The Environmental Services, Land Use, Population Growth and Climate Change in Mexico Valley Metropolitan Zone

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Abstract: - Precipitation, minimum and maximum temperature of two periods (1951-1980 and 1980-2010) indicated significative variation in water availability and the relationship with environmental services, land use, population growth, and climate change in Mexico Valley Metropolitan Zone (MVMZ). Pearson correlation coefficient, Student's "t" test was applied to 90 homogenized meteorological stations and the Cluster Analysis of 97 drought indices. The urban sprawl of the MVMZ grew 2870% from 1953 to 2020. The conservation land was subject to various pressures that gradually diminished its capacity to provide environmental services. Urban planning focused on the linked functioning of the ecosystems, rural regions, biodiversity, the extension of vegetation cover, social participation, and intergovernmental coordination is required.

Key-Words: - Ecosystem service, climatic vulnerability, environmental impact, sistemic analysis, growth policies.

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1 Introduction

Water security is under severe pressure considering global population growth rates, rapid shifts from rural to urban areas, changing diets with development, increasing contamination of water resources and over-groundwater extraction. As well as, the risks associated with the adverse impacts of climate change on the sustainability of the world's natural resources, the global economy and political stability, [1], [2]. Climate change increases the global average temperature of the earth's surface and greater variability in precipitation regimes with an increase in the frequency of extreme events, [3]. Precipitation is one of the most important hydrologic elements for the climate. Rainfall is the main environmental factor that modifies the ecosystem conditions and human life and it represents the principal and major source of freshwater on Earth, [4]. Rainfall is directly correlated to global climate change causing the intensification of rainfall variability. The water supply systems are under continuous stress due to increasing water demand, an increase in the population, and economic and sustainable development, [5]. Climate change will generate extreme conditions with catastrophic results with technological, economic, and sociological impacts on water resources and processes, [6], [7]. In Europe and North America there have been observed increases in precipitation, it leading to devastating flooding and resulting in damage to infrastructure, water treatment processes, and increased transport of contamination to recipients. Conversely a decrease in rainfall, increases water scarcity challenges even in non-arid areas where demand no longer meets supply support, [8]. Millennium Ecosystem Assessment [9], points out that droughts and reduced rainfall will also increase the use of severely limited groundwater, leading to drying up or saltwater intrusion into coastal fringes. The impacts of climate change have vast consequences in the water sector, increasing health risks, and environmental pollution with substantial economic impacts. Likewise, habitat change, invasive species, resource overexploitation and pollution are recognized as drivers of change for freshwater and terrestrial ecoystems, [10], [11]. The adaptation strategies must consider these drivers along with climate change, as they threaten the ecological integrity of ecosystems. Adaptation to climate change requires the determination of water availability for the basins through precipitation in order to be able to quantify the changes in water for the rivers. As well as, to establish the change in the consumption of water for the population, agricultural activities, industry, and electricity generation, among others, in order to compensate for the variations in the annual precipitation rates in the planning of the water resource through different actions, such as the transfer of industries to regions with higher humidity or the change in the morphology of cities to compensate for floods the availability of water for irrigation and flood control, [12].

Precipitation changes have important consequences on economic activities, population health and biodiversity. In particular, mountainous areas face enormous pressure from climate change likely to experience far-reaching effects on natural resources, biodiversity, and socioeconomic conditions. In these regions small changes in temperature can turn ice and snow into water, slopes over small distances can lead to rapid changes in climate zones, and impacts can be marked in terms of biodiversity, water availability and agriculture, impacting the goods and services provided by these ecosystems and thus human well-being in general [3]. In this sense, there is a need to generate and use the tools applicable to ecological, socioeconomic and political analysis to achieve the rational use of resources, [13]. In Mexico there is little information about the effect that climate change is having on the quantity and quality of water, pollution, ecosystem services, and climate vulnerability of the country's different regions. For this reason in this study the comparative analysis of the variation of precipitation, minimum and maximum temperature between two periods (1951-1980 and 1980-2010), was carried out to determine the variation in the availability of water for environmental services and its relationship with the land use, population growth, and climate change.

2 Problem Formulation

The Mexico Basin is located in the central part of the Trans-Mexican Volcanic Belt with 9000 Km^2 and 2400 masl, approximately. It is the highest altitude in the region and is surrounded by mountains that reach elevations above 5000 m. Its geographic coordinates are: 20° 03' N, 18° 56' S; 98° 36' E, 99° 40' W. Mexico City is part of the Mexico Valley Metropolitan Zone (MVMZ). The territorial surface represents 0.1% of the national territory, an entity with a smaller extension of the country. The urban area occupies 95% of the territory of Mexico City, while almost 2.8% is rural area under the category of "conservation land" located mainly to the south of the city, (Figure 1). The 1.52% is urban mixed population and 0.6% is rural mixed. The 18.4% of Mexico City área has natural vegetation (27 275 ha), distributed in the forest (11.6%), grassland (6.3%) and xeric scrub (0.5%). Agriculture, urban areas, water bodies, areas without vegetation, and secondary vegetation, product of anthropic alteration and natural events 81.6%. Various agricultural, forestry and livestock activities are still carried out in this area which is important biodiversity and represents the main aquifer recharge area. The conservation land of the Mexico City to 2000 included 88,442 ha of the rural and forest area of the entity [14]. The Mexico basin is divided into 10 large hydrological zones according to the most important rivers which have large construction of dikes and canalization. The climate is temperate sub-humid with an average annual temperature of 16 ºC. The annual precipitation in the dry region is 600 mm and in the humid temperate part 1 200 mm.

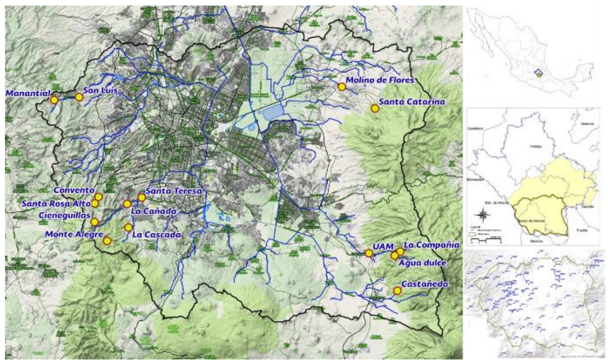

Fig. 1: Location of Mexico Valley Metropolitan Zone and weather stations (Original creation image)

Climate data from 150 stations located within the Mexico Valley Subregion plus a 10 km radius buffer was selected from the National Meteorological Service (SMN), [15]. The homogenization process was carried out with the software CLIMATOL. It is a R package that contains functions for quality control and filling in missing data from climatological series to obtain statistical summaries and grides of the series resulting from homogenization. The homogeneity test was carried out by applying the Standard Normal Homogeneity Test (SNHT), [16]. The homogenization period for precipitation, minimum, and maximum temperature was carried out from 1951 to 2010 were selected in the homogenization process for precipitation, and maximum and minimum temperatures in order to reduce the missing information gaps. The period with the most data availability corresponding to 1961-1990 was considered and the data loss was considerable after that period. The period with the fewest stations available was from 1951-1960. The degree of similarity and homogenization between the time series of 103 stations was obtained by calculating the Pearson Correlation Coefficient finding eight clusters with similar precipitation characteristics between the stations. The correlogram was applied to obtain the highest correlations and the lowest distance between the stations. The standardized anomalies during the homogenization period 1951-2010 were obtained for weather station 9048 corresponding to the Tacubaya Central observatory in the SMN. The box and whisker plot was applied to the maximum and minimum temperature to observe the dispersion of the data and suspect values through the three quartiles, as well as the mean value of the sample. Drought indices with ClimPACT2 required the time series of daily minimum temperature (TN), daily maximum temperature (TX) and daily precipitation (PR). The mean daily temperature (TM) was calculated from TM = (TX + TN) / 2. The diurnal temperature range (DTR) was calculated from DTR = TX - TN. The core and non-core indices of the ET-SCI (Expert Team on Sector-Specific Climate Indices) and the ETCCDI (Expert Team on Climate Change Detection Indices) were considered to calculate the sectorial climatic sencibility.

The use of land and vegetation for the Mexico Valley Metropolitan Zone (MVMZ) was analyzed through geographic information systems. Student's "t" test was applied to the 90 homogenized weather stations of the Mexico Valley Subregion between the recent period (1951 to 1980) and the later period (1980 to 2010). The Clustering Analysis was applied to 97 drought indices from 89 meteorological stations, [17].

3 Problem Solution

The homogenization and quality of the databases of the climatic stations of the Mexico Valley Metropolitan Zone for the period 1951-2010, indicated the greatest availability of data in the period 1961-2010 with a decreasing the number of stations after the 1990s. The period with the greatest absence of data was 1951-1960. The different correlations in the near-neighbor stations in the correlogram analysis were due to their location to windward or leeward of a mountainous area. Maximum temperature had a normal distribution and the minimum temperature was slightly biased towards the maximum values. The homogenization of the 90 meteorological stations indicated that the maximum temperature did not present inhomogeneities (only missing data was completed). For the minimum temperature with an inhomogeneity in the second half of the 1980s choosing the series with the highest percentage of observed data and the lowest root mean square error.

The land use of the MVMZ of the urban area or localities, correspond corresponds to 37% of the territory and 95% of the total population, in an área of 177 866.75 ha. The rural population was 3% and the urban mixed population was 2% of the territory. Rainfed agriculture represented 27.99% of the total area of the subregion. The forest was 16% (Pine 7.18%; Encino 5.88% and Oyamel 3.82%). The induced grassland (3.44%) and the halophilous (3.33%). The cultivated forest was 2.92%, the crasicaule scrub was 2.56%, without apparent vegetation 2.18%, the oak-pine forest was 1.31%, the pine-oak forest was 1.13%, and the bodies of wáter 0.78%. The high mountain meadow, the sarcocaule scrub, the juniperus forest, the cultivated grassland, and the halophilic and hydrophilic vegetation with a percentage of less than 0.5%. The area of the urban sprawl of the MVMZ subregion (37%) in the centralwestern part is in gray in Figure 2, and in yellow the area of rainfed agriculture to the east of the subregion, with 28%.

The urban surface in the MVMZ for 1953 only 24000 ha of CDMX were urbanized, [18]. Actually the MVMZ has 688 816.84 ha urbanized (205 289.17 ha of the conurbation zone and 483 527.67 ha of the CDMX), this represents a growth of 2870% of the urban area and therefore the consequent loss of ecosystem services.

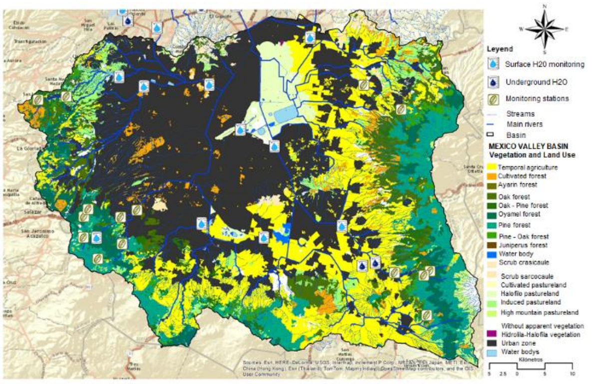

Fig. 2: Land Use of MVMZ (Original creation image)

The MVMZ for 1980 occupied an area of 61820.37 ha, and for 2017 an area of 235 987.29 ha, which represents an increase of 382%. By 2010, the urbanized area of the MV occupied 42.6% of its territory, and the natural areas were only 57.4%, (Figure 3). Its inhabitants added to residents of the metropolitan municipalities of the State of Mexico represent 20% of Mexicans. In 2000 the urban area was extended in what was originally a lake, places of flooding and regulation of the rivers that crossed it of what was the original basin with the Texcoco Lakes mostly dried, came to store approximately 255 million m^3 on an area of 16 000 ha and the Xochimilco Canals, reduced to a series of channels that surrounds the town and farmland with a calculated capacity for useful storage in 234.6 ha of approximately 4.26 millionm^3, [14].

The population in the MVMZ for 2020, is indicated to be constituted by the mixed urban population settled around the southwestern spot (the most populated). The mixed rural population in the central part of the MV and the rural population scattered throughout the sub-basin with an urban population of 1 815 786 people, (Figure 4).

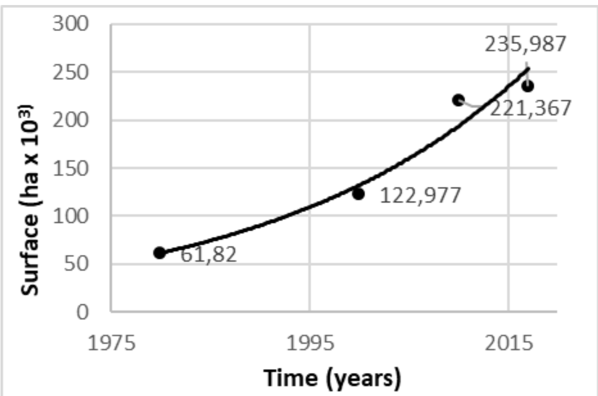

Fig. 3: Population growth over time in the MVMZ

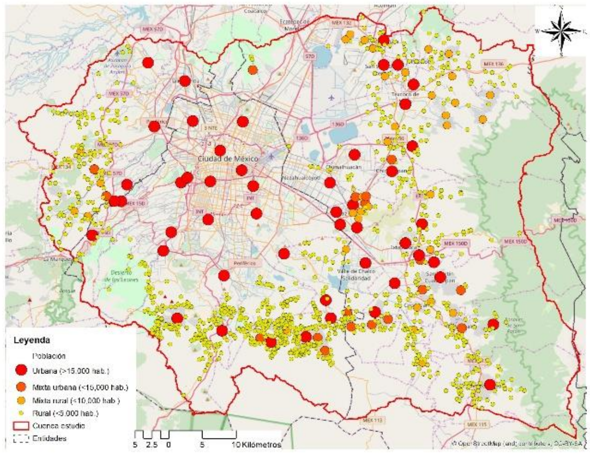

Fig. 4: Growth of the urban area of the MVMZ over time and type of population (Original creation image)

The Student's "t" test applied to meteorologic data average to the recent period (1951 - 1980) and later (1980 - 2010) indicated significant differences in the 90 stations for precipitation, the minimum and maximum temperature at a $P \geq 0.05$, and showed maximum increases of 0.24 mm for precipitation and the maximum decreases were of -0.57mm, (Figure 5). In Figure 6, the minimum temperature with increments of 4.06 and decrements of -1.85 (ºC) and for the maximum temperature elevations of 1.55 (ºC). And decrements of -0.81 (ºC), Figure 7.

Likewise, Student's "t" test indicated highly significant decreases in precipitation in the Mexico City area, which can be associated with the greatest changes in land use and population growth in the subsequent period (1980-2010). The minimum temperature was significantly less low in all the stations analyzed, except for a station located to the south and west of the of CDMX (also in the highest part of the wooded area with low population density).

The Maximum temperature indicated significant increases in all stations except one, characterized by being located at higher altitudes sparsely populated with wooded vegetation.

The relationship between land use change, demographic growth and climate change (trough of precipitation decrement, increases in the maximum temperature and minors minimum temperature in the later period 1980-2010 for all the homogenized meteorological stations), can be associated with the decreace rainfall averages in the subsequent period and with it the decline in the availability of water for the MVMZ aspects that propician the decreace and deterioration of the ecosystem services.

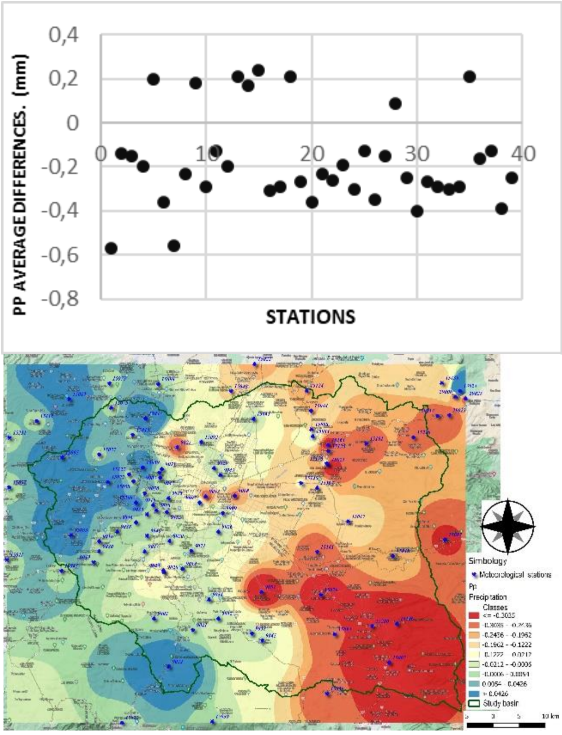

Fig. 5: Differences between the precipitation averages (mm) for the recent period (1951 - 1980) and later (1980 - 2010) and its location in MVMZ

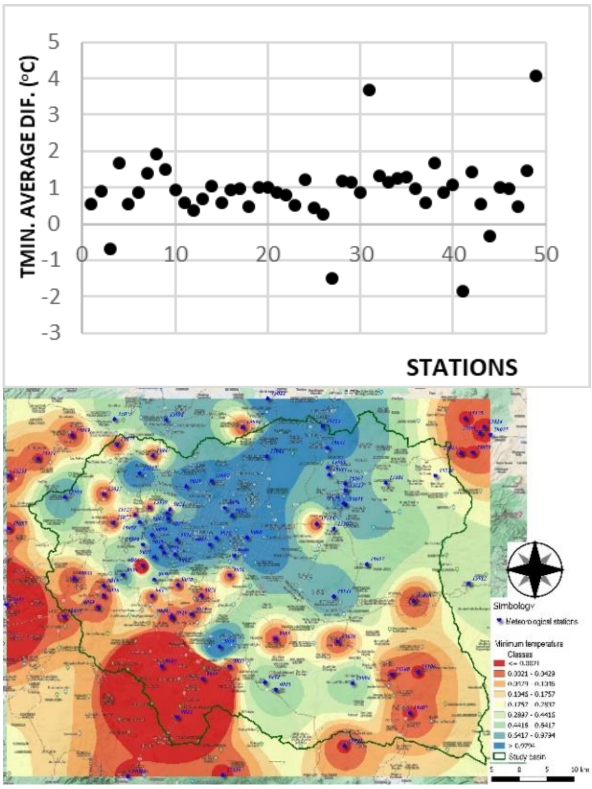

Fig. 6: Differences between the mínimum temperature averages (mm) for the recent period (1951 - 1980) and later (1980 - 2010) and its location in MVMZ

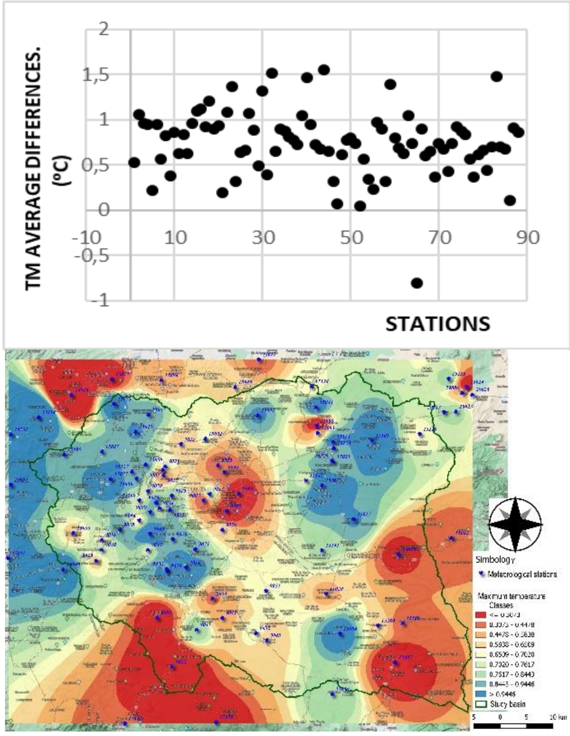

Fig. 7: Differences between the maximum temperature averages (mm) for the recent period (1951 - 1980) and later (1980 - 2010) and its location in MVMZ

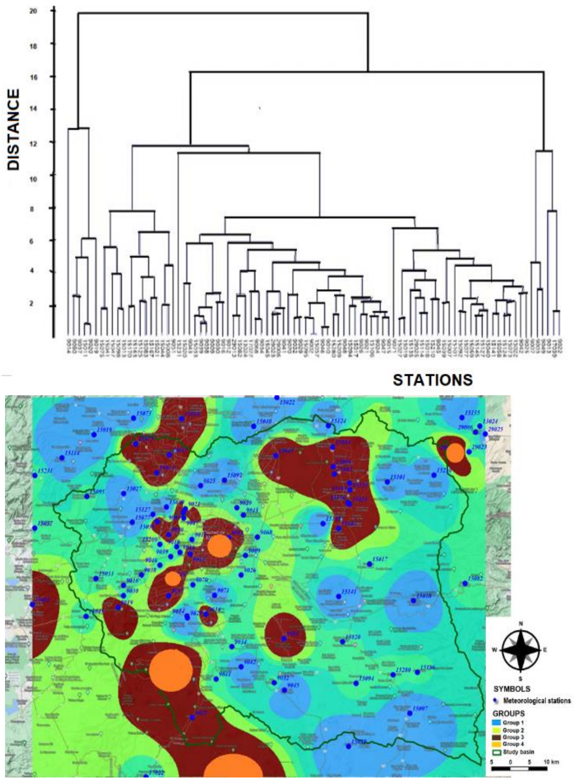

Fig. 8: Location drought índices of Cluster Analysis on MVMZ

The grouping analysis (Custer Analysis) applied to the drought indices at the 90 homogenized stations shows four main groups: 1) located in the urbanized area with completely altered vegetation and some on the periphery located in populated áreas in blue, 2) located in the peripheral zones to the urban area characterized by presenting little altered or semi-rural vegetation (green-yellow), and 3) located in the urbanized central without or poor vegetation and in the northern zone with arid vegetation. Also, in semirural zones with perturbed vegetation and temporal agriculture in the south (brown). 4) Two small groups characterized by being located in areas with less impact on vegetation (wooded área) sparsely populated and little change in land use located in the highest parts of the urban area between 2,326 and 2,995 masl, marked in orange. An aspect that indicates the relationship with land use, population growth, and the synergistic effect of climate change in the MVMZ (Figure 8).

Depending on the basin area considered the urbanized area occupied between 24.5 and 30% of the Mexico Valley in 2017. If evaporation was reduced in the same proportion this represents between 1 250 and 1 869 x 10^6 m^3 according to the Intrinsic Value of Water concept (method to calculate the amount of solar energy required to evaporate in the hydrological cycle the volume of water that precipitates through the latent heat of evaporation), [19]. And it allowed estimating the loss of this environmental service between 43.3 million and 64.3 million of USA Dollars. Also, the extraction of groundwater not compensated with the recharge causes the constant differential subsidence of the Valley of Mexico (MV), at maximum speeds ranging from 30.7 cm $year^{-1}$ over an area of about 500 km^2 of the aquifer [20], and 40 cm year $^{-1}$ [21], despite being compensated by accidental leaks from the distribution system of around 21 m^3s^{-1} according to by The Word Bank. Such subsidence has migrated from the center of Mexico City to the east of the MV, which accumulated to reach 13 m in the East Zone. Also, pumping since 1952 affected buildings and dislocated drainage facilities. For 2020, the differential subsidence was estimated at 12 m, where the aquitard is 140 m; and 19 m where it is 300 m thick, [22]. These data allow us to estimate the maximum volume displaced by the subsidence at 150 to 200 hm^3 $year^{-1}$.

4 Conclusion

The urban sprawl in the MVMZ grew 2870% from 1953 to 2020 with the consequent reduction in green areas especially on the slopes and ravines in the south and west of Mexico Valley, where the aquifers that supply the city are recharged and are biologically rich areas. With the technological development in the MVMZ the demand for more and better products and the explosive demographic increment generated an increase in water consumption through the main basic activities, which constitute the main satisfiers of needs, such as: agriculture, livestock and fishing. As well as industry and public and urban services that demand greater volumes of water with adequate quality for their use every day, [23]. Land use/cover changes in urban areas affect ecosystem function and services, because the rural lands provide ecosystem services to cities, such as: food, air quality, favorable climatic conditions, soil productivity, flood prevention in extreme rainy seasons, water supply to cities with high water stress in their water table, cultural aspects of the local population, landscape aesthetics, and recreation, thus contributing to its sustainability. The ecosystems that have suffered the most from the effect of human activities are those located on the periphery of large urban settlements, [24].

The conservation land in the MVMZ is subject to various pressures that have gradually altered its natural conditions and diminished its capacity to provide environmental services. The deterioration is associated with the growth of human settlements, illegal felling, the opening of roads, forest fires, piped rivers, the overexploitation of the aquifer, water contamination, the poor disposal of solid waste, agricultural practices, and buildings. Likewise, the massive problems of forest disturbance (livestock activity, overgrazing, illegal extraction of forest land, pests and forest diseases), have caused loss of natural cover with the subsequent fragmentation of biological corridors that leads to decreased connectivity of the landscape, reduce migratory movements of organisms, and increases the risk of local extinction of flora and fauna in the region, especially for endemic or restricted-distribution species, [23]. Clandestine felling in communal limits, uncontrolled tourism, artisanal agriculture, disorderly livestock, and forest fires are impacts that affect the MVMZ, [25]. For this reason, the average relative humidity in cities is usually several percentage units lower than that of adjacent rural areas mainly due to lower evapotranspiration due to lack of vegetation and reduced precipitation due to the effects of climate change, and the fact that the precipitation is conducted almost immediately towards storm drains, avoiding its absorption into the soil and subsequent evapotranspiration [26] and the reduction of precipitation due the effects of climate change. Therefore, another decreasing environmental service in the city is the thermal buffering of the urban climate due to the deficit of water vapor (morning dew or frost), which generates islands of heat of variable intensity and frequency, being more frequent and intense during the dry season, which reaches 7.8 °C, while the urban/rural temperature contrasts are positive throughout the year and vary from 5 °C at dawn, in the middle of the dry season, of 1 to 3 °C around the noon during the wet months in the MVMZ pointing out, the synergistic effect of climate change, [27]. This increase in temperature in the city is related to a sensible heat surplus due to the corresponding latent heat deficit of water vapor, coupled with the proportional increase in urban land or the loss of natural land. This evaporation decreases when the density of the forest is reduced due to felling in conservation areas with irregular human settlements, due to the increase in the surface of cement and pavement, and due to storm drainage from the urban sprawl.

Terrestrial water storage change (groundwater levels and reserves) plays an important role in the terrestrial and global water cycles mainly including the sum of water changes in canopy water content, snow and ice water, surface runoff, soil water and groundwater, reflecting the net change in water storage resulting in the total supply and consumption fluxes of water in the terrestrial water cycle, [28]. In recent decades, the increasing use of water resources under the influence of global warming and increased human activities has led to serious challenges such as water scarcity in some areas of the country, as seems to be the case in MVMZ, where one-third of the subsidence problem is attributed to the waterproofing of the soil by urbanization and two thirds to the extraction of groundwater. Differential subsidence has caused damage to urban infrastructure and is considered responsible for the high rate of leaks in water and drainage systems, [22].

Climate change, chemical pollution, overexploitation for irrigation, alteration of water flow, morphological alteration of superficial water bodies, drainage of wetlands, deforestation, and dam construction are only a small portion of the activities that determine and have resulted also in significant alterations of ground waters, with irreversible loss of biodiversity and severe changes in the composition of communities. Global biodiversity is challenged under the pressure of several human-induced changes in the global environment at an unprecedented rate. The extent and rate of this change are so relevant and so strongly linked to the exploitation of natural resources and to ecosystem processes that biodiversity change has to be considered an important global change in its own right, [11].

It is necessary to carry out activities for conservation, such as: the retention of soil, humidity and vegetation cover, to achieve a greater capture of water and reduce the removal of mass, [14]. The contribution of water in a basin changes depending on the type and use of the soil and the climatic conditions. The forest in particular, has a close relationship between water, vegetation and soil; a change in one of them modifies the behavior of the others, [29]. Studies carried out in different parts of the world show that the annual yield of water is modified when the vegetation is altered in a hydrological basin, [30]. Changes that reduce evapotranspiration increase the amount of water that reaches the lower part of the basins, [31]. This process can be reduced by changing the structure and/or composition of the vegetation, for this reason the arboreal vegetation has an important role in the regulatory function of quantity, quality and temporality of the water flow in the protection of soil erosion and the sedimentation, it also prevents the degradation of rivers and other aquatic systems. As well as carbon capture, particle retention and maintenance of the microclimate, [32].

It is important to identify the role of non-climatic stressors and how climate aggravates or reduces stress given the specific configuration of resources at the basin level, between basins and within water transfer and infrastructure of the basin and institutions in charge of the allocation, distribution, contribution and treatment of wastewater and land use. Climate change is also a stress factor and must be considered in the adaptation and vulnerability processes of cities. While this may be appropriate in a developed country context, such research may run the risk of not including other aspects, such as adequacy, sustainability, fairness overlooking the role of other stressors such as migration and change of land use, [33].

The increasing frequency and intensity of extreme weather events are testing the limits of risk management strategies, as well as the ability of populations to adapt to environmental change as indicated by the complex relationships between urbanization and climate change, land use and what this process implies in the accumulation of risk and regional resilience, [34]. The governments of cities and countries allow the change in land use with the construction of urban areas, which respond to individual interests and institutional economic challenges. In this complex process individual actions satisfying individual aspirations not only create individual vulnerabilities but also alter terrestrial, climatic, and hydrological processes, which together lead to amplification of risk and greater vulnerability, [10]. The vulnerability arises from social, political and economic relationships between people, technology, and the environment [35] and is subject to interdependencies among trade routes, administrative boundaries, and information flows. New metrics are needed to quantify these relationships along with multiple spatial and temporal scales, [36].

Factors of natural and anthropogenic origin affect ecosystems and the services they provide causing a direct or indirect change to the environment in a synergistic way. Coordination between socio-economic and cultural development and environmental protection is required to mitigate its impact. Urban planning focuses on the linked functioning of ecosystems and rural regions that support biodiversity, condition of vegetation cover, social participation and intergovernmental coordination is required, [14], [18]. Aspects that require interdisciplinary dialogue in terms of their scientific integration and public policies. It is necessary to consider the interrelationship of the biotic, abiotic and human elements of the basin for the preservation of environmental goods and services, as well as for their sustainable use for the benefit of the entire city, [24]. Climate change effects are typically superimposed upon those of multiple stressors and climate change is thus often regarded as a threat multiplier, [11]. In addition to achieving adaptation to climate change a number of water security imperatives have to be met if we are to continue to make progress on the social, environmental and economic dimensions of development, [1]. It is necessary to ensure equitable access to environmental services and water resources through robust policies and legal frameworks at all levels. Build resilience in communities to face extreme water events. Manage water more sustainably as part of green economies. Restore ecosystem services of the basins to improve river health. Increasing productivity and water conservation in all water user sectors and sharing the economic, social and environmental benefits of transboundary rivers, lakes and aquifers are necessary to reduce vulnerability and achieve adaptation for environmental sustainability. Factors of natural and anthropogenic origin affect ecosystems and the services they provide causing direct or indirect changes in the ecosystem in a synergistic manner. Coordination between socioeconomic and cultural development and environmental protection to mitigate the impact on ecosystemic services it is necessary.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

- Rebeca González-Villela carried out: formulation of the problem, precipitación statistical analysis and the final findings and solution.
- José Martín Montero Martínez carried out: the homogenization and databases quality of climatic stations and drought índices calculation.
- Alfonso Guillermo Banderas Tarabay carried out: evaporation, diferencial subsidence of Mexico Valley and loss ecosystem service calculation.
- Marco Mijangos Carro carried out: Vegetation áreas and population quantification of the Mexico Valley through Geographycal Information Systems and images.

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The authors have no conflicts of interest to declare.