

CHEMICAL COMPOSITION OF PRECIPITATION AT COASTAL AND MARINE SAMPLING SITES IN MEXICO

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ABSTRACT

Chemical characteristics of wet precipitation were measured in Acapulco, Cancun, Tapachula, Puerto Morelos and Tropical Pacific Ocean; from August 1999 to October 2001. The samples were analyzed for pH, Na⁺, K⁺, Ca²⁺, Mg²⁺, NH₄⁺, SO₄²⁻, NO₃⁻ and Cl⁻. Ionic abundance revealed a significant variation, however, the most abundant ions were sodium, chloride and magnesium in all sites. pH values observed were within the normal pH value considered for rainwater, and agree with that reported by other authors in marine and coastal sites; sea-salt aerosol contributed with most of Na⁺, Cl⁻ and Mg²⁺, whereas, a significant proportion of K⁺ and Ca²⁺ originated in particles from soil; finally sulfate excess concentration was in agreement with the background hemispheric values.

In the other hand, in Puerto Morelos, during sampling campaign performed at the end of the mid-summer drought, NO₃⁻ levels were the highest and also higher than SO₄²⁻ concentrations, exceeding background level; and pH values observed were low. Excluding, Puerto Morelos, where other sources influenced the rain chemistry composition; all remaining sampling sites were clearly influenced by marine aerosol, showing ionic concentrations typical of sites with a minimal anthropogenic influence, and therefore, their ionic concentrations can be considered as representative of background values for this region.

KEY WORDS: Tropical oceanic rain; coastal rainwater chemistry; Mexico.

INTRODUCTION

Temporal and spatial trends in precipitation chemistry are affected by seasonal variations in biogenic emissions, local agricultural practices, long-range transport, local meteorology, marine salt, and episodes like hurricanes and volcanic activity. In coastal sites, sea-salt aerosol dominates precipitation chemistry, accounting for 95-100% of Na⁺, Cl⁻ and Mg²⁺. On the other hand, K⁺ and Ca²⁺ show an excess that exhibit a geographical variation and whose origin is in most of cases limestone particles.

Additionally, SO_4^{2-} concentration frequently presents an excess, whose origin is different of sea salt. Numerous studies report a good correlation between sulfate excess in precipitation and atmospheric SO_2 , and concluded that both species have a marine origin. It has been demonstrated that SO_2 levels in a marine atmosphere increase with primary productivity in surface waters (probably due to production of dimethyl sulfide), suggesting that biological processes can be important to explain sulfate excess in rainwater in marine and coastal zones. Even in remote sites, it has been found that the presence of a sulfate fraction does not depend on sea salt. Reported levels are mostly low and agree with background level proposed by Galloway *et al* (1983) as representative from remote marine sites. Background concentrations are usually measured at remote sites from anthropogenic sources, and are useful to establish a reference point for comparison with urban and industrial areas (Vong, 1990). So, when $(\text{SO}_4^{2-})_{\text{xs}}$ levels exceed this background value, there are three possible sources: local production of acids, natural emission from biogenic activity in surface ocean, and long-range transport.

The lack of NO_3^- and NH_4^+ in rainwater marine fraction in remote coastal sites, confirms its anthropogenic origin. NH_4^+ and NO_3^- concentrations are very low, however, when the site becomes less remote, depending on influence of anthropogenic sources or biomass fires, their concentrations tend to exceed the background value proposed by Casimiro *et al.* (1991) for remote marine sites.

Some authors have depicted different patterns associated with dry and humid periods, and has been observed that dilution contributes at least in part to this patterns (Eklund *et al.*, 1997). However, influence of local anthropogenic sources, long-range transport, and the occurrence of extraordinary events like hurricanes, volcanic fumaroles and forest fires, can modify such patterns. In this case, besides year season and the correlation between rainwater constituents, the analysis of air-mass trajectories and of surface winds during individual precipitation events with a high NO_3^- or $(\text{SO}_4^{2-})_{\text{xs}}$ content is a useful tool to identify possible sources.

In the Caribbean Sea, there is a clear increase in H_2SO_4 and HNO_3 contribution to rainwater acidity when air masses move toward Gulf of Mexico; furthermore, in Yucatan Peninsula, some previous non systematic studies of rainwater acidity and their effects on Mayan monuments revealed $(\text{SO}_4^{2-})_{\text{xs}}$ levels, comparable to background value proposed by Galloway *et al.* (1983) for remote marine sites (Bravo *et al.*, 2000); however, NO_3^- levels found, were four times higher than background concentration proposed by Casimiro *et al.* (1991).

There are several works about precipitation chemical composition in urban, semi-urban and industrial areas in Mexico (Báez and Belmont, 1987; Báez *et al.*, 1993; Báez *et al.*, 1997a; Báez *et al.*, 1997b). In contrast, reports regarding coastal and marine sites with a minimal anthropogenic influence are scarce or non-existent; consequently, background characteristics and the impact from marine aerosol and anthropogenic emissions on chemical composition of rainwater in these zones, are unknown yet. Therefore, the purpose of the present research was to study chemical composition of rainwater in marine and coastal sites in the southeast of Mexico in order to identify the influence of sea salt aerosol on precipitation chemistry and the possible sources of ions in precipitation.

METHODS

Site description

Five campaigns were performed during present research work. Samples were collected in Acapulco, Cancun, Puerto Morelos, Tapachula and Tropical Pacific Ocean (Figure 1).

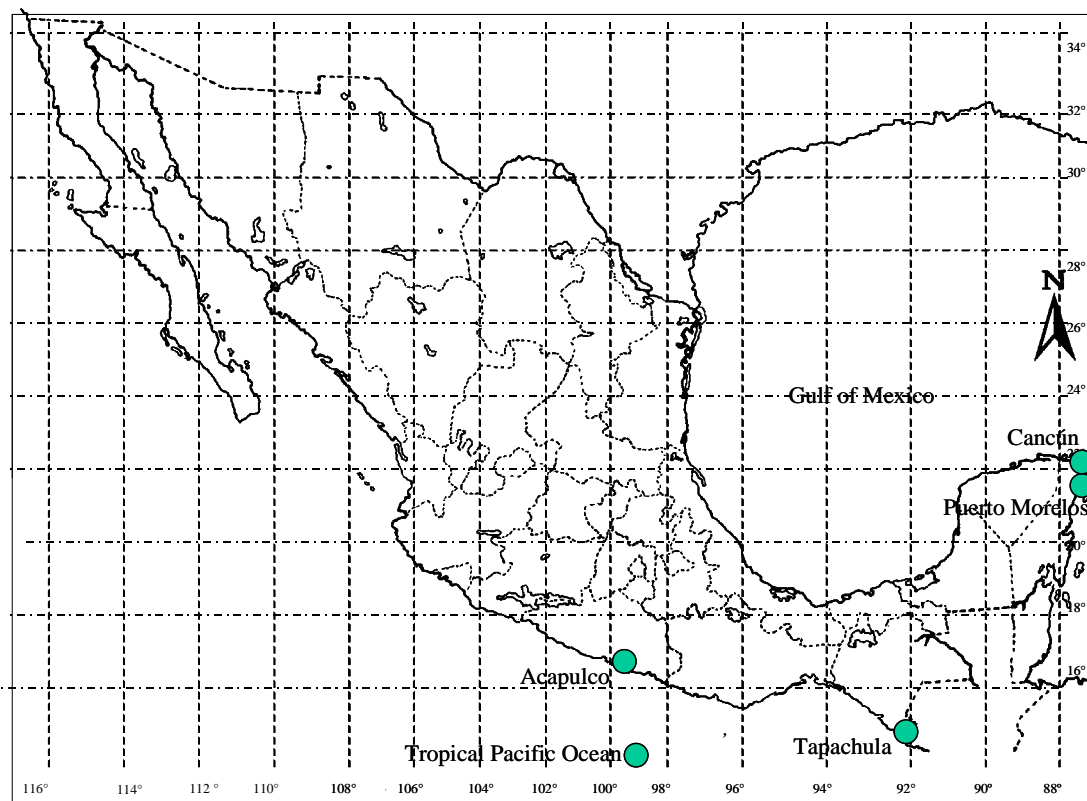


Figure 1. Sampling sites location: Acapulco., Cancún., Puerto Morelos., Tapachula and Tropical Pacific Ocean

Acapulco is a coastal site located in south region of Guerrero state at $16^{\circ} 41' N$, $99^{\circ} 32' W$. Cancun ($21^{\circ} 11' N$, $86^{\circ} 43' W$) is placed on the Caribbean coast of the Yucatan Peninsula with a maximal altitude of 10 meters above sea level. Puerto Morelos is situated in northeastern coast of Yucatan Peninsula at $20^{\circ} 50' N$, $86^{\circ} 54' W$ along Mayan Riviera. Because of its latitude, Cancun and Puerto Morelos are exposed to marine winds from the Caribbean Sea most of the year. Tapachula ($14^{\circ} 54' N$, $92^{\circ} 16' W$) is a coastal city located in the south of Chiapas state. All sites were flat, without volcanic activity, and located at maximal distance of 20 km from coast. Some samples were collected on board of oceanographic ship "PUMA"; this sampling station in Tropical Pacific Ocean was limited by geographical coordinates $12-14^{\circ} N$ and $98-100^{\circ} W$. All sampling sites were located upwind from local or regional pollution sources.

Sampling method

Sampling protocol followed all recommendations proposed by Galloway and Likens (1978). Only wet precipitation was collected, in all sampling sites during summer season, from 24 August 1999 to 4 October 2001. In the case of Acapulco, Cancun and Tapachula, collectors were located on the roof of hotels; while, in Puerto Morelos, the rain collector was placed at the top of a meteorological station on a near wharf. On the other hand, on board of oceanographic ship "PUMA", collector was placed similar to Galloway *et al* (1983) work. In all cases, the rain sampler consisted of a 27 cm diameter funnel connected to a 2 l HDPE bottle, and a standard rain gauge was used to determine rain quantity. Individual rain events were collected, and when it was possible, a sequential sampling was performed. The funnel was manually covered between rain events, uncovered and rinsed with deionized water just before each precipitation event started. Rainwater samples were stored at $4^{\circ}C$ immediately after collection and sent to Atmospheric Chemistry Laboratory of National University of Mexico, in Mexico City at the end of the sampling period.

Meteorological data

Meteorological data were obtained from field station operated by the Sea Sciences Institute Experimental Station of the National University of Mexico. Wind parameters were obtained and handled for each individual rain event to identify possible polluting sources. Moreover, air-parcel back trajectories (at surface level and at three different heights) for whole sampling period were performed (Cerón, 2002) by HYSPLIT model.

Analytical procedure

Sodium, K^+ , Ca^{2+} and Mg^{2+} , were analyzed by flame atomic absorption spectrometry, using a GBC 932AA double beam atomic absorption spectrophotometer. Chloride, nitrate and sulfate were analyzed by non-suppressed chromatography, and ammonium by suppressed chromatography with a Perkin-Elmer chromatograph. Injection volume was 100 μ l for anions, while for ammonium was 50 μ l. Minimum detectable concentrations in $mg\ l^{-1}$ were: 0.22, 0.04, 0.17, 0.002, 0.006, 0.01, 0.002, and 0.042 for SO_4^{2-} , Cl^- , NO_3^- , Na^+ , K^+ , Ca^{2+} , Mg^{2+} , and NH_4^+ , respectively. Measurements of sample pH were made using an Orion 960 autochemistry system with a combination glass electrode. Calibration was performed using buffer solutions at pH 4 and 7. Conductivity measurements were performed using an YSI 3200 conductivity meter.

Ion balance and conductance percent data differences were used for quality assurance following the criteria established by Peden *et al* (1986). Also, field blanks were analyzed to guarantee the cleanness of the sampling material; and replicates were run routinely to assure appropriate precision and accuracy.

RESULTS AND DISCUSSION

Ionic characteristics

Table 1 shows the volume-weighted mean concentrations (VWM) of all collected samples in Acapulco, Gro; Cancun, QRoo; Tapachula, Chis; Puerto Morelos, QRoo; and Tropical Pacific Ocean. The ionic abundance in rainwater showed the following general trend for anions: $Cl^- > SO_4^{2-} > NO_3^-$, except for Puerto Morelos, where nitrate levels were higher than sulfate one. In the case of cations, the ionic abundance showed a significant variation, however, in all sites, the most abundant cations were sodium and magnesium.

Measured concentrations in wetfall samples for all sites considered in this research were compared with representative data from other marine and coastal sites of the region (Table 2). Except for Ca^{2+} and NO_3^- , ionic concentrations of all constituents were in agreement with that reported by several authors in marine and coastal sites (Bravo *et al.*, 2000; Clark *et al.*, 1998; Eklund *et al.*, 1997; McDowell *et al.*, 1990; Galloway *et al.*, 1989; Hendry *et al.*, 1984; Galloway *et al.*, 1983; Galloway *et al.*, 1982).

Since some ions did not have a lognormal distribution, in order to determine if there were significant differences among ionic concentrations in rainwater collected in all sites considered, the Kruskal-Wallis test was applied to data (Table 3). All ions showed significant differences at a significance level of 95% ($p \leq 0.05$), so it was necessary to apply the Mann-Whitney Test for paired samples. Sodium and Cl^- levels were higher in sites exposed mainly to maritime air, like Cancun, Puerto Morelos and Tropical Pacific Ocean. Ca^{2+} and K^+ concentrations were very low, significant differences were observed among sampled sites, and relative high concentrations were found in Cancun and Tapachula, where the uptake of soil particles was probably abundant. The low calcium levels found in Acapulco and Tropical Pacific Ocean can have two explanations: First, that Ca^{2+} levels present in marine aerosol or soil particles were low, and second, because of high precipitation rates, the high moisture soil avoid the uptake of limestone particles to rainwater.

Table 1. Volume-weighted mean concentrations (VWM) in $\mu\text{Eq l}^{-1}$ for wet precipitation collected in all sampling sites considered by this research

Sampling site	SO_4^{2-}	Cl^-	NO_3^-	Na^+	K^+	Ca^{2+}	Mg^{2+}	NH_4^+	H^+
Acapulco. N = 16.	7.2	34.3	3.2	26.1	0.9	3.9	6.6	3.0	1.1
August 24-26 (1999)									
Cancún. N = 10.	11.8	62.3	1.9	57.7	2.7	26.8	11.6	3.7	0.7
October 1-2 (1999)									
Tapachula. N = 15.	12.9	17.5	6.7	8.5	1.6	5.0	2.1	14.5	5.2
August 25-September 25 (1999)									
Puerto Morelos. N = 11.	28.1	140.9	67.9	118.6	3.1	12.9	26.0	6.8	69.8
August 27–September 7 (2000)*									
Tropical Ocean Pacific. N = 21.	18.4	86.9	3.9	102.9	2.7	4.2	24.1	8.5	1.7
May 23–September 6 (2001)									
Puerto Morelos. N = 43.	20.4	126.9	4.2	116.2	1.5	2.3	25.9	2.3	3.1
September 13–October 4 (2001)									

N= Number of samples.

* Sampling performed during occurrence of forest fires (at the end of the mid-summer drought).

Table 2. Volume-weighted mean concentrations (VWM) in $\mu\text{Eq l}^{-1}$ for wet precipitation collected in other coastal and marine reference sites

Sampling site	SO_4^{2-}	Cl^-	NO_3^-	Na^+	K^+	Ca^{2+}	Mg^{2+}	NH_4^+	H^+
La Selva, Costa Rica.	17.7	47.6	5.3	38.9	2.3	7.1	10.1	8.7	5.4
Eklund <i>et al</i> (1997).									
El Verde, Puerto Rico.	17.0	82.0	4.3	66.0	1.8	8.5	15.0	2.9	7.5
McDowell <i>et al</i> (1990)									
Turrialba, Costa Rica.	9.0	15.0	1.4	11.3	3.8	3.0	4.0	4.2	3.5
Hendry <i>et al</i> (1984).									
SS Doric Ship NY-Bermuda.	27.2	185.3	1.7	165.0	3.4	10.8	38.8	6.8	13.1
Galloway <i>et al</i> (1983).									
SS Oceanic Ship NY-Bermuda-Nassau.	28.7	142.6	7.1	116.5	16.2	9.5	21.8	3.7	21.5
Galloway <i>et al</i> (1983).									
Yucatán Peninsula.	25.4	150.7	11.4	128.7	5.8	17.8	28.6	6.4	4.5
Bravo <i>et al</i> (2000).									
Bermuda.	36.3	175.0	5.5	147.0	4.3	9.7	34.5	3.8	16.2
Galloway <i>et al</i> (1982).									

Sulfate excess levels agreed with background hemispheric values ($10 \mu\text{Eq l}^{-1}$) reported by Galloway *et al.* (1983) and Casimiro *et al.* (1991). Significant differences in NH_4^+ levels among sampled sites were observed (Table 3), the highest concentrations was found in Tapachula; it suggests an evident but not significant influence from continent because of land agricultural use in this site. Nitrate concentrations were very low, with exception of Puerto Morelos, where NO_3^- levels were significantly high, exceeding the atmospheric background value ($2.8 \mu\text{Eq l}^{-1}$) proposed for marine and coastal sites. The main source identified for these high NO_3^- levels was forest fires influence that occurred during mid-summer drought (Ceron *et al.*, 2002).

An interelemental regression analysis was performed to obtain correlation matrices at a significance level of 95%. The high correlation coefficients between $\text{Na}^+\text{-Cl}^-$, $\text{Na}^+\text{-Mg}^{2+}$, $\text{Na}^+\text{-K}^+$, $\text{K}^+\text{-Cl}^-$, $\text{Mg}^{2+}\text{-Cl}^-$, $\text{Mg}^{2+}\text{-K}^+$, $\text{Ca}^{2+}\text{-K}^+$, and $\text{SO}_4^{2-}\text{-Cl}^-$; suggests a common source between these constituents; whereas the good correlation between $\text{Na}^+\text{-SO}_4^{2-}$, $\text{K}^+\text{-SO}_4^{2-}$, $\text{Ca}^{2+}\text{-SO}_4^{2-}$, $\text{Mg}^{2+}\text{-SO}_4^{2-}$, $\text{NH}_4^+\text{-SO}_4^{2-}$, $\text{Na}^+\text{-NO}_3^-$, $\text{K}^+\text{-NO}_3^-$, $\text{Mg}^{2+}\text{-NO}_3^-$, and $\text{NH}_4^+\text{-NO}_3^-$, is result of neutralization processes of strong acids with alkaline species in precipitation. Only rainwater collected in Puerto Morelos showed a significant inverse correlation

between H^+ - NO_3^- and pH - NO_3^- , suggesting a strong contribution from nitrate to rainwater acidity in this site.

Table 3. Comparison among sampling sites in this research (Acapulco, Tapachula, Cancun, Puerto Morelos and Tropical Pacific Ocean) using the Kruskal-Wallis Test

Ion	χ^2 Statistic
SO_4^{2-}	33.496*
Cl^-	53.422*
NO_3^-	80.148*
NH_4^-	51.432*
Na^+	55.071*
K^+	20.142*
Mg^{2+}	48.457*
Ca^{2+}	53.195*

Sampling sizes were: 16 in Acapulco (1999); 10 in Cancún (1999); 15 in Tapachula (1999); 28 in Puerto Morelos (2000); 21 in Tropical Pacific Ocean (2002) and 43 in Puerto Morelos (2001).

* Significance level of 95%.

Sequential sampling

Chemical composition of sequentially collected samples was determined in all sampling sites. At the beginning of the rain event, pollutant concentration in the air is relative high, and a rapid decrease in ionic concentration in the early portion of the rainfall is observed; as the rain event progresses, drops evaporating and available pollutants decrease; whereas ionic concentrations increase or stay without change during the latter part of the event. Scavenging processes controlling wet precipitation, are determined by the properties of the particulated matter, gas solubility and type of precipitation (Lim *et al.*, 1991). Influence of these scavenging processes is evident in changes of concentration of the ionic components in rainwater. This decrease in constituents concentration during rain events has also been observed by other authors (Seymour and Stout, 1983; Ahmed *et al.*, 1990; Lim *et al.*, 1991; Báez *et al.*, 1993), and it has been attributed to several possible effects: within cloud scavenging, dilution with cloud droplet growth, below cloud scavenging, evaporation and evaporation followed by accumulation of aerosol particle aloft and precipitation of these accumulated particles.

Precipitation acidity

Values of pH observed in rainwater of all sampling sites are given in Table 4. With exception of Puerto Morelos, pH values observed were within the pH considered normal for rainwater, and agree with that reported by other authors in marine and coastal sites (Bravo *et al.*, 2000; Clark *et al.*, 1998; Eklund *et al.*, 1997; McDowell *et al.*, 1990; Galloway *et al.*, 1989; Hendry *et al.*, 1984; Galloway *et al.*, 1983; Galloway *et al.*, 1982). More than 80 % of rainwater samples in Puerto Morelos had pH values below the limit of natural rain ($\text{pH} < 5.6$), this acidity was attributed to forest fires that occurred during mid-summer drought. The importance of Washout process is evident in all sequential studies of rainwater chemical composition: due to rainout processes of acidic material within the clouds, the pH of precipitation is initially acidic, subsequently, during the passage of raindrops from the cloud base downwards, washout processes of alkaline substances in the atmosphere, result in the rapid neutralization of precipitation acidity. As rainfall progresses in time, washout of alkaline particles is completed and then, precipitation acidity picks up again as a result of input due to rainout processes.

The contribution of NO_3^- and SO_4^{2-} to rainwater acidity was obtained from average ionic equivalent ratios NO_3^-/H^+ and $\text{SO}_4^{2-}/\text{H}^+$. In all sampled sites SO_4^{2-} contributed in a major proportion to the acidity in comparison with NO_3^- , with exception of Puerto Morelos, where NO_3^- was the main donator of protons.

Table 4. Average pH values for all sites sampled in this study

Sampling Site.	Mean	Minimum	Maximum
Acapulco	5.96	5.75	6.24
Cancún	6.14	5.95	6.84
Tapachula	5.28	4.67	6.27
Puerto Morelos*	4.16	3.48	5.96
Tropical Pacific Ocean	5.56	5.45	6.22
Puerto Morelos**	5.59	5.06	6.02

* During mid-summer drought (2000).

** In the plenitude of the wet season (2001).

Meteorological influence

Several authors have assessed the influence of environmental factors like precipitation intensity, velocity and wind direction upon chemical composition of rainwater (Singh *et al.*, 1987; Raynor and Hayes, 1982; Savoie *et al.*, 1987); and is a common practice to use meteorological data to explain this variability.

Precipitation quantity was significantly inverse correlated with Na^+ , K^+ , Ca^{2+} , Mg^{2+} , NH_4^+ , SO_4^{2-} and Cl^- ; therefore, the highest ionic concentrations were observed with slight rains, and there was a trend to lower concentrations as the precipitation intensity increased. This effect of dilution has also been reported by other authors (Savoie *et al.*, 1987; Saylor *et al.*, 1992; Báez *et al.*, 1997a; Eklund *et al.*, 1997), however, except for Puerto Morelos, in the remaining sampled sites, nitrate ion did not show a significant inverse correlation with rain quantity, probably due to low concentrations measured.

Because of sampling campaigns were performed only during summer months, seasonal patterns could not been assessed. Air mass back trajectories obtained for the whole sampling period from HYSPLIT model showed that all sites were under maritime air influence as was expected. However, from an analysis of surface wind data during individual events of precipitation, forest fires were identified as the main source of the high nitrate levels observed in Puerto Morelos at the end of the mid-summer drought (Cerón *et al.*, 2002).

Sources of dissolved ions in precipitation.

In order to explore possible geochemical and anthropogenic sources for dissolved compounds in rainwater, Cl^- was used as a tracer element for marine aerosol (Duce and Hoffman, 1976); therefore, it was carried out the following analysis:

1. Enrichment factors (EF) for each ion relative to sea salt were calculated as follows:

$$EF_{\text{Cl}^-}(\text{X}) = (\text{X}/\text{Cl}^-)_{\text{rain}} / (\text{X}/\text{Cl}^-)_{\text{sea water}}$$

where $(\text{X}/\text{Cl}^-)_{\text{rain}}$ is the ratio between substance X concentration and Cl^- concentration in rainwater; and $(\text{X}/\text{Cl}^-)_{\text{sea water}}$ is the ratio of substance X relative to Cl^- in sea water, reported elsewhere (Culkin and Cox, 1966; Morris and Riley, 1966).

2. The ions excess relative to chloride for the constituents of rainwater was determined as follow:

$$(\text{X})_{\text{xs}} = (\text{X})_{\text{rain}} - (\text{X}/\text{Cl}^-)_{\text{sea water}} (\text{Cl}^-)_{\text{rain}}$$

where $(\text{X})_{\text{xs}}$ is the concentration in excess of X substance, and, $\text{Cl}^-_{\text{rain}}$ and X_{rain} are the dissolved concentration of substance X and Cl^- ion in rainwater.

3. Sea salt fractions of ions (SSF) were determined as follow:

$$\text{SSF} = \text{Cl}^-_{\text{rain}} (\text{X}/\text{Cl}^-)_{\text{sea water}} (100) / \text{X}_{\text{rain}}$$

The mean enrichment factors $(EF)_{\text{Cl}^-}$ and sea salt (SSF), crustal (CRF), and non-sea-salt-non-crustal (NSSCRF) fractions of dissolved ions in precipitation are shown in Table 5. An $(EF)_{\text{Cl}^-}$ close to one means a marine origin, whereas, a large $(EF)_{\text{Cl}^-}$ suggests that other sources are responsible. The results show clearly that Na^+ and Mg^{2+} have a 100% marine origin; even more since chloride ion was taken as the basis for excess calculations, obviously, sea salt also contributed with 100% for Cl^- . Except, in Puerto

Morelos and Tropical Pacific Ocean, the crust contribution was significant for Ca^{2+} and K^+ . In all cases, sulfate ion showed a marine fraction that depends on Cl^- ion, and other fraction in excess with a non-marine source. Since the NO_3^- levels in seawater are very low, it was assumed that sea aerosol contribution to rainwater mineralization for this ion was zero, and, its origin in the case of Puerto Morelos at the end of the mid-summer drought, where high NO_3^- levels were found, was an anthropogenic origin: The forest fires.

Table 5. Mean enrichment factors and sea salt, crustal and non-sea-salt-non-crustal fractions of ions in rainwater for all sampling sites in this research.

Element	Acapulco	Cancún	Tapachula	Puerto Morelos *	Tropical Pacific Ocean	Puerto Morelos **
Na⁺						
(EF) _{Cl⁻}	0.91	1.09	0.76	1.14	1.10	0.91
SSF(%)	100	100	100	100	100	100
CRF(%)	0	0	0	0	0	0
NSSCRF(%) ^o	0	0	0	0	0	0
K⁺						
(EF) _{Cl⁻}	1.37	3.81	9.2	1.32	0.64	0.40
SSF(%)	87	48	18	88	100	100
CRF(%)	13	52	82	12	0	0
NSSCRF(%) ^o	0	0	0	0	0	0
Ca²⁺						
(EF) _{Cl⁻}	2.66	14.63	10.40	2.65	1.05	0.90
SSF(%)	49	11	17	73	100	100
CRF(%)	51	89	83	27	0	0
NSSCRF(%) ^o	0	0	0	0	0	0
Mg²⁺						
(EF) _{Cl⁻}	0.97	0.87	1.96	1.14	0.71	0.92
SSF(%)	100	100	100	100	100	100
CRF(%)	0	0	0	0	0	0
NSSCRF(%) ^o	0	0	0	0	0	0
SO₄²⁻						
(EF) _{Cl⁻}	2.2	2.43	14.7	2.26	1.61	1.74
SSF(%)	54	52	12	53	48	68
CRF(%)	0	0	0	0	0	0
NSSCRF(%) ^o	46	48	88	47	52	32
Cl⁻						
(EF) _{Cl⁻}	1.12	0.99	1.70	0.90	0.84	1.01
SSF(%)	100	100	100	100	100	100
CRF(%)	0	0	0	0	0	0
NSSCRF(%) ^o	0	0	0	0	0	0
NO₃⁻ - NH₄⁺						
(EF) _{Cl⁻}	-	-	-	-	-	-
SSF(%)	0	0	0	0	0	0
CRF(%)	0	0	0	0	0	0
NSSCRF(%) ^o	100	100	100	100	100	100

* During mid-summer drought (2000).

** In the plenitude of the wet season (2001).

^o Non-sea salt non-crustal fraction also can include fraction originating due biogenic activity in the sea surface (formation and oxidation of dimethyl sulfide).

CONCLUSION

We can conclude that except for Puerto Morelos at the end of the mid-summer drought, all remaining sampling sites were clearly influenced by marine aerosol, showing ionic concentrations typical of sites with a minimal anthropogenic influence, and therefore, ionic concentrations measured can be considered as representative of background values for this region.

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