Impact of lithium mining on climate change in the Atacama Desert, South America

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Abstract

The present study aims to highlight the possible impacts of lithium mining coupled with extremely dry weather conditions such as La Nina on its local weather patterns over a high-altitude location along the Chile-Argentina-Bolivia border on both short- and long-term basis. Extensive statistical analysis established that intense lithium mining over such dry and lofted locations during strong La Nina episodes lead to prominent aridification which in turn promotes dust emission, ice cloud nucleation and widespread lightning occurrences without the need of any additional influences such as instability, moisture, or aerosols.

1. Introduction

Thunderstorm occurrences constitute a major climatic feature over tropical regions and are normally characterized by various components like wind gusts and extreme rainfall [1-2] which causes a lot of socio-economic hazards. But apart from these, lightning activities emerge as the most devastating component primarily due to its erratic spatiotemporal behavior of occurrence. In the past, a plenty of studies have attempted to unravel the physical mechanisms driving such extreme weather phenomena [3-6], but the number of holistic studies appropriately addressing this problem remains very scarce. Recently, some researches have utilized satellite observations for lightning research either to investigate the spatio-temporal distributions of lightning or to identify all potential factors controlling it [7-8]. Some new studies identified the slopes of mountainous regions like the Himalayas to be potential lightning hotspots due to orographic convection despite lower moisture and weaker atmospheric instability [9-10]. Likewise, other researchers have demonstrated how particular types of aerosols can assist towards ice-cloud formation and lightning [11]. However, all these hypotheses need to be tested on multiple locations.

Simultaneously, there has been a recent inclination to migrate towards renewable energy; hence a business stream involving the manufacture of electric vehicles running on lithium batteries have increased exponentially since the last decade. Hence, the annual production of lithium also witnessed a steep increase by ~135% between 2008-2018 alone [12]. Here It may be noted that the greatest and the most utilized lithium ore source of the world come from an elevated, barren and highly arid region sitting on the Andes mountains (in the Atacama Desert) along the intersection of Chile, Argentina and Bolivia international borders; hence it is called the Lithium Triangle. Now recently, the locals in that region have started to complain about frequent droughts, aridification, and underground water depletion. Also, a recent study has illustrated how in last 20 years extensive mining has led to increased surface heating, soil dryness and more frequent drought episodes over this region [13]. Similarly, some studies have also correlated the declining atmospheric moisture with the recent lithium mining trends [14]. But sadly, these types of studies warning about the climate impacts of renewable energy farming are very rare. Hence, the present study aims to investigate whether extensive lithium mining leads to adverse climate over the Lithium triangle region in South America. Also, from another angle, this study will try to retest whether extremely dry and cold weather events (as during La Nina) in association with aerosols can produce conditions conducive for ample lightning even in absence of sufficient moisture or instability.

2. Dataset

For the present study, the rainfall accumulation data are utilized from GPM IMERG monthly gridded datasets at 0.1X0.1 degrees [15]. Secondly, this study uses the moisture, instability, clouds, and other associated datasets from the fifth generation European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis, ERA5 [16] reanalysis datasets at 0.25 degrees resolution during the period 1979-2020. Gridded datasets of aerosols and especially its dust component is obtained from MERRA-2 modelled datasets provided by NASA for the same time span. Finally lightning frequency and intensity datasets are taken over the study region from ~95800 passes of Lightning Image Sensor (LIS) inside Tropical Rain Measurement Mission (TRMM) satellite during 1998-2014 [17].

3. Results and Discussion

3.1. Description of the region of study

The region of study is centered at the Lithium triangle at the intersection of Chile, Argentina and Bolivia border as depicted in the left panel of Figure 1. The right panel provides a zoomed orographic view with height mentioned in log scale of base 10. It can be observed that a particular section hugging the western boundary of the study region has been marked separately and will be referred to as “Small area” in contrast to the entire region hereafter mentioned as the “Large area” for simplicity. Here, the small box is considered separately due to its maximum altitude (4-4.5 km above sea level), driest climate and the maximum availability of Lithium ore mines.

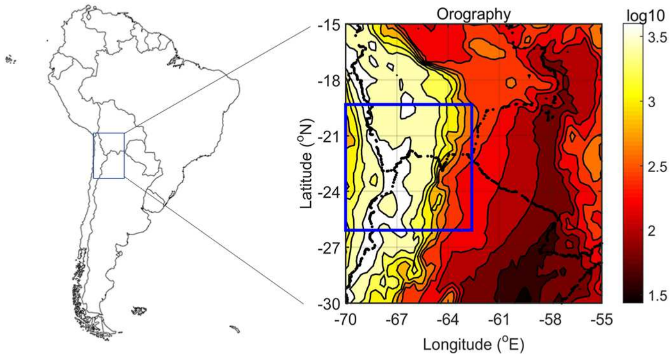

Figure 1. Map of the Atacama Desert and lithium triangle used in this study with its altitude in log scale of base 10

To further explain the climatic differences between the two regions the annual and seasonal averages of rainfall, humidity and temperature are depicted in Table1.

Table 1: Average meteorological conditions of the regions used in this study

Particulars		Parameters			
Region & Season		Rainfall	Temp	ABLH	RH
Small	NDJF	1.51	11.21	576.07	30.96
	Rest	0.36	6.80	474.06	23.42
Large	NDJF	4.37	21.89	392.71	34.45
	Rest	1.82	17.28	302.83	27.46

Since this study region lies in the southern hemisphere hence the period November – February (hereafter referred to as NDJF) experiences strongest temperatures and rainfall while the rest 8 months undergo very cold and dry weather conditions as also evident from rainfall and humidity values in the table. However, it may be noted that the small region remains exceptionally dry throughout the year compared to the large region. But the most important characteristic in this table is that the small region during non-rainy period (except NDJF; hereafter referred as NM period) witnesses surface temperatures as cool as 7 C while the boundary layer height itself is 500m. Hence it is expected for moisture however to be directly lifted to near zero temperatures where it can directly form ice and thereby produce conducive conditions for lightning without any additional support from instability, moisture, or aerosols. However, this specialty is not observed over large region; hence this hypothesis will not work there.

3.2. Impact of lithium mining on the meteorological conditions of Atacama Desert

Next, the yearly trends of lithium ore mined over the study region are depicted in Figure 2. It can be observed that the amount of lithium ore mined has taken a sharp jump in magnitude range since year 2007. This explains that the impact of mining on weather and climate can be conveniently highlighted by observing the changing climatologies of all atmospheric parameters before and after year 2006. For further ease of representation, the period before year 2006 is referred as Pre-mining period while that after 2006 is represented by the Postmining period. Next, the annual average values of rainfall, soil moisture, atmospheric humidity and cloud cover are plotted for both small and large regions before and after year 2007 in Figure 3.

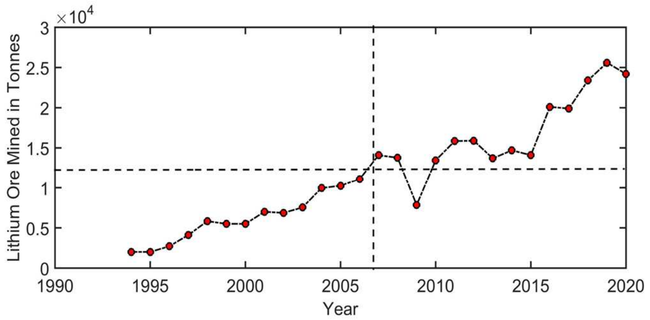

Figure 2. Climatic trend of lithium mining in Atacama Desert

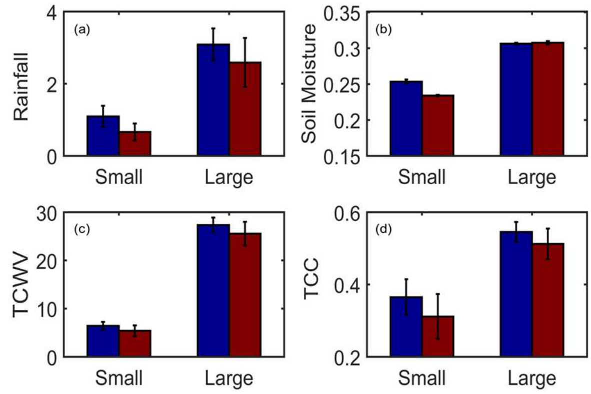

Figure 3. Climatological averages of meteorological parameters over both regions during pre-mining and postmining periods (denoted by blue and red respectively) for (a) Rainfall, (b) Soil Moisture, (c) TCWV and (d) TCC

The figure depicts that the small region experiences very low values of rainfall, moisture and clouds compared to the whole area primarily because of its large altitude. But interestingly, the postmining periods experience much weaker rainfall, moisture and clouds than during the pre-mining period which also goes in line with previous research attempts.

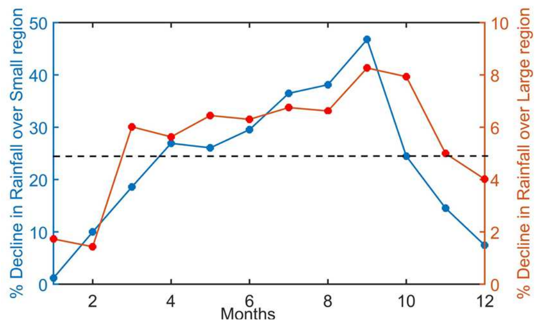

Figure 4. % Decline between pre and post mining periods in average rainfall over the small and large region (blue and red)

After this, the monthly averages of rainfall are calculated for pre and post mining period for both small and large regions and then the % depletion is plotted in Figure 4. It can be clearly seen that the rainfall accumulation has decreased whole year in both regions. However, the depletion is far more prominent with ~40% reduction over the NM period while nothing appreciable is found in NDJF. This may be because, the NDJF or summer monsoon months get adequate moisture supply from nearby water bodies; hence it shows a weak reduction due to mining. But over NM period, there is no moisture advection component thereby highlighting this drop. Another point to note is that the large area follows similar pattern, but with a weak decline rate as it encompasses a very large area including the mining zone.

3.3. Relationship between aridification, mining and ENSO events

Next, it is investigated whether this reported aridification can also be caused by large scale factors such as the ENSO variability. Years witnessing El Nino events experience intense convections, moisture ingress and cloudiness over Chile in which the present study location also lies [18]. Conversely during La Nina these regions are expected to face dry weather with no clouds or rainfall. To investigate this concept, annual averages of rainfall, soil moisture, total cloud cover (TCC) and instability (represented by convective available potential energy CAPE) are depicted in Figure 5 over the study region. As expected, rainfall and soil moisture show a sharp monotonic decline from El Nino to La Nina; however, in case of clouds and instability, La Nina conditions depict a slightly unexpected rise with respect to the normal years, the reason for which has been investigated next.

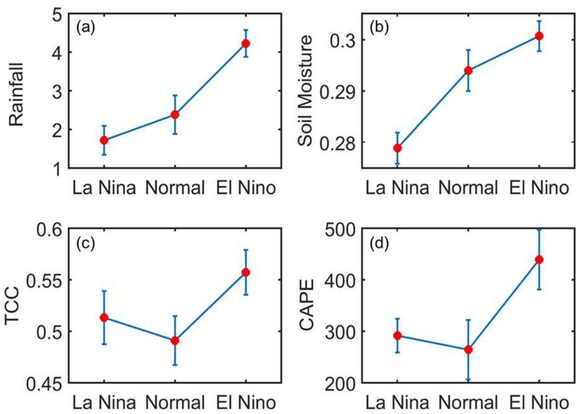

Figure 5. Climatological averages of meteorological parameters during various ENSO phases for (a) Rainfall, (b) Soil Moisture, (c) TCC and (d) CAPE.

The variation in clouds, rainfall, instability, and aerosols are considered for the large and small regions respectively during pre and post high mining periods during the NM period with respect to SST anomalies in a normalized scale and the results are depicted in Figure 6. As expected, rainfall did not show any nonlinearities. Next in case of clouds and instability, the small and large regions depicted a linear decline from El Nino to La Nina during pre-mining times. However, during post mining period, the small region starts to rise during La Nina conditions. So it follows that the impact of large-scale teleconnection responses have started to alter over the Lithium Triangle as a result of extensive mining activity.

Next, the third factor effecting clouds namely aerosols are observed to understand the cause of this nonlinearity. Here, only Dust AOT is shown as they act as excellent ice nuclei (ICN) in near zero temperature environments as already available near the surface of the small region during the NM period. A hypothesis is proposed that extremely dry weathers loosen the earth surface leading to dust emissions which assist to form clouds by acting as ICNs. Further these clouds release latent heat which further increases instability and triggers convective processes. Interestingly, this hypothesis is supported from a huge rise dust AOT during La Nina conditions over the small region during the post mining period thereby explaining the anomalous nonlinearities developing due to excess mining.

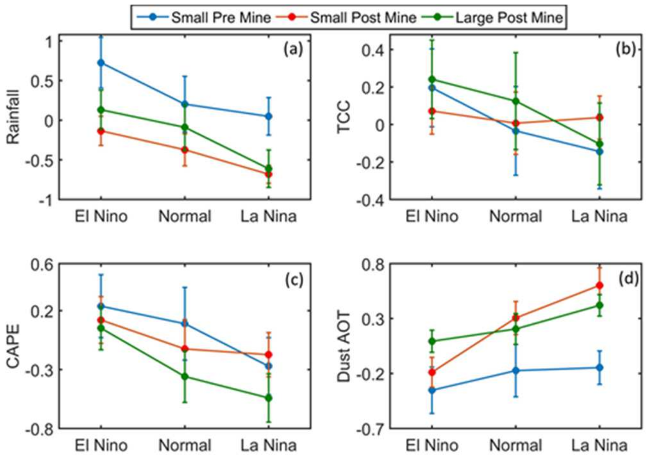

Figure 6. Climatological averages of meteorological parameters during various ENSO phases of both pre and post mining periods over the large and small region for (a) Rainfall, (b) TCC, (c) CAPE and (d) Dust AOT

3.4. Impact of mining and ENSO on lightning

Here, it is investigated whether mining, coupled with dry La Nina conditions can really modulate the cloud properties hence lightning. The cloud liquid and ice water contents (TCLW and TCIW) are plotted for post mining period for both regions in Figure 7. Results indicate that TCLW drops linearly from El Nino to La Nina with slight non linearities in mining region; however, in TCIW, the small regions exhibit a strong increase during La Nina periods. This clarifies the role played by Dust aerosols on the ice clouds as proposed earlier.

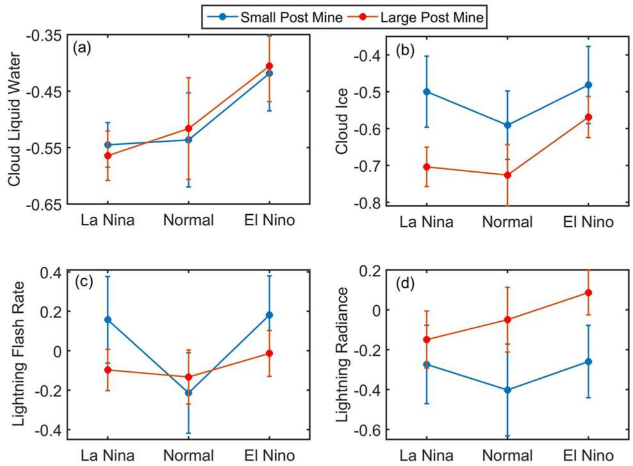

Figure 7. Climatological averages of meteorological parameters during various ENSO phases of the post mining periods over the large and small region for (a) Cloud Liquid Water, (b) Cloud Ice, (c) Lightning Flash Rate and (d) Lightning Radiance

Now, as cloud ice has increased, hence lightning frequency too much rise. Likewise, the figure shows congruent results exhibiting huge nonlinearity with the strongest lightning activity during La Nina conditions over the small region. However, in case of lightning radiance, it did not exhibit a strong nonlinearity over the small region. This is because, lightning radiance unlike its frequency also requires the abundance of high liquid water content in mixed layer which again is absent here owing to its high altitude; hence it cannot experience strong lightning intensities over the small region.

4. Conclusions

The present study attempts to depict the influences exerted by extensive lithium mining activities over a highly arid and mountainous region along the Chile-Argentina-Bolivia border. Initial results reveal a sharp aridification over the mining regions during the non-monsoon months over the mining hotspot regions. Further, it has been demonstrated how this aridification effect has led to profuse dust aerosol emissions particularly during strong La Nina events which resulted in ample ice cloud nucleation and lightning even in the absence of requisite moisture content or atmospheric instability. In near future, it will be attempted to utilize multiple global and regional models to project the near future trends of prevailing climate in this region assuming various rates of lithium mining activities in coming decades.

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