135 from August to April and season 15263 is slightly dry 12 months of the year according to the categorization before described however according to the trend is to present an upward behavior in terms of the amount of precipitation rain is taken as significant data that in 1983 there was an accumulated annual rainfall well below the historical average of the basins that drain towards the Texcoco Lake with 324 mm being the month of September the one that presents the greatest anomaly. But you also have those seasons 15008, 15044 and 15083 reach the extremely rainy category in the months of June to August. Likewise, the historical review of the satellite images from study area for the years 1992 and 2022 was carried out, which can be seen in Figure 5 (year 1992) and Figure 6 (year 2022).

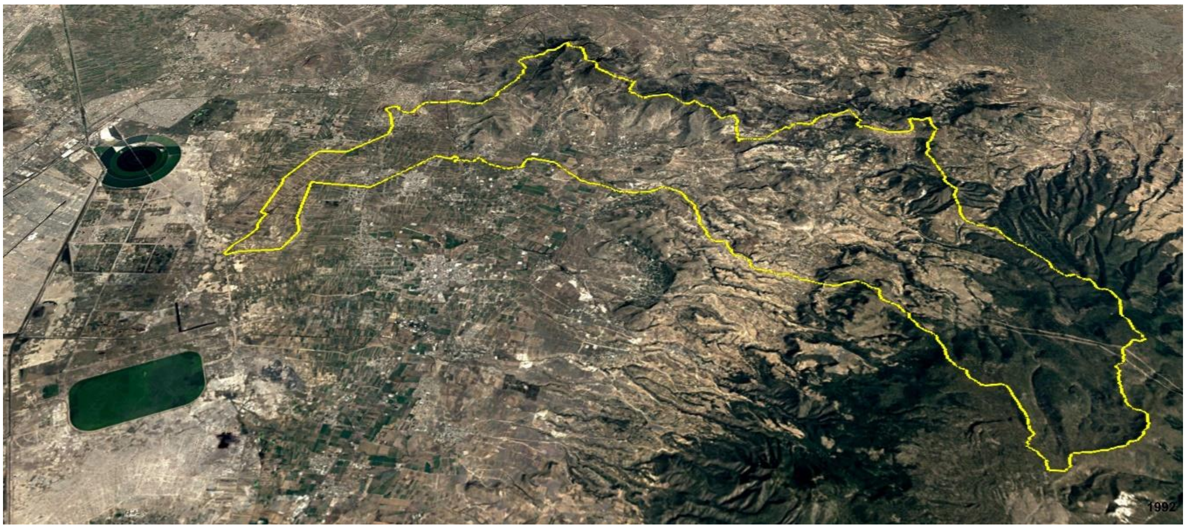


Fig. 5. Satellite image of the Papalotla basin in 1992

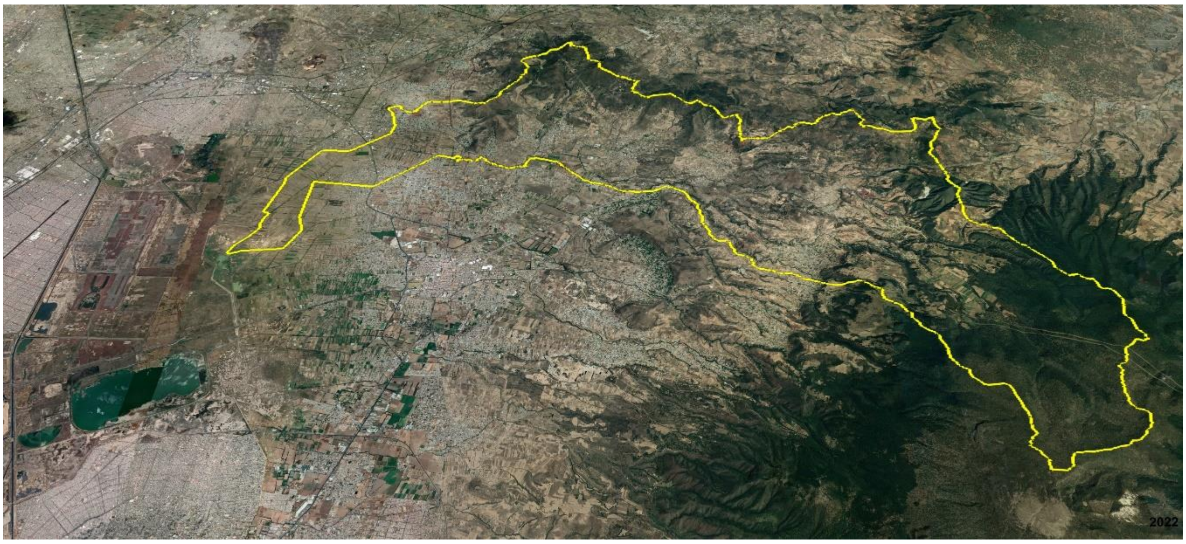


Fig. 6. Satellite image of the Papalotla basin of the year 2022

Figures analysis shows urban areas growth of both downstream basin near to area of the former Texcoco lake and in the middle basin part, and an imminent change of land use from Rainforest to agricultural areas near to upstream part of the basin and mountainous area with great reliefs and rugged terrain. The Papalotla river basin has experienced a process of change in land use, where forest areas have been transformed into agricultural areas and those of agricultural use have been urbanized. These processes of change have affected the functioning of the environments present in this basin, generating a negative impact on hydrological processes, as soil loss increases, as well as the decrease in downstream runoff as shown in Figure 7.

From results obtained there is no clear trend towards droughts in the study basin, which is why it is stated that, due to human activities, such as deforestation and overexploitation of aquifers, among others, the basin is being led towards desertification, induced by anthropogenic action. As can be seen in Figure 7, it can be said that there is a clear downward trend in the runoff at the exit of the Papalotla basin, currently, domestic demand for food and raw materials continues to increase, which generates an increasing pressure on natural resources. Such is the case of fertile soils, which experience a high degree of deterioration, as well as vulnerability to drought and desertification processes. Some international studies mention that due to erosion it is necessary to increase production costs annually by 27% to maintain the same productive level of farmland.

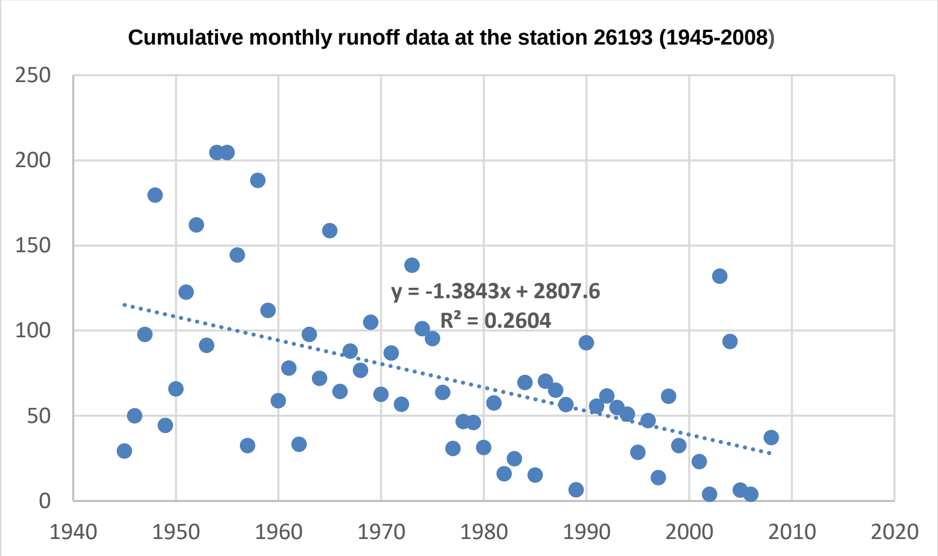


Fig. 7. Monthly accumulated runoff data for hydrometric station 26193 (Bandas-Conagua 2016)

Soil degradation occurs by different processes, the most important being wind and water erosion. When erosion is severe, it hinders the development of vegetation; significantly affects water availability and quality; contributes to the silting of artificial and natural water bodies; causes a decrease in aquifer recharge; human security is sometimes compromised due to landslides, floods and damage to infrastructure works, and eroded soils become a natural source of air pollution due to the emission of particles which can affect human health [9]. Among the Sustainable Development Goals (SDGs) approved by the UN is SDG 15 (Life on Land), which aims to protect, restore and promote the sustainable use of terrestrial ecosystems, sustainably manage forests, halt and reverse land degradation, combat desertification and halt biodiversity loss (United Nation, 2020).

The solution in case of Papalotla river basin to curb desertification is sustainable management of natural resources, especially the conservation of fertile soils and water resources. In this sense, some of the keys found in the literature that can help avoid desertification are:

- ✓ Promote coordinated planning of land uses that includes the management of water resources and livestock and agricultural activities.
- ✓ Preserve vegetation cover, which plays a key role in protecting soil from wind and water erosion, building barriers and stabilizing dunes.
- ✓ Promote climate change education to raise awareness, showing in particular the consequences of desertification and ways to prevent it.
- ✓ Bet on organic farming and certain sustainable practices, such as cover or rotation crops, which prevent soil erosion and prevent drought.
- ✓ Bet on reforestation to regenerate vegetation cover, reactivate moisture circulation and generate biodiversity.
- ✓ Encourage rotational grazing, which limits pressure to a specific area while others regenerate, through their coexistence with crops that allow a more effective nutrient cycling.

4. Conclusions

The statement highlights the increasing visibility and rapid occurrence of adverse effects of climate change, which are having significant impacts on various systems, including social and economic aspects. The Intergovernmental Panel on Climate Change has indicated that there has been a global warming trend since the 1950s. The continuous emission of greenhouse gases (GHGs) contributes to climate change and raises the likelihood of severe, adverse, and irreversible impacts on both people and ecosystems. Environmental degradation is a global issue influenced by multiple factors, including population growth, resource deterioration, and societal perspectives on nature and the environment. In the specific context of the Papalotla River basin, human activities, particularly land use changes, have seriously disrupted the environmental balance. These activities have led to soil degradation, biodiversity loss, environmental pollution, and a reduction in runoff due to upstream water resource usage. It is crucial to reflect on the territorial planning models implemented in the study area, considering the balance between water demand, unplanned population growth, and the cost associated with ensuring water availability. To avoid an environmental crisis that could disrupt the balance between humans and the environment, it is necessary to evaluate and address these phenomena. With improved understanding of the causes and mechanisms of desertification, as well as the means to prevent and remedy it, it becomes even more important to take proactive measures before the degradation of essential resources such as soil, water, and vegetation reaches irreversible thresholds. In summary, the statement emphasizes the urgency of promoting evaluation, awareness, and action to prevent an environmental crisis and maintain the equilibrium between humans and the environment.

References

[1] National Institute of Ecology and Climate Change / Instituto Nacional de Ecología y Cambio Climático (INECC). *National Atlas of Vulnerability to Climate Change Mexico / Atlas Nacional de Vulnerabilidad al Cambio Climático México*. 1st ed., Vol. 1, 2019. Accessed May 31, 2023. https://atlasvulnerabilidad.inecc.gob.mx/page/fichas/ANVCC_LibroDigital.pdf.

[2] World Meteorological Organization / Organización Meteorológica Mundial. *User's Guide on the Standardized Precipitation Index / Índice normalizado de precipitación. Guía del usuario. OMM-No 1090.* 2012. Accessed May 30, 2023. https://www.droughtmanagement.info/literature/WMO_standardized_precipitation_index_user_guide_es_2012.pdf.

[3] Morales, César, and Soledad Parada (Eds.). *Poverty, desertification and degradation of natural resources / Pobreza, desertificación y degradación de los recursos naturales*. Vol. 1. Santiago de Chile, Comisión Económica para América Latina y el Caribe (CEPAL), 2005.

[4] López Bermúdez, F., and M.C. Sánchez Fuster. "The droughts and its impact in the desertification on Segura basin. Notes to management and water sustainability areas." *International Journal of Social Sciences* 17 (2012): 155–168.

[5] Comisión Nacional de Áreas Naturales Protegidas. Albores González, M.L., R. Aviña Carlin, C. Sánchez Ibarra, and G. F. Tavera Alonso. "Preliminary supportive study for the establishment of the natural protected area. Lake Texcoco natural resources protection area." / "Estudio previo justificativo para el establecimiento del área natural protegida. Área de protección de recursos naturales Lago de Texcoco." December 2021. Accessed May 25, 2023. https://www.conanp.gob.mx/pdf/separata/EPJ-APRN-LagodeTexcoco.pdf.

[6] Mormeneo, Ines, and Raúl Díaz. "A method of classifying rainfall anomalies." / "Método para clasificar la anomalía de las lluvias." *Revista Brasileira de Agrometeorologia, Santa Maria* 11, no. 1 (2003): 159–167.

[7] Institute of Hydrology, Meteorology and Environmental Studies / Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM). *Determination of a normal range for precipitation - Comparative analysis between normal thresholds (80-120%) and (90-110%)* / *Determinación de un rango normal de precipitación - Análisis comparativo entre umbrales normales (80-120%) y (90-110%)*. Santa Fe de Bogotá, April 2014. Accessed May 30, 2023. http://www.ideam.gov.co/documents/21021/21789/Nota+T%C3%A9cnica+-+Umbrales+de+Normalidad.pdf/2909eb15-ccd1-4c30-a20f-a50922a3514e.

[8] Government of Mexico. *Tzolkin: Mesoamerican Drought Monitor.* / *Tzolkin: Monitor Mesoamericano de Sequía.* Accessed May 31, 2023. http://galileo.imta.mx/Sequias/moseq/marcoteoricoGob.html.

[9] Martínez Sifuentes, Aldo Rafael, José Villanueva Díaz, Juan Estrada Ávalos, Cirilo Vázquez Vázquez, and Ignacio Orona Castillo. "Soil loss and runoff modification caused by land use change in the Conchos river basin, Chihuahua." *Nova Scientia* 12, no. 25 (October 2020): 1 - 26. Accessed June 1, 2023. http://nova_scientia.delasalle.edu.mx/ojs/index.php/Nova/article/view/2321.

[10] United Nation. "Goal 15: Sustainably manage forests, fight desertification, halt and reverse land degradation, halt biodiversity loss." / "Objetivo 15: Gestionar sosteniblemente los bosques, luchar contra la desertificación, detener e invertir la degradación de las tierras, detener la pérdida de biodiversidad." *Sustainable Development Goals*. 2020. Accessed June 1, 2023. https://www.un.org/sustainabledevelopment/es/biodiversity/.

[11] Intergovernmental Panel on Climate Change (IPCC). *Climate Change 2014: Synthesis Report*. 2014. Accessed May 30, 2023. https://www.ipcc.ch/site/assets/uploads/2018/05/SYR_AR5_FINAL_full_wcover.pdf.