CHAPTER 7

ENSO drought effects and their impact in the ecology and economy of the state of Chihuahua, Mexico

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Abstract

In this chapter, the relationship between El Niño–Southern Oscillation (ENSO) and a drought that occurred in the last two decades in Chihuahua, and whose effects lasted for more than 10 years are evaluated. Using hydrologic drought standard indices, the historical natural flow and anomalies for the three most important hydrological regions of Chihuahua are studied. The results show the presence of at least three continuous years of an intense hydrological drought per decade, which severely impacted the state's ecology and economy when it went on longer. The analysis shows that natural flow deficits are linked preferably to the ENSO (El Niño) mild phase even though an ENSO (La Niña) cold phase was concurrent during three to five hydrologic drought events. This is a fact that stresses the vulnerability of this region to drought-derived impacts, such as forest fires, migration, and decrease in plant biomass, which hamper forest and livestock farming activities. A permanent monitoring system for drought cycles in Chihuahua is necessary to allow planning the sustainable use of the state's natural resources, especially water.
Keywords: Vulnerability, climate monitoring system, hydro-meteorological damage, sustainable planning, stream weather.

1 Introduction

Extreme weather variation in Mexico is largely determined by the occurrence of global atmospheric ocean phenomena known as El Niño, La Niña, or Southern

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Oscillation (SO) [1, 2]. Other studies mention that rainfall of central and northern Mexico is also influenced by phenomena such as cold fronts, cyclones, and tropical storms that are generated at different times of the year [3–6]. All these global processes have been extensively studied to try to explain the occurrence of extreme weather events and social, environmental, and ecological impacts such as floods, drought cycles, and cold and warm waves [7–12]. El Niño/La Niña is one of the atmospheric-ocean processes commonly linked to hydro-climatic disasters. It refers to the irregular condition of the tropical Pacific Ocean temperatures located along the coasts of Peru, known as sea surface temperature (SST) [13–15]. The El Niño phase corresponds to the climate stage in which the monthly temperature of the sea surface experiences an increase of beyond 0.5°C with respect to the corresponding historical average for at least 5 consecutive months [7, 16]. These anomalies in ocean temperature generally occur in accordance with atmospheric circulation anomalies known as SO that generate temperature and rainfall pattern variation; this whole process is known as El Niño/SO (ENSO) [17–19]. The presence of El Niño/La Niña does not show a periodical occurrence pattern and an El Niño event is not necessarily followed by a La Niña event or vice versa; nevertheless, it has been observed that the duration of mild or cold monthly anomalies may lengthen for more than 12 months, as it occurred in 1970–1972, 1973–1975, and 1982–1984.

Currently there are questions as to whether ENSO phenomena are truly related to the temperature and rainfall anomaly patterns in the continental zone of central and northern Mexico and North America [11, 20]. Moreover, statistics tests have been conducted to establish the correlation degree between seasonal rainfall and other indices such as the Multivariate ENSO Index (MEI) in Niño and Niña periods [21]. The results show that the total annual precipitation during an El Niño event decreases in the south and increases considerably in central and northern Mexico, unlike seasonal rainfall that increases in the south and decreases in the central part of the country, keeping no apparent effect in the north. SST and ENSO effects on droughts have been reported by various authors who have evaluated the severe meteorological drought occurrence in Northwestern Mexico using a different approach [22]: drought severity and intensity in accordance with continental hydro-climatic variability [11, 14] and agricultural productivity cost in Mexico during an ENSO event [23]; nevertheless, the real effects of ENSO phenomena on the ecology and agriculture in the states of Chihuahua, Sonora, Sinaloa, and the Baja California peninsula [20] have always been unclear. In this sense, it has been observed that the drought–flood cycles are more frequent and intense in Mexico and in other countries every time, which requires a major investment of resources and time for the affected zones to go back to their ‘normal’ state after the catastrophe [10]. The essence of this study is to analyze the relationship between El Niño and La Niña phenomena and drought occurrences in the State of Chihuahua since it is well known that ENSO relates well with rainfall variability in some zones of Mexico [21], and in some mountain areas of Chihuahua [24, 25]. However, the unique effects of ENSO concerning natural runoff volume resulting from hydrological droughts in continental zones, such as those in northern Mexico, are still unknown, especially when the runoff deficit prolongs for several consecutive years as it happened in Chihuahua and its nearby states in the 1990s.

2 Objective

The main goal is to evaluate the effects of ENSO events on periods of severe droughts in the State of Chihuahua to prove that this relationship can explain the natural flow (NF) of the seasonal-space variability observed; this assessment will shed light on how the occurrence, duration, intensity, and space distribution of hydrological drought have impacted the economy and the ecology of the State of Chihuahua.

3 Materials and methods

The study area corresponds to the State of Chihuahua, Fig. 1, located in the northern part of the country between latitudes 25° 30' and 31° 47' N and longitudes 103° 18' 109° 7' W with elevations between 900 m (Mexican Plateau Zone) and 3300 m (Cerro Mohinora) above sea level. The Chihuahuan landscape is made up of three large regions: The Sierra Madre Occidental (SMO); mountains, hills, and central valleys (SLVC); and the plateau and the Sierra de Oriente (ASO) distributed from west to east as big band shapes [26]. The dominant weather pattern is mild humid

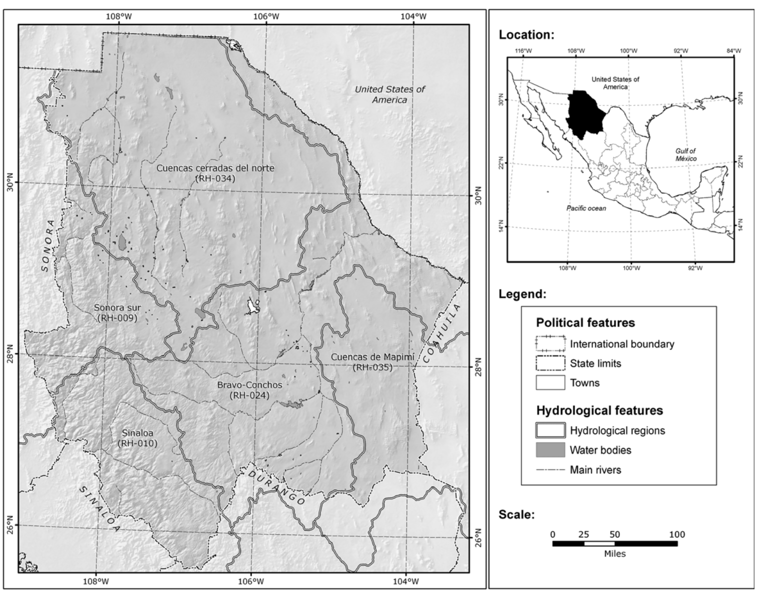

Figure 1: The State of Chihuahua and the three hydrologic regions referred to in the text (RH24, RH34, and RH35, CNA nomenclature).

(Cw) in SMO; semi-arid dry in SLVC, and arid dry in ASO; in the SMO canyon area, the weather is mild [6].

3.1 Hydrologic drought characterization

To define the hydrologic drought (Hd) in Chihuahua, we considered the estimated NF data in each one of the hydrological sections included in the three main hydrologic regions: RH34 (*Cuencas Cerradas del Norte*); RH24 (*Bravo Conchos*) including the total section of the Rio Conchos Basin in the state of Chihuahua; and RH35 (*Cuencas Cerradas de Mapimí*), Fig. 1. The NF estimate followed the Official Mexican Standard criteria NOM-011-CNA-2002 [27]. For the Hd analysis we followed the description in Bergaoui and Alouini [28] and Byun and Wilhite [29] who considered anomalies, duration, and intensity of any of the hydrologic cycle components in a river basin with drainage capacity. The average NF anomaly indices were estimated, representing the annual deficit (Hd−) or surplus of NFs (Hd+) in proportion to the historical NF average. To know the decadal tendency of Hd, the surplus and deficit flows of the complementary fraction values were integrated in relation to the historical average [8, 9, 30]. A positive value of Hd anomaly indices indicates a humid period where flows occur above the expected value and vice versa, a negative Hd value indicates a flow deficit period that turns into Hd.

3.2 ENSO concurrence with drought

To evaluate the ENSO effect on drought occurrence and its severity, El Niño and La Niña periods were determined through the SST monthly anomalies in zone three (SST3) (http://www.cpc.ncep.noaa.gov/data/indices/) and the SO average values related to El Niño as ENSO. El Niño/La Niña classifying criteria were the same described by Klaassem [7] and Magaña [31], indicating that a cold period or La Niña is when anomaly values persist below −0.5°C, which is the historical average for at least 5 months, whereas a hot period or El Niño is defined by anomaly values remaining above 0.5°C. ENSO data are based on the standardized value of the pressure difference between the Darwin Zone and the Tahiti Pacific Ocean. The SST3 value evolution estimated by NOAA was used to detect its relationship with NF in the cooling and heating periods of the sea water surface.

3.3 Ecological and economical impact

For this analysis, economic and socio-demographic censuses were used [32–37]. These are records of forest fires, drought, agricultural productivity, irrigated land, and costs for natural disasters. The purpose of the analysis was to detect the relationships between ENSO and the hydro-meteorological events of the region, specifically drought which is known to damage both the ecology and the economy of Chihuahua.

4 Results

4.1 Annual natural flows

The annual NF utilized in the Hd analysis corresponded to the 1950–2005 period for the RH24, 1960–2004 for the RH34, and 1961–2004 for the RH35. Basic statistics in each hydrological region of Chihuahua (RH) shows a variation of the NF historic average which goes from 201.22 Mm^3 in the RH24, followed by 184.3 m^3 in RH 35, up to 77.3 Mm^3 in the RH34, Table 1. The registered maximum values were 985.7, 229.1, and 202.9 Mm^3 (respectively, for RH24, RH35, and RH34), while the minimum NF was in the order of 6.4, 130.4, and 0.66 Mm^3 up to 2004, which showed a minor NR variability of the historical annual value that corresponded to the Mapimí closed watershed basin.

4.2 Hydrologic drought occurrence

According to the annual hydrologic index values (Hd), the occurrence of dry years was 30 for the Rio Conchos River basin zone, 28 for the northern region, and 27 for the south-central zone (RH34 and RH 35), which represent 46% of the total analyzed region and around 36% in the other two zones of Chihuahua in contrast with humid years, Table 2.

Table 1: Basic statistics of natural runoff in Chihuahua.

Hr	NF_a (Mm^3)	DS (Mm^3)	Max (Mm^3)	Min (Mm^3)	CV	Years	SH
[1]RH24	201.22	291.84	985.69	6.42	1.45	56	11
[2]RH34	77.33	50.78	202.94	5.83	0.66	45	22
[3]RH35	184.34	45.68	229.10	130.44	0.25	44	4

Hr = Hydrologic regions; NF_a = average natural flow; [1]Conchos/Bravo; [2]Cuencas Cerradas del Norte; [3]Cuencas Cerradas de Mapimí; SD = Standard deviation; SH = hydrometric station number.

Table 2: Frequency of dry (Hd–) and wet (Hd+) years in Chihuahua.

Hydrologic regions	Hd–	Hd+	Drought > 2 years	Wet > 2 years
RH24	30	26	7	4
RH34	28	16	7	2
RH35	28	16	9	2

[1]Conchos/Bravo; [2]Cuencas Cerradas del Norte; [3]Cuencas Cerradas de Mapimí; Hd– = Negative Hydrologic deficit or drought; Hd+ = Positive Hydrologic deficit or wet.

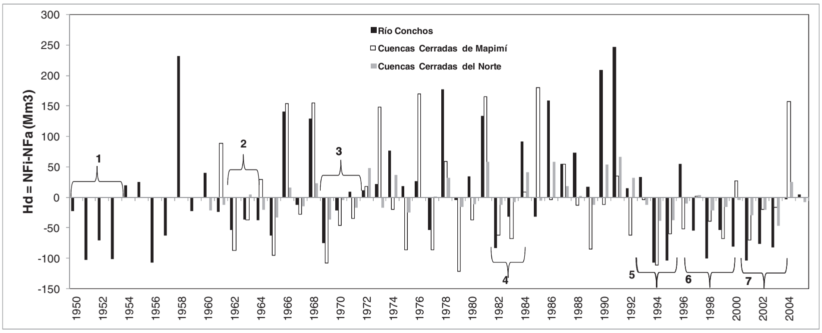

Figure 2: Interannual variation of the hydrological drought index (Hd anomalies); Hd+ = wet phase; Hd– = dry phase; NF_i = annual natural flow; NF_a = average natural flow.

The consecutive two or more periods of hydrological drought were 7 for RH 24 and RH 34 and 9 for the Mapimí Zone, Fig. 2, in which drought periods could be seen after uninterrupted 5–7-year rank and where runoffs were less compared to the normally expected values. In contrast, there were prolonged periods of heavy rainfall years with runoff above historical average in a consecutive 2–4-year rank, with volumes up to 150% more than the observed maximum deficit. For example, this situation happened in the Rio Conchos River basin zone in the years 1990 and 1991 right before the most prolonged drought ever occurred since 1950. The results on Hd intensity showed that, for the Conchos region, there was a missing rate of NF of −74.4 Mm^3 per year between 1950 and 1953; for the 1997–1999 period it was −69.2 Mm^3, 50% drier than the RH35 and in Northern Chihuahua, where during this same period, a NF deficit of the annual rate was obtained in the order of −31 and −23 Mm^3, respectively.

4.3 Accumulated tendency of the runoff deficit

Once the hydrologic tendency indices were analyzed (Ht), it could be seen that to a 10-year seasonal scale (decade), there is a similar hydrological behavior across all Chihuahua State, Fig. 3. In general, we can see that between 1970 and 1990, the three hydrological regions had an accumulated tendency of positive runoffs. It means that during those 20 years, there was the occurrence of available superficial water in rivers and water bodies of Chihuahua, preventing severe impacts to the ecology and economy of the state. In the Conchos zone however, there was a negative tendency period in the 1950s followed by an apparent hydrological equilibrium until 1965, a year when RH35 (Cuencas de Mapimí) continued showing a negative tendency. It was mimicked by RH34 (Cuencas Cerradas del Norte) until 1971, after which all three started heading up to the NR values. During the 1990s, and despite a rainy year (1996) for the Conchos zone and one for the Mapimí closed basin in the year 2000, Fig. 3, it is clearly seen that the drought of that period

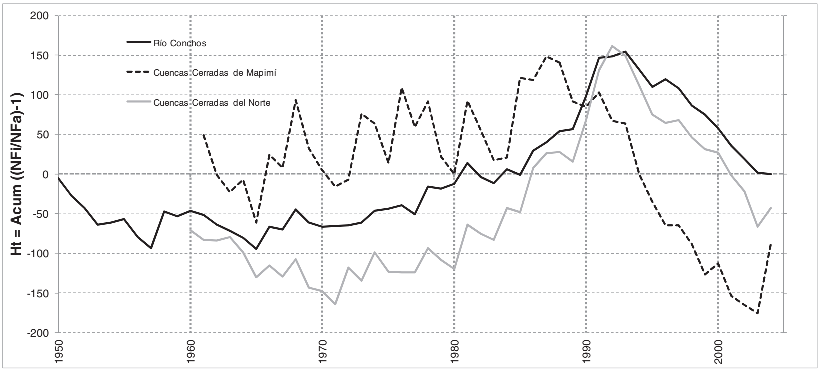

Figure 3: Accumulated decadal trends in deficits or surpluses in the runoff deficit of Hd in the three major hydrological regions of Chihuahua. Ht = Trends of cumulative hydrologic drought index; NF_i = annual natural flow; NF_a = average natural flow.

persisted in all the regions. Starting in the year 2004, again, due to the copious rainfall of the previous years, the hydrological tendency was positive, suggesting an end to the drought.

4.4 ENSO years

The El Niño and La Niña years were identified for the period between 1950 and 2009, Table 3. A total of 32 events were found, of which 15 were El Niño and 17 were La Niña (47% and 53%, respectively). During El Niño events from 1972–1973, 1982–1983, and 1997–1998 in which SST3 anomalies occurred with a greater intensity (an average of 1.48°C, 1.81°C, and 2.48°C, respectively), the ENSO values for these same periods were −1.8, −2.06, and −2.04, respectively. This contrast between SST3 versus ENSO is shown in Fig. 4, where dark zones represent sea temperature anomalies, while clear zones are the Darwin–Tahiti pressure anomalies. The opposite correspondence was confirmed by a regression analysis,

in which the r^2 value was 0.80 and $p < 0.001$, Fig. 5, because these two ocean-atmospheric processes are frequently combined in just one phase, the SO El Niño or ENSO in brief, that is ENSO mild phase to describe El Niño or ENSO cold phase to describe La Niña.

4.5 Concurrences between ENSO and hydrologic drought

Comparing the Hd index data versus the Pacific SST3 anomalies, NF deficits or surplus can be seen when they exceed the El Niño or La Niña events, Fig. 6. The peaks of the SST3 curve can be seen when they stand out above the shaded areas (ENSO mild event or El Niño) or vice versa, if they surpass the lower part of this area (ENSO or La Niña cold event). The results of this comparison show a

Table 3: El Niño and La Niña periods, according to SST3 and ENSO.

NIÑAS				NIÑOS			
Period	Months	SST3	ENSO	Period	Months	SST3	ENSO
1951–52	5	0.92	−1.13	1950–51	5	−0.72	1.7
1957–58	7	1.12	−0.92	1954–55	9	−1.06	0.27
1963–64	6	0.8	−0.95	1955–56	11	−1.04	1.04
1965–66	10	1.095	−1.14	1956–57	7	−0.77	0.8
1969–70	6	0.80	−0.73	1962–63	6	−0.69	0.53
1972–73	11	1.48	−1.26	1964–65	11	−1.07	0.46
1976–77	9	0.7975	−0.55	1967–68	11	−1.02	0.14
1982–83	17	1.81	−1.95	1970–71	21	−1.07	0.92
1986–87	17	1.14	−1.19	1973–74	14	−1.09	1.28
1991–92	8	1.225	−1.73	1975–76	12	−1.10	1.48
1994–95	5	0.76	−1	1984–85	22	−0.87	−0.06
1997–98	13	2.49	−2.04	1988–89	14	−1.39	1.14
2002–03	8	0.96	−0.9	1995–96	7	−0.77	−1.97
2006–07	6	1.05	−0.78	1998–99	6	−0.92	1.25
2009–10	11	0.94	−0.72	1999–00	11	−1.08	0.73
				2000–01	8	−0.57	0.65
				2007–08	11	−1.15	0.78

SST3, ENSO = Average values

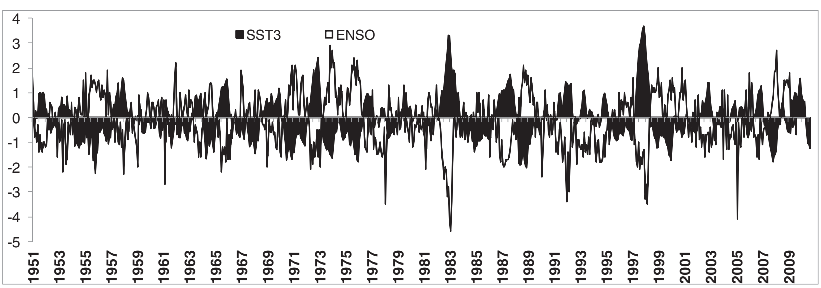

Figure 4: Correspondence between El Niño/La Niña and ENSO events. Positive dark areas are El Niño, negative are La Niña; Positive clear ENSO areas correspond to El Niño, negative clear to La Niña.

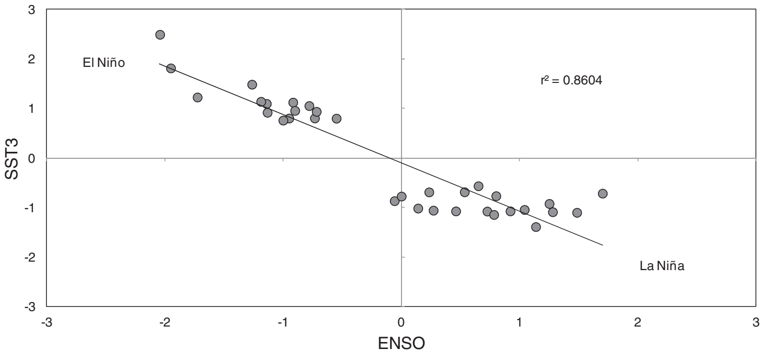

Figure 5: Relationship between SST3 anomalies and the standardized values in pressure difference between Darwin and Tahiti zones (ENSO) during El Niño and La Niña phases (1951–2010 period).

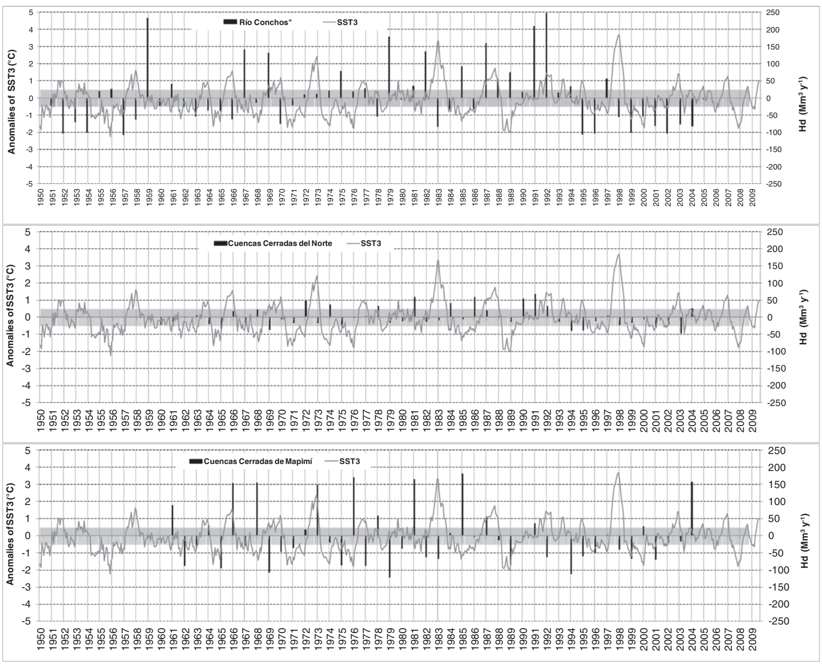

Figure 6: Value confrontation of Hd versus SST3 anomalies in the three major hydrological regions of Chihuahua (RH24, above; RH34, centre; RH35, lower).

large number of Hd concurrences with the ENSO mild phase (9, 8, and 7 times, respectively for RH12, RH34, and RH35); in contrast, that same phase showed a coincidence between ENSO and Hd positive values, 5, 3, and 4 times. In the same way, when the ENSO cold phase was analyzed the coincidence was higher

Table 4: Hydrologic drought coincidences with El Niño or La Niña events in Chihuahua.

Hr	Niño Hd+	Niño Hd−	Niña Hd+	Niña Hd−	Niño 1972–73	Niño 1982–83	Niño 1998–99
RH24	5	9	6	10	+	-	-
RH34	3	8	2	9	-	-	-
RH35	4	7	3	8	+	-	-
Total	12	24	11	27	2+, 1−	3−	3−

Hd+ = positive values or surplus on natural flow; Hd− = negative values or deficits of natural flow; Hd− is the hydrological drought status.

between Hd− and the SST3 negative values, slightly higher than those of the mild phase (10, 9, and 8, respectively for RH24, RH34, and RH35).

The total of concurrence instances showed that the negative Hd indices reached the highest frequency with a coincidence of 24 and 27 times, and minimum values of 12 and 11 for positive indices, Table 4. In other words, a double negative effect of the El Niño and La Niña phases was found in the three hydrological regions as shown, which seem to stress the Hd indices of the periods and intensity, resulting on either hydrological drought or NF. During the three more intense ENSO mild phase periods, the index concurrences of Hd negative values were 7, indicating that during an El Niño period, there is a decrease in NFs in the region, Table 4. The Hd statistical analysis versus SST3 concurrence yielded r^2 values between 0.09 and 0.175 ($p > 0.001$); in some hydrometric stations the increase was above 0.22, which indicates the existence of the relationship of the El Niño or La Niña NF periods.

5 Discussion

5.1 Drought impact in the ecology and economy of Chihuahua

Evidence shows that drought occurrence is prevalent, Fig. 2, in Chihuahua, and it is likely associated with El Niño episodes as Magaña [31] and Seager *et al.* [11]. suggested. They also reported that in El Niño winters, northern Mexico is more humid, and just the opposite occurs in the summers, that is, less rainfall and less NFs, mainly in the states of Chihuahua and Coahuila. These effects seem to be stronger because the most important rainfalls occur during the summer in Chihuahua; they are mostly due to the fact that droughts which appear in the El Niño phase continue the following year in the presence of ENSO cold phases (Niña), Table 3, Fig. 6. This could be seen during the Niño/Niña alternations from 1992–2003 through the decennial NF deficit tendency, where a prolonged drought in the three hydrological regions of Chihuahua periods lasted for almost 10 years, Fig. 3. Diaz *et al.* [24]. point out that one of the most severe droughts in Chihuahua appeared during the 1950s, which coincides with this analysis in the Rio Conchos region where records are available. It can be seen that drought was associated in the first place to one of La Niña phases (1950–1951), followed by other three or four dry years linked to El Niño 1951–1952, Fig. 7 and Hd− in the above chart, Fig. 6.

After the 1950s the results show that there have been three intense periods 1972–1973, 1982–1984, and 1997–1998 in the ENSO (El Niño) mild phase, where rainfall and NF were significantly reduced, Table 3, Fig. 6. During the 1960s and 1970s, a strong tendency toward the decrease of dry periods occurred, Fig. 7, and the state benefited from the ecological and economical point of view. However, during the 1990s drought conditions returned. Landa *et al.* [10]. point out that at the end of the 1990s there was a loss caused by drought; around 11,600 livestock and 145,000 hectares of crops were affected in the states of Sonora, Sinaloa, Tlaxcala, Veracruz, and San Luis Potosi. During the 1990s the prolonged and intense drought caused loss in cattle, crop reduction on the surface by irrigation with around 75% less than 434,000 ha planted in 2001, Fig. 8, a decrease in water supply, and a reduction in water storage levels in the main reservoirs of the Rio Conchos impacted greatly the state's economy [30].

A deficit in rain, infiltration, and NFs caused drying of the forest biomass, bushes, and grassland in Chihuahua [31–33], which in turn caused an increase in forest fires and loss in agriculture during those dry years, Fig. 9. For example, the number of fires in 1999 was twice as much as the ones in 1995, which resulted in around 30,000 ha damaged during the ENSO mild phase and around 72,000 in the cold phase, causing important loss of trees, bushes, and grassland, and thus vegetation biomass throughout the state [37]. During 2005–2009, the surface affected by forest fires had importantly increased again; grassland biomass was mainly affected with a burned annual surface above 10,000 hectares, reaching a maximum peak of 31,500 ha in 2009. There were also internal and external problems

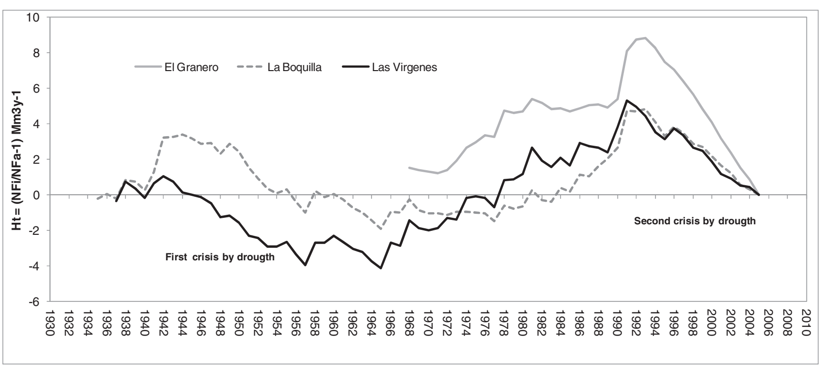

Figure 7: Cumulative trends of NF in three major dams of Chihuahua. Nf_i = Annual natural flow; Nf_a = average natural flow.

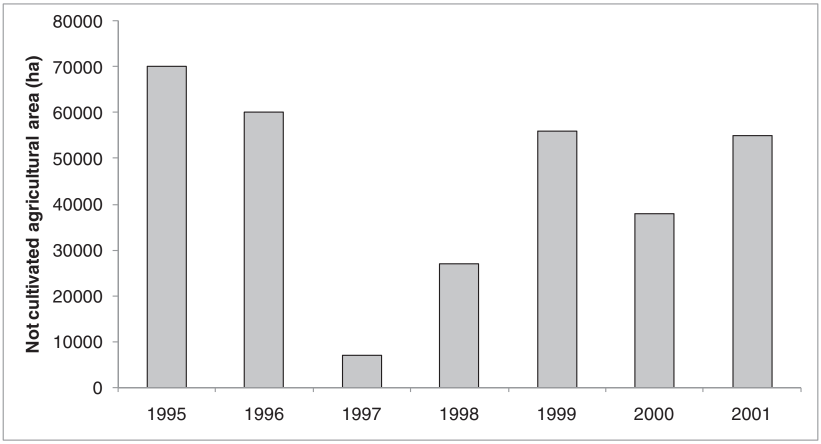

Figure 8: Economic impact in terms of area affected by drought in Chihuahua.

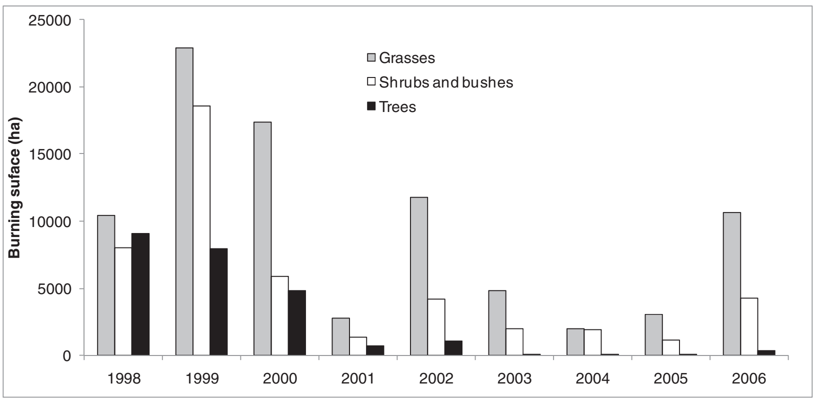

Figure 9: Ecological impact of the drought in terms of land area with burnt vegetation (Source: CONAFOR, 2007).

concerning the use of water in the Rio Bravo region bordering the United States as a result of the very intense drought in the same period of 1997 and 1998 [38], which is now considered as the most severe drought of the century in northern Mexico.

Magaña [31] presented an evaluation of economic losses linked to droughts in Mexico between 1977 and 1999 and reported several impacts; among those that stand out are an increase in the price of grains, a drop in water supply, seedtime surface reduction, loss of crops and cattle, and even livestock mortality, and some cases of child mortality by heat waves. During the period of 2002–2005 $576,000 million pesos were destined to help people affected by contingencies caused by extreme climatologic events [39]; paramount among these was the atypical drought and the climate event that required the most economic resources of around

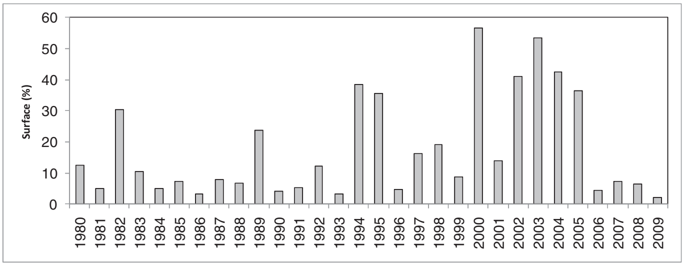

Figure 10: Rain-fed agricultural surface affected by drought (Source: SAGARPA, 2009).

$360,000 million pesos for its attention, which represented approximately 65% of the total sum allocated. The northern states of the country, such as Chihuahua, Durango, Tamaulipas, and Zacatecas received approximately 70% of the assigned resources to attend drought contingencies [32]. During the 1980s and until 1993, the damaged seasonal crops of agricultural land (rain-fed agriculture) was maintained at an average of below 10% in all the state, Fig. 10; however, during the 1990s and until 2005, the average increased to 30%, linked to the registered rain gauge deficit during that severe drought period [38].

In 2009, hydro-meteorological damage and losses in Mexico surpassed the $14,500.8 million pesos ($1,079,800 USD), of which $3,041 million pesos corresponded to drought [34]. According to CONAFOR [37], 41% of the forest fires were caused by farming activities, presence of large amount of plant biomass, and low levels of humidity in those flammable areas. The states with the largest number of forest fires were Mexico, Michoacan, Chihuahua, and Puebla, which together concentrated 56.7% of the total reported fires. From the ecological point of view CONAFOR [37] reports that during 1998–1999 El Niño, forest fires affected 23,000 ha of grassland, 18,500 of bush, and 8000 of forest land in 1999. In the intense drought linked to 1998–1999, El Niño, apart from leading to losses of wildlife, livestock, and even drops in arid ecosystems [40], has been linked to leaving ground with lack of vegetation and leading to agricultural losses [41], reflected in crop surface decrease of cultivated area in Mexico of around 2,273,502 ha equivalent to 3,000,000 t of grain, with a value higher than $3.500.000 million pesos [42].

6 Conclusion

The atmospheric processes, such as the ENSO, are interfering with space variability and temporal rainfall, and NFs in Chihuahua. The mild phase and the cold phase (El Niño or La Niña) may be combined. This situation causes a double effect in decreasing NFs in the hydrological regions of Chihuahua; it lead to an intense hydrological drought as it was observed during 1992–2003 (except for 1997) when accumulated tendency showed a clear drop in the volume of NF. The prolonged period of Hd in Chihuahua (1992–2003) along with the presence of El Niño/LaNiña alternation caused an important ecological, social, and economic crisis, leading to a loss of plant biomass and a loss in animal life as a result of forest fires. Also, the absence of NFs caused a total emptiness in some of the main reservoirs, causing a drastic reduction in irrigation crop surface and an increase in aquifer exploitation. Livestock movement to other states of Mexico together with less profitable sales and late payment for the Rio Bravo water service (in the NF delivery from the Rio Conchos River basin through the CILA treatment, Mexico–USA) further strained the economy of the area. The periodicity of long lasting droughts in Chihuahua in the last five decades has been every 10 years at least (three consecutive years of hydrological deficit). It has placed the state in an almost permanent alert of possibly falling in an economic and ecologic crisis by severe droughts, when an increase of forest fires, soil and animal loss (both wildlife and livestock), land abandonment, migration of communities, as well as a negative impact in livestock and in farming productivity can be observed. It is necessary to increase hydro-climatic monitoring in the state and use forecasting models for precipitation in extreme conditions and temperatures. This will allow to better understand rain gauge tendencies and NF in a medium and long term to promote efficient water use in the arid and semi-arid zones of Chihuahua and in other areas in northern Mexico, and thus be better prepared to prevent deleterious effects due to global climate change in the Chihuahuan desert.

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References

[1] Magaña, V.O., Vázquez, J.L., Pérez, J.L. & Pérez, J.B., Impact of El Niño on precipitation in Mexico. *Geofísica Internacional*, **42(3)**, pp. 313–330, 2003.
[2] Cruz-Medina, I., Análisis de la influencia del ENSO en el Valle del Yaqui (Sonora, México) mediante modelos de regresión dinámica y múltiple. *Rev. Lat. de Rec. Nat*, **2(2)**, pp. 65–80, 2006.
[3] Cornet, A., Principales Caractéristiques Climatiques (Chapter 2). *Estudio integrado de los recursos vegetación, suelo y agua en la reserve de la biosfera de Mapimí. I. Ambiente Natural y Humano*, ed. C. Montaña, Instituto de Ecología, A.C.: Xalapa, Veracruz, México, pp. 45–76, 1988.
[4] Velasco, V.I., Severe droughts becoming recurrent more persistent in Mexico. *Drought Network News*, **11(1)**, pp. 3–6, 1999.
[5] Brito-Castillo, L., Douglas, A.V., Leyva-Contreras, A. & Lluch-Belda D., The effect of large-scale circulation on precipitation and streamflow in the Gulf of California continental watershed. *International Journal of Climatology*, **23(7)**, pp. 751–768, 2003.

[6] García, E., Distribución de la precipitación en la República Mexicana. *Investigaciones Geográficas*, *Boletín*, **50**, pp. 67–76, 2003.

[7] Klaassen, J.M., *A Climatological Assessment of Major 20 the Century Drought Years in the Grand River Basin*. Contracted Report for the Grand River Conservation Authority, Meteorological Service of Canada-Ontario-Region, Environment Canada, Downsview, Ontario. (Published as an Internal MSC Ontario Region report), ASD-01-1, 2001.

[8] Wilhite, D.A., Droughts as a natural hazard, concepts and definitions (Chapter 1). *Drought a Global Assessment*, Vol. I, ed. D.A. Wilhite, Toutledge: London, UK, pp. 1–18, 2001.

[9] Wilhite, D.A., Combating drought through preparedness. *Natural Resources Forum* **26**, pp. 275–285, 2002.

[10] Landa, R., Magaña, V. & Neri, C., *Agua y Clima: elementos para la adaptación al cambio climático*, SEMARNAT, CCA-UNAM: México, pp. 13–73, 2008.

[11] Seager, R., Ting, M., Davis, M., Cane, M., Naik, N., Nakamura, J., Li, C., Cook, E. & Stahle, D.W., Drought: an observational modeling and tree ring study of variability and climate change. *Atmósfera* **22(1)**, pp. 1–31, 2009.

[12] Vetter, S., Drougth, change and resilience in South Africa's arid and semiarid rangelands. *South African Journal of Science*, **107**, pp. 29–36, 2009.

[13] Barros, V.R. & Scaso M.L., Surface pressure and temperature anomalies in Argentina in connection with the Southern Oscillation. *Atmósfera*, **7**, pp. 159–171, 1994.

[14] Pereyra Díaz, D., Angulo, Q., Cordoba, B. &, Palma Grayeb, E., Effet of ENSO on mid-summer drought in Veracruz State, México. *Atmósfera*, **7**, pp. 211–219, 1995.

[15] Hernández de la Torre, B., Gaxiola-Castro, G. & Nájera Martínez, S., Efectos del ENSO en la producción primaria frente a Baja California. *Ciencias Marinas*, **30(3)**, pp. 427–441, 2004.

[16] Magaña, V.O. & Morales, C., El clima y la sociedad (Chapter 1). *Los impactos de El Niño en México*, ed. V.O. Magaña, SEP-CONACYT: México, pp. 1–22, 2004.

[17] De la Lanza, G. & Galindo, E.I., ENSO 1986–87 an Mexican subtropical Pacific offshore waters. *Atmósfera*, **2**, pp. 17–30, 1989.

[18] Schneider, U. & Schönwiese, C.D., Some statistical characteristics of El Niño/southern oscillation and North Atlantic Oscillation indices. *Atmósfera*, **2**, pp. 167–180, 1989.

[19] Gochis, D.J., Brito-Castillo, L. & Shuttleworth, W.J., Hydroclimatology of the North American Monsoon region in northwest Mexico. *Journal of Hydrology*, **316**, pp. 53–70, 2006.

[20] Adams, R.M., Hpuston, L.L., MacCarl, B.A., Tiscareño, M., Matus G. & Weiher, R.F., The benefits to Mexican agriculture of an El Niño-southern Oscillation (ENSO) early warning system. *Agricultural and Forest Meteorology*, **115**, pp. 183–194, 2003.

[21] Bravo-Cabrera, J.L., Azpra Romero, E., Zarraluqui Such, V., Gay García, C. & Estrada Porrúa, F., Significance tests for the relationship between "El Niño" phenomenon and precipitation in Mexico. *Geofisica Internacional*, **49(4)**, pp. 245–261, 2010.

[22] Nicholas, R.E. & Battisti, D.S., Drought recurrence and seasonal rainfall prediction in the Río Yaqui Basin, Mexico. *Journal of Applied Meteorology and Climatology*, **47**, pp. 991–1005, 2008.

[23] Meerhoff, E., *Análisis de los impactos causados por el fenómeno meteorológico El Niño 1997–1998 a escala regional y por países*, PHI-LAC, UNESCO: Montevideo, 2008.

[24] Díaz, S.C., Therrell, M.D., Stahle, D.W. & Cleaveland, M.K., Chihuahua (México) winter-spring precipitation reconstructed from tree rings, 1647–1992. *Climate Research*, **22**, pp. 237–244, 2002.

[25] Cerano Paredes, J., Villanueva-Díaz, J., Arreola-Ávila, J.G., Sánchez-Cohen, I., Valdez-Cepeda, R.D. & García- Herrera, G., Reconstrucción de 350 años de precipitación para el suroeste de Chihuahua, México. *Madera y Bosques*, **15(2)**, pp. 27–44, 2009.

[26] INEGI (ed.), *Anuario Estadístico de Chihuahua*, Instituto Nacional de Estadística, Geografía e Informática, Aguascalientes: México, 2004.

[27] Norma Oficial Mexicana NOM-011-CNA, Conservación del Recurso agua, que establece el método para determinar la disponibilidad media anual de las aguas nacionales, Diario Oficial de la Federación del 17 abril, 2002.

[28] Bergaoui, M. & Alouini, A., Caractérisation de la sécheresse météorologique et hydrologique : Cas du bassin versant de Siliana en Tunisie. *Science et Changement Planétaire - Sécheresse*, **12(4)**, pp. 205–213, 2001.

[29] Byun, H. & Wilhite, D.A., Objective quantification of drought severity and duration. *Journal of Climate*, **12**, pp. 2747–2756, 1999.

[30] Reyes-Gómez, V.M., Núñez-López, D., Muñoz-Robles, C.A., Gadsden, H., Rodríguez, J.A., López, M.A. & Hinojosa, O.R., Caractérisation de la sécheresse hydrologique dans le bassin versant Rio Conchos, Chihuahua, Mexique. *Science et Changements Planétaires – Sécheresse*, **17(4)**, pp. 475–484.

[31] Magaña, V. (ed.), *Los Efectos del Fenómeno El Niño en México*, CCA-UNAM-CONACYT: México, 2004.

[32] Bitrán, B.D., Espinosa, M.J., Eslava, H., Salas, M.A., Vázquez, M.T., Matías, L.G., Camacho, K.S. & Acosta Colsa, L.A. *Características e impacto socioeconómico de los principales desastres ocurridos en la República Mexicana*, 1st edn, D.F. CENAPRED: México, pp. 88–95, 2001.

[33] Bitrán, B.D., Acosta Colsa, L., Eslava Morales, H., Gutiérrez Martínez, C., Salas Salinas, M.A. & Vázquez Conde, M.T., *Características e impacto Socioeconómico de los principales desastres ocurridos en la República Mexicana*, 1st edn, D.F, CENAPRED: México, p. 197, 2004.

[34] Bitrán, B.D., Espinosa, M.J., Eslava, H., Salas, M.A., Vázquez, M.T., Matías, L.G., Camacho, K.S. & Acosta Colsa, L.A., *Características e impacto socioeconómico de los principales desastres ocurridos en la República Mexicana*, 1st edn, D.F, CENAPRED: México, p. 272, 2009.

[35] Fondo para Atender a la Población Rural Afectada por Contingencias Climatológicas -FAPRACC Fondo Nacional contra Desastres Naturales -FONDEN- CNA. SAGARPA, México, D.F, p. 160, 2005.
[36] Comisión Nacional del Agua (ed.), *Estadísticas del agua en México, Sistema Nacional de Información sobre Cantidad, Calidad, Usos y Conservación del Agua*, D. F, CNA: México, p. 201, 2006.
[37] Comisión Nacional Forestal (ed.), *Reporte semanal de Incendios Forestales*, D.F, CONAFOR-SEMARNAT: México, pp. 17–25, 2007.
[38] Núñez-López, D., Muñoz-Robles, C.A., Reyes-Gómez, V.M., Velasco-Velasco, I. & Gadsden-Esparza, H., Caracterización, de la sequía a diversas escalas de tiempo en Chihuahua, México. *Agrociencia*, **41(3)**, 253–262, 2007.
[39] Bitrán, B.D., Espinosa, M.J., Eslava, H., Salas, M.A., Vázquez, M.T., Matías, L.G., Camacho, K.S. & Acosta Colsa, L.A., *Características e impacto socio-económico de los principales desastres ocurridos en la República Mexicana*, 1st edn, D.F., CENAPRED: México, p. 172, 2006.
[40] Álvarez Castañeda, S.T. & Cortés Calva, P., Análisis de la Población de Mamíferos pequeños como respuesta a los cambios de la vegetación por el efecto de El Niño en una zona semiárida (Chapter 6). *Los efectos del fenómeno El Niño en México*, CONACYT, D.F.: México, pp. 216–222, 2001.
[41] Díaz Delgado, R., Efectos de la recurrencia de los incendios sobre la resiliencia post-incendio de las comunidades vegetales de Cataluña a partir de imágenes de satélite. *Ecosistemas*, **3**, pp. 1–11, 2003.
[42] Delgadillo Macías, J., Aguilar Ortega, T. & Rodríguez Velázquez, D., Los aspectos sociales y económicos de El Niño. *Los Impactos de El Niño en México*, ed. R.V. Magaña, UNAM-IAI-PEMBU-SEP-CONACYT: México, D.F, pp. 181–211, 2004.