LA GRANJA:
REVISTA DE
CIENCIAS DE LA VIDA
pISSN:1390-3799; eISSN:1390-8596
http://doi.org/10.17163/lgr.n25.2017.02

Artículo científico / Scientific paper

CIENCIAS DE LA TIERRA

HEAVY RAINFALL AND TEMPERATURE PROYECTIONS IN A CLIMATE CHANGE SCENARIO OVER QUITO, ECUADOR

PROYECCIONES DE LLUVIA Y TEMPERATURA EXTREMA EN ESCENARIOS DE CAMBIO CLIMÁTICO SOBRE QUITO, ECUADOR

Sheila Serrano Vincenti[1,*], Jean Carlos Ruiz[2] and Fabián Bersosa[3]

[1] *Grupo de Investigación en Ciencias Ambientales GRICAM, Centro de Investigación en Modelamiento Ambiental CIMA-UPS/ Universidad Politécnica Salesiana/Red de Universidades Frente al Cambio Climático y Gestión de Riesgos, Quito, Ecuador.*
[2] *Escuela Politécnica Nacional/Red de Universidades Frente al Cambio Climático y Gestión de Riesgos, Quito, Ecuador*
[3] *Grupo de Investigación en Ecología y Gestión de Áreas Protegidas, Centro de Investigación en Modelamiento Ambiental CIMA-UPS/ Universidad Politécnica Salesiana/Red de Universidades Frente al Cambio Climático y Gestión de Riesgos, Quito, Ecuador.*

*Autor para correspondencia: sserranov@ups.edu.ec

Manuscrito recibido el 14 de noviembre de 2016. Revisado el 14 de diciembre de 2016. Aceptado el 30 de diciembre de 2016. Publicado el 31 de diciembre de 2016.

Abstract

This research analyzes daily extreme events of minimum, maximum temperatures and rain in the Metropolitan District of Quito using data of more than 30 years from the meteorological network of INAMHI (Instituto Nacional de Meteorología e Hidrología de Ecuador) using the R- ClimDex computer program. A scenario for the year 2032 combining statistical results of extreme events and physical forcing from PRECIS scenarios A2 and B2 is also presented; using the extreme value theory from extReme computer program. The results showed an increase in extreme minimum and maximum monthly temperature values in both, magnitude and frequency; and an increase in the intensity of heavy rainfall. Projections to 2022 maintain this behavior, with results that should be taken into account by policy makers and scientists due to the danger they mean for Quito's ecosystem.

Keywords: extreme values, precipitation; temperature, Metropolitan District of Quito, climate change scenarios

---

LA GRANJA:*Revista de Ciencias de la Vida* 25(1) 2017:16-32.

Resumen

Esta investigación analiza eventos extremos a nivel diario de temperaturas mínimas, máximas y lluvias en el Distrito Metropolitano de Quito utilizando datos con más de 30 años de la red meteorológica del INAMHI (Instituto Nacional de Meteorología e Hidrología de Ecuador), y utilizando el programa R-ClimDex. Se presentan escenarios el año 2032 combinando resultados estadísticos de eventos extremos con el forzamiento físico de los escenarios A2 y B2 del modelo de cambio climático PRECIS A2 y B2, y utilizando la teoría de valores extremos del programa extReme. Los resultados mostraron un incremento en los valores mensuales mínimos y máximos de temperatura tanto en magnitud y frecuencia; además de un aumento en la intensidad de lluvias extremas. Las proyecciones para 2032 mantienen este comportamiento, con resultados que deben ser tomados en cuenta por los tomadores de decisión y científicos debido al peligro que significan para el ecosistema de Quito.

Palabras claves: valores extremos, precipitación; temperatura, Distrito Metropolitano de Quito, escenarios de cambio climático.

Forma sugerida de citar: Serrano, S., J. C. Ruiz and F. Bersosa. 2017. **Heavy rainfall and temperature proyections in a climate change scenario over Quito, Ecuador.** La Granja: Revista de Ciencias de la Vida. Vol. 25(1):16-32. pISSN:1390-3799; eISSN:1390-8596.

1 Introduction

The last report of the Intergovernmental Panel on Climate Change (IPCC AR5, 2014) indicated that there is a change in frequency and intensity of extreme weather events such as heat waves, intense precipitation, flooding, etc., in various regions of the world as a result of global climate change. These changes are particularly important for society and the environment, since by definition, they are outside the range of usual ecosystem adaptability, and thus can lead to severe impacts in biodiversity, agriculture, health infrastructure and economic losses (García *et al.*, 2012).

Particularly, a general increase of temperature in Latin America was reported (Samaniego *et al.*, 2009). It was also registered an increase in temperature of one tenth of a degree per decade over the Andes (Martínez *et al.*, 2009); studies of Ecuadorian weather have shown that the temperature is gradually increasing over the region (Vuille *et al.*, 2008; cited in Villacis *et al.*, 2012). And studies have shown an increase of temperature in the four regions of Ecuador (Nieto *et al.*, 2002; Cáceres, 1998). On the DMQ Zambrano-Barragán *et al.* (2010), and Villacis (2008), reveal an increase of annual temperature by 0.12°C per decade over a period of the last 100 years.

1.1 Extreme events indexes

In addition to the gradual behavior of a variable such as temperature, extreme events should also be recorded. The CCI / CLIVAR / JCOMM (Expert Team on Climate Change Detection and Indices) proposed a methodology which includes the RClimDex program for study extreme events in a climate change scenario (Karl *et al.*, 1999; Peterson, 2001).

Thus, using RClimDex over the Metropolitan District of Quito DMQ, three possible threats related to climate change were identified: the extreme values of maximum and minimum daily temperatures all over the region, and the intensity of rainfall over the 90th percentile in the south and southwest of the DMQ. This analysis was constructed using available data from weather stations of INAMHI (Instituto Nacional de Meteorología e Hidrología de Ecuador) of the past 47-48 years (except station Tomalón-Tabacundo) with 21 years, located in four points of the District (Table 1). The trends are shown in Table 2.

When studying extreme values, it is necessary to change the statistical distribution because intense climate extreme events are more frequent than expected by normal distributions (Gilleland and Watts, 2005). The National Science Foundation (NSF) through the National Center for Atmospheric Research (NCAR), the Weather and Climate Impact Assessment Science Initiative, and the NCAR Geophysical Statistics Project (GSP), have recommended the use of the Extreme Value Theorem (EVT) and developed tools for the study of extreme weather events included in a specific software called eXtreme.

Table 1. Available weather stations with daily data selected for the study.† Cotopaxi-Clirsen station not presented continuous data.

Station	Code Station	Latitude	Longitude	Altitude (m.a.s.l.)	From	To	Temporal range
Izobamba	M003	0°22’S	78°33’W	3058	1964	2011	47
Papallacta	M188	0°21’54”S	78°8’41”W	3150	1963	2011	48
Tomalón-Tabacundo	MA2T	0°2’N	78°14’W	2790	1990	2011	21
†Cotopaxi-Clirsen	M120	0°37’24”S	78°34’53”W	3510	1964	2011	47

Table 2. Annual trends of each R-Climdex indicator of climate change for extreme temperatures and precipitation for the four weather stations of DMQ and surroundings, *mean values with a significance superior to 90% (p<0.2).

INDEX	**Izobamba** M003	**Papallacta** M121	**Tomalón-Tabacundo** M188	**Cotopaxi-Clirsen** MA2T
Maximum daily minimum temperature [°C/year] (TNx)	0.03^*	0.095	0.067^*	0.051
p-value	0	0.404	0.033	0.243
Maximum daily maximun temperature (TXx) [°C/year]	0.01^*	–	0.031^*	0.125^*
p-value	0.2		0.11	0.001
Number of heavy precipitation days (greater than 10 mm/day) [day/year] (R10 mm)	0.16^*	0.049	-0.063	-0.037
p-value	0.135	0.756	0.796	0.863
Number of very heavy precipitation days (20 mm/day) (R20 mm) [day/year]	0.135^*	0.057^*	-0.127	-0.137^*
p-value	0.005	0.038	0.464	0.028

Table 3. Studied ecosystem classification in DMQ.

Station/Code	Ecosystem Classification	Altitudinal Variation (m.a.s.l.)	Minimum Annual Temperature (°C)	Maximum Annual Temperature (°C)	Annual Precipitation (mm)
Izobamba/M003	Artificial urban areas	2400-3100	10	16	960 (Murray, 1997)
Papallacta/M188	High montane evergreen forest. Polylepis Upper montane Andean north forests Polylepis (Josse *et al.*, 2003)	4100-2900	6	17	922 (Baquero *et al.*, 2004; cited in MECN, 2009)
Tomalón-Tabacundo/ MA2T	Espinar dry montane (Valencia *et al.*, 1999), Matorral semi humid montane forest (Valencia *et al.*, 1999) y (Baquero *et al.*, 2004)	2000-3000	5	18	575 (Josse *et al.*, 2003; cited in MECN, 2009)

1.2 Ecosystem description of the sample points

The DMQ is characterized by a great climatic and orographic variety, with the northwestern tropical, desert in the Guayllabamba Valley, the inter-andean permanently clouded forest in the cold mountain to urbanized city of Quito between the mountains that surround it. Giving as result a wide variety of ecosystems. However, due to the nature of the research, daily station data available only describe three types of ecosystems –with enough confidence–, which are presented in Table 3.

1.3 Generalized Extreme Value Distribution

Let $X_1,\ldots,X_n$ be a sequence of independent random variables, and let $M_n = \max\{X_1,\ldots,X_n\}$ the maximum (or minimum) values measured on a regular timeline, so M_n represents the extreme values of the process in n time units of observation. For this data, and using a linear renormalization, the distribution of the set of M_n is given by the Generalized Extreme Value (GEV), which has the form:

$$G(z) = \exp\left\{-\left[1+\xi\left(\frac{z-\mu}{\sigma}\right)\right]^{-\frac{1}{\xi}}\right\} \tag{1}$$

where $\left\{1+\xi\left(\frac{z-\mu}{\sigma}\right)>0\right\}$ and $(-\infty<\mu<\infty)$, $\sigma>0$, $(-\infty<\xi<\infty)$ are the parameters of location, scale and shape respectively (Coles, 2004).

This distribution depends on the sign of ξ, if $\xi<0$ we have the Weibull distribution, usually associated with temperature data if $\xi=0$, we have the Gumbel distribution, and if $\xi>0$ it is a Fréchet distribution, commonly used to simulate the behavior of precipitation (García *et al.*, 2012).

An advantage of GEVD is the possibility of a non-stationary model, allowing a time-dependent distribution by the parameter μ_1:

$$\mu(t) = \mu_0 + \mu_1 t. \tag{2}$$

The parameter μ_1 corresponds to the change of the location parameter, and could simulate the increasing or decreasing effects of climate change on weather variables.

1.4 Climate change models

In order to simulate the behavior of climate change in the planet, Global Circulation Models (GCM) were implemented by supercomputers, with horizontal resolutions of 300 km. In order to understand the behavior of the weather at smaller scales, there are Regional Climate Models (RCM), which work with scales of 50 km or less, allowing for more precise characteristics of the land surface and complicated mountainous topography, coastlines and the inclusion of small islands and peninsulas.

RCMs are very complete dynamic models, based on the physics of the climate system, and virtually represent all processes, interactions and feedbacks between climate systems and the components of the GCMs (PRECIS, 2004).

An example is PRECIS (Providing Regional Climates for Impacts Studies), which is a regional climate modeling system developed by the Hadley Centre of the Met Office in the United Kingdom. It is a free software that allows the use of high-resolution data in impact, vulnerability and adaptation studies as recommended by the United Nations Framework Convention on Climate Change (Articles 4.1, 4.8 and 12.1).

PRECIS works with HadCM GCM model, which is forced by surface boundary conditions such as sea surface temperature and sea-ice fraction. It has two time periods: 1960-1990 a base time or "control" period, used for comparisons with real data; and 2000-2100, period used for forecasting. According to the IPCC (2001), circulation models are suggested to work with the A2 and B2 future scenarios agreeing to the economic and productive behavior of the planet and the possible incorporation of clean technologies. Where B2 scenario describes a world with a greater emphasis on local solutions to economic, social and environmental sustainability than A2. Both should be considered equally right. The scenarios do not include additional climate initiatives. In this work, these two scenarios are used.

2 Materials and methods

2.1 DGVE, return levels and confidence intervals with real data

This study recorded maximum and minimum temperatures in four stations, which were the only available in to DMQ with sufficient temporal range (more than 30 years) and daily resolution; as shown in Table 1, their behavior and trends were calculated using R-Climdex (Serrano *et al.*, 2012), and then used to calculate the climate change indexes shown in Table 2. With these outputs, and using the extReme software and DGVE functions, future behaviors were estimated of the maximum allowance for extreme events of rain and temperature, with return levels for 2, 5, 10, 15 and 20 years and confidence intervals of 95 %, for both A2 and B2 scenarios since 2012.

2.2 Fitting PRECIS data for each scenario

In order to determine the validity of PRECIS, its gridded outputs for temperature, were used in the "control" period from 1960 to 1990 and compared with similar temporal periods for each station. A linear correlation for both the observed data and the modeled by PRECIS was made, finding the slope, the intersection in the middle of the series and the p-value for each case and achieving a correction factor by the difference in to the middle of the studied series (Table 4).

3 Results

3.1 Analysis of Maximum Temperatures by meteorological station

3.1.1 Izobamba

In Figure 1 the behavior of the maximum monthly value of the daily maximum temperature (TXX) in Izobamba, analysis achieved by R-ClimDex is shown. The trend of 0.01oC per year is statistically significant at 76.3 % (Serrano *et al.*, 2012).

Table 4. Correction factor by available meteorological station, between PRECIS time series and observed data, for temperature.

Observed data				Control PRECIS			Correction factor
Station	Slope	p-value	Intersection	Slope	p-value	Intersection	PRECIS-Observed data
M003	1,08E-05	0,0089	11,93	4,13E-05	8,27E-67	11,64	0,294970646
M180	3,92E-05	4,27E-14	9,76	4,34E-05	2,47E-45	10,11	-0,352601947
M120	1,6693E-04	2,19E-22	11,93	4,50E-05	1,45E-72	10,16	-0,712912888

Figure 1. Behavior of annual maximum of daily maximum temperature (TXX) in Izobamba.

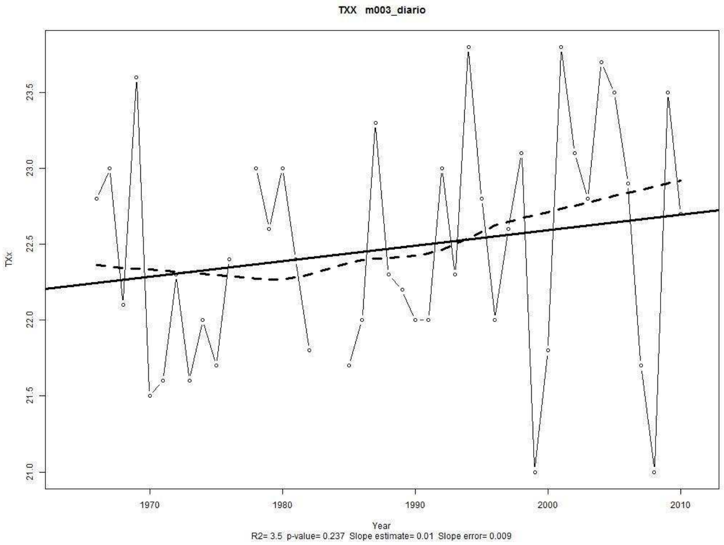


Figure 2. Adjusting of the maximum annual value of daily maximum temperature (TXX) in Izobamba for DGVE Weibull type distribution. The first two upper graphs show the proper fit of the model, while the lower left and right graphs show the return periods with confidence limits of 95% (blue line) and the probability density distribution.

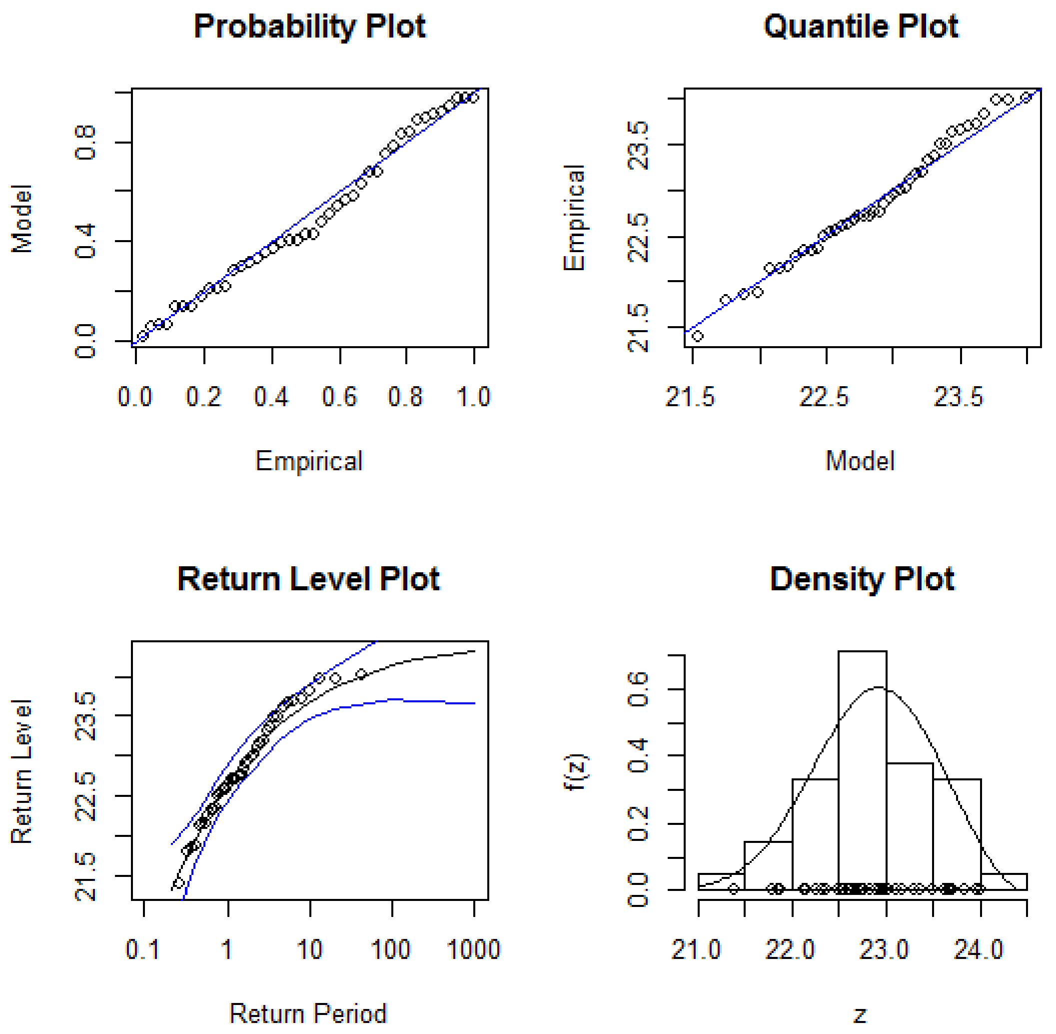


Figure 2 shows the data set to a covariant DGVE where the results, after the maximum likelihood method, indicate that the location parameter varies over time like: $\mu = 22{,}65353(0{,}11592) + 0{,}01t$ the scale parameter is $\sigma = 0{,}65709(0{,}08777)$, and the shape parameter is $\xi = -0{,}36045(0{,}14134)$, following a Weibull distribution. The maximum likelihood was 0.01303611, and the p-value has a significance value above 98%. Values in parentheses indicate the standard deviations of each parameter.

Return values and confidence limits for the Izobamba data studied up to 100 years are presented in the lower part of Figure 2, but in detail, and for 2022 year are shown in Table 5. The value of the shape parameter for all periods is $\xi = -0{,}3604(-0{,}61849, -0{,}10241)$. Also, the settings of trend data achieved with PRECIS for A2 and B2 scenarios are presented in Table 4 The value of the shape parameter for all periods is $\xi = -0{,}1751(-0{,}31983, 0{,}02098)$ to A2; and $\xi = -0{,}2264(-0{,}40246, -0{,}03666)$ to B2.

Table 5. Return periods, return levels and confidence intervals at 95 % for the actual data of maximum temperatures in Izobamba.

Return	**Observed**			**PRECIS A2**			**PRECIS B2**		
period (years)	Return level [°C/day]	LI [°C/day]	LS [°C/day]	Return level [°C/day]	LI [°C/day]	LS [°C/day]	Return level [°C/day]	LI [°C/day]	LS [°C/day]
2014	22.879	22.652	23.1144	23.133	22.91	23.3696	23.168	22.8978	23.4483
2017	23.414	23.1986	23.6392	23.807	23.551	24.1132	23.9056	23.6147	24.2505
2019	23.666	23.4628	23.9786	23.999	23.7303	24.3542	24.1082	23.8077	24.5028
2022	23.781	23.5809	24.1296	24.185	23.9005	24.6095	24.2996	23.9878	24.7644
2027	23.851	23.6515	24.2306	24.377	24.0736	24.9012	24.494	24.1674	25.0563
2032	22.879	22.652	23.1144	24.503	24.1851	25.0895	24.6195	24.2809	25.2437

Table 6. Return periods, return levels and confidence intervals at 95 % for analyzed data and both A2 and B2 scenarios of PRECIS, for the maximum annual temperatures in Tomalón-Tabacundo.

Return	**Observed**			**PRECIS A2**			**PRECIS B2**		
period (years)	Return level [°C/day]	LI [°C/day]	LS [°C/day]	Return level [°C/day]	LI [°C/day]	LS [°C/day]	Return level [°C/day]	LI [°C/day]	LS [°C/day]
2014	27.7286	27.1488	28.3307	28.5509	28.2998	29.5172	28.0392	27.4989	28.0392
2017	28.6298	28.0676	29.3502	29.2193	29.0496	29.5375	28.7569	28.2599	29.3245
2019	28.858	28.3054	29.7135	29.3278	29.2666	29.6931	28.9228	28.4614	29.5541
2022	29.0654	28.5221	29.9473	29.4081	29.2859	29.825	29.0671	28.6424	29.67
2027	29.2674	28.7319	30.2188	29.4709	29.4015	29.7692	29.2013	28.8123	29.8465
2032	29.3929	28.8606	30.4183	29.5028	29.4487	29.7336	29.2812	28.9124	29.9996

3.1.2 Tomalón-Tabacundo

The same statistical treatment as performed to Izobamba was applied, and was recorded the highest slope of DMQ (0.125°C / year) with a statistical significance of 0.999 %. By simulating the data with a covariant DGVE the maximum likelihood method indicate a temporal variation of the location parameter: $\mu = 27{,}35713(0{,}29314) + 0{,}125t$, the scale parameter was $\sigma = 1{,}07630(0{,}21311)$, and the shape parameter was $\xi = -0{,}33074(0{,}19109)$, showing that these data follow a Weibull distribution; the p-value was 0.1150664. The return levels and confidence limits of the observed data and for the A2, B2 scenarios is presented in Table 6.

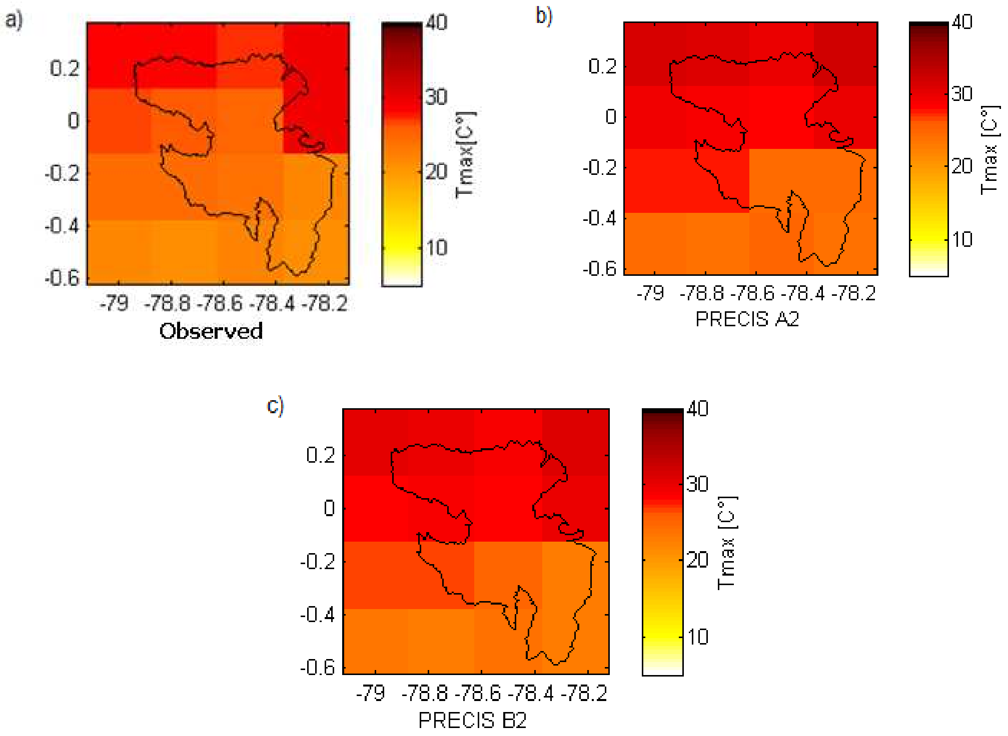
3.1.3 Papallacta

In the serie of the maximun value of maximun temperature there is a positive trend of 0.031°C/year, with a statistical significance of 0.89 %. The simulation a covariant DGVE and using the maximum likelihood method indicate that the location parameter varies over time as $\mu = 19{,}39455(0{,}26281) + 0{,}031t$, the scale parameter $\sigma = 0{,}96090(0{,}19836)$, the shape parameter $\xi = -0{,}28744(0{,}22732)$, showing that these data follow a Weibull distribution, the value-p-value 0.2363144, significant at 76 % level. Comparison of return levels and confidence intervals for the two scenarios and the observed data is presented in Table 7.

Table 7. Return periods, return levels and confidence intervals at 95% for analyzed data and both A2 and B2 scenarios of PRECIS for the next 20 years, for the maximum annual temperatures in Papallacta.

Return	**Observed**			**PRECIS A2**			**PRECIS B2**		
period (years)	Return level [°C/day]	LI [°C/day]	LS [°C/day]	Return level [°C/day]	LI [°C/day]	LS [°C/day]	Return level [°C/day]	LI [°C/day]	LS [°C/day]
2014	19.7288	19.2086	20.2856	20.0045	19.4826	20.6801	20.4026	19.9515	20.928
2017	20.5654	20.0355	21.2828	21.231	20.4309	22.7266	21.2677	20.7114	22.1982
2019	20.7845	20.2607	21.5991	21.6826	20.75	23.5557	21.5366	20.9423	22.5901
2022	20.9868	20.468	21.8494	22.1763	21.0762	24.5801	21.8067	21.1655	23.0488
2027	21.1874	20.6696	22.1613	22.7625	21.4322	25.9559	22.0995	21.3945	23.6352
2032	21.314	20.7932	22.4003	23.1975	21.6749	27.083	22.2998	21.5419	24.0935

Figure 3. Maximum annual daily temperatures expected for the next 10 years in the DMQ in the color bar. Horizontal data shows the Longitude, Vertical the Latitude. a) forecast using the observed trend with real data from the studied meteorological stations, b) forecast using the product of dynamic forcing trend calculated by PRECIS A2 scenario c) Forecast using the product calculated by the dynamic forcing B2 (optimistic) scenario of PRECIS trend.



The GCM simulated data were regionalized using the technique of approaching averages, taking into account the annual mean temperature maps of the Ministry of Environment (MDMQ, 2011) and PRECIS model outputs, thus maps are presented with the resolution of this latter model. In Figure 3(a) shows the highest values of annual maximum temperatures that can be expected to 2032 year, these results take into account the dynamic forcing calculated by PRECIS scenarios A2 and B2, which are shown in Figure 3(b) and 3(c) respectively.

3.2 Analysis of daily minimum temperatures for Izobamba, Tomalón-Tabacundo y Papallacta

The behavior of the annual maximum values of minimum temperatures (early hours of dawn) for Izobamba station, located south of the DMQ is presented, into the series there is a positive trend of 0.03°C/year with a statistical significance of 75.7%. By simulating the data with a covariant DGVE, the location parameter was $\mu = 10{,}05092(0{,}13680) + 0{,}03t$, the scale parameter was $\sigma = 0{,}78644(0{,}09780)$, and the shape parameter $\xi = -0{,}22174(0{,}11901)$. Showing that these data follow a Weibull distribution. Also the test of maximum likelihood indicates that the p-value was 0,09103756.

In Tomalón-Tabacundo the trend was 0.051°C/year, and the DGVE has a location parameter of $\mu = 14{,}38173(0{,}29938) + 0{,}051t$, a scale parameter of $\sigma = 1{,}07082(0{,}23624)$, and a shape parameter of $\xi = -0{,}27288(0{,}27655)$, in a Weibull distribution, the p-value was 0.3372716. Since in Papallacta, the trend is positive too: 0.067°C/year with a significance of 96.7%. The return levels and confidence intervals for the two scenarios and the observed data for the three stations for 2032 year is presented in Table 8.

Similarly, the regional data of annual maximum values of minimum temperatures in the DMQ, for real data and the A2, B2 scenarios are presented in Figure 4.

3.3 Behavior of the heavy rainfall in Izobamba, Tomalón-Tabacundo and Papallacta

The behavior of maximum annual values of maximum precipitation days (above the 95th percentile = 20 mm/day) for Izobamba station, located south of the DMQ, shows a positive trend of 0.366 mm/year with a statistical significance of 96.7% (Figure 5).

However, in the case of precipitation, there was not detected a direct dynamic forcing producing its increase over time (IPCC, 2014), but the increase in extreme weather events in general. That is why we did not use PRECIS scenarios. Return levels and confidence intervals are calculated only with the observed data, as shown in Table 9.

By simulating covariant DGVE results achieved after the maximum likelihood method in Izombamba, indicates that the location parameter varies $\mu = 52{,}16587(2{,}98138) + 0{,}366t$, the scale parameter $\sigma = 17{,}45288(2{,}34374)$, the shape parameter $\xi = 0{,}18686(0{,}11512)$, showing that these data follow a Frechtel distribution with a p-value of 0.0622325. The results are shown in Table 9(a).

In Tomalón-Tabacundo, the dryest region, the maximun precipitation has a negative trend of -0.161 mm/year with a p-value of 0.649, the location parameter was chosen as $\mu = 27{,}44210(2{,}31995)$, with a $\sigma = 8{,}65550(1{,}98911)$, and $\xi = 0{,}33574(0{,}22768)$, into a Frechtel distribution, the p-value was 0.02581635 (Table 9(b)).

In Papallacta there is another negative trend of -0.473 mm/yer (p-value of 0.211). The DGVE has a location parameter of $\mu = 52{,}81604(7{,}64252)$, $\sigma = 34{,}79840(6{,}15202)$, and $\xi = 0{,}24224(0{,}14866)$, in a Frechtel distribution with a p-value of 0.03283383 (Table 9(c)).

The regional data in Table 7 for maximum value per year of heavy precipitation into DMQ is presented in Figure 6.

4 Conclusions and discussion

4.1 Behavior of temperatures and ecosystemic impacts in the DMQ

In the DMQ were identified three types of threats related to climate change or climate variability: a statistically significant increase in the magnitude of both maximum and minimum temperatures and an increase in the frequency of heavy rainy days (Serrano *et al.*, 2012).

Figure 4. Annual maximum of daily Minimum Temperatures expected for 2032 year in the color bar. Horizontal data shows the Longitude, Vertical the Latitude. a) forecast using the observed trend of real data from the meteorological stations, b) forecast using the product of dynamic forcing trend calculated by the A2 scenario PRECIS, c) forecast using the trend product calculated by the dynamic forcing B2 scenario of PRECIS.

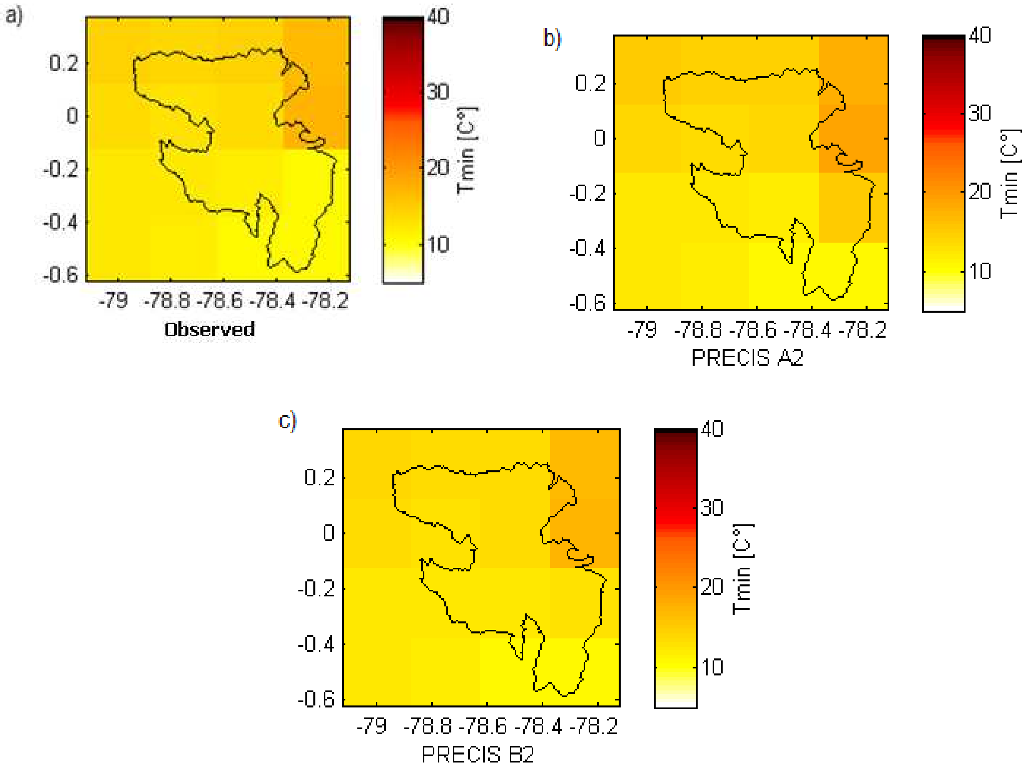
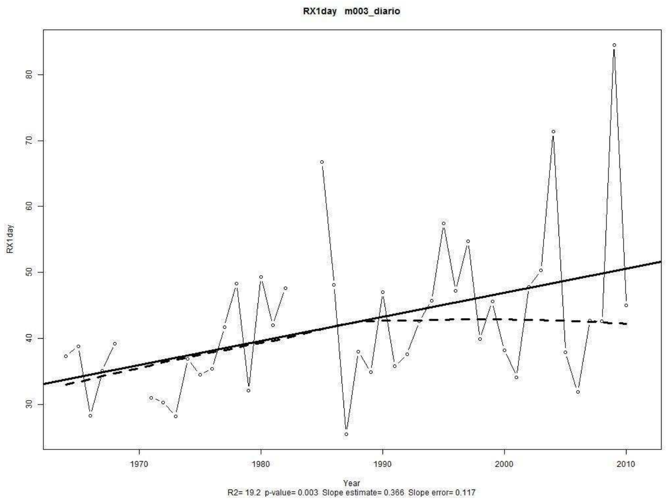


Figure 5. Annual behavior of the daily maximum precipitation values recorded since 1964 in the year 2011 in Izobamba.



a) Izobamba

Return period (years)	**Observed**			**PRECIS A2**			**PRECIS B2**		
	Return level [°C/day]	LI [°C/day]	LS [°C/day]	Return level [°C/day]	LI [°C/day]	LS [°C/day]	Return level [°C/day]	LI [°C/day]	LS [°C/day]
2014	10.327	10.053	10.6168	10.5158	10.2428	10.7971	10.7593	10.465	11.0544
2017	11.054	10.7566	11.4034	11.2254	10.9413	11.546	11.4875	11.2043	11.788
2019	11.254	10.9494	11.6696	11.4139	11.1264	11.7798	11.6688	11.3901	11.9941
2022	11.444	11.129	11.958	11.5891	11.2972	12.0264	11.8321	11.5578	12.2047
2027	11.637	11.3068	12.2385	11.7641	11.465	12.2838	11.989	11.7192	12.4346
2032	11.761	11.418	12.4268	11.8753	11.5697	12.4345	12.087	11.818	12.5507

b) Tomalón-Tabacundo

Return period (years)	**Observed**			**PRECIS A2**			**PRECIS B2**		
	Return level [°C/day]	LI [°C/day]	LS [°C/day]	Return level [°C/day]	LI [°C/day]	LS [°C/day]	Return level [°C/day]	LI [°C/day]	LS [°C/day]
2014	14.7552	14.16747	15.40656	14.7282	14.04727	15.50257	14.9877	14.30136	15.67958
2017	15.6998	15.09104	16.54288	16.0592	15.22647	17.44137	16.055	15.39729	16.82908
2019	15.95	15.35243	16.86408	16.4696	15.58255	18.02369	16.3168	15.68436	17.25251
2022	16.1824	15.59416	17.16913	16.8801	15.92611	18.6907	16.5512	15.94356	17.48822
2027	16.4141	15.82815	17.58124	17.3233	16.27861	19.5283	16.7759	16.19098	17.76637
2032	16.5611	15.96987	17.90907	17.6253	16.50622	20.17527	16.9135	16.3407	17.9754

c) Papallacta

Return period (years)	**Observed**			**PRECIS A2**			**PRECIS B2**		
	Return level [°C/day]	LI [°C/day]	LS [°C/day]	Return level [°C/day]	LI [°C/day]	LS [°C/day]	Return level [°C/day]	LI [°C/day]	LS [°C/day]
2014	9.098	8.51747	9.09802	11.3319	9.92041	11.33188	9.8874	9.17342	10.67584
2017	9.8408	9.29491	10.59829	12.9631	11.83807	14.12185	10.9109	10.12034	12.13227
2019	10.0219	9.4964	10.79966	13.312	12.27014	14.68806	11.1987	10.40246	12.48641
2022	**10.1835**	**9.67933**	**10.96891**	**13.6047**	**12.64676**	**14.92382**	**11.4739**	**10.6679**	**12.9048**
2027	10.338	9.855	11.19093	13.8665	12.99694	15.09987	11.7569	10.93114	13.45406
2032	10.4323	9.96152	11.36773	14.0171	13.20499	15.22524	11.9416	11.09534	13.88822

Table 8. Return periods, return levels and confidence intervals at 95% for both scenarios A2 and B2 of PRECIS for the next 20 years, for the minimum annual temperatures in a) Izobamba b) Tomalón-Tabacundo c) Papallacta.

a)

Return period [years]	Year	Return level [mm/day]	IL 95% [mm/day]	SL 95% [mm/day]
2	2014	58.7867	52.3806	66.39552
5	2017	82.381	71.81226	98.9752
7	2019	91.2272	78.53774	113.82874
10	2022	100.9893	85.58649	131.11258
15	2027	112.6984	93.54083	152.2947
20	2032	121.4659	99.1595	169.26421

b)

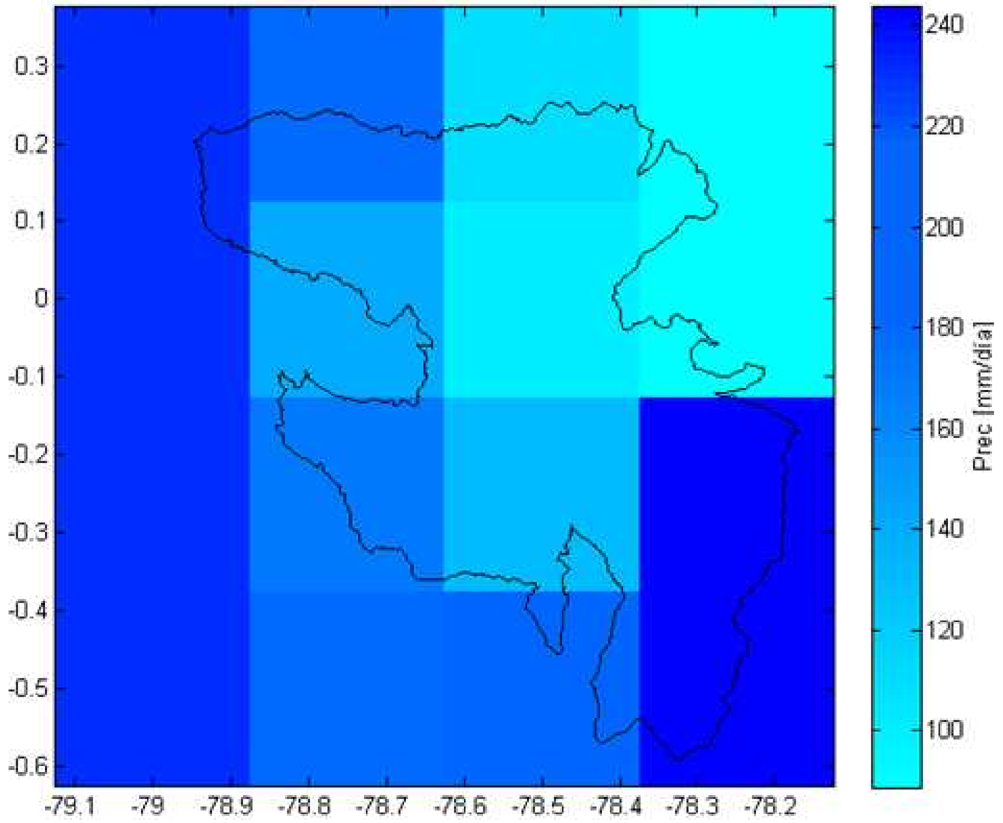
Return period [years]	Year	Return level [mm/day]	IL 95% [mm/day]	SL 95% [mm/day]
2	2014	30.8179	25.83315	37.5405
5	2017	44.3192	35.40184	61.89684
7	2019	49.9595	38.958	73.53879
10	2022	56.5417	42.74972	88.82883
15	2027	64.9244	19.16253	110.68628
20	2032	71.5448	13.47774	71.54475

c)

Return period [years]	Year	Return level [mm/day]	IL 95% [mm/day]	SL 95% [mm/day]
2	2014	66.1534	49.78686	86.86547
5	2017	115.7551	87.95392	167.84057
7	2019	135.1206"	101.41638	201.95179
10	2022	156.9403	115.64823	243.90614
15	2027	183.7016	131.87326	300.17372
20	2032	204.1415	143.44968	143.44968

Table 9. Return periods, return levels and confidence intervals at 95% for the actual data of maximum heavy rainfall in a) Izobamba, b) Tomalón-Tabacundo, c) Papallacta.

Figure 6. Possible values of maximum daily precipitation forecasts for the next 10 years in the DMQ year in the color bar. Horizontal data shows the Longitude, Vertical the Latitude. The figure shows the values of extreme events by day expected during this period, since Table 7.



The first part of this study, was aimed to know the intensity of extreme events of the minimum and maximum temperatures in the near future (2032 year), using DGVE distributions which indicated that the best fit to the temperature values was given by a Weibull covariant distribution i.e. involving a forcing behavior data. Thus, we have worked with the atmospheric forcing presented in PRECIS for A1 and B1 scenarios. In consequence, this study used both: a dynamic and statistical prediction.

Results show that for 2032 year, in the southern area (Izobamba), where the average daily maximum temperature is 14.6°C, it will be possible observe extreme events such as temperatures up to 23.7°C, and according to the A2 and B2 scenarios temperatures as high as 24.3°C and 24.2°C respectively could be observed, i.e. an eventual increase of about 10° over the average. It is expected to occur in the months of August and September, which corresponding to the dry season in Quito.

In the southeastern region (Papallacta) where the average daily maximum temperature is 14.4°C, it is expected to register extreme events of 21°C, and according to the A2 and B2 models 21.8°C and 21.1 respectively, about 7°C above average temperature. While in the north-east, the warmest region in DMQ, averaging 21.6°C, in 10 years it is possible to find extreme values up to 29°C and using the A2 and B2 scenarios of 29.4°C, and 29°C respectively, *i.e.* 8°C more than average.

In the case of minimum temperatures, in Izobamba whose average daily minimum temperatures are 6°C, is expected to record extreme events of 11.4°C, 11.6°C and 11.8°C according to statistical data and scenarios A2 and B2 respectively, an increase of nearly 7°. In Papallacta, with an average lowest temperature of 5.5°C, it is expected to have extreme temperatures as low as 10.1°C and A2 and B2 respectively 13.6°C and 11.4°C models, an increase of more than 8°C. Also, in the warmest region of the DMQ, where station Tabacundo Tomalon is located, has an average of 9.11°C, and the model can be registered 16.2°C, 16.8°C and 16.5°C according to statistical trend and the two scenarios A2 and B2, i.e. more than 7°C for the next 10 years.

It should be noted that these values are possible extreme temperature events, whose frequency is casual, but the intensity has been shown to consistently rise may experience extreme events between 6 and 10°C more than average temperatures to which ecosystems are already accustomed.

4.2 Behavior of heavy precipitation

In the case of the precipitation DGVE indicate that the better option is to use a no covariant Fretchel distribution. In Izobamba, registered as the rainiest region, with a mean daily rainfall of 6.8 mm, it is expected to register single events to up 100 mm/day, 14 times more than the average. The southeastern area represented by Papallacta has daily rainfall averages 3.7 mm/day, and in the next 10 years may register 156 mm/day, i.e. 42 times more. This phenomena occurs because Papallacta has historically registered record rainfall of 183 mm/day and 160 mm/day on 27 and 25 March 2003 respectively. Therefore it is very likely that the coming years will see a similar events of this magnitude.

As for the northeast, where the station Tomalon-Tabacundo is located, average rainfall of 4.3 mm/day and can record maximum of 56.5 mm/day are recorded. It should be noted that in this area the rains are often scarce, and there is a tendency to decrease precipitation and hence the hardening of dry regime.

4.3 Ecosystem impact

Because the DMQ have varied ecosystems with well defined characteristics, it becomes clear that these areas are affected differently.

On what it refers to the increase in minimum temperatures, even though it is a measure generally taken in the early hours of the morning, it is a direct measuring of warm nights. And it would be an indicator of potentially harmful effects by the lack of night cooling and main contributor of heat stress in animals and plants, especially those located in the transition zone of the paramo and are not adapted to these conditions. Also, it is noted that besides the presence of greenhouse gases that increase nighttime temperatures, must be added the heat island effect, which must be taken into account in all sampling points, as the effects urbanization resulting in increased heat released during the night by modern infrastructure.

The increase in maximum temperatures, usually achieved at noon, directly affecting the adaptability of animal and plant species, including humans; because in a context of physical stress, coupled with high temperatures can be triggered death. Also, this indicator can also be interpreted as a measure of greater or lesser heliophany cloud cover, which can also favor the drought (Frich, 1999).

Also in the context of climate change, greenhouse gases favor the hydrological cycle and collaborating nucleation of water vapor into rain. While the increase of temperature favors the greatest amount of water vapor available, and hence is generated more intense precipitation. Those ecosystems that have more absorbency due to its vegetation cover would not be as affected by these sporadic events, although the edges urbanized city located in areas at risk by landslides are. Furthermore, it is noted that in the dry Northeast of DMQ has identified a negative trend in the presence of rain, which could result in the tightening of dry conditions in the area, affecting mainly to their biodiversity (Riebeek, 2005).

On the behavior of disease vectors, investigations of Rodriguez and Buitrón (20014) had been established that the increase of temperature and humidity favors the occurrence of diseases produced by insect vectors such as Anopheles mosquitoes and Aedes, responsible for the transmission of malaria and dengue. It was reported in 2010, in the provinces of Carchi (300- 4.723 m.a.s.l.) and Imbabura (1200 a 3000 m.a.s.l.) seven cases of dengue fever were confirmed, since National Institute of Hygiene Izquieta Perez (INHIP). Aedes currently aegypti is able to survive between 1,500 and 1,700 meter, meanwhile Varsovia Cevallos (El Comercio, 2010) conclude that under certain conditions of microclimate the mosquito could adapt to Quito and therefore could be cases of dengue, as happened in Galapagos in 2002 where the disease first and then the vector was reported. Ramirez *et al.* (2009), estimated that 34% of the world population would be at risk of contracting dengue. In Ecuador 70% of its territory is favorable for the presence of Aedes aegypti.

Acknowledgements

This research was funded by the Climate Development Knowledge Network-CDKN within the Vulnerability Study DMQ. And it was done under the direction of Stokolm Eviroment-SEI Institute, the University Network for Climate Change represented by the Polytechnic National-EPN, the Pontifical Catholic University the Ecuador-PUCE and the Research Modeling Environment Center CIMA-UPS Salesian Polytechnic University. It also appreciated the product management and validation of the Secretariat of the Environment of Illustrious Metropolitan District of Quito, and to MAE (Ministry of Environment) an INAMHI for the data.

5 References

Baquero, F., R. Sierra, L. Ordoñez, M. Tipán, L. Espinoza, M. Ribera and P. Soria. 2004. La Vegetación de los Andes del Ecuador. Memoria explicativa de los mapas de vegetación potencial y remanente de los Andes del Ecuador a escala 1:250.000 y del modelamiento predictivo con especies indicadoras.

Cáceres, L., G. Mejía and Ontaneda. 1998. Evidencias del cambio climático en Ecuador. **Bull. Inst. fr. Étudesandines.** 27(3):547-556.

Coles, Stuart. 2004. S-plus functions for extreme value modeling: An accompaniment to the book an introduction to statistical modeling of extreme values. http://www.stats.bris.ac.uk/masgc/ismev/uses.ps

El Comercio. 2010. El mosquito del dengue sí se adapta a Quito. 22 de marzo. http://www.elcomercio.com/actualidad/mosquito-del-dengue-adapta-quito.html

Frich, P. 1999. REWARD–A Nordic Collaborative Project. Annex of Meeting of the Joint CCl/CLIVAR Task Group on Climate Indices, Bracknell, UK, 2-4 September 1998. **World Climate Data and Monitoring Programme.**

García, O. Rafael Cueto, N. Santillan Soto, S. Ojeda Benitez and M. Quintero Nuñez. 2012. Escenarios de temperaturas extremas en Mexicali, México bajo condiciones de cambio climático. páginas 349-358.

Gilleland, Eric and Richard W. Katz. 2005. Extremes Toolkit (extRemes): Weather and Climate Applications of Extreme Value. National Science Foundation (NSF) through the National Center for Atmospheric Research (NCAR) Weather and Climate Impact Assessment Science Initiative, with additional support from the NCAR Geophysical Statistics Project (GSP).

IPCC. 2001. Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K.]

IPCC. 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. **IPCC, Geneva, Switzerland.** page 151.

Josse, C., G. Navarro, P. Comer, R. Evans, D. Faber-Langendoen, M. Fellows, G. Kittel, S. Menard, M. Pyne, M. Reid, K. Schulz, K. Snow and J. Teague. 2003. Ecological Systems of Latin America and the Caribbean: A Working Classification of Terrestrial Systems. **NatureServe.** Arlington, VA.

Karl, T., N. Nicholls and A. Ghazi. 1999. Clivar/gcos/wmo workshop on indices and indicators for climate extremes: Workshop summary. **Climatic Change.** 42:3-7.

Martínez, R., D. Ruiz, V. Marcos, M. Andrade, L. Blacutt, P. Daniel, *et al.* 2009. Synthesis of the climate of the tropical Andes.

MDMQ-Secretaría de Ambiente. 2011. Memoria Técnica del Mapa de Cobertura Vegetal del Distrito Metropolitano de Quito (DMQ). Quito.

MECN. 2009. Ecosistemas del Distrito Metropolitano de Quito (DMQ). **Serie de Publicaciones del Museo Ecuatoriano de Ciencias Naturales (MECN)–Fondo Ambiental del MDMQ.** Publicación Miscelánea (6):1-51. Imprenta Nuevo Arte. Quito, Ecuador.

Murray, Sharon. 1997. Urban and Peri-Urban Forestry in Quito, Ecuador: a Case-Study. **Forestry Department.** Food and Agriculture Organization of the United Nations. Rome.

Nieto, J., R. Martínez, J. Regalado and F. Hernández. 2002. Análisis de tendencias de series de tiempo oceanográficas y meteorológicas para determinar evidencias de cambio climático en la costa del Ecuador. **Acta oceanográfica del Pacífico.** 11(1):17-21.

Peterson, T. 2001. Report on the activities of the working group on climate change detection and related rapporteurs 1998-2001. **WMO, Rep. WCDMP-47, WMO-TD 1071.** página 143. Geneve, Switzerland.

PRECIS. 2004. The PRECIS Handbook, Generating High Resolution Climate Change Scenarios using PRECIS. **This handbook was published jointly by the UNDP and the Hadley Centre.**

Ramírez, M. G. Zepeda, H. E. Velasco-Mondragón, C. Ramos, J. E. Peñuelas, *et al.* 2009. Caracterización clínica y epidemiológica de los casos de dengue: experiencia del Hospital General de Culiacán, Sinaloa, México. **Rev. Panamá Salud Pública 2009.** 25:16-23.

Riebeek, Holli. 2005. The Rising Cost of Natural Hazards. **Earth Observatory.**

Rodríguez, A. and M. Buitrón. 2015. Enfermedades sensibles al clima en el Distrito Metropolitano de Quito, un análisis temporal en el periodo 2001-2010. **La Granja: Revista de Ciencias de la Vida.** 21(1):16-33.

Samaniego, J. 2009. Cambio climático y desarrollo en América Latina y el Caribe: una reseña. CEPAL, Santiago, documento de Proyecto.

Serrano, S., D. Zuleta, V. Moscoso, P. Jácome, E. Palacios y M. Villacís. 2012. Análisis estadístico de datos meteorológicos mensuales y diarios para la determinación de variabilidad climática y cambio climático en el Distrito Metropolitano de Quito.La Granja. 16(2):23-47. ISSN: 1390-3799.

United Nations. 1995. Framework Convention on Climate Change. Conference of the parties. First session. Berlin.

Valencia, R., C. Cerón, W. Palacios and R. Sierra. 1999. Las Formaciones Naturales de la Sierra del Ecuador. Propuesta Preliminar de un Sistema de Clasificación de Vegetación para el Ecuador Continental. **Proyecto INEFAN/ GEF-BIRF y EcoCiencia.** páginas 79-108. Quito, Ecuador.

Villacís, M., F. Vimeux and J. Taupin. 2008. Analysis of the climate controls on the isotopic composition of precipitation (d18o) at nuevo rocafuerte, 74.5°W, 0.9°S, 250 m, Ecuador. **Comptes Rendus Geoscience.** 340:1-9.

Villacís, M., A. Fernández, J.C. Pouget and M. Escobar. 2012. Impactos del cambio climático en el sector agua durante los últimos 30 años se identificación de los aspectos que constituyen la vulnerabilidad. Estudio de Vulnerabilidad del DMQ (not published).

Zambrano-Barragán, C., O. Zevallos, M. Villacís and D. Enriquez. 2010. Quito's climate change strategy: A response o climatic change at the metropolitan district of Quito, Ecuador. **Resilient Cities: Cities and Adaptation to Climate Change.**