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ANALYSIS OF CLIMATE CHANGE EFFECT ON EXTREME PRECIPITATION EVENT IN CONSTANTINE ALGERIA

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ABSTRACT

Extreme precipitation events are critical climatic indicators that offer substantial insights into climate change and its variability. This study aims to investigate whether climate change has impacted precipitation frequencies in the Constantine region of Algeria, known for its semi-arid climate with hot-dry summers and cold-wet winters. Temporal variations of monthly air temperature and precipitation were analyzed from 1981 to 2014. Statistical analysis identified a threshold for estimating monthly extreme precipitation during the period from 1981 to 2005 using the Gumbel distribution method. Additionally, a climatic projection of precipitation for return periods of 50 ($t = 50$) and 100 ($t = 100$) years was conducted to forecast extreme precipitation values in the future. The results indicate a gradual increase in precipitation levels during the study period, with values generally remaining below extreme thresholds. This suggests no significant escalation in the occurrence of extreme precipitation events. Furthermore, the findings highlight that climate change has had a more pronounced impact on altering air temperature than on influencing extreme precipitation trends.

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Introduction.

Climate change has emerged as one of the most critical challenges of our time, with its effects becoming increasingly evident and alarming. These effects transcend mere shifts in weather patterns, demanding significant transformations in the global climate system. Notably, one of the most visible outcomes of climate change is the escalation in the frequency and intensity of extreme weather events, a trend observed since the latter part of the twentieth century (Lazoglou et al., 2019; Liu et al., 2019). This surge in extreme weather phenomena has led to profound environmental and socioeconomic consequences, ranging from habitat loss and species extinction to food and water insecurity, displacement of populations, and increased vulnerability to natural disasters.

Particularly concerning are extreme precipitation events, which have garnered significant attention due to their adverse impacts, including floods, crop damage, and challenges in land cultivation. These events not only disorder ecosystems but also strain infrastructure and resources, intensifying existing vulnerabilities in both urban and rural areas.

According to Gimeno et al. (2022), extreme precipitation events are typically defined based on two main aspects. Firstly, they are defined by their potential to cause disasters, either due to their intensity or their impacts. Secondly, these events are often characterized using statistical approaches that consider the amount of precipitation within a short timeframe. Thus, nonparametric methods are commonly employed among the statistical techniques used, where fixed values or percentiles are used to establish a threshold for extreme events (Anagnostopoulou & Tolika, 2012; Gimeno et al., 2022). Following this statistical method, a series of indices based on daily precipitation data have been developed, where some are defined by specific thresholds, with the index calculated based on the number of days that exceed the threshold within a given period (Gimeno et al., 2022). For example, some researchers (Barbero et al. 2017; Donat et al. 2016; Li et al. 2018) have focused on analyzing these indices such as the maximum precipitation accumulated over one day or five consecutive days in various regions worldwide to estimate the probability of rare events, such as 100-year return values, which are essential for infrastructure design and risk assessment. (Sun et al., 2021).

In Constantine, Algeria, there is a growing interest in extreme weather events (Boudiaf et al., 2020; Guerroudj, 2023). Recent research studies (Sahabi and Matzarakis, 2017; Sahnoune et al., 2021; Taïbi et al., 2022) have mainly focused on extreme air temperature events, showing a significant increase, especially during summers. Given the region's vulnerability to extreme heat, it is important to expand these studies to understand the dynamics of extreme precipitation, which could worsen current challenges and bring new ones.

The aim of the research is to investigate whether climate change has impacted precipitation frequencies in the Constantine region of Algeria, known for its semi-arid climate with hot-dry summers and cold-wet winters, using the statistical method of Gumbel distribution. Understanding the changing precipitation patterns in this region is crucial for developing effective adaptation strategies and informing policymakers about the potential risks associated with climate change.

Methods And Data.

Study Area.

The study was conducted in Constantine, located in North-East of Algeria at a latitude of 36°17′North, an altitude of 7°23′East, and 687m above sea level. Positioned within the (Cfa) zone, Constantine is categorized as having a cold semi-arid climate, characterized by hot, dry summers, and cold, rainy winters according to the Köppen-Geiger climate map (Peel et al., 2007).

As follows from (Fig.1), the hot season spans from June to September, with July being the hottest month, recording maximum temperatures exceeding 40°C. Conversely, the cold season extends from December to February, presenting temperatures ranging from 2.1°C to 19.4°C, with January being the coldest month and registering minimum temperatures below 2°C. A moderate temperature range of 15.08°C to 23.7°C is observed during March, April, October, and November. Mean relative humidity varies throughout the year, from 87% in December and January to 53% in July.

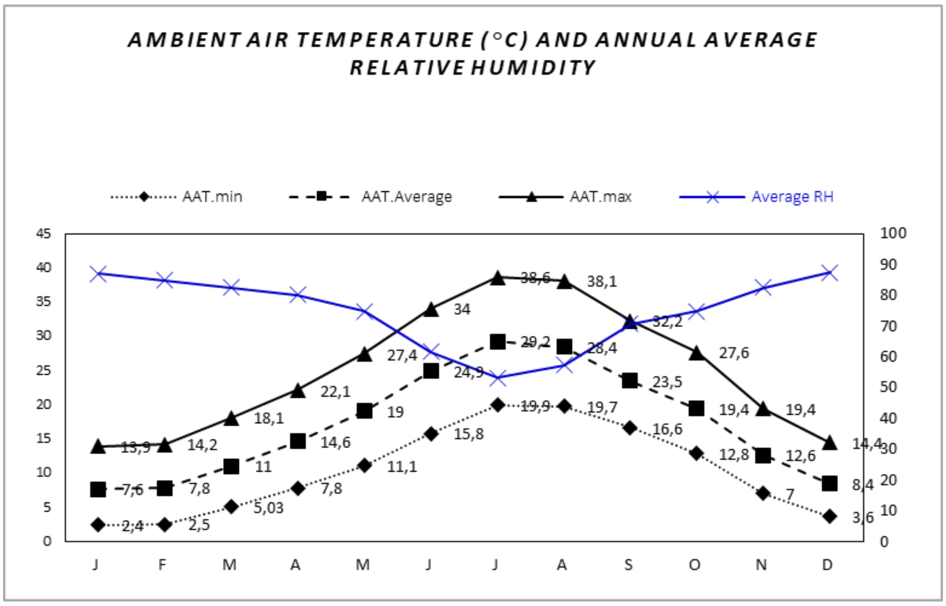

Figure 1. Annual average of air temperature and relative humidity in Constantine.
(Source: Constantine weather forecast center, 2015).

Data used.

To fulfill the study's objective, data for daily air temperature and precipitation from the meteorological station Mohamed Boudiaf International Airport Station were utilized. This station is located at a latitude of 36° 16' 58.80" N, a longitude of 6° 37' 1.20" E, and an altitude of 690 meters (Fig. 2). It is crucial to recognize the limitations of using data from a single meteorological station, as it may not entirely reflect the broader climatic conditions of the region.

Figure 2. Location of the meteorological station of Constantine
(source: Farah &Benderradji, 2014).

Research method.

The research method consists of three main steps. The initial step involves analyzing annual air temperature and precipitation data from 1981 to 2014. The study period was divided into three 12-year intervals: 1981-1992, 1992-2003, and 2003-2014. The aim was to identify long-term trends and historical variations in the selected climatic variables in the study area over time.

The subsequent step involves estimating monthly extreme precipitation events from 1981 to 2005 using the Gumbel distribution method. This method is commonly used to model extreme events, such as heavy precipitation, by fitting historical data to a probability distribution function (Koutsoyiannis, 2003). By applying this method, we can identify and quantify the frequency and magnitude of extreme precipitation events, which are crucial for assessing the potential impacts of climate change on precipitation pattern. The Gumbel distribution function is expressed as follow.

$$\mathbf{F(x)=exp}\left[-\boldsymbol{exp}\left[-\frac{x-\mu}{b}\right]\right] \tag{1}$$

where:
F(x) is the Gumbel cumulative distribution function,
x is the extreme event magnitude
μ is the location parameter (determines where the curve is centered on the horizontal axis),
β is the scale parameter (determines how much the curve is horizontally stretched or compressed).

This equation allows us to estimate the threshold at which extreme precipitation events occur, we used the inverse cumulative distribution function (quantile function) of the Gumbel distribution is as follow;

$$\boldsymbol{\mu} \geq \mathbf{Pmoy+z}\ ((\mathbf{1}-\boldsymbol{\alpha})/\mathbf{2})^{*}\boldsymbol{\delta} \tag{2}$$

where:
μ is the extreme event of precipitation
Pmoy is the mean precipitation
α is the standard deviation which is represent (α =0.05)

Lastly, a climatic projection of precipitation for the period with a return period of 50 (t = 50) and 100 (t = 100) years, respectively, was conducted to anticipate future extreme values that could lead to risk according to the following equation;

$$\mathbf{P} = \frac{\mathbf{1}}{\boldsymbol{\alpha}}\mathbf{Y+x_0} \tag{3}$$

$$\mathbf{Y = -\ Ln}\left[-\boldsymbol{Ln}\left[\mathbf{1}-\frac{\mathbf{1}}{\boldsymbol{T}}\right]\right]$$

where:
Y represent the non-exceedance frequency (FND)
T represents the average time interval between two events where the intensity exceeds a certain threshold
P calculates a certain quantity based on the variable Y.

Results &Discussion.

Temporal variation of climatic parameters.

Across all the divided series, the analysis of air temperature shows a visible warming trend, demonstrated by a consistent rise in temperature values over the years (Fig. 3). This observed warming trend is likely linked to a notable decrease in built-up areas from 1981 to 2014, indicating potential urban development or changes in land use practices (Bourenane & Bouhadad, 2021).

The 2003-2014 series exhibits higher average temperatures for October, August, and June compared to the earlier periods, reaching 28.01°C. This suggests a potential warming trend during these months, which is consistent and culminates in a remarkable increase of 2.96 °C over the ensuing 33 years. This alarming rise, equivalent to approximately 1.8°C per decade, indicates the emergence of a heat island in the studied area, characterized by localized zones with elevated temperatures exceeding those of cooler areas (Khellaf & Abdou, 2021; Sahnoune et al., 2021).

Conversely, lower temperatures in March during the 1992-2003 period were registered compared to the other periods with a value reaching 1.25°C, which could suggest a cooling trend. Temperatures for November and September temperatures are relatively consistent, ranging between 11.48°C and 11.56°C, indicating stability in temperature patterns during these months over the studied years.

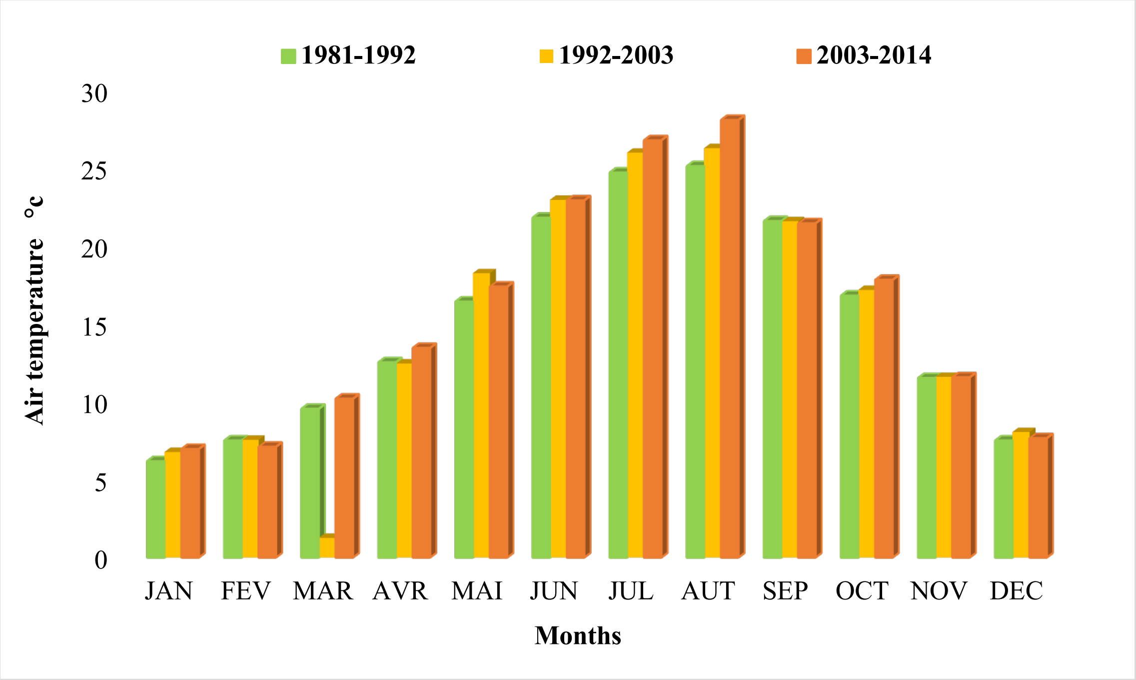

Figure 3. Variation of annual air temperature from 1981-2014.

Regarding the of average monthly precipitation data from three periods (1981-1992, 1992-2003, and 2003-2014) reveals notable trends and variations. Generally, there is consistency in precipitation patterns across the three series, with similar values for most months. However, some seasonal variations are evident, with higher precipitation values typically observed during winter months (November, December, January, February) and lower values during summer months (June, July, august and September).

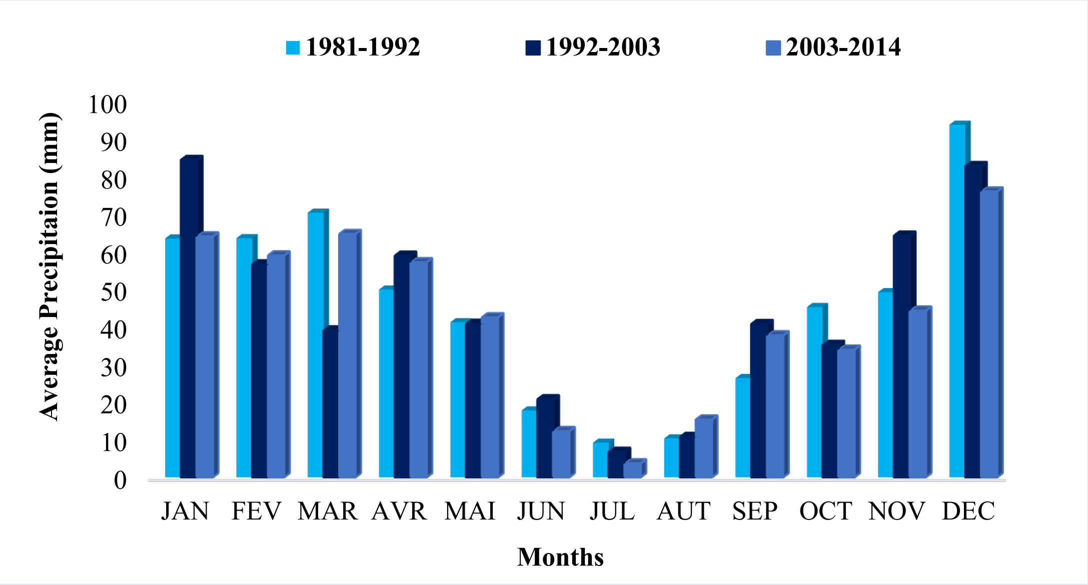

Figure 4. Variation of monthly precipitation from 1981-2014.

Inter-annual variability is also apparent, as slight differences in precipitation values exist between the three series for certain months. For example, the 2003-2014 series shows slightly lower precipitation values for most months compared to the other two series. Overall, while there are fluctuations in precipitation values between the series, there does not appear to be a consistent increasing or decreasing trend in precipitation over the study period.

Extreme precipitation value.

Based on the data obtained for the city of Constantine Ain El Bey regarding daily maximum precipitation from 1981 to 2005, we conducted an evaluation of extreme precipitation events. Our calculations yielded a threshold value equal to or greater than 192.95 mm for daily maximum precipitation, as shown in Table 2.

Table.1. Calculation of threshold value.

Pmoy (mm)	**δ**	**α**	*z*	**μ**
1047,66	24,0186	0,05	3,676	1925,95

The data presented in the Table.3 show the daily maximum precipitation (Pj max) values for the city of Constantine Ain El Bey from 1981 to 2005, along with a calculated threshold value (μ) of 192.95 mm for extreme precipitation events.

Table 2. Comparison of Threshold with the daily maximum precipitation (Pjmax).

Years	**Pj max**	**μ**
1981	94	192,95
1982	105	192,95
1983	98	192,95
1984	111,5	192,95
1985	98	192,95
1986	98	192,95
1987	202	192,95

Table 2. Continuation.

1	2	3
1988	98	192,95
1989	96	192,95
1990	94	192,95
1991	148	192,95
1992	99	192,95
1993	95	192,95
1994	89	192,95
1995	94	192,95
1996	99	192,95
1997	95	192,95
1998	98	192,95
1999	99	192,95
2000	138	192,95
2001	84	192,95
2002	96	192,95
2003	99	192,95
2004	96	192,95
2005	93	192,95

The analysis of these results shows that the Pj max values vary from year to year, indicating fluctuations in extreme precipitation events over the studied period. Notably, the year 1987 stands out with a particularly high Pj max value of 202 mm, suggesting an intense precipitation event during that year.

Additionally, by comparing the Pj max values to the threshold, we can assess the frequency and severity of extreme precipitation events over the years. Years with multiple occurrences of Pj max values exceeding the threshold may indicate periods of increased risk for extreme precipitation in the region.

As mentioned, the calculated threshold value of 192.95 mm provides a reference point for identifying extreme precipitation events. Therefore, the Pj max value equal to or exceeding this threshold can be considered an extreme event.

Future Projections of Precipitation.

The Gumbel distribution was used following the previously detailed steps to arrive at the relationship that allows us to calculate the forecast for the coming years, as shown in the following graph in (Fig.5).

The relationship we have obtained has allowed us to calculate the projection of precipitation (the return period). It is described as follows:

$$\mathbf{P = 18.73x + 93.85} \tag{4}$$

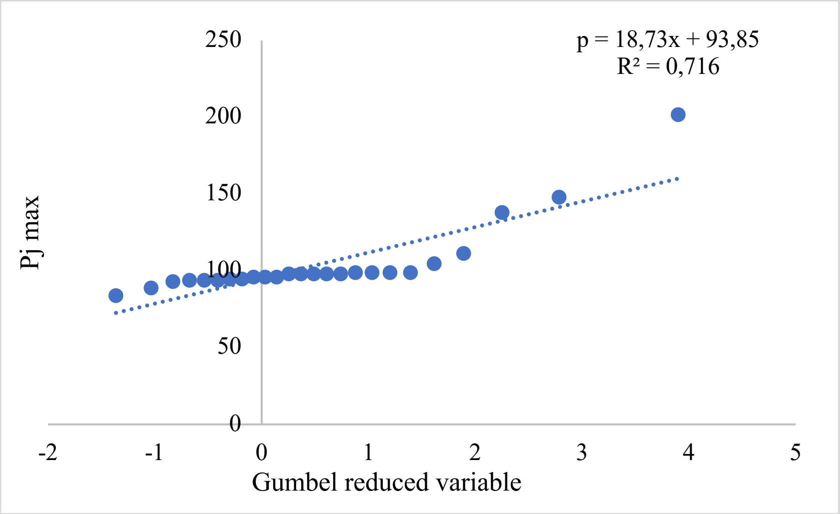

Figure 4. Graphical representation of Pj max and Gumbel reduced variable.

The calculated precipitation values for the first two series from 2006- 2016 for the first series and from 2017-2026 for the second series are presented in (Tab.3) and (Tab.4) respectively. Additionally, the extrapolated results for years t = 50 and t = 100 are provided in (Tab.5).

Table 3. Calculation of precipitation future projections during the Period (2006-2016).

Years	**T**	**FD**	**FND**	**Y**	**P (mm)**
2006	19	0,05263158	0,94736842	2,9175	148,49
2007	20	0,05	0,95	2,9701	149,48
2008	21	0,04761905	0,95238095	3,0202	150,42
2009	22	0,04545455	0,95454545	3,0678	151,31
2010	23	0,04347826	0,95652174	3,1133	152,16
2011	24	0,04166667	0,95833333	3,1568	152,98
2012	25	0,04	0,96	3,1985	153,76
2013	26	0,03846154	0,96153846	3,2385	154,51
2014	27	0,03703704	0,96296296	3,277	155,22
2015	28	0,03571429	0,96428571	3,314	155,92
2016	29	0,03448276	0,96551724	3,3498	156,59

Table.4. calculation of future precipitation projections during the period (2017-2026).

Years	T	FD	FND	Y	P (mm)
2017	30	0,03333333	0,96666667	3,3843	157,24
2018	31	0,03225806	0,96774194	3,4176	157,86
2019	32	0,03125	0,96875	3,4499	158,47
2020	33	0,03030303	0,96969697	3,4811	159,05
2021	34	0,02941176	0,97058824	3,5114	159,62
2022	35	0,02857143	0,97142857	3,5408	160,17
2023	36	0,02777778	0,97222222	3,5694	160,70
2024	37	0,02702703	0,97297297	3,5972	161,23
2025	38	0,02631579	0,97368421	3,6242	161,73
2026	39	0,02564103	0,97435897	3,6506	162,23

Table.5. Calculation of future precipitation projections of 50 (t = 50) and 100 (t = 100) years.

Years	**T**	**FD**	**FND**	**Y**	**P (mm)**
2037	50	0,02	0,98	3,9019	166,93
2087	100	0,01	0,99	4,6001	180,01

The analysis of the results reveals a decrease in the frequency of extreme events, as indicated by the exceedance frequency (FD) values, with higher precipitation thresholds corresponding to less frequent extreme events. Additionally, the non-exceedance frequency (FND) shows a decrease in the intensity of extreme events relative to the threshold. This suggests that extreme events are becoming less intense compared to the threshold value.

Over the studied years (2006-2026), there is a general trend of decreasing FND and FD values, indicating a potential decrease in the frequency and intensity of extreme precipitation events over time. Inferring these trends to t = 50 (2037) and t = 100 (2087) shows a continuation of this pattern, with even lower FND and FD values anticipated in the future, which suggest a shift towards less frequent and less intense extreme precipitation events in the study area. These results can be related to the climate characteristics of the region, where precipitation is generally limited and irregular in a semi arid climate, leading to less frequent and intense precipitation events compared to regions with more abundant precipitation. Additionally, higher evaporation rates and lower moisture availability, typical of semi-arid climate, may further limit the potential for extreme precipitation event to occur.

Conclusion.

This study aimed to analyze the impact of climate change on extreme precipitation events in the Constantine region of Algeria from 1981 to 2014, using the Gumbel distribution method. The analysis revealed an increase in the frequency and intensity of precipitation over the study period. However, this increase did not exceed the threshold for extreme precipitation events, indicating a shift in the distribution of precipitation extremes. This observed pattern contradicts the expectations of climate change models, which anticipate alterations in precipitation patterns due to warming temperatures and changing atmospheric dynamics.

Additionally, a significant increase in air temperature frequency was observed during the study period, particularly noticeable in summer. These results underscore the importance of implementing practical measures in response to changing air temperatures driven by climate change.

However, this research is limited by the method used, the Gumbel distribution, which considers only one extreme value per year, resulting in the exclusion of several extreme events. Future work will be directed towards determining extreme values using alternative approaches such as detailed spatial analysis that could provide insights into the localized impact of these events.

Declaration of Interest Statement.

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendices

Appendix 1. Monthly Air Temperature Data (°C) for the Period 1981-2014.

Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug.	Se	Oct	No	Dec
1981	4,5	6,9	12	14	17,4	21,4	22,9	23,7	21	17,6	10,2	9,4
1982	7,8	7,5	8,7	11	16,1	24,4	27,7	24,7	21	16	10,8	6,2
1983	5,2	6,7	9,1	14	17,6	22	27,3	24,6	21,4	15,8	12,5	7,7
1984	6,8	5,9	7,9	13	15,2	21,6	16	23,5	20,3	14,2	11,9	7
1985	5,3	10	7,7	13	15,4	23	27	24,7	20,1	15,7	12,5	7,8
1986	6,2	7,6	9	12	19,1	20,9	24,2	26,2	20,9	16,7	10,5	6,5
1987	6,1	7,1	8,6	14	14,8	21,7	25,7	27,2	23,9	19,2	10,7	9,6
1988	8,4	7	9,2	14	18,4	21,5	26,7	26	20,3	18,5	12	6
1989	5,8	7,8	11	12	16,6	20,5	25,5	26,2	21,4	16,1	13	10,9
1990	6,8	10,4	11	12	17,1	24,1	24,5	23,5	24,3	18,5	11,4	5,7
1991	5,9	6,1	11	9,9	12,9	20,7	25,5	25,4	22	16,1	10,4	5,8
1992	5,1	6,8	8,9	11	16	19,2	22,7	24,9	21,8	16,7	11,9	7,1
1993	5	5,8	8,6	12	17,3	22,6	25,4	26,2	21,7	17,8	10,9	7,8
1994	7,5	8,3	11	10	19,7	22,5	26,7	28,7	22,9	16,8	12,7	7,9
1995	5,9	9,7	9	11	18,2	21,9	25,9	24,5	20,7	16,7	11,5	10,1
1996	9,1	6,5	10	12	16,4	19,7	24,9	25,6	19,3	14,5	12,2	9,6
1997	8,3	9,1	9,1	12	19,9	24,9	25,5	25,3	21	16,7	11,7	8,3
1998	7,1	8,1	9,4	13	16,2	23,6	26,5	25,4	22,2	14,5	10	6,4
1999	7,1	5,5	10	13	21	24,2	25,4	28,8	23,1	19,3	10,4	7,5
2000	4,6	8,2	11	15	20,1	22,3	26,9	26,4	21,9	15,9	12,3	9,1
2001	8	7,4	14	12	17,2	23,8	27,1	26,3	21,6	20,2	10,9	6,6
2002	6,4	8,6	11	14	18,7	24,8	25,6	25	21,3	17,9	12,3	9,2
2003	7	6,3	11	14	17,7	25,3	28,4	27,4	20,9	18,6	12	6,8
2004	7,2	8,8	10,6	11,9	15,1	21,4	25,7	26,9	21	19,4	9,9	7,9
2005	4,6	4,7	10,8	13,2	19,2	23,9	26,8	24,6	21,1	17,8	11,8	7
2006	5,5	6,9	11	15,6	20,1	24,9	26,8	24,4	21	19,1	12,5	8,4
2007	8,3	9,4	9	13,4	17	23,2	26,2	25,9	21,2	16,9	9,9	6,8
2008	7,4	8,2	9,7	13,6	18,3	21,8	27,1	26,2	21,7	16,9	10,3	6,8
2009	7,1	6,5	9,4	10,9	17,7	23	28,3	25,6	19,9	15,3	11	9,8
2010	7,8	9,1	10,5	13,6	15,3	21,2	26	25,5	20,6	16,4	11,6	8,2
2011	7,2	6,5	9,9	14,5	16,9	21,3	26,2	26,5	22,1	15,8	12,1	7,7
2012	6,2	3,7	10,1	12,7	17,8	25,6	27,4	28,3	21,7	18,4	12,9	7,8
2013	6,9	5,9	11,2	13,8	16,1	20,2	26	24,5	21,3	20,1	10,5	7
2014	8,1	8,9	8,7	13,7	16,9	22,6	25,6	26,3	24,2	18,5	13,9	7,3

Appendix 2. Monthly Precipitation Data (mm) for the Period 1981-2014.

Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Se	Oct	No	Dec
1981	86,3	70,4	41,2	94,9	17,9	20,8	0,8	20,4	47,7	31,3	26,6	62,4
1982	86,9	73,6	99,9	64,6	47,2	14,9	3,6	6,1	17,8	62,6	82,7	103,6
1983	11,7	15,3	59,9	6,8	25,7	3,9	8,1	10,8	7,1	35,4	46,4	21,6
1984	132,6	164,3	31,2	43,6	9,8	10,8	6,5	3,4	24,2	115	6,1	335,1
1985	67,8	27,3	157,4	20,6	63,2	1,1	0,6	1,4	39,2	30,9	26,8	26
1986	99,9	31,9	90,5	29,2	9,5	23,8	3,3	5,6	37,7	43,1	78,6	108,3
1987	48,5	129,8	86,1	22	43,3	27	25	8,4	3,1	53,7	36,5	15,3
1988	66,8	47	62,5	37,3	41,2	56,6	14,3	2,6	31,9	4,1	17,7	130
1989	31	44,3	48,9	51,9	31,2	22,4	25,8	27	21,6	45,5	15,3	7,8
1990	56	57,9	23,3	33,6	26,7	12,4	1,8	26,3	21,3	9,5	115,4	99,9
1991	20,9	67,1	92,8	59,3	81	8,5	3,1	1,5	43,7	88,3	21,8	21
1992	52,8	33,2	49,5	134,5	97,3	10,7	17,3	10,3	20,6	22,9	116,1	192,8
1993	49,5	58	25,5	12,3	52,8	3	2,9	4,8	22,1	11,9	22	126,6
1994	66,1	87,5	18,1	78,8	6	0	0,3	2	28,8	90,6	24	49,4
1995	216,1	17,5	84,7	30,1	5,9	52,4	0	1,2	47,5	8,3	42,5	28,4
1996	88	181	54	67	62	42	21	15	15	10	26	47
1997	33,1	22,4	59	57,7	18	33,2	1,2	17,2	38,9	50,2	110	65,5
1998	36,4	52,7	37,4	70,8	49,6	18,3	6,5	8,9	75,2	32,6	135,3	53,1
1999	73,7	42,1	57,6	31,7	10,5	20,4	3,3	7,7	58,7	35,7	79,2	93,6
2000	17,4	36	14,4	32,9	84,4	43,6	6,5	15,7	18,4	38,3	31,7	57,7
2001	123,4	44,7	17,6	38,3	52,9	18,9	0,2	10,4	79,2	48,3	28,5	20
2002	23,5	53,3	18,2	31,8	17	4,5	19,4	24	22,3	26,8	134,7	109,7
2003	231,2	50,2	31,7	120,1	44,4	1,2	2,4	11,1	61,5	46	19,8	148
2004	87,2	11,5	66,4	47,5	66,2	29,7	0,6	12,9	24,5	30,4	142,9	181,2
2005	46	55,8	28,7	61,4	6,8	13,9	7,9	6,8	14,4	2,1	18,6	63,1
2006	78,9	50,3	33,4	14,7	83,8	3,6	0,9	18,6	26,2	10	19,1	118,8
2007	14,2	28,9	117,8	66,2	26,1	13,6	4,3	2,4	59,9	39,1	23,8	84,4
2008	9,9	8,7	72,6	23,1	58,2	5,8	11,3	33,9	38,8	21	37,6	27
2009	76,4	48,6	81,1	113,3	43,4	0	2	37,5	103,9	49,4	24,9	47,1
2010	74	30,5	46,9	67,2	50	16,5	2	8	37,3	48,1	76,4	33,7
2011	8	174,5	65,4	66,4	40,6	24,2	7	5,2	13,4	87	26,8	53,3
2012	34,6	104,6	52	68,4	19,5	6,2	1,8	10,5	36,2	33,4	29,4	19
2013	64	111,9	47,4	31	10	17	2,6	36	23	26,8	86,2	29,6
2014	42,8	31	131,7	5,7	60,3	14,8	1	0,4	12,8	13	25,1	105,4