Comparation of two climate methodologies on Lerma Chapala basin: moving mean and climate variability indices with RClimDex

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Abstract. The objective of this study is the comparation of two climate methodologies with the next variables, average maximum and minimum temperatures, and precipitation, said another way, it was calculated by two different methods, the moving mean and climate change indices with complements of R software (RClimDex and RhTest) on Lerma Chapala basin, which is located. The data were analyzed for representative periods of 30 years since 1960 to 2016, which, were collected from National Water Commission due to compiling with control qualify. Finally, the results will help for supporting international climate variability report and demonstrated that independently the methodology the results are similar, it means, the select variables showed modifications through the time that causing drier environments.

1. Introduction
The climate variability is one of the most important challenge in our days, however, adding the anthropogenic factors such as pollution and bad driving of natural resources, Accorded to International investigations, have showed the consequences from higher mean temperatures and precipitation changes, the results have presented evidences that fluctuations since earlier industrial revolution have increased almost 0.74° Celsius [1]. In the last 30 years, in every decade, has been warmest than before, it is likely the period of 1983 to 2012 has presented the highest temperatures in the last millennium. The different results of modifications about land and ocean temperatures show an increase of 0.65 to 1.06° C [2].

Mexico is the second largest country in Latin America, in terms of population and economic performance, after Brazil. Mexico covers 1’964, 375 Km², the 14th largest country in the world. Precipitation is varied ranging from 2 095 mm in humid regions and less 200 mm in driest areas in the northern of the country. The arid and semi-arid zones represent 27.4% of Mexico, a substantial area where most economic, political and social activities take place, including 76.8% of nation’s Gross GDP and where 67.6% population lives. Rainfall is concentrated from June to October (68%) with an intensive hurricane season, occurring specially in Pacific and Southeast [3].
In 2010 was a special year according to National Meteorological Service published the nationally averaged annual mean temperature was about 0.3°C above the normal temperature of 20.7°C. However, precipitation in 2010 was the second wettest year since 1941, total amount was about 935.5 mm and the normal value is 777.9 mm [4].

The main objective of this study is the evaluation of climate variability (maximum and minimum temperature and precipitation) on Lerma Chapala basin since 1960 to 2016 and the comparison of technics evaluating the climate variability. It is important the context of Lerma Chapala basin, where it is a strategic region for Mexico development, mass around 10% of Mexican population and generate 10% of Gross Domestic Product (GDP). However, the socioeconomic growing dynamics hope to suffer hard problems related to environmental degradation and deterioration [5].

2. Methodology
   2.1 Study area
Lerma Chapala basin is located on west center of Mexico, with geographic coordinates of 19° 03’ to 21° 34’, it finds on 5 entities; Guanajuato (43%), Michoacán (30%), Jalisco (13%), Mexico City (10%) and Querétaro (4%). On the figure 1 shows that the basin starts since beginning of Lerma river (4600 mams) to mouth on Chapala lake (1600 mams). The basin covers a region of 54.451 Km², approximately 2.75% of the Mexican territory with a population of 10.44 million inhabitants, their main economic activities are high agricultural and industrial production, for domestic and export markets, representing 11.5 % of Mexico GDP (2009). By 2003, the basin generated 53% of all Mexican production in good exports 143 000 million USD per year [6]. It’s considered as fundamental area for Mexico development, generates around 10% of GDP and 10% of population lives in this region. By its dimensions, the Chapala lake is the largest lake in Mexico [7]. It is imperative to say that the lake has international importance, in 2007 was declared like Protected Natural Area due to important area of birds migrating from Canada [8].

Figure 1. Lerma Chapala region and study area.

2.2 Material and methods
The area was selected because is the major economy area and has the largest lake in the country. However, due to its importance in the development has been changed its natural structure involve modifications. Sixty databases were collected from National Water Commission specifically from
National Meteorological Center. The data used is daily maximum and minimum temperature and rainfall for 56 years, since 1960 to 2016.

The mistakes found in the databases, were necessary while processing the information to remove suspects data and databases that didn’t have a density at least 75% of values or mistrust behaving. However, is was applied the homogenization, exist mistakes in the registered of information in meteorological stations like: undergo relocation or changes in observation instruments, rules and methods; the homogenization has moved its focus from the adjustments to climate mean status to the regulations to information about climate extremes; once time, homogenizing the stations with RhTest, was identified and removed data and stations with suspect values, finally, just eighteen stations got the quality control [9].

The parameters were analyzed with statistical methods. The basic for this investigation was moving mean and the trend, the moving mean is the substitution of values depending the observation, it means, with the previous or subsequent data [10]. Subsequently, the study was categorized in representative periods of 30 years (1961 – 1990, 1971 – 2000, 1981 – 2010, 1991 – 2016), was calculated mobile mean and accumulate rainfall; like so, climate change indices like a comparative methodology; this analysis shows specially the change on average through time, on the figure 2 you can see the process followed.

2.3 Analysis
The climate variability calculated with statistics methods by RClimDex, where by lineal regression had given the results of means, tendencies and variances; the result of calculation is showed with graphics and maps. The table 1 shows the eighteen station that get the quality control on Lerma Chapala basin.

| Station | Latitude | Longitude | Date |
|---------|----------|-----------|------|

Figure 2. Methodology for comparing mobile mean and extreme indices.
3. Results and Discussion

3.1 Maximum temperature pattern

The research showed a pattern well defined of trend, first, it was calculated a mean and anomalies per period where it can be observed upward behaviors. The basin counts with different ranges of temperature, depends of the region analyzed. Occurred to studio in general, it was calculated of general way the mean temperature; in the first representative period of 1961–1990 was an average temperature of 25.8° C, however, in the last timeline was a normal temperature of 26.5°, it means, that the temperature has increased 0.7° C. With a positive trend, that indicates an increased behavior (figure 3).

3.2 Minimum temperature pattern

The trend calculated by means of average in each period showed decreasing temperature, on the first period of 1961 to 1990 was an average minimum temperature of 9.8° C, however, on the second range

|    |    |    |    |
|---|---|---|---|
| 11078 | 20.00 | -100.51 | 1960 - 2016 |
| 15029 | 19.862 | -99.918 | 1960 - 2016 |
| 15063 | 19.411 | -99.699 | 1960 – 2016 |
| 15086 | 19.476 | -99.714 | 1960 – 2016 |
| 15104 | 19.855 | -99.968 | 1960 – 2016 |
| 15251 | 19.798 | -99.874 | 1960 – 2016 |
| 15308 | 19.689 | -99.872 | 1960 – 2016 |
| 11033 | 20.848 | -100.826 | 1960 – 2016 |
| 11052 | 20.522 | -101.118 | 1960 – 2016 |
| 11072 | 20.298 | -101.067 | 1960 – 2016 |
| 11142 | 20.28 | -100.9 | 1960 – 2016 |
| 11146 | 20.276 | -101.359 | 1960 – 2016 |
| 14002 | 20.421 | -103.591 | 1960 – 2016 |
| 14016 | 20.395 | -103.136 | 1960 – 2016 |
| 14072 | 20.426 | -103.242 | 1960 – 2016 |
| 14156 | 20.154 | -103.184 | 1960 – 2016 |
| 14168 | 20.228 | -103.569 | 1960 – 2016 |
| 14379 | 20.336 | -103.018 | 1960 – 2016 |

![Figure 3. Average of maximum temperature per representative period of 30 years.](image-url)
was 9.5°C, the lowest period; the two last ranges were 9.5 and 9.6°C, respectively; It had a declined of 0.2°C, a comparison of the first and last period and has a negative trend, due to the reduction on the temperature will generate a driest environment and higher probability of extreme conditions (figure 4).

![Minimum temperature graph](image)

**Figure 4.** Average of minimum temperature per representative period of 30 years.

### 3.3 Rainfall pattern
In the first period analyzed of 1960 to 1990 was the best period with major rainfall, the storm reached up an average of 710 mm annual, nevertheless, over time has been reducing even though the last period is better, it has not been able to reach the first season. The time with lowest value has been 1981 to 2010, however, in the next period increased around 25 mm annual. The trend shows a negative behavior, it means, it forecasts less precipitation on the future, generating driest environment. (figure 5).

![Rainfall graph](image)

**Figure 5.** Average of precipitation per representative period of 30 years.

On the next map (figure 6) we can observe the result of maximum temperature, where the hot area is meanly surrounding of the lake, however, the fresher zone is upstream. It is important to say that the mostly territory has higher temperatures about upstream.
Figure 6. Behavior of maximum temperatures on Lerma Chapala basin from 1960 to 1990.

Compared with the last representative period (figure 7) shows an increased on maximum temperature of 0.6 °C and the highest temperatures are located in Jalisco and the central basin, it should be noted that even though the upstream is lower temperatures also it has suffered an increase of temperatures around 0.9 °C.

Figure 7. Behavior of maximum temperatures on Lerma Chapala basin from 1990 to 2016.
3.4 Climate variability indices

The stations were analyzed by RClimDex with daily information since 1960, and it was applied lineal regression equation for 20 different indices, described on table 2.

| Index     | Description                                           |
|-----------|-------------------------------------------------------|
| TMAXmean  | Maximum temperature means                            |
| TMINmean  | Minimum temperature means                            |
| SU25      | Summer days                                           |
| FD0       | Frost days                                            |
| TXx       | Maximum monthly value of maximum temperature          |
| TNx       | Maximum monthly value of minimum temperature          |
| TXn       | Minimum monthly value of maximum temperature          |
| TNn       | Minimum monthly value of minimum temperature          |
| DTR       | Daytime range of temperatures                         |
| RX1day    | Maximum rainfall on 1 day                             |
| RX5day    | Maximum rainfall on 5 days                            |
| SDII      | Simple index of daily intensity                       |
| R10mm     | Days with regular rainfall                            |
| R20mm     | Days with intense rainfall                            |
| R25mm     | Days with very intense rainfall                       |
| CDD       | Consecutive dry days                                  |
| CWD       | Consecutive wet days                                  |
| R95p      | Very wet days                                         |
| R99p      | Extremely dry days                                    |
| PRCPTOT   | Annual precipitation                                  |

For every parameter, it was analyzed the significance level, mean, trend and variance by a graphic. The results showed a mostly positive behavior, 15 of them are positive and just 4 have a negative behavior with a significance less to 0.05; just annual precipitation showed a major significance, considering unreliable result. However, the figure 8 shows increased behavior on maximum temperature, summer days, maximum value of maximum temperature, minimum value of minimum temperature, diurnal temperatures range, maximum rainfall on 1 and 5 days, simple index of daily intensity, on regular, intensity and very intensity rainfall, consecutive dry days, very wet and dry days and annual precipitation. Nevertheless, there are four negatives values, minimum temperature, maximum value of minimum temperature, minimum value of maximum temperature and consecutive wet days. It should be noted that the graphic value is given by slope rate, generated on RClimDex graphics.
Figure 8. Indices of climate variability

On the figure 9 we can observe a thematic map of maximum temperature, where it shows 12 stations presents an increase trend and only 6 have decreasing behavior. It was classified on 5 ranges; the blue color indicates declining trend and red color growing conduct.

Figure 9. Map of maximum temperatures created with extreme indices.

4. Conclusion
The two different methodologies count with good results, with similar conclusions, however, if the objective is known punctual outcomes, it is better calculated climate indices. Both reflect an increase of maximum temperature, an important decreased of minimum temperature and rainfall. It means, that the two different methods indicated a driest environment, with higher daily means temperatures.

Although some stations had a suspect data with a low significance, some stations were added due to a major trust level; Nevertheless, from the nineteen indices calculated, fifteen show an increased
behavior and only four indicated a negative comportment, the indices with increased values are maximum temperature, summer days, higher rate of maximum temperature, lower date of minimum temperature, mean temperature, maximum precipitation for one and five days, simple index of diary intensity; regular, intense and very extreme rainfall, consecutive dry days, very wet days, extremely dry days and total precipitation. The others four negative indicators were minimum temperature, higher data of minimum temperature, lower value of maximum temperature and consecutive wet days.

The detail of climate indicators helps us to understand better the consequences of the climate variability; where it’s excepted a dominated of extremely climate conditions, the results of this study coincide with the international prognostics. So, we can deduce there is a strong presence of climate variability in Lerma Chapala basin and it predicts extreme situations in the climate; it’s important to increase the techniques and alternatives to avoid important damages in economy development and life quality of the population.

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