Natural Resources Conservation and Research (2020) Volume 3 Issue 1
doi:10.24294/nrcr.v3i1.1542

ORIGINAL RESEARCH ARTICLE

Climatic water balance of mesophilic montane forest in the Huasteca region

Alberto Santillán-Fernández[1,2*], Samantha Zurisadai Cruz-Ramírez[2], Abimael Calva-Castillo[2], Arely del Rocío Ireta-Paredes[3], Jaime Bautista-Ortega[4]

[1] *Catedrático CONACYT, Colegio de Postgraduados, campus Campeche, CP. 24450, Champotón, Campeche, Mexico. E-mail: asantillanf@conacyt.mx*

[2] *División de Ingeniería Forestal, Instituto Tecno-lógico Superior de Venustiano Carranza, CP. 73049, Venustiano Carranza, Puebla, Mexico.*

[3] *Universidad Interserrana del Estado de Pue-bla-Ahuacatlan, CP. 73330, San Andrés Tlayehual-ancingo, Puebla, Mexico.*

[4] *Departamento de Ciencias Agrícolas, Colegio de Postgraduados, campus Campeche, CP. 24450, Champotón, Campeche, Mexico.*

ABSTRACT

We worked in areas of mesophilic mountain forest in the states of Puebla, Hidalgo and Veracruz, located within the Huasteca region. By its nature, the mountain mesophyll forest is a good water catcher. But its forest cover has decreased as a consequence of anthropogenic activities, negatively impacting water catchment. The temporal evolution (1979–2015) of the humidity index of the areas where mountain mesophyll forest exists was associated with the changes in its cover from 1997 to 2016. The results show that from 1979 to 2004, the humidity index decreased as a consequence of more than 29% deforestation. From 2005 to 2016, the deforestation rate did not exceed 1% and the humidity index presented an increasing trend. The conservation of this ecosystem is recommended as a priority to improve the amount of water in the region.

Keywords: Deficit; Excess; Evapotranspiration; Humidity; Fog

ARTICLE INFO

Received: 23 March 2020
Accepted: 27 April 2020
Available online: 11 May 2020

1. Introduction

The mountain mesophyll forest (MMF), also known as cloud forest or mountain rainforest, occupies less than 1% of the national territory but contains 82% of the families, 52% of the genera and 10% of the species of vascular flora in Mexico[1]. It develops in regions with altitudes between 500 and 2,800 meters above sea level, rainfall between 1,000 and 3,000 mm per year-1, and temperatures between 12 to 23[2]. The Huasteca region (bordering Puebla, Hidalgo and Veracruz) occupies an area corresponding to 11.78% of the national territory[3].

The MMF is one of the most important ecosystems due to its great biological diversity and the multiple ecosystem services it provides, such as carbon storage and capture, soil fertility regulation, erosion control, regulation of the water balance and surface water runoff, as well as water supply for cities[4,5]. Due to its nature, the main eco-systemic service it provides is water catchment[6]. The presence of fog on the vegetation has the property of extracting an additional amount of water to that which arrives in the form of rain, so that, even in the dry season, these forests provide an important contribution of water to local and regional hydrology[7].

Evidence on water capture by forest ecosystems in Syria[8], Indonesia[9] and Spain[10] indicates that it improves the water balance. In Mexico, Zavaleta *et al*.[11] report that forest areas regulate the hydrological cycle and improve the quantity and quality of water infiltrating into aquifers. However, the MMFs are poorly studied ecosystems, due to their complex functioning[4]. In this regard, recent studies deal with their dynamics and diversity[12,13], conservation importance [14-16], effects of anthropogenic activities on their functions[17-19], and ecosystem resilience to climate change[20,21]. But few studies deal with water uptake dynamics[22-24].

The Climatic Water Balance (CWB) methodology is a useful tool to determine the amount of water available to vegetation, but it also serves to relate the influence of vegetation on water uptake by allowing the comparison of specific water resources in a system at different time periods[25]. The calculation of CWB includes variables of precipitation, temperature, and soil properties; and allows knowing the potential evapotranspiration, water excretion and deficit over time[26]. According to Malamos *et al*.[27], among the methods to determine the CWB, the simplest calculation is the one proposed by Thornthwaite and Mather, requiring only data on temperature, precipitation and soil water storage capacity. Under this context, the objective of this study was to associate the temporal evolution of the humidity index (1979–2015) of the areas where there is mountain mesophyll forest in the Huasteca region, with the changes in its cover from 1997 to 2016 to determine the influence that the ecosystem cover has on water uptake.

2. Materials and methods

2.1 Study area

From the VI series of land use and vegetation of the National Institute of Statistics and Geography[3], the areas with mountain mesophyll forest in northern Puebla, northwestern Hidalgo and northern Veracruz, located within the Huasteca region, were selected using geographic information systems tools (**Figure 1**).

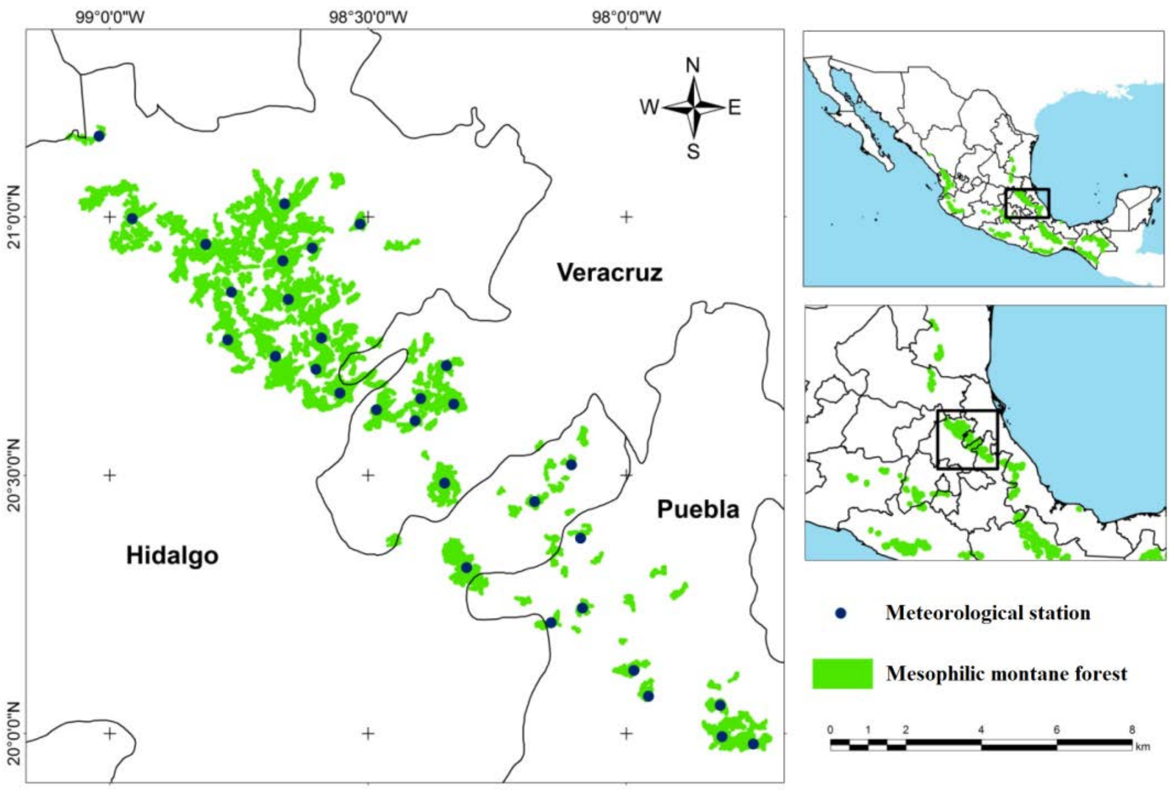

Figure 1. Study area showing the geographic distribution of weather stations and mountain mesophyll forest cover in the Huasteca.

The region has temperatures between 18 and 25 °C, altitudes above 1,500 meters, with precipitation between 1,000 and 2,500 mm per year^{-1}, and humidity ranges from 60% to 80%, temperate to warm climates in vertisol soils; factors that make possible the development of grasslands, jungles and forests, among which the mountain mesophyll forest is found, in addition to agricultural activities such as extensive cattle ranching and the cultivation of oranges, sugar cane, tobacco, corn and beans[3].

2.2 Climatic water balance and humidity index

From the National Climatological Database[28], meteorological stations that were within the areas with mountain mesophyll forest of the Huasteca and that reported continuous information from 1979 to 2015 were selected. A total of 31 meteorological stations were analyzed: Puebla (8), Hidalgo (17) and Veracruz (6) (**Figure 1**). From each weather station, the monthly average of temperature (°C), precipitation (mm) and evaporation (mm) was obtained for each year. This information served as the basis for the regional calculation of the Climatic Water Balance (CWB) per month and humidity index per year (HI) with the following methodologies.

To determine the CWB, the one proposed by Thornthwaite and Mather was used, since only temperature, precipitation and Soil Water Storage Capacity (SWSC) values are required for its calculation. According to Rolim *et al.*[29], the temperature and precipitation values per month of the 31 meteorological stations for the 1979–2015 series were averaged and a SWSC of 200 mm was used[30], which allowed estimating the monthly potential evapotranspiration (MPE), excess water (EW) and water deficit (WD) of the Huasteca region. For the calculation of the HI per year expressed in %, the monthly values of MPE, EW and WD were averaged per year, while the HI was calculated with the formula proposed by Ruíz-Álvarez *et al.*[25]:

$$\text{HI} = \frac{100(EW - WD)}{MPE}$$

2.3 Moisture index and its relationship to MMF coverage

Because of their nature, the MMFs are good water collectors[7]. For this reason, special consideration was given to the HI, since its calculation takes into account precipitation, mean temperature, potential evapotranspiration, water deficit and water excess. Although the HI can be affected by isolated events such as droughts or hurricanes, in general, it expresses the incidence that vegetation has on water uptake[26]. By virtue of this, the temporal evolution of the HI was associated with precipitation from 1979 to 2015 and with changes in MMF cover from 1997 to 2016, calculated from the areas reported by the land use and vegetation series I, II, III, IV, V and VI of the National Institute of Statistics and Geography[3,31-35]. The statistical indicators used were the Average Annual Growth Rate (AAGR), correlation coefficient and a Tukey test of means.

3. Results and discussion

3.1 Climatic water balance

In the Huasteca region with MMF, precipitation is greater than the evapotranspiration potential, which means that the dry season is minimal and only occurs from February to April, with ample water available for vegetation from May to January (**Figure 2**). This fact contrasts with what occurs in sugarcane growing areas in the same Huasteca region, where according to Santillan-Fernández *et al.*[36], the water deficit is more prolonged and occurs from November to June, so sugarcane production is maintained thanks to the use of irrigation. The property of good water catchers that MMFs possess has been extensively documented by CONABIO[7], González-Espinosa *et al.*[16], Muñoz-Villers *et al.*[24], Galicia and Gamfeldt *et al.*[5] and Galicia and Zarco-Arista[6]. However, none of these authors relate the coverage of the MMF with the water catchment capacity in a region, but they do agree that the conservation of the MMF is important to improve the quantity and quality of water in the regions surrounding the MMF.

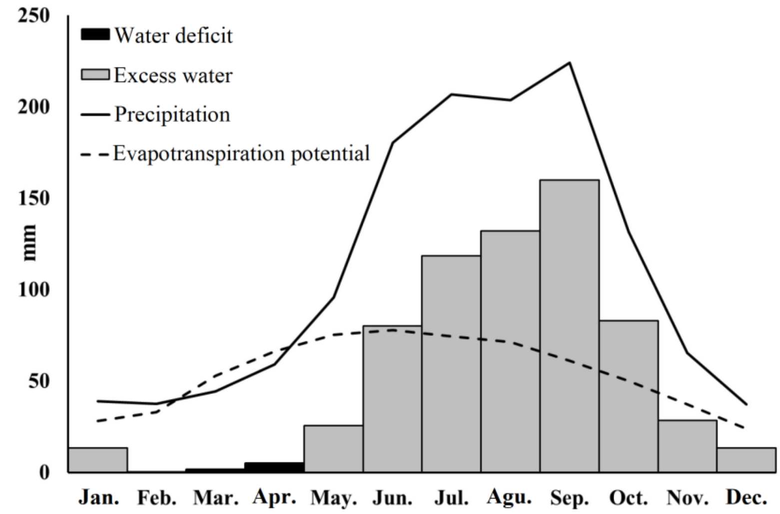

Figure 2. Climatic water balance of the Huasteca region with mountain mesophyll forest constructed from averages of precipitation, evapotranspiration potential, water deficit and excess water from 31 meteorological stations for the period 1979–2015.

3.2 Moisture index and its relationship to MMF coverage

The mean HI from 1979 to 2015 for the MMF zones of the Huasteca region was 103.51%, according to the climate classification proposed by Thornthwaite corresponds to a Perhumid Climate A[25]. But as shown in **Figure 3**, the HI presented values less than or equal to 100% in 16 of the 37 years analyzed, with a negative SSS (-2.97%) from 1979 to 2004 and an extreme value in 2002 of -6.53% that corresponded to a dry sub-humid year as a result of the extreme drought that occurred that year in the region[37]. These results help explain why CONABIO[38] classifies the MMF region in the Huasteca as a transition zone between temperate humid and semi-warm humid climates, highly vulnerable to the effects of climate change due to instability in precipitation[21].

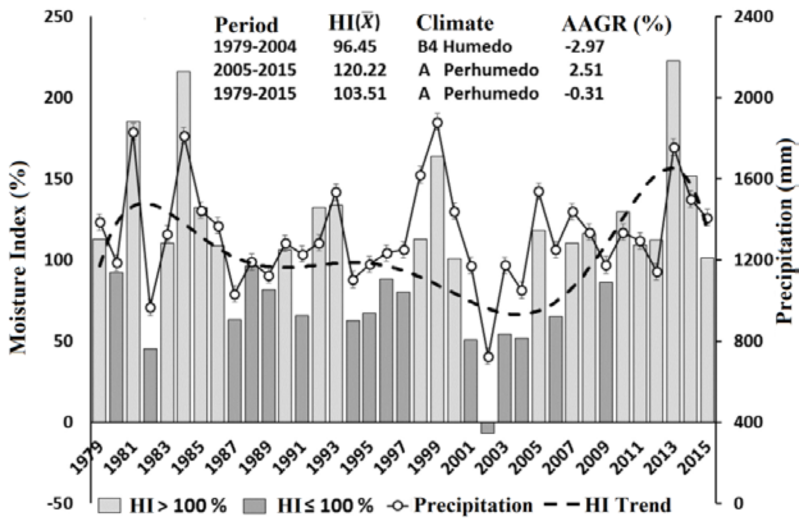

Figure 3. Trend of the humidity index and its relationship with precipitation in the Huasteca region with mountain mesophyll forest constructed from the averages of 31 meteorological stations for the period 1979–2015.

To establish the relationship between the HI and the MMF cover of the Huasteca region, the 1979–2015 series was divided into three periods: 1979–1996, 1997–2004 and 2005–2015, based on the HI trend and MMF covers (**Figure 4**). In each period, the variations of HI (%), annual precipitation (mm) and MMF cover (ha) were associated (**Table 1**). The results show that from 1979 to 2004, the HI, precipitation and MMF cover had negative AAGR. The period 1997–2004 presented the lowest values for the AARR of the HI with -5.36%, which coincides with the loss in MMF cover of -29.64%, mainly due to logging. The correlation between both variables was 0.59, suggesting a direct relationship between HI and MMF cover. This fact has been documented by Ungar *et al*.[8], Suryatmojo *et al*.[9] and Del Campo *et al*.[10] who found that in forest ecosystems the higher the cover, the greater the water captured.

The positive AAGR (4.49%) presented by the HI for the 2005–2015 period coincided with a MMF deforestation rate of less than 1% (-0.91%). According to Manson[22], water catchment by forest cover is very sensitive to drastic changes in its surface area, such as the one that occurred from 1997 to 2004 (-29.64%), and resilient to minimal deforestation rates. In this regard, Monterroso-Rivas *et al*.[21] found that the deforestation of MMF in the Huasteca after 2002 was mainly due to the increase in pastures for extensive cattle ranching, which converted areas of MMF to forage grasses, classified as good water retainers[39]. This fact, together with the creation of the National Forestry Commission in 2001, which gave priority to the restoration and conservation of the MMF in the Huasteca[40], may explain why the HI in the region presented positive AAGR even though rainfall did not show statistically significant increases in the period of analysis (**Table 1**).

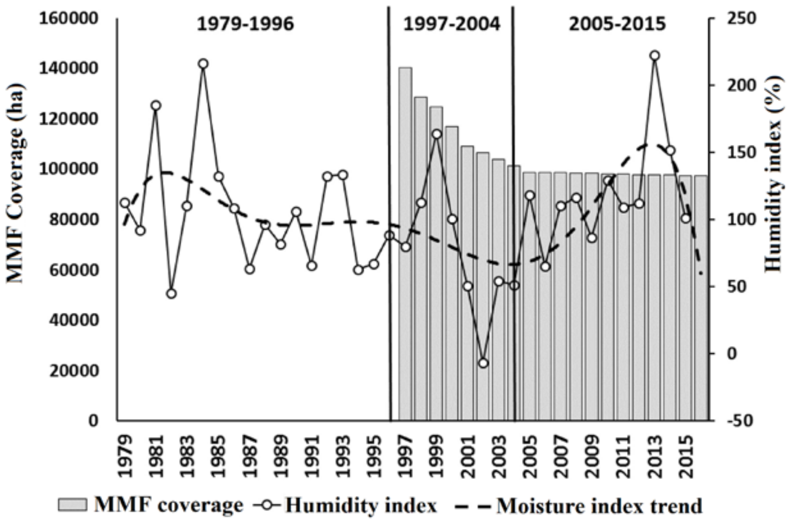

Figure 4. Trend of the humidity index and its relationship with the mountain mesophyll forest cover in the Huasteca region for the periods 1979–1996, 1997–2004 and 2005–2015.

Table 1. Tukey mean test and mean annual growth rate (%) for the variables humidity index (%), precipitation (mm) and mountain mesophyll forest cover (ha) in the Huasteca region for the periods 1979–1996, 1997–2004 and 2005–2015

Period	HI			PRE		Coverage		
	Media	AAGR	Weather	Media	AAGR	Media	AAGR	Loss (%)
1979–1996	105.56 AB	-1.35	To Perhumedo	1,306.7 A	-0.64	No data	1979–1996	105.56 AB
1997–2004	75.94 B	-5.36	B3 Wet	1,289.2 A	-2.14	116,372 A	1997–2004	75.94 B
2005–2015	120.21 A	4.49	To Perhumedo	1,379.6 A	1.20	98,135 B	2005–2015	120.21 A

Means with the same letter per column are not statistically different (Tukey, a = 0.05).

The HI directly relates in its calculation: water excess, water deficit and evapotranspiration potential in a region, and indirectly precipitation and temperature. For this reason, it was considered as an indicator of the amount of water captured by the MMF ecosystem in the Huasteca region. This fact allowed determining the importance that the MMF cover has in the regional Climatic Water Balance. It was found that the HI tends to decrease when the MMF cover is aggressively reduced in short periods, so the restoration and conservation of this ecosystem is a priority to improve the amount of water in the region. A limitation of this research is that the calculations developed are based on information available from official sources, so it is recommended that the proposed methodologies be complemented with data taken in situ.

Acknowledgement

To the Forest Engineering students of the Higher Technological Institute of Venustiano Carranza, Selene Romero Mérida and Velázquez Castillo Yadeli, for their willingness and enthusiasm in putting together databases and cartography. As well as the anonymous reviewers who contributed to the enrichment of the study.

Conflict of interest

The authors declare that they have no conflict of interest.

References

1. Villaseñor JL. El bosque húmedo de montaña en México y sus plantas vasculares: Catálogo florístico-taxonómico (Spanish) [The montane rainforest in Mexico and its vascular plants: A floristic-taxonomic catalog]. México, D.F.: Universidad Nacional Autónoma de México; 2010. p. 42.
2. García-De la Cruz Y, Olivares-López LA, Ramos-Prado JM. Tree structure and composition of a fragment of cloud forest in Veracruz state. Revista Chapingo Serie Ciencias Forestales y del Ambiente 2013; 19(1): 91–101.
3. Instituto Nacional de Estadística y Geografía. Uso del suelo y vegetación, escala 1:250000, serie VI (Spanish) [Land use and vegetation, scale 1:250000, series VI]. Aguascalientes, Mexico: INEGI; 2016.
4. Álvarez-Zúñiga E, Sánchez-González A, López-Mata L, *et al*. Composition and abundance of Pteridophytes in a cloud forest of Tlanchinol municipality, Hidalgo, Mexico. Botanical Sciences 2012; 90(2): 163–177.
5. Gamfeldt L, Snãll T, Bagchi R, *et al*. Higher levels of multiple ecosystem services are found in forests with more tree species. Nature Communications 2013; 4(1): 1–8.
6. Galicia L, Zarco-Arista AE. Multiple ecosystem services, possible trade-offs and synergies in a temperate forest ecosystem in Mexico: A review. International Journal of Biodiversity Science, Ecosystems Services & Management 2013; 10: 275–288.
7. Toledo Aceves T. El bosque mesófilo de montaña en México: Amenazas y oportunidades para su conservación y manejo sustentable (Spanish) [The mountain mesophyll forest in Mexico: Threats and opportunities for its conservation and sustainable management]. México: CONABIO; 2010. p. 197.
8. Ungar ED, Rotenberg E, Raz-Yaseef N, *et al*. Transpiration and annual water balance of Aleppo pine in a semiarid region: implications for forest management. Forest Ecology and Management 2013; 298: 39–51.
9. Suryatmojo H, Fujimoto M, Yamakawa Y. Water balance changes in the tropical rainforest with intensive forest management system. International Journal of Sustainable Future for Human Security J-SustaiN 2013; 1: 56–62.
10. Del Campo AD, Fernandes TJ, Molina AJ. Hydrology-oriented (adaptive) silviculture in a semiarid pine plantation: How much can be modified the water cycle through forest management? European Journal of Forest Research 2014; 133: 879–894.
11. Zavaleta HE, Cruz-Jiménez H, Márquez-Ramírez J. Potential water infiltration of rain from the retention of a forest planting. Foresta Veracruzana 2012; 14(1): 23–28.
12. Williams-Linera G, Vizcaíno-Bravo Q. Cloud forests on rock outcrop and volcanic soil differ in indicator tree species in Veracruz, Mexico. Revista Mexicana de Biodiversidad 2016; 87: 1265–1274.
13. Gual-Díaz M, Rendón-Correa A. México's mountain mesophyll forests. Agroproductividad 2017; 10(1): 3–9.
14. Alvarez-Aquino C, Williams-Linera G, Newton AC. Experimental native tree seedling establishment for the restoration of a Mexican cloud forest. Restoration Ecology 2004; 12: 412–418.
15. Cayuela L, Golicher DJ, Benayas JMR, *et al*. Fragmentation, disturbance and tree diversity conservation in tropical montane forests. Journal of Applied Ecology 2006; 43: 1172–1181.
16. González-Espinosa M, Meave JA, Ramírez-Marcial N, *et al*. Cloud forests of Mexico: conservation and restoration of their tree component. Ecosistemas 2012; 21(1–2): 36–54.
17. Williams-Linera G, Manson RH, Vera EI. La fragmentación del bosque mesófilo de montaña y patrones de uso del suelo en la región oeste de Xalapa, Veracruz, México (Spanish) [Fragmentation of mountain mesophyll forest and land use patterns in the western region of Xalapa, Veracruz, Mexico]. Madera y Bosques 2002; 8(1): 73–89.
18. Bautista-Cruz A, Del Castillo RF. Soil changes during secondary succession in a tropical montane cloud forest area. Soil Science Society of America Journal 2005; 69: 906–914.
19. Williams-Linera G. El bosque de niebla del centro de Veracruz: ecología, historia y destino en tiempos de fragmentación y cambio climático (Spanish) [The cloud forest of central Veracruz: ecology, history and destiny in times of fragmentation and climate change]. México: CONABIO; 2007. p. 208.
20. Foster P. The potential negative impacts of global climate change on tropical montane cloud forests. Earth Science Reviews 2001; 55: 73–106.
21. Monterroso-Rivas A, Gómez-Díaz J, Tinoco-Rueda J. Cloud forest and climate change scenarios: An assessment in Hidalgo, Mexico. Revista Chapingo. Serie Ciencias Forestales y del Ambiente 2013; 19(1): 29–43.
22. Manson RH. Los servicios hidrológicos y la conservación de los bosques de México (Spanish) [Hy-

drological services and the conservation of Mexico's forests]. Madera y Bosques 2004; 10(1): 3–20.
23. Martínez ML, Pérez-Maqueo O, Vázquez G, *et al*. Effects of land use change on biodiversity and ecosystem services in tropical montane cloud forests of Mexico. Forest Ecology and Management 2009; 258: 1856–1863.
24. Muñoz-Villers LE, McDonnell JJ. Runoff generation in a steep, tropical montane cloud forest catchment on permeable volcanic substrate. Water Resources Research 2012; 48: 1–17.
25. Ruíz-Álvarez O, Arteaga-Ramírez R, Vázquez-Peña MA, *et al*. Water balance and climatic classification of the state of Tabasco, Mexico. Universidad y Ciencia 2012; 28(1): 1–14.
26. Sentelhas PC, Dos Santos DL, Machado RE. Water deficit and water surplus maps for Brazil, based on FAO Penman-Monteith potential evapotranspiration. Ambiente e Agua-An Interdisciplinary Journal of Applied Science 2008; 3: 28–42.
27. Malamos N, Barouchas PE, Tsirogiannis IL, *et al*. Estimation of monthly FAO Penman-Monteith evapotranspiration in GIS environment, through a geometry independent algorithm. Agriculture and Agricultural Science Procedia 2015; 4: 290–299.
28. CLImate COMputing Project [Internet]. Ensenada, B.C. Mexico: CLICOM; 2018 [accessed 2018 Feb 17]. Available from: http://clicom-mex.cicese.mx/mapa.html.
29. Rolim GS, Sentelhas PC, Barbieri V. Spreadshets in excel^{TM} environment to calculation of water balance: Normal, sequential, culture, and POTENTIAL, real productivity. Revista Brasileira de Agrometeorologia 1998; 6(1): 133–137.
30. Santillán GE, Dávila-Vázquez G, De Anda SJ. Assessment of hydric balance through climatic variables, in the Cazones River Basin, Veracruz, Mexico. Revista Ambiente & Água 2013; 8(3): 104–117.
31. Instituto Nacional de Ecología e Instituto Nacional de Estadística (INE-INEGI). Uso del suelo y vegetación, escala 1:250000, serie I (Spanish) [Land use and vegetation, scale 1:250000, series I]. CDMX, Mexico: Instituto Nacional de Ecología e Instituto Nacional de Estadística, Geografía e Informática; 1997.
32. Instituto Nacional de Estadística y Geografía (INEGI). Uso del suelo y vegetación, escala 1:250000, serie II (Spanish) [Land use and vegetation, scale 1:250000, series II]. Aguascalientes, México: Instituto Nacional de Estadística y Geografía; 2001.
33. Instituto Nacional de Estadística y Geografía (INEGI). Uso del suelo y vegetación, escala 1:250000, serie III (Spanish) [Land use and vegetation, scale 1:250000, series III]. Aguascalientes, México: Instituto Nacional de Estadística y Geografía; 2005.
34. Instituto Nacional de Estadística y Geografía (INEGI). Uso del suelo y vegetación, escala 1:250000, serie IV (Spanish) [Land use and vegetation, scale 1:250000, series IV]. Aguascalientes, México: Instituto Nacional de Estadística y Geografía; 2009.
35. Instituto Nacional de Estadística y Geografía (INEGI). Uso del suelo y vegetación, escala 1:250000, serie V (Spanish) [Land use and vegetation, scale 1:250000, series V]. Aguascalientes, México: Instituto Nacional de Estadística y Geografía; 2013.
36. Santillán-Fernández A, Santoyo-Cortés VH, García-Chávez LR, *et al*. Influence of drought and irrigation on sugarcane yields in different agroecoregions in Mexico. Agricultural Systems 2016; 143: 126–135.
37. SMN CONAGUA. Monitor de sequía en México (Spanish) [Drought monitor in Mexico]. CDMX, Mexico: Comisión Nacional del Agua; 2018.
38. CONABIO. Climas (Spanish) [Climate]. CDMX, Mexico: Comisión Nacional para el Conocimiento y Uso de la Biodiversidad; 2017.
39. Cruz-Martínez A, Pedroza-Sandoval A, Trejo-Calzada R, *et a*l. Rain water harvesting and soil moisture retention in the establishment of buffel grass (*Cenchrus ciliaris* L.). Revista Mexicana de Ciencias Pecuarias 2016; 7(2): 159–172.
40. CONAFOR. Restauración de ecosistemas forestales: Guía básica para comunicadores (Spanish) [Restoration of forest ecosystems: Basic guide for communicators]. National Forestry Commission. Zapopan, Jalisco, México: Comisión Nacional Foresta; 2009. p. 69.