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Natural Water Conductivity Behavior within the Seismic Pacific Coast of Southern Mexico

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Abstract

Near faults or unstable areas where an earthquake could happen with capacity to damage buildings or infrastructure, there is often a previous energy that wanders around surroundings, this energy regularly is associated with electromagnetic emissions that generate an electric potential frequently studied as very, ultra-low and extreme frequency emissions (VLF-ULF-ELF_ EM) by remote sensing; under the assumption that this natural potential exists, in aquatic environment within the micro-seismic active area in the coastal border of Guerrero and Oaxaca estates, Mexico, an intensive conductivity monitoring in two artesian well was carried out. The results of intensive conductivity (µS/cm) monitoring done since March to July of 2015, using a low-cost Data logger sensor are presented. The results obtained of the study of 235 seismic events show that 61.64% of them manifest prior conductivity oscillation *versus* 38.36% of early conductivity oscillation, the possible origin of such oscillation and the likely relation with underground water recharge flux, ground light compression, ground tilt, local electromagnetic energy emissions, human interaction, was debated. The data analysis for long periods of conductivity monitoring and seismic events show that when the number of seismic events becomes intense, conductivity decreases and *vice versa*, resulting large fluctuations that grow over time like waves; within the study area a possible previous fluctuated long-term energy associated with earthquakes produced around could be arising.

Keywords

Electromagnetic Emissions, Earthquakes, Natural Water Conductivity, Water Recharge,

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Previous Phenomenon of Earthquakes, Cocos Plates, Subduction Zones

Subject Areas: **Geochemistry**

1. Introduction

In the surrounding environment near areas with intense seismic activity there is a tight relationship among the electric and electromagnetic energy emanating from the Earth's interior and the earthquakes. Although the lithosphere is considered insulating and do not allow the flux of energy to arise from Earth's deep layers, there are discontinuities or weakness zones that make it possible; in general these areas are located all over the world where oceanic and continental plates collide giving rise to subduction zones [1]-[3]. The kind of energy regularly mentioned corresponds to electromagnetic emission (EME) studied in the range of very, ultra-low and extremely low frequency waves by remote sensing.

When this energy arrives at the Earth' surface [4]-[6], it affects the local ionosphere by changing the local atmospheric electricity [4]-[16], heating and increasing the local relative humidity [9] [12] [17] [18]; all of these anomalies that upset the local environment lead to luminous phenomena [9] [12] [19]-[21] and formation of aerosols and clouds [22]-[28]; some of these phenomena have been associated with changes in animal and human behavior because of presence of a charged atmosphere with positive ions [9] [12] [13] [24] [29]-[36]. It is known that the electromagnetic emission (EME) also enhances natural radiation related to molecular decay of Radon gas that issues from each fracture of rock, particularly enhances its ionizing energy, as occurs near power transmission lines [37]-[40].

Taking in account the main importance of this type of energy that emanates from the ground and flows in the natural environment preceding earthquakes and natural phenomena involved, the purpose of this research is to detect this energy indirectly by determining natural water conductivity under the assumption that this energy wanders around near faults or unstable areas where an earthquake occurs.

2. Study Area Description

Mexico is one of the most seismic countries in the world, after Japan, Indonesia, Chile, Papua New Guinea and Turkey, particularly to the south and southeast of the country within the States of Michoacán, Guerrero, Oaxaca and Chiapas, this is due to the process of subduction associated to The Middle America Trench (MAT) in the Pacific coast of southern Mexico. In this place converge the continental North America and the oceanic Cocos plates, considered the most important tectonic features of Mexico [41]. The plate of Cocos moves almost horizontal 300 kilometers below the North American plate at rate of six centimeters per year downwards in the terrestrial mantle with a 55˚ inclination angle [42].

Of 2006 to 2015 were registered 32819 seismic events (>3 Mw), of which 18773 have taken place in the Pacific Ocean and 14046 in the continental area, of last grouped near the coast in a fringe of 12 × 100 kilometers is concentrated 52% of them with 7337 events. Within this coastal border in Oaxaca estate limits is located the Pinotepa National municipality, demarcation with a territory of 719.56 km^2, in this place is registered the biggest number of seismic events with 1850; this municipality is the most micro-seismic active area per square kilometer with three events [37] [41]; in the interior of this are a occurred on June 30, 2010 an earthquake of M6.0 at 02:22:27 hours and another one by June 25, 2015 of M5.1 at 05:31:46 hours.

The geology of surrounding area represents a transition zone between the coastal lowlands and the southern Sierra Madre (SMS), is complex because of convergence of different cortical blocks bound by faults that include a variety of exposed metamorphic rocks and intrusive bodies. The geomorphology and geology of this area correspond to a coastal plain with Quaternary alluvial materials; it is common to see these accumulations topping the intrusions and gneiss of the Xolapa complex next local rivers courses, hills and piedmonts [41].

The selected area of study correspond to a site called "Corralero" within Pinotepa Nacional municipality in the state of Oaxaca, Mexico, **Figure 1**, region with the largest number of earthquakes per square kilometer above mentioned [37] [41]. Two places were selected for the intensive conductivity monitoring in aquatic environment, one of them at the geographic coordinates 16˚14'10.6"N and 98˚11.406'W, and the other one at 16˚14'10.5"N

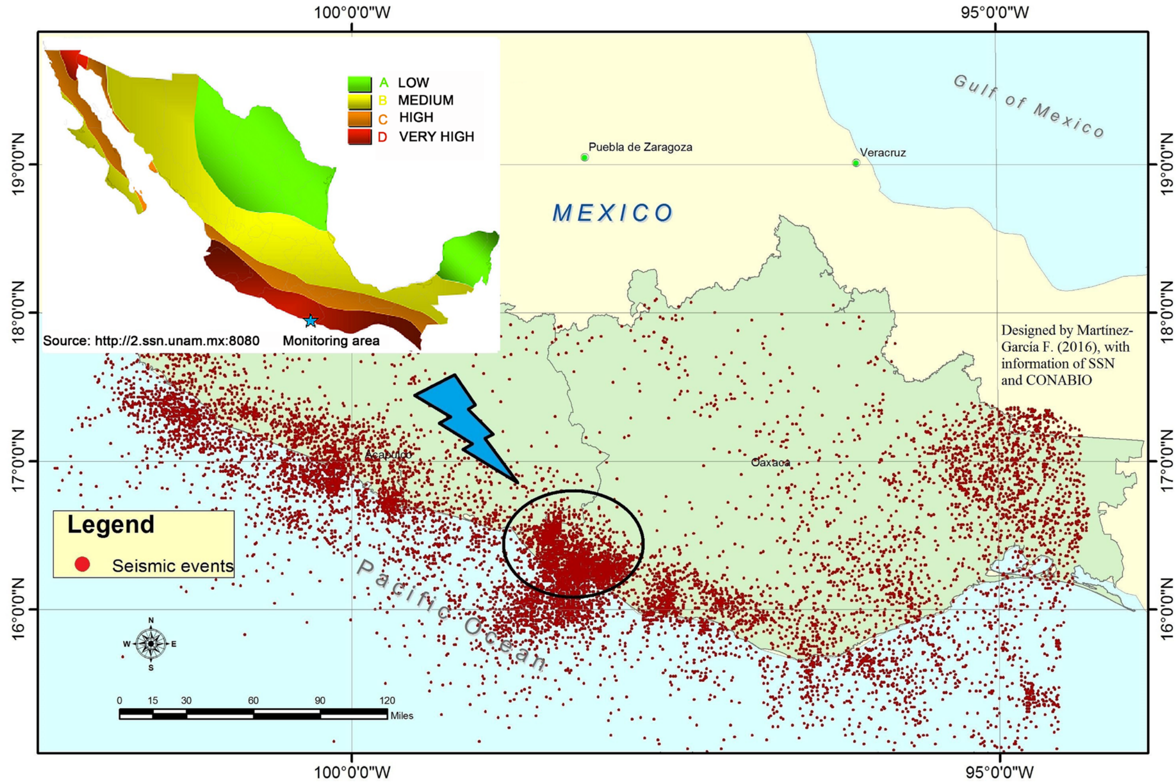

Figure 1. Study area geographic position, this place has the highest number of earthquakes per km^2. Obtained from Martínez-García *et al.*, 2015: support information obtained of National Commission for Knowledge and Use of Biodiversity (CONABIO: http://www.conabio.gob.mx) and SSN.

and 98˚11'14.5"W; they correspond to artesian well of 1 × 1 × 6 meters (CAW01) and 1.3 × 1.3 × 3 meters dimensions (CAW02), respectively.

3. Scientific Background

Since past century, the electromagnetic energy(EME) has been studied through of the very, ultra-low and extreme frequency electromagnetic emissions (VLF-ULF-ELF_EM), regularly by remote sensing; considered a previous phenomenon of earthquakes, sometimes is used in short-term prediction of a large earthquake but his study is controversial to date [15] [43] [44]. Apparently there is a subtle correlation between the increase in VLF-ULF-ELF field emissions and the increased seismic activity although other parameters like solar wind could be involved too [5] [45] [46].

This energy is concentrated often near faults or unstable areas where an earthquake could happen and often flow by periods of a few hours or one day during the seismic preparation process, although this period could be longer prior the main event [23] [46], this kind of perturbations prove that is not a casual phenomenon and could be associated with earthquakes [36] [46] [47]. In the earthquake's local neighborhood this phenomenon is associated with thermal anomalies commonly observed by remote sensing [48]-[50].

VLF-ULF-EM field emissions reported show a particular behavior, preceding the earthquake; there is an increase in the number of short pulses until a couple of weeks previous the earthquake [24] [51]. In general, the perturbations observed are responsible for increasing the Earth´s surface potential (electric induction) associated with earthquakes; sometimes these anomalies are related with piezoelectric and triboelectric effects; emanation of warm gases from the ground; activation of positive holes; radioactive gas or metallic ions emissions such as Radon gas [10] [12] [52]. The detection of ULF EM signals are in several forms, either asranges of frequency from: 0.01 to 80 kHz and sometimes until to 18 MHz, or magnetic signals levels of 0.9 a 5.0 Nano Tesla, nT [9] [14].

4. Materials and Methods

Electromagnetic signals have extensively used to study the lower ionosphere anomalies previous to earthquakes [1] [5] [45]-[47]. By the inherent importance of this type of energy and his relations with the natural electric induction that produce, if this energy emanates from the ground and flows in the natural environment preceding earthquakes, then this energy could be detectable using a conductivity sensor to ground level. Under the assumption that this energy wanders around to faults or unstable areas where an earthquake could happen, as an indirect way to detect this energy, intensive monitoring were conducted in two artesian wells using a low-cost Data logger HOBO U24-001 sensor to measure the local natural conductivity understood this as a measure of a solution's ability to conduct electricity.

The Data logger HOBO U24-001 [53] uses a non-contact capacitive sensor. This technology consists in an electronic piece called "capacitor" or "condenser" that contain two conductive sensitive electrodes (plates) and materials with low conductivity and high insulation characteristics called dielectric. The water conductivity and the sensor capacitance create a resistor-capacitor circuit (RC circuit) as response to AC stimulation, which varies as a function of the conductivity; essentially this instrument measures the changes of impedance of the circuit as response to water conductance changes.

This investigation in aquatic environment through the intensive conductivity (μS/cm) monitoring was carried out since March to July 2015, using a conductivity sensor emplaced in two artesian well, CAW01 and CAW02 using a sample frequency of 45 seconds; CAW01 site was monitored from March 2 to May 11, 2015 and the monitoring period for CAW02 was from May 11 to July 17, 61 days of monitoring for each.

Information of all earthquakes manifested in the period of March to July were acquired, particularly inside the territorial limits of the states of Guerrero and Oaxaca, Mexico, **Figure 1**: the data were downloaded of the page Web of the Seismological National (SSN) Service of Mexico, http://www2.ssn.unam.mx:8080/index.html.

In each artesian well the monitoring period was performed in three steps due to limited memory and battery capacity of the Data logger. Related to seismic data, each earthquake obtained was to less than 50 kilometers away, taking in consideration that both artesian wells are in a place with the highest seismicity of the region [37], [41]. For spatial distribution of seismic data, seismic event statistics obtained from the National Seismological Service (SSN: http://www2.ssn.unam.mx:8080/index.html) of Mexico, were imported to a geographic information system (GIS) to edit and depurate them. Every seismic event in the marine environment and those located beyond the distances of 50 kilometers were eliminated, thus obtaining a preliminary table. The seismic events resulting from the filtering were time synchronized graphically with the conductivity monitoring data by adding seismic events' series to conductivity series, replicating each step twice, one by each artesian well.

In natural environments, physical and biogeochemical processes called diel cycles influence the conductivity [54]. This measure is affected too by factors like temperature, mixing or recharge of different qualities of water because of the increases or decreases of ion concentration, or inclusive too mixing due to terrain compression or slight tilting of ground [9] caused by very light earthquakes which increase internal water flow in seismic areas [37]. These kind so fit references make difficult to identify how the electromagnetic frequency signals manifest in the results, even so the analysis of intensive monitoring conductivity (μS/cm) within the place selected could show interesting outcomes. In order to filter it, the conductivity data (μS/cm) were pre-processed and transformed using the first derivative of function (x, $y = f(x)$, $y' = f'(x)$) applying the equation *Sine* (x), $(-25*X3 + 48*X4 - 36*X5 + 16*X6 - 3*X7)/\rho t$, using a spread sheet calculus routine, **Figure 2**.

5. Results

Under aquatic environment through the intensive conductivity (μS/cm) monitoring a research were conducted in two places using a low-cost Data logger HOBO U24-001 sensor to measure the local natural conductivity as an indirect way to detect the electromagnetic natural energy coming from the interior of the Earth and its possible relation to earthquakes afterward manifested. According to the foregoing, from March 2 to July 17, 2015, two artesian wells were monitored, using a sampling frequency of 45 seconds. In order to find the possible relationship of natural energy that wanders around surroundings with local seismicity, 2012 records of seismic activity were downloaded of the page web of the Seismological National Service of Mexico(SSN), http://www2.ssn.unam.mx:8080/index.html, were subsequently pre-processed according to the method abovementioned in previous paragraphs. Under this pre-process, as result 235 earthquakes were analyzed and confronted with the results of intensive conductivity monitoring data (μS/cm) obtained from two artesian well, by adding graphically, seismic events' series to conductivity series.

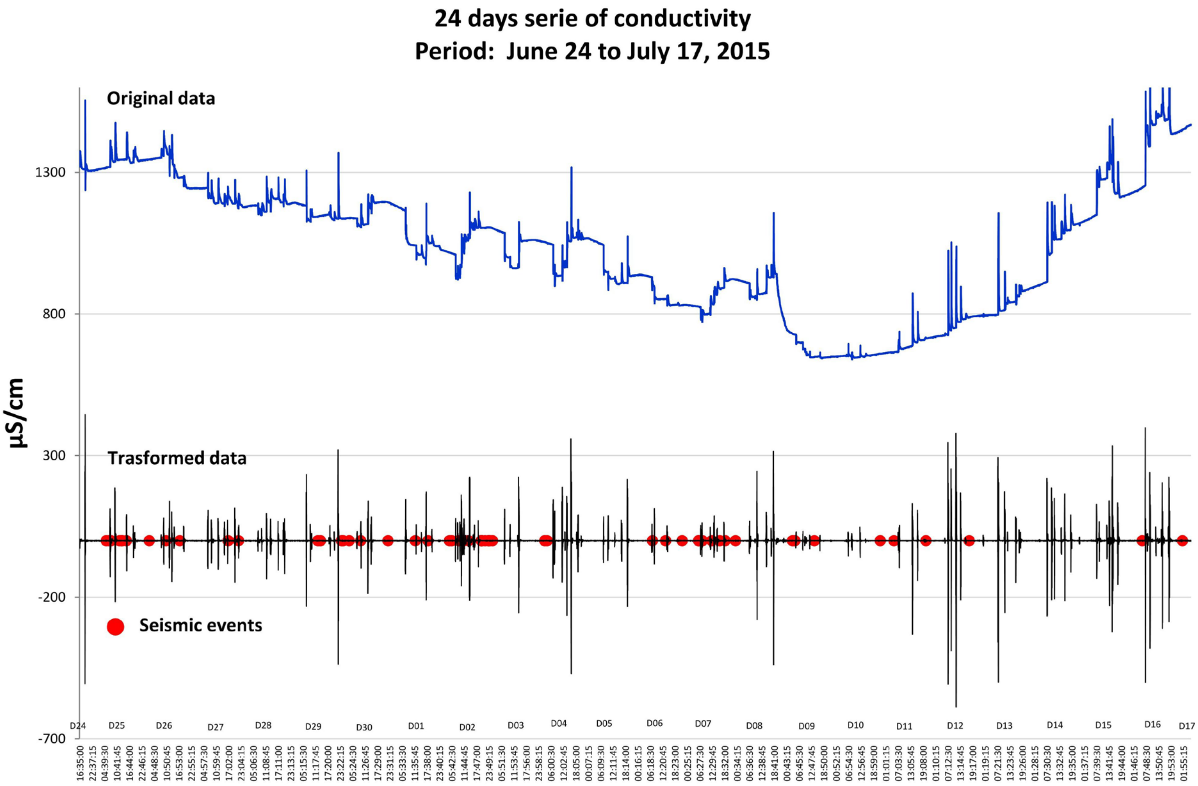

Figure 2. Mathematical pre-processed analysis of conductivity data (example): results of obtaining the first derivative.

The monitoring period of artesian well CAW01 started since March with three continuous stages, the first was of March 2 to 16; the second was of March 23 to April 15; and the third took place of April 20 to May 11. Related to artesian well CAW02 the first monitoring stage was started from May 11 to June 1; the second one started on June 1 to 24; and the last one was monitored from June 24 to July 17. The results of conductivity (µS/cm) monitoring in the three stages conducted in each artesian well are shown in high resolution graphs, **Figures 3-8**, and the possible previous and after relationship with the seismic activity per each period in both sites CAW01 andCAW02 is included in **Tables 1-6** and debated in discussion section.

6. Discussion

Seismicity statistics show that the area designated for conductivity monitoring is the most active per square kilometer [37] [41], locally and taken the Data Logger as central reference for this, the 36.18% of the seismic events were located to the NW, nevertheless the seismic most important event registered during monitoring was located to the SE (M5.0; 06/25/2015; 5:31:46).

In relation to the linking between conductivity records and seismic activity during period of monitoring research, 61.64% of seismic events occurred prior conductivity oscillation *versus* 38.36% of early conductivity oscillation, **Tables 1-6**. The visual observation between graphs conductivity records and seismic activity by short times periods highlight that there is no clear correspondence about to conductivity oscillation and the seismic activity, however certain and subtle tendency was observed for long time period of monitoring, this trend corresponds to the aggregation of seismic event and conductivity oscillation, however is not frequent; this behavior can be seen it in **Figure 6(1)**, **Figure 7(2)** and most undoubtedly in the **Figure 8(1)** and **Figure 8(2)**.

From the 232 earthquakes studied, the statistics analysis shows that 159 earthquakes be like linked to conductivity oscillation, of which 98 events showed a significant variation in the conductivity preceding to the seismic events, these represent 61.63%. 42 of 98 events (42.85%) again were placed to the NW and 20 toward E (20.4%). 61 events (38.36%) occurred before of conductivity oscillations; of them, 18 events were located to the E and 18 toward NW.

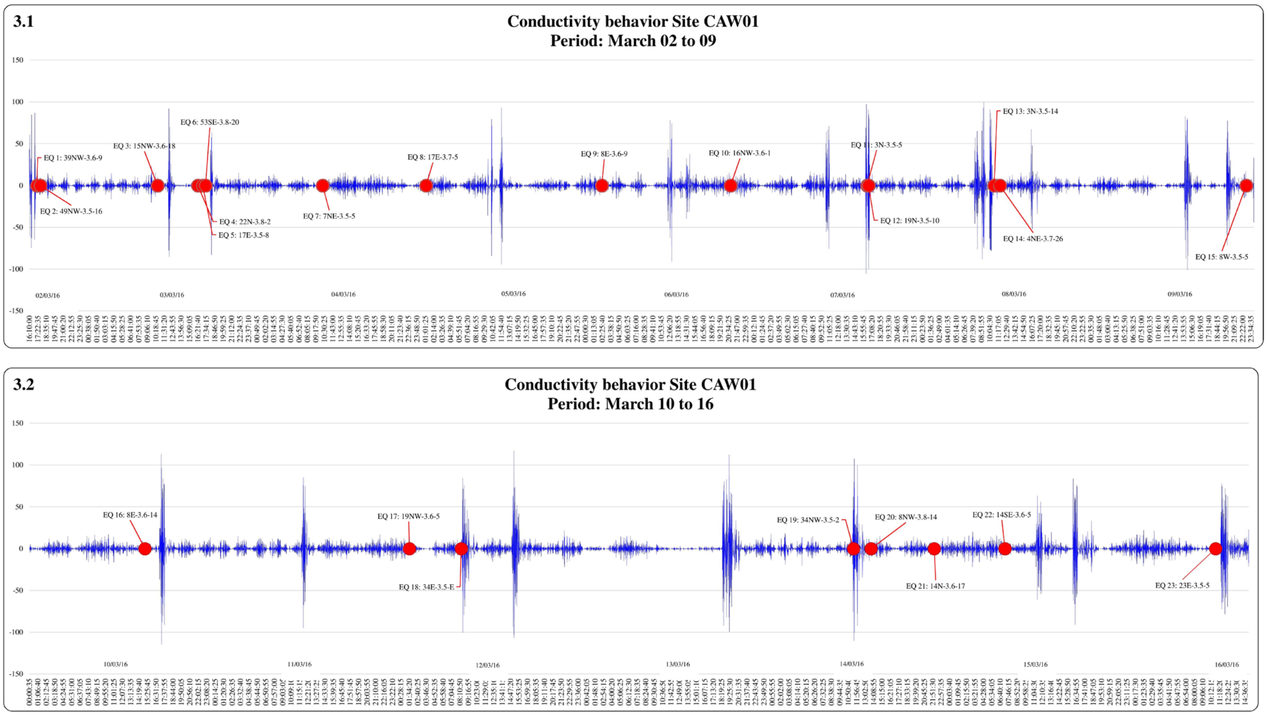

Figure 3. Conductivity behavior in artesian well CAW01 within the period of March 2 to 10. During that period 23 earthquakes were manifested with an average magnitude of 3.6.**Red dot (*EQ 1: Cardinal point-wM-Depth*).**

Table 1. Analysis of seismic activity and the conductivity behavior in artesian well CAW01. 20 of 23 earthquakes were related with important oscillation conductivity, 50 % of them display a prior oscillation and 50% early.

Figure	Event	Cardinal point	Distance	Magnitude	Depth	µS/cm Oscillation	
						Previous	Later
3.1	1	NW	39	3.6	9	•	
3.1	2	NW	49	3.5	16	•	
3.1	3	NW	15	3.6	18		•
3.1	4	N	22	3.8	2		•
3.1	5	E	17	3.5	8		•
3.1	6	SE	53	3.8	20		•
3.1	8	E	17	3.7	5		•
3.1	9	E	8	3.6	9		•
3.1	10	NW	16	3.6	1	•	
3.1	11	N	3	3.5	5	•	
3.1	12	N	19	3.5	10	•	
3.1	13	N	3	3.5	14	•	
3.1	14	NE	4	3.7	26	•	
3.1	15	W	8	3.5	5	•	
3.2	16	E	8	3.6	14		•
3.2	17	NW	19	3.6	5		•
3.2	18	E	34	3.5	13		•
3.2	19	NW	34	3.5	2	•	
3.2	20	NW	8	3.8	14	•	
3.2	23	E	23	3.5	5		•

Table 2. Analysis of seismic activity and the conductivity behavior in artesian well CAW01. 40 of 48 earthquakes were related with important oscillation conductivity, 42.5% of them display a prior oscillation and 57.5% early.

Figure	Event	Cardinal point	Distance	Magnitude	Depth	µS/cm Oscillation	
						Previous	Later
4.1	1	E	18.6	3.6	5		●
4.1	2	E	10	3.8	7		●
4.1	3	E	9	4.2	14	●	
4.1	4	NW	20.8	3.5	6		●
4.1	7	N	15.7	3.7	20	●	
4.1	6	E	28.2	3.6	80	●	
4.1	7	NW	16.3	3.5	29		●
4.2	8	SE	8.3	3.8	10		●
4.2	9	E	7.1	3.8	13	●	
4.2	10	E	24	3.5	3		●
4.2	11	NW	11.2	3.8	36		●
4.2	12	SE	12	3.8	7		●
4.2	13	NE	30.1	3.7	25		●
4.2	14	E	13.3	3.7	9	●	
4.2	15	NW	33.8	3.5	3	●	
4.2	17	NW	37.6	3.6	24	●	
4.2	18	E	2.9	3.6	15		●
4.2	19	NE	36.1	3.6	5	●	
4.2	20	N	11.9	3.6	12	●	
4.2	21	N	3.4	3.5	14	●	
4.2	22	SE	5.3	3.8	3	●	
4.2	24	NW	45	3.9	5		●
4.2	26	NE	30.5	3.9	9		●
4.2	29	SE	61.7	4	11		●
4.2	27	NW	43.4	3.6	7	●	
4.3	29	NW	41.8	3.7	20	●	
4.3	30	N	16.8	3.6	16	●	
4.3	31	NW	44.3	3.5	8		●
4.3	33	N	13.3	3.6	16		●
4.3	36	E	9	3.6	3		●
4.3	37	E	9	4	11	●	
4.3	39	SE	65.4	4	14		●
4.3	40	E	40.8	4.1	10		●
4.3	42	NE	8	3.7	13		●
4.3	43	NE	10.5	3.6	12		●
4.3	44	NW	47.6	3.6	4		●
4.3	45	NW	49.6	3.6	15		●
4.3	46	NW	28.9	3.5	6		●
4.3	47	NW	44.1	3.9	9	●	
4.3	48	E	12.2	3.6	10	●	

Table 3. Analysis of seismic activity and the conductivity behavior in artesian well CAW01. 25 of 46 earthquakes were related with important oscillation conductivity, 60% of them display a prior oscillation and 40% early.

Figure	Event	Cardinal point	Distance	Magnitude	Depth	µS/cm Oscillation	
						Previous	Later
5.1	1	W	15	3.6	5	•	
5.1	5	NE	11	3.5	13		•
5.1	6	NW	34	3.8	29	•	
5.1	7	E	28	3.5	5	•	
5.1	8	E	24	3.5	10	•	
5.1	13	E	16	3.5	5		•
5.1	14	E	15	3.5	5	•	
5.1	15	E	26	3.6	10	•	
5.1	16	E	42	3.5	21	•	
5.1	17	NW	43	3.6	2		•
5.1	18	NW	20	4.7	27	•	
5.1	19	NW	26	3.6	8	•	
5.1	20	NW	24	3.5	11	•	
5.1	21	W	4	3.5	8	•	
5.2	22	SE	7	3.7	5		•
5.2	25	N	24	3.8	21		•
5.2	26	NW	26	3.5	2		•
5.2	27	E	13	3.5	7	•	
5.2	28	E	5	3.6	9		•
5.2	29	NW	34	3.7	19		•
5.2	30	NW	42	3.9	5	•	
5.2	31	W	1	3.5	15	•	
5.2	33	SE	11	3.5	3		•
5.2	34	SE	15	3.7	6		•
5.2	35	NE	8	3.7	11	•	
5.3	37	NW	20	3.5	12		•
5.3	38	NW	17	3.5	16		•
5.3	40	SE	11	3.7	5	•	
5.3	41	N	36	3.5	5	•	
5.3	43	E	9	3.7	4	•	
5.3	44	NW	36	3.5	22	•	
5.3	45	NE	7	3.8	13		•
5.3	46	SE	8	3.8	11		•

Table 4. Analysis of seismic activity and the conductivity behavior in artesian well CAW02. 23 of 36 earthquakes were related with important oscillation conductivity, 78.3% of them display a prior oscillation and 21.7% early.

Figure	Event	Cardinal point	Distance	Magnitude	Depth	µS/cm Oscillation	
						Previous	Later
6.1	1	NW	13	3.6	5	●	
6.1	2	NW	35	3.6	31	●	
6.2	9	NW	52	3.8	16	●	
6.2	10	NW	52	3.8	33	●	
6.2	11	SE	8	3.5	3		●
6.2	12	E	20	3.6	5		●
6.2	13	NW	47	3.7	5	●	
6.2	14	W	3	3.5	12	●	
6.2	15	NW	24	3.6	10	●	
6.2	16	E	15	3.8	12		●
6.2	17	NW	16	4.1	4	●	
6.2	18	N	8	3.7	13	●	
6.3	22	E	3	3.6	14	●	
6.3	23	NW	8	3.8	10	●	
6.3	24	E	11	3.6	10	●	
6.3	25	NW	33	3.8	7	●	
6.3	26	W	6	3.5	12		●
6.3	27	NW	49	3.7	5	●	
6.3	28	NW	8	3.7	14		●
6.3	29	SE	18	3.6	5	●	
6.3	30	NW	44	3.8	18	●	
6.3	31	NW	36	3.6	13	●	
6.3	33	NW	39	3.6	29	●	

Table 5. Analysis of seismic activity and the conductivity behavior in artesian well CAW02. 19 of 27 earthquakes were related with important oscillation conductivity, 73.7% of them display a prior oscillation and 26.3% early.

Figure	Event	Cardinal point	Distance	Magnitude	Depth	µS/cm Oscillation	
						Previous	Later
7.1	3	NW	55	3.8	38	●	
7.1	4	NE	34	4	5		●
7.1	5	NE	32	3.6	5		●
7.1	6	NW	13	3.6	30		●
7.1	7	NE	32	3.6	7	●	
7.1	8	NE	34	3.5	2	●	
7.1	9	NW	44	4	6	●	
7.2	12	NE	32	3.9	13		●

Continued

7.2	13	NW	41	4.1	14	●	
7.2	14	W	14	3.5	6	●	
7.2	15	E	33	3.8	5	●	
7.2	16	SE	20	3.8	9		●
7.2	17	NE	14	3.8	5	●	
7.2	18	NE	19	3.5	16	●	
7.2	19	NW	43	3.6	5	●	
7.2	20	NW	40	3.9	4	●	
7.3	23	NW	39	3.6	31	●	
7.3	34	W	10	3.8	54	●	
7.3	35	NE	7	3.5	5	●	

Table 6. Analysis of seismic activity and the conductivity behavior in artesian well CAW02. 32 of 55 earthquakes were related with important oscillation conductivity, 75% of them display a prior oscillation and 25% early.

Figure	Event	Cardinal point	Distance	Magnitude	Depth	µS/cm Oscillation	
						Previous	Later
8.1	1	SE	17	5	16	●	
8.1	2	NE	17	3.6	56	●	
8.1	3	NE	7	3.6	34	●	
8.1	4	NE	21	3.7	72	●	
8.1	5	NE	16	3.6	15	●	
8.1	6	E	11	3.5	30	●	
8.1	7	SE	15	3.6	30	●	
8.1	9	NE	28	3.6	13		●
8.1	10	NW	25	3.9	12	●	
8.1	13	NE	18	3.5	25		●
8.1	14	E	23	3.5	5		●
8.1	15	NW	20	3.5	28	●	
8.1	16	NW	50	3.9	16	●	
8.1	17	NE	15	3.5	12	●	
8.1	21	NW	7	3.7	14	●	
8.2	22	NW	12	3.8	13		●
8.2	23	NW	26	3.6	27		●
8.2	24	NW	10	3.8	9	●	
8.2	25	NW	15	3.6	5	●	
8.2	26	NW	25	4.1	5	●	
8.2	27	E	34	3.6	29	●	

Continued

8.2	28	E	37	3.7	26	●	
8.2	29	E	38	3.9	20	●	
8.2	30	E	30	3.7	11	●	
8.2	35	SW	2	3.7	12		●
8.2	36	E	25	4	6		●
8.2	47	NW	39	3.6	30	●	
8.2	48	SE	19	3.6	16	●	
8.3	52	NE	41	3.8	29	●	
8.3	53	SE	10	308	20	●	
8.3	54	NW	50	3.7	29		●
8.3	55	NE	43	3.8	57	●	

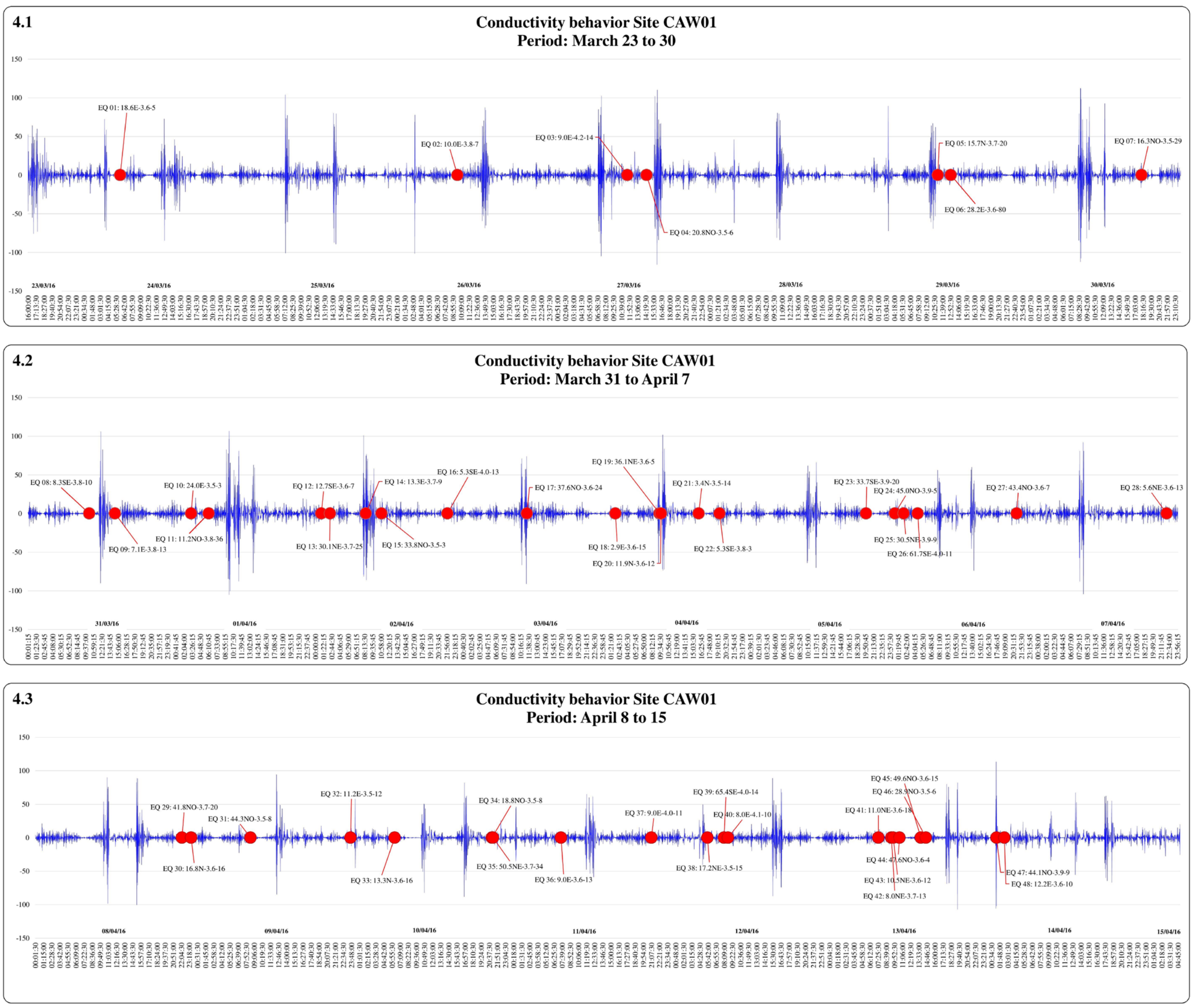

Figure 4. Conductivity behavior in artesian well CAW01 within the period of March 23 to April 15. During that period 48 earthquakes were manifested with an average magnitude of 3.7. **Red dot (*EQ 1: Cardinal point-wM-Depth*)**.

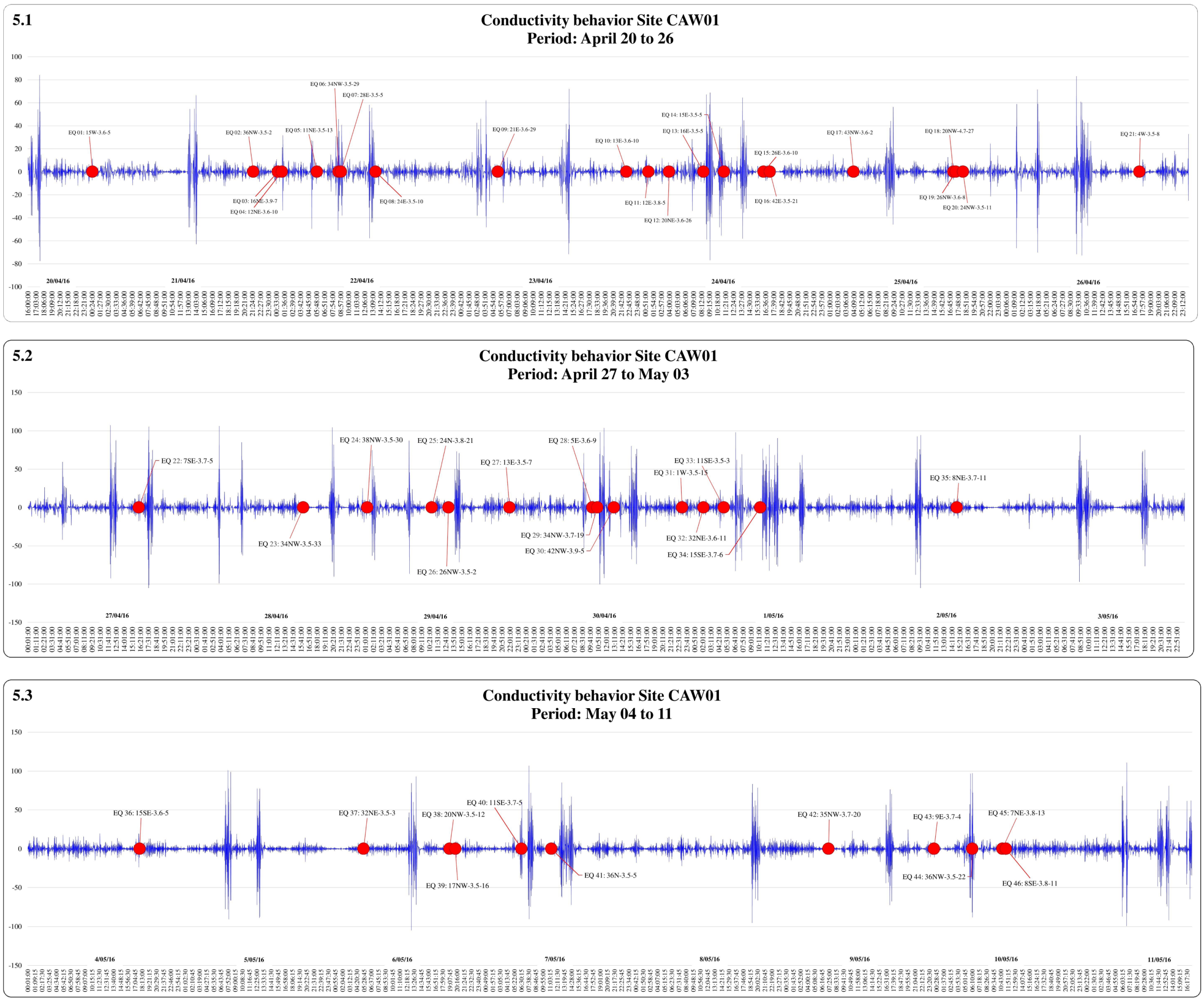

Figure 5. Conductivity behavior in artesian well CAW01 within the period of April 20 to May 11. During that period 46 earthquakes were manifested with an average magnitude of 3.6. **Red dot (*EQ* 1: *Cardinal point-wM-Depth*)**.

In terms of the conductivity behavior observed, the graph without data transformation of the artesian wells CAW01 and CAW02 data showed significant differences between them. The CAW01 site showed drops in conductivity with very marked fluctuation, the average values were 14.12 to 1203.6 µS/cm, **Figure 9**; while the site CAW02 oscillations were less marked, the oscillation value was 610 to 1700 µS/cm, however the general behavior of the data appears to be odd, **Figure 10**.

In both graphs the data conductivity trending showed-up to three diurnal variations, either decreasing or increasing the conductivity, this behavior may point out that the internal flow of water is extremely fast indicating a vigorous recharge. Some possible explanations for these anomalies could be the proximity of the sampling site to a lagoon or groundwater stream, although several of conductivity oscillations are more than normally of those expected in one day.

Another possible explanation is the frequent seismic activity in the area where are the sampling sites because of slight seismic movements or tremors [55]-[57], these movements also cause possible ground compression, like squeezing a sponge [9] [37], which is reflected in sudden changes in water chemistry by apparent flows of groundwater, this directly impacts the amount of ions and so reflected in conductivity oscillations.

Likewise, the atypical variations in conductivity may be associated with electromagnetic energy wandering in the surroundings [5] [46] [47] [58], which interacts with ionic local particles move them away of the conductivity sensor or also, triggering an interference to the conductivity sensor's operation. Finally, the use of artesian

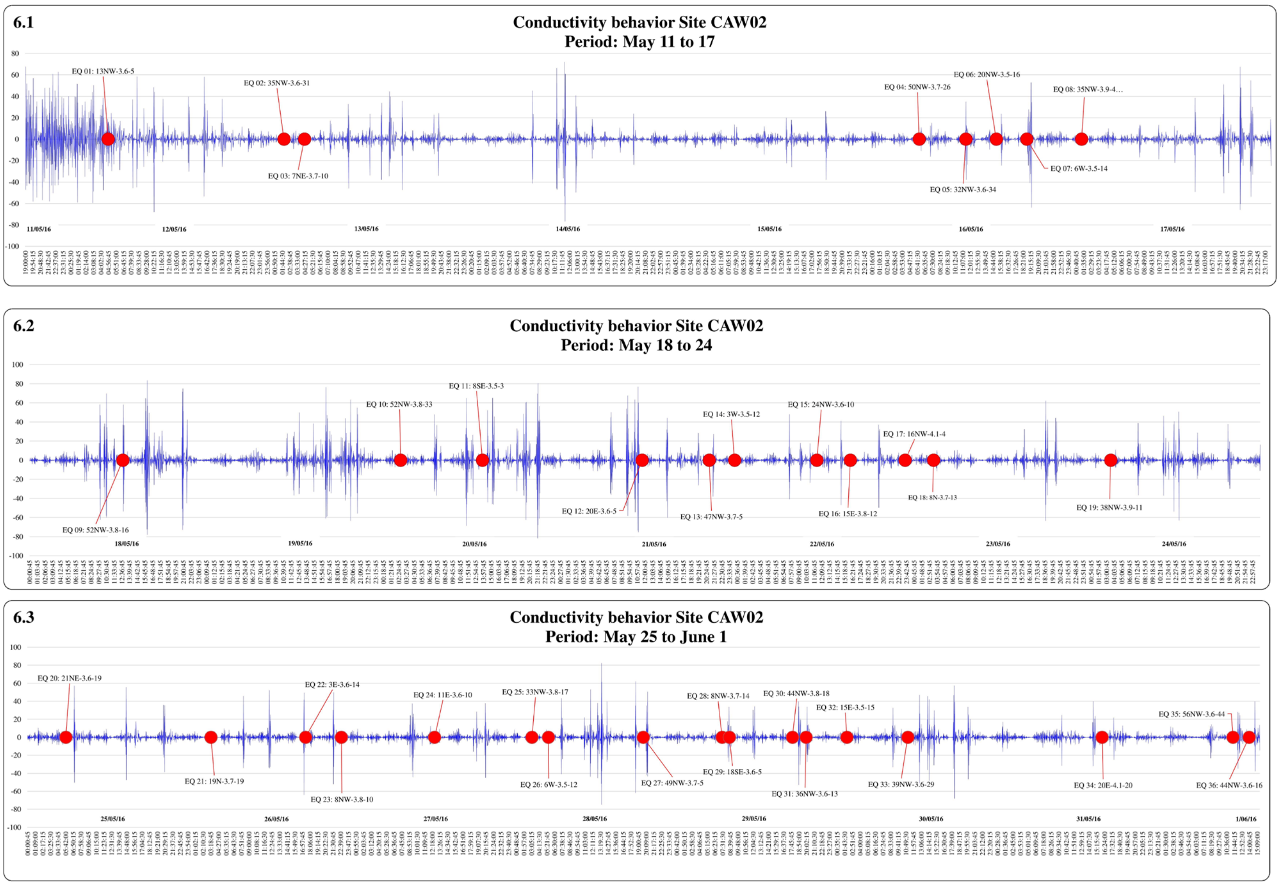

Figure 6. Conductivity behavior in artesian well CAW02 within the period of May 11 to June the first. During that period 36 earthquakes were manifested with an average magnitude of 3.7. **Red dot (*EQ* 1: *Cardinal point-wM-Depth*).**

wells that their owners do to their household domestic chores can be others factors that promote changes in conductivity.

In accord with data plotted no transformed, **Figure 10**, from June 24 to July 9 a downward trend of conductivity was maintained and this period and is associated with a previous and important seismic activity; after that, seismic activity decrease, afterwards the tendency of conductivity oscillation was slightly again.

The partial analysis of a multiple 24-hour data series sets of site CAW02no transformed, during 16 days (June 24 to July 17), and the total monitoring period of CAW01 (March 2 to May 11, 61 days) and CAW02 (May 12 to July 17, 61 days) of 2015, show interesting divergence. In the first series of data the conductivity behavior shows noticeable oscillations between 7:00 to 22:00 hours, **Figure 11**, after this period, the oscillations decrease. This data conduct point to the possible human factor is causing the variability, but this it is not very clear; despite of coincidences between some series the oscillations' data had a wide range of conductivity values: 600 to 1700 μS/cm.

The analysis of total data monitoring through 61 days of sites CAW01 and CAW02 without data transformation, show the subtle tendency between seismic event aggregation and conductivity oscillation mentioned and referred in **Figure 6 (1)**, **Figure 7 (2)**, **Figure 8 (1)** and **Figure 8 (2)**, this pattern enhance the possible correspondence between the previous conductivity oscillation and later seismic activity. From March 2 to May 11 (CAW01), **Figure 12**, at the beginning of the graph there is an increasing of the conductivity values whose positive trend was maintained until half of the monitoring period, afterward the trend was negative with very erratic behavior that keep up until the end of the sampling period. During the positive trend of conductivity the presence of seismic events was more dispersed, but when the negative trend of the data starts, showed a higher concentration of seismic events which is maintained afterwards.

Of May 11 to July 17 (CAW02) the graph with data no transformed shows three major fluctuations that grew

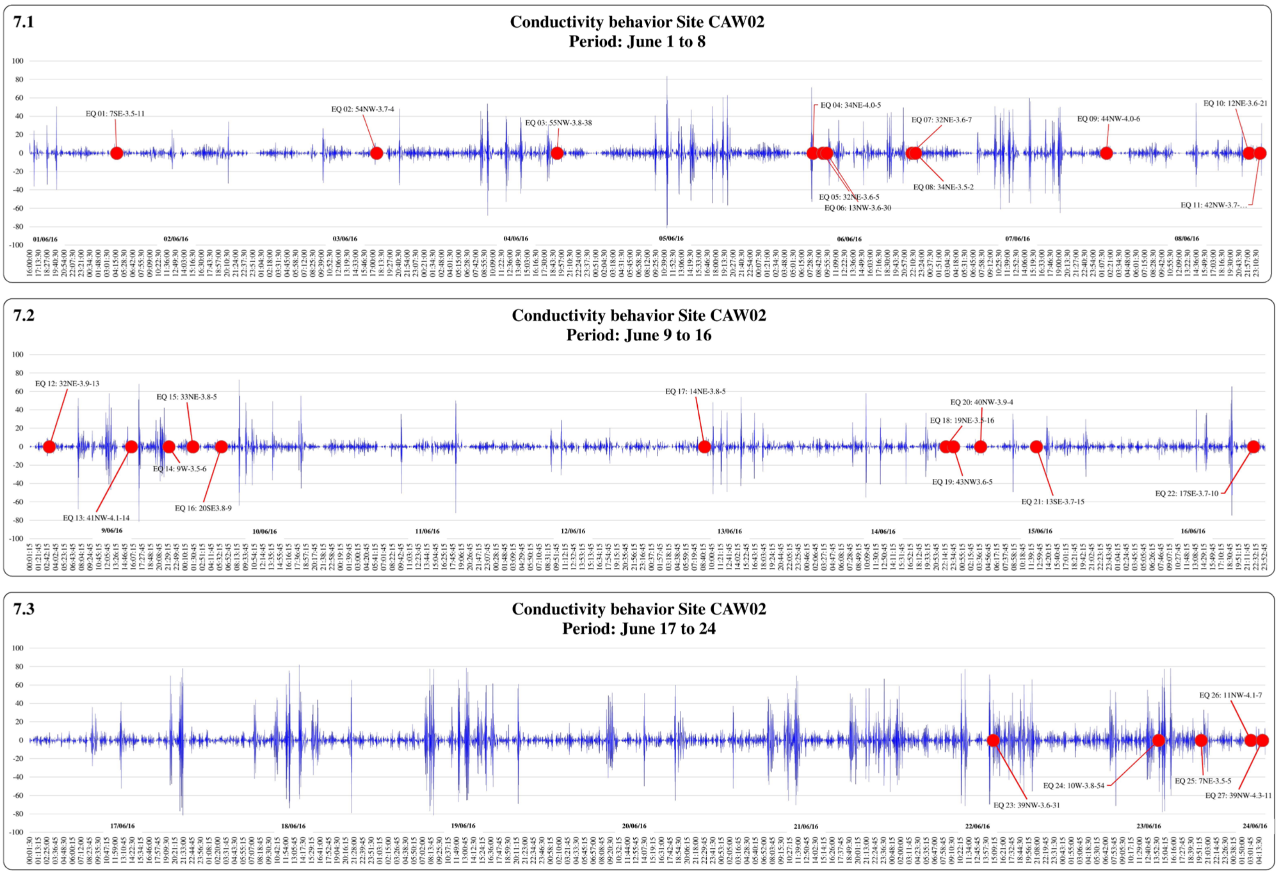

Figure 7. Conductivity behavior in artesian well CAW02 within the period of June 1 to 24. During that period 27 earthquakes were manifested with an average magnitude of 3.6. **Red dot (*EQ 1: Cardinal point-wM-Depth*)**.

over time, the average conductivity records were close to 600 µS/cm before the first seismic activity oscillation, **Figure 13**. As the number of earthquakes decreased conductivity increased, the highest values grew-up to 1700 µS/cm; during the period from June 15 to July 17 this behavior was more evident. When compared the graphs of 24 hours data series and the 61 days data series, the difference between them are outstanding, last one shows possible long term oscillations associate to the earthquakes' manifestation, therefore the future systematic long term monitoring of any manifestation of direct energy (electromagnetic fields) or indirectly (conductivity) can contribute more to ratify the possible presence of long time phenomena observed in this research in order to determine if this behavior is specific of Pinotepa Nacional surroundings or could be identified within other subduction zones.

Only part of the seismic events manifested in the period of May 11 to July 17 in this analysis were processed (118 earthquakes, **Figure 13**), those considered most likely to have some correspondence with the conductivity fluctuations records, particularly those occurred to less than 50 kilometers away, considering that the sites of monitoring were located in a place with the highest seismicity of the region; in fact the total number of seismic events occurred between of Guerrero and Oaxaca estates limits during 61 days were 724 distributed at different distances around the Dada Logger conductivity sensor, with a magnitude average of 3.8, some of them at 450 kilometers away.

7. Conclusions

Statistically the area designated for conductivity monitoring of Pinotepa Nacional between the border of Guerrero and Oaxaca, Mexico, is the most active per square kilometer with three seismic events per day with average of 3.8 Mw.

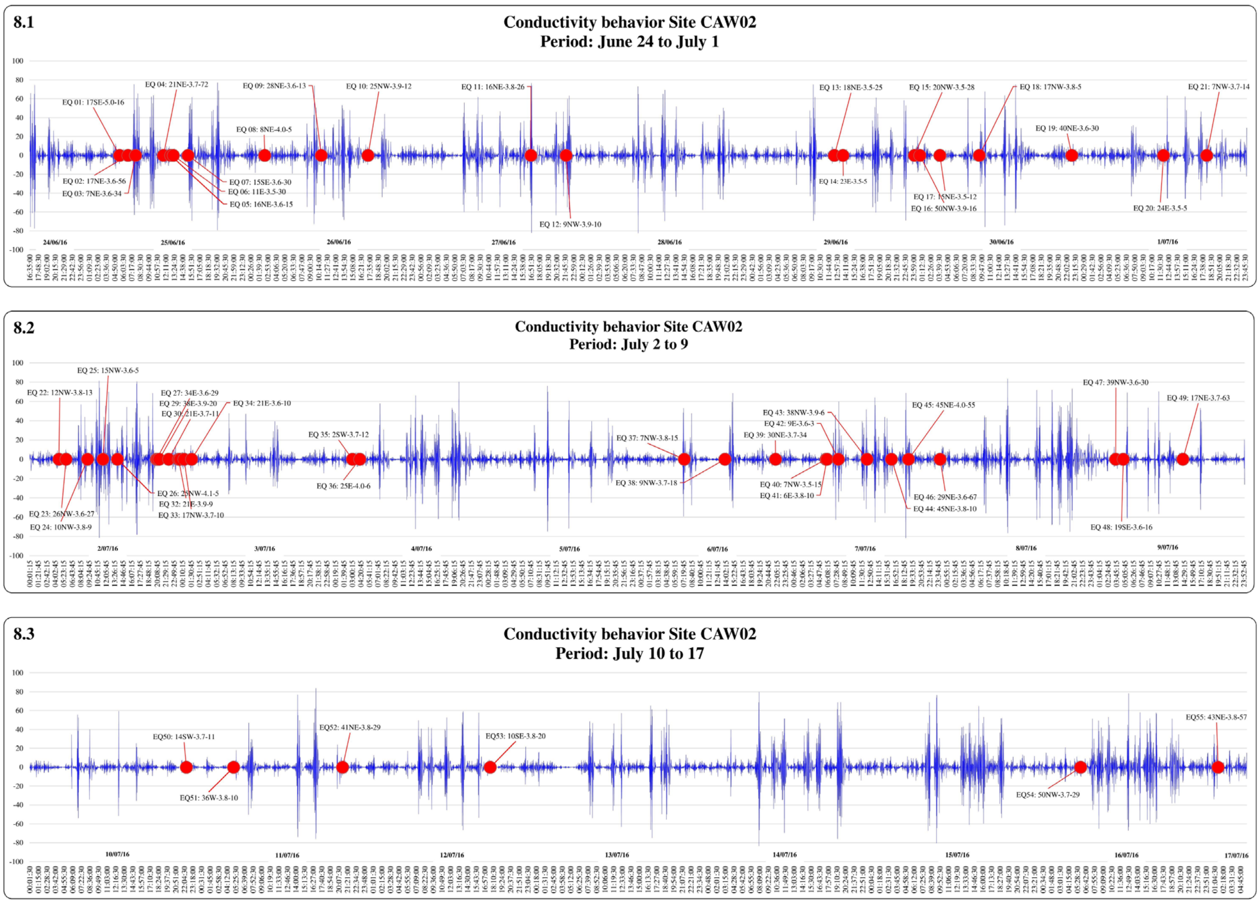

Figure 8. Conductivity behavior in artesian well CAW02 within the period of June 24 to July 17. During that period 55 earthquakes were manifested with an average magnitude of 3.7. **Red dot (*EQ 1: Cardinal point-wM-Depth*)**.

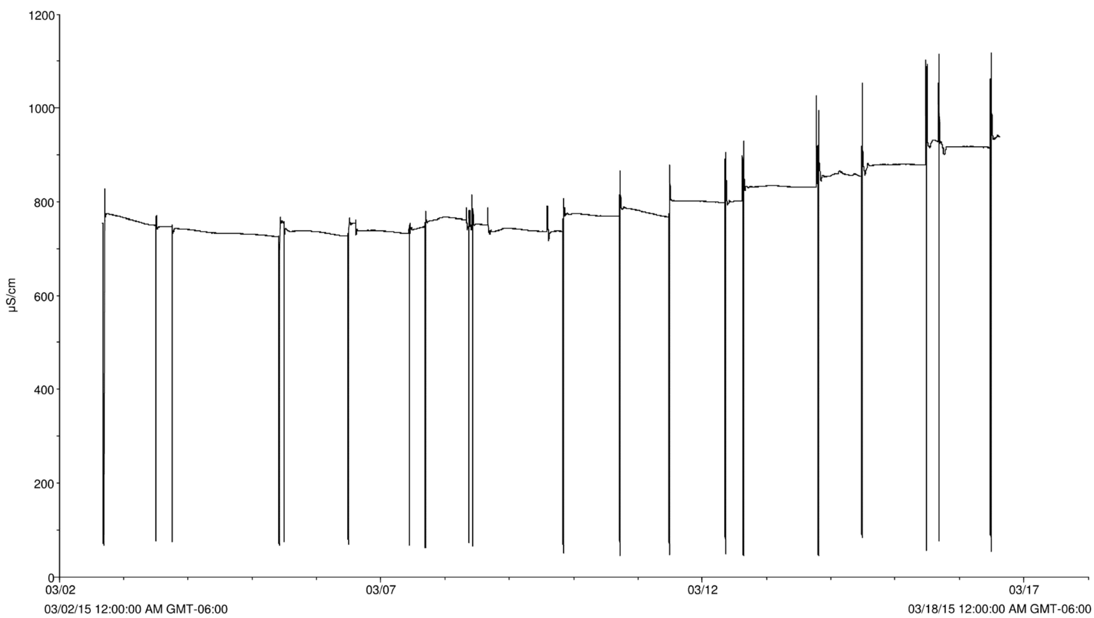

Figure 9. General behavior conductivity observed in the CAW01 site. This monitoring data correspond to a period of March 2 to 15 of 2015 only.

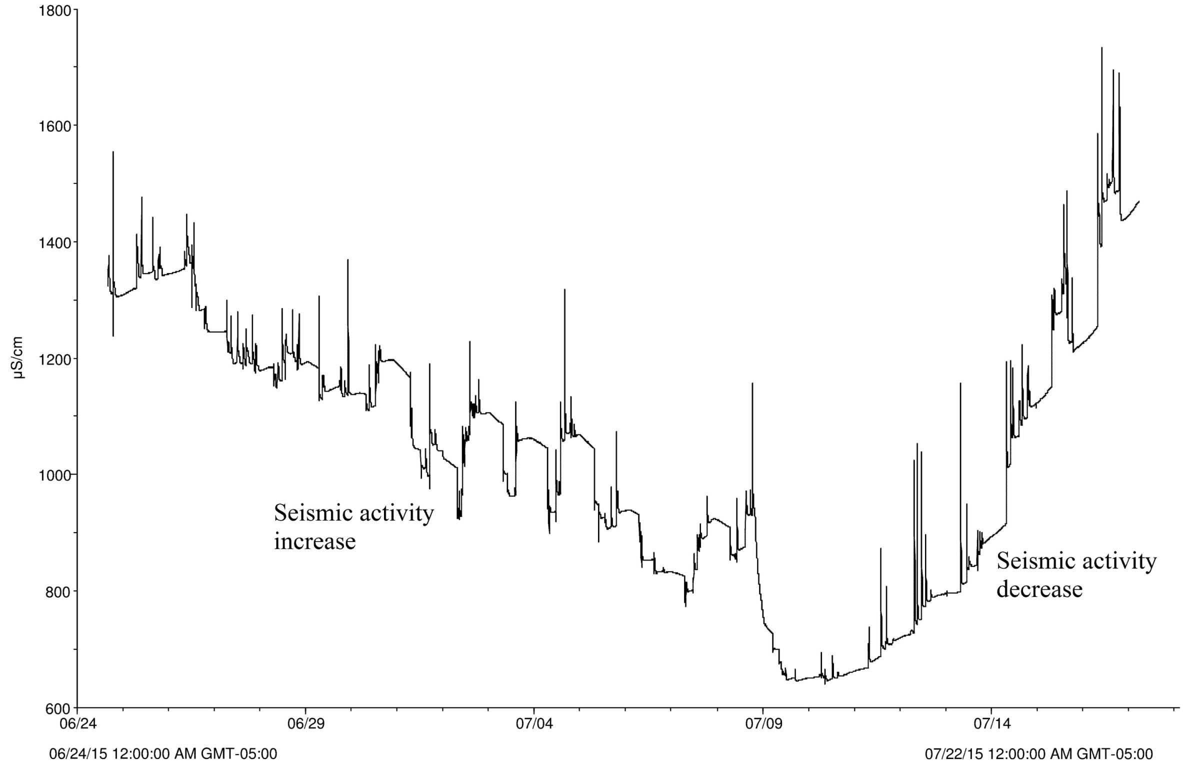

Figure 10. General behavior conductivity observed in the CAW02 site. This monitoring data correspond to a period of June 24 to July 14 of 2015 only.

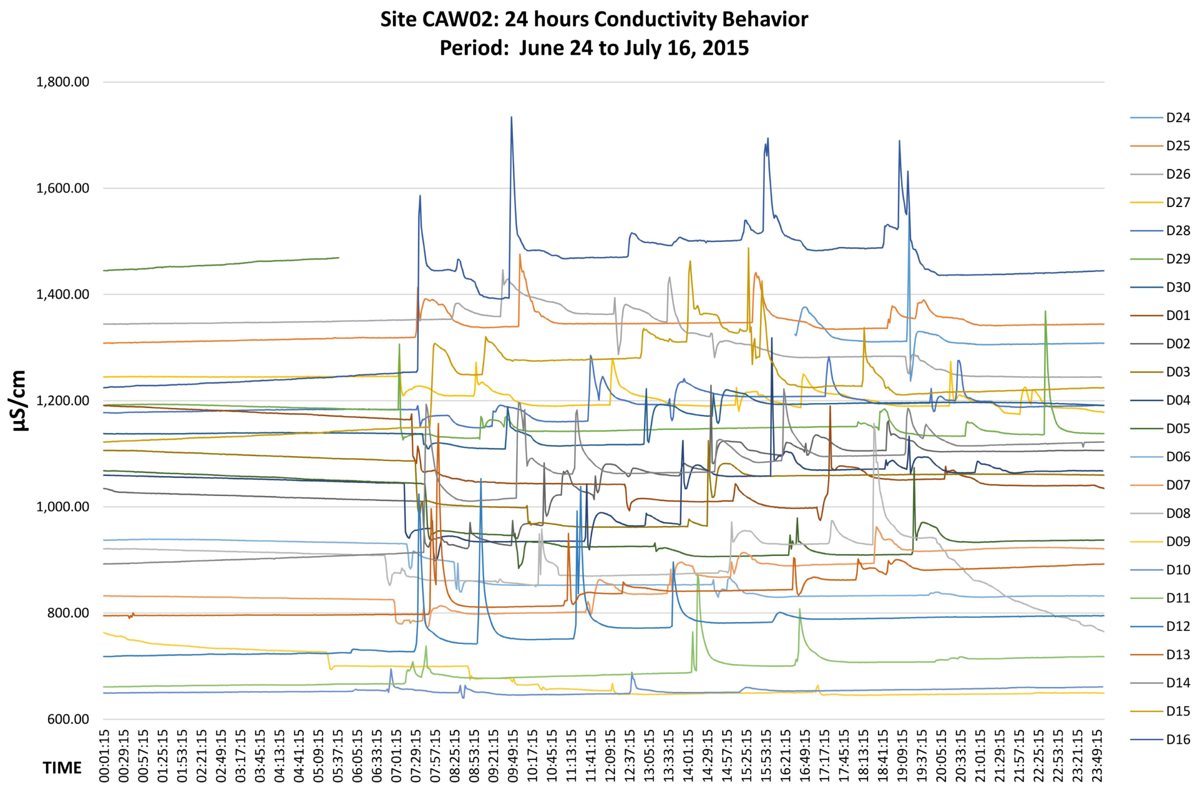

Figure 11. Conductivity behavior in multiple 24-hour data sets during 16 days.

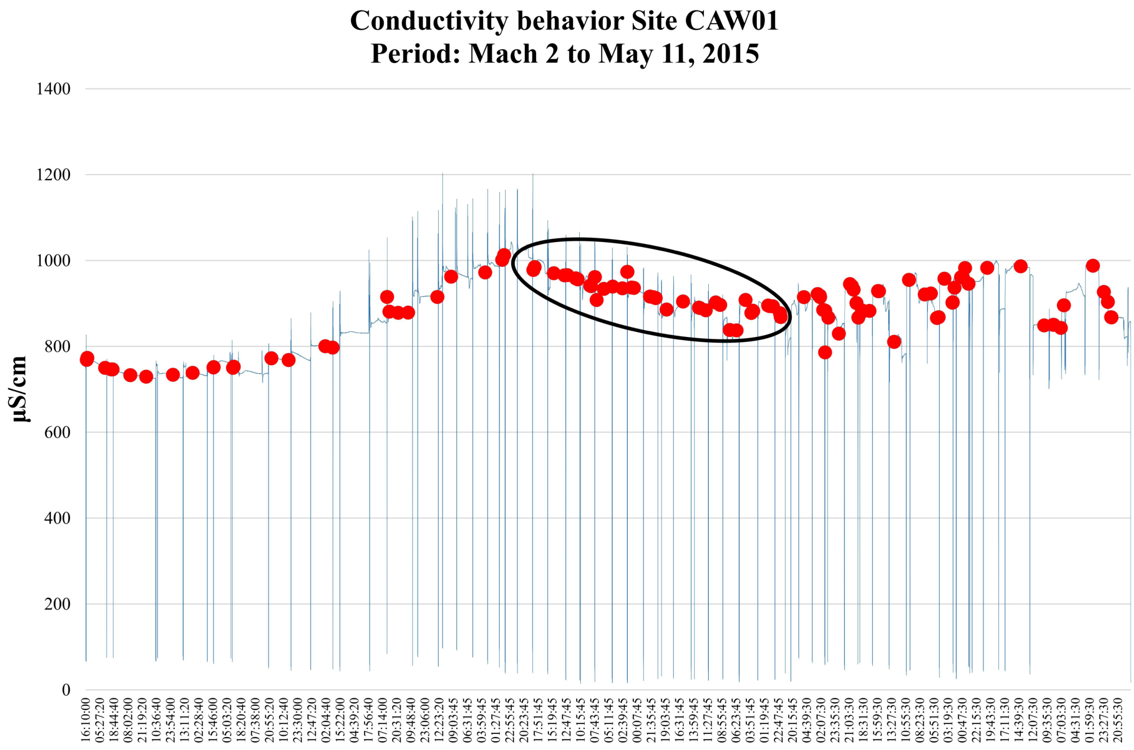

Figure 12. Conductivity behavior from March 2 to May 11 of 2015, corresponding to 61 days of monitoring. During that period 117 seismic events (**red dots**) were presented, 29 events matched with the data positive trend, and 90 events with the data negative trend, 44 of them (enclosed in the ellipse in black) were presented before the line graph become erratic.

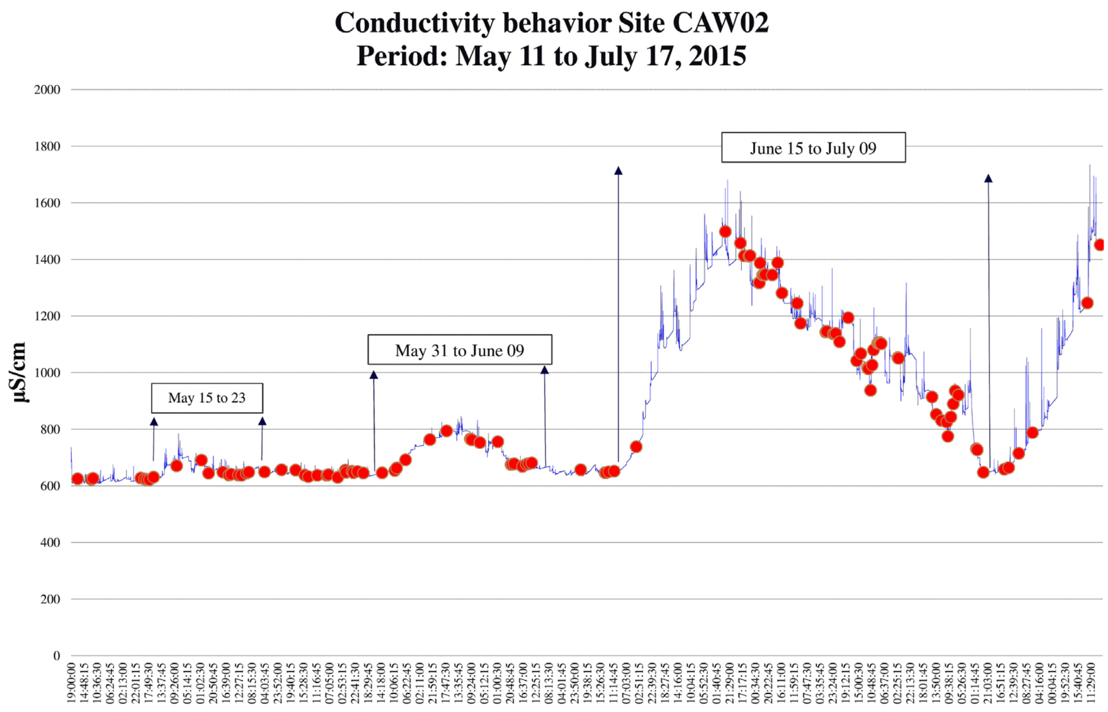

Figure 13. Conductivity behavior from March 11 to July 17 of 2015, corresponding to 61 days of monitoring, 118 seismic event (**red dots**) were manifested during this period; in the main oscillation 54 seismic events leading up to an earlier period of six days of no presence of seismic activity.

The conductivity trending of data shows until three diurnal variations, either decrease or increase the conductivity, this behavior may point out that the internal flow of water is extremely fast indicating a vigorous recharge.

- The use of artesian wells by owners to do their household domestic chores could be an important factor that promotes fast changes in conductivity, but not at all, other phenomena could be involved (presence of slight seismic movements; electromagnetic energy fluxes around surroundings; slight tilting of ground by recurrent seismicity).

The conductivity records of artesian wells show fluctuations at several scales of time, from short periods of less than an hour, more than one day or a week and possibly months. The records until now obtain at least two interesting behaviors:

- In shorts series of time there is not clear evidence in the conductivity monitoring results that prove the flux of electromagnetic energy around surroundings. For periods of monitoring time of 24 hours (16 days) after 22:00 hours almost no conductivity occurred, from 7:00 to 22:00 the tendency is positive and very fluctuated and the possibly human factor is the cause of such atypical variations.
- The data analysis for long periods of data series of conductivity (61 days) and seismic events shows that there is a subtle relationship between seismic intensity and large conductivity fluctuation: when the number of seismic events becomes intense, conductivity decreases and *vice versa*, resulting large fluctuations that grow over time.

Before an earthquake, the behavior of conductivity records shows a possible swing long-term energy like a wave.

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