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Climate change forecasting in Ranohira, southern of Madagascar, using linear and ARIMA models

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Abstract

The purpose of this work is to analyze the behavior of temperature and rainfall in Ranohira, southern of Madagascar, using climate data from 1961 to 2016 in order to predict future trend. Modeling and Forecasts have been performed using the ARIMA (Auto-Regressive Integrated Moving Average) model. The predictions concern the next 50 years. The data have been subdivided into 13 groups corresponding to each month of the year and the 13th group is the annual average. Before the application of the ARIMA modeling, we performed linear regressions to have a general view of the trends. Results showed that the average annual temperature is strictly increasing with a linear growth rate of about 0.2°C per decade. The mean of the average annual temperatures from 1961 to 2016 is 21.77°C. Total annual rainfall trend shows a decrease of about 47.2 mm per decade. The mean of annual precipitation from 1961 to 2016 is 917.26mm. Concerning the ARIMA modeling, each of the time series corresponding to the 13 groups of data can be fitted in ARIMA form model$(1,1,1)(1,1,1)^S$*. The seasonal part of the model was exploited to have a good description of the fluctuations and the value of S was chosen to obtain the best model for each series. Forecast for the next 50 years permits to predict a significant increase of the average annual temperature which is expected to be equal to 23.94°C in 2066. The mean of the average annual temperatures between 2017 and 2066 is predicted to be equal to 22.8°C. The forecast also shows a decrease of 22.19 % in the mean annual precipitation for the 50 next years compared to the average of the observation years. The dry season, from April to September, will be the most affected, with a deficit of up to 90%. It is predicted that in 2066, the annual rainfall would be 470.18 mm against 605.9mm in 2016. The economic development of the Ihorombe region eventually requires strategies to deal with these future changes, especially in the water sector, which would be the most affected.*

Keywords: Climate change, forecast, ARIMA, temperature, rainfall, ranohira.

Introduction

In line with the global trend, climate change has become a reality in Madagascar. As a tropical country subject to natural disasters, impacts and climate disturbances began to be felt on the Big Island. At the UN Climate Summit on 23 September 2014 in New York, the Journal "Jeune Afrique" reported that Madagascar has been ranked among the fifteen African countries most threatened by global warming[1].

The National Office of Risk and Disaster Management (BNGRC: Bureau National de Gestion des Risques et Catastrophes) said that after Bangladesh and India, it is the third country in the world most affected by natural disasters and the first most exposed to cyclone in Africa with 25% of its population living in areas at risk[2]. A study carried out in 2008 by the Meteorology Department predicted the following phenomena for the next 50 years: i. the temperatures will increase, ii. the amounts of rainfall will increase over a large part of Madagascar except on the east and south-east slopes, iii. the number of dry days will increase, iv. the onset of rainfall will be delayed, v. the heavy rains will be frequent, and vi. the intensity of cyclones affecting Madagascar will increase with a slight shift of trajectories to the North. Even in the absence of cyclones, floods occur and destroy crops, property and infrastructure[3].

Southern Madagascar is a region marked by aridity. In particular, the Ihorombe region is a transitional zone that benefits both a tropical highland climate in the eastern part and a subhumid tropical climate in the western and southwestern part. It has an important floristic and faunistic biodiversity. On the other hand, it suffers from anthropogenic pressures in the form of bush fires, wild fires, massive cuts for firewood and coal mining[4]. These environmental disorders affect the ecosystem of the region.

This study presents a statistical analysis of the climatic variation in the Ihorombe region. Linear regression and ARIMA model were used to study the trend and to forecast the future variation. The main variables considered are temperature and precipitation. The analyzed data comes from the Ranohira station, the only weather station in the Ihorombe region, which is currently functional.

Understanding the nature and possible variations of the climate in the Ihorombe region is important for policymakers and the people working in this area. It may be for instance useful to anticipate negative effects and taking appropriate action to prevent or minimize eventual damage. Time series analysis and forecasting have become major tools used in hydrometeorological applications to study trends and variations in climate variables[5,6]. In this study, Ranohira air temperature and precipitation from 1961 to 2016 are used. The objectives of this analysis are: i. To study the variation and trend of temperatures and precipitation of Ranohira from 1961 to 2016. ii. To build ARIMA models for temperature and precipitation, iii. To make a prediction for the next 50 years.

Methodology

Study area and database: The Ihorombe region (Figure-1) is one of the 22 regions of Madagascar. It is located in the South-Center of Madagascar and is part of the province of Fianarantsoa. It is delimited in the North by the HauteMatsiatra region, in the South by the Anosy region, in the East by the AtsimoAtsinanana region and in the West by AtsimoAndrefana region. It extends geographically between longitudes 44°98'and 46°62' and between latitudes 21°61'and 23°10', with an area of 26 930 km^2.

The climate data of this region is very poor because among the four meteorological stations of the region (Betroka, Ranohira, Kelivondraka, Ihosy), only the Ranohira station is currently operational. Ranohira is a rural area located on the national road number 7 between Tuléar and Fianarantsoa towns, 93 km from Ihosy city which is the capital of the region.

Climatic data from Ranohira meteorological station, (lat: 22°33'21 " S, long 45°25'15"E, alt 826m), precisely the annual precipitation and average annual temperature from 1961 to 2016, were analyzed to provide a record of past climate behavior in order to determine the trends and to assess the future climate variation.

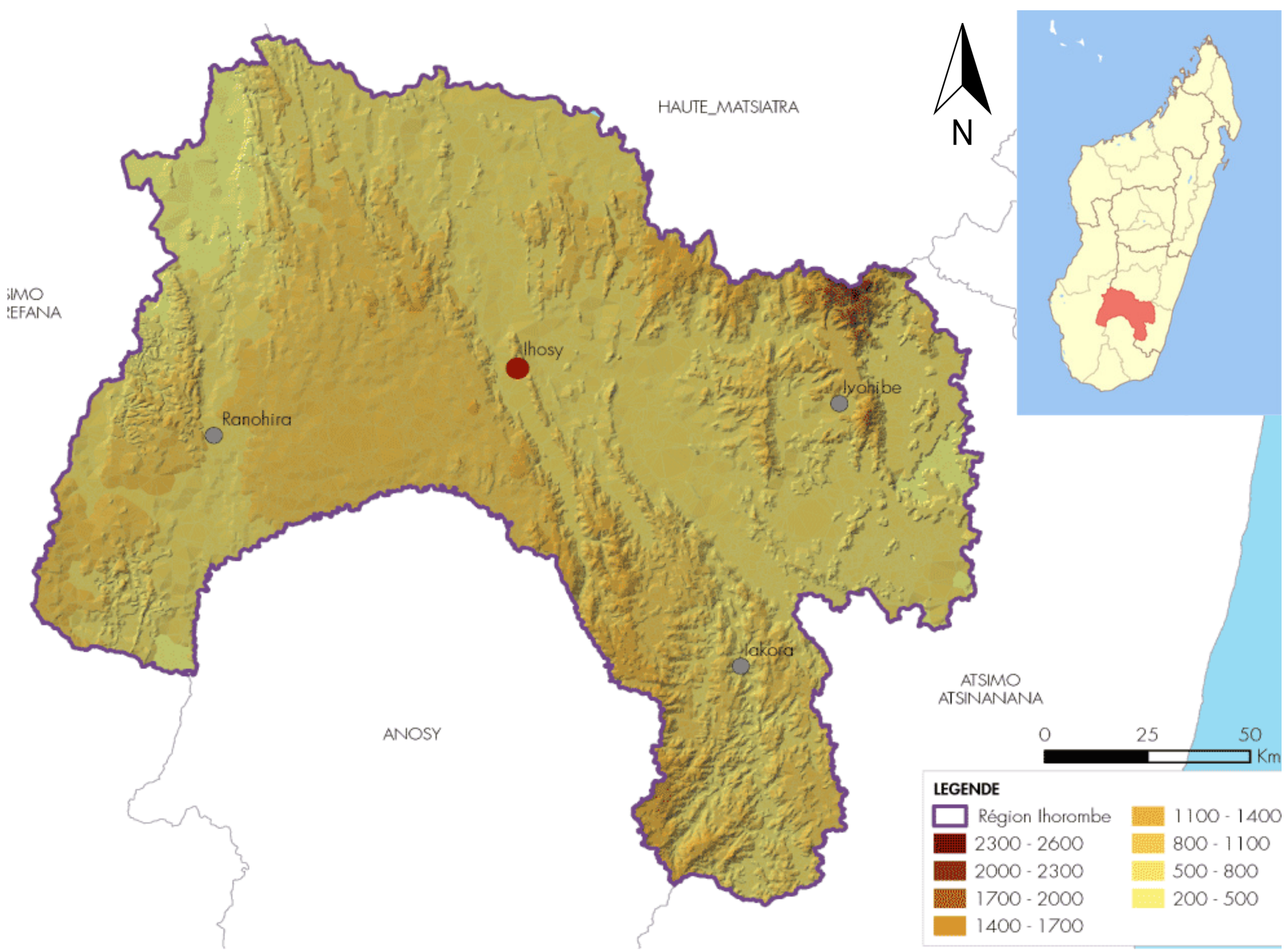

Figure-1: Ihorombe region[7].

The ARIMA and SARIMA models: ARIMA (Auto Regressive Integrated Moving Average) is the acronym used to refer to a family of mathematical models which permits to represent a phenomena described by a time series. An ARIMA model can be used to make prediction for the future values of the series describing the phenomena with a confidence interval around the forecasts[8-12]. Let$\{X_t\}_{t\in\mathbb{N}^*}$be the time series describing a particular phenomenon and μ it mean values. For the case of the ARIMA modeling used in the software XLSTAT that we consider here, the mathematical relations which define the ARIMA model, denoted $ARIMA\ (p,d,q)(P,D,Q)^S$ corresponding to the series $\{X_t\}_{t\in\mathbb{N}^*}$ are

$$\begin{cases} Y_t = (1-B)^d(1-B^S)^D X_t - \mu \\ \phi(B)\Phi(B^S)Y_t = \theta(B)\Theta(B^S)Z_t \\ Z_t \propto \mathcal{N}(0,\sigma^2) \end{cases} \quad (1)$$

In which, B is the lag operator (backshift operator) defined by the relation.

$$BX_t = X_{t-1} \Leftrightarrow B^i X_t = X_{t-i} \quad (2)$$

$1-B$ is the difference operator (denoted sometime ∇)

$$\nabla X_t = (1-B)X_t = X_t - X_{t-1} \quad (3)$$

$1-B^S$ is the deseasonalization operator (denoted sometime ∇_S)

$$\nabla_S X_t = (1-B^S) = X_t - X_{t-S} \quad (4)$$

The operator ∇ permits to eliminate the polynomial trend of the series X_t and the operator ∇_S permits to eliminate seasonal (periodical) trend. The new series Y_t defined from X_t according to the first relation in (1) is a series in which polynomial trend of order d and seasonal polynomial trend with order D are removed. The integer numbers$d$ and D are respectively called the differencing order of the model and the differencing order of the seasonal part of the model. S is the period of the data.

$\phi(B)$ and $\Phi(B^S)$ are lag polynomials (polynomials of the lag operator B) respectively with degree equal to p and P

$$\begin{cases} \phi(B) = 1 + \sum_{i=1}^{p} \phi_i B^i \\ \Phi(B^S) = 1 + \sum_{i=1}^{P} \Phi_i B^{Si} \end{cases} \quad (5)$$

The integer numbers p and P are respectively called the order of the autoregressive part of the model and the order of the autoregressive seasonal part of the model.

$\theta(B)$ and $\Theta(B^S)$ are lag polynomials respectively with degree equal to q and Q

$$\begin{cases} \theta(B) = 1 + \sum_{i=1}^{q} \theta_i B^i \\ \Theta(B^S) = 1 + \sum_{i=1}^{Q} \Theta_i B^i \end{cases} \quad (6)$$

The integer numbers q and Q are respectively called the order of the moving average part of the model and the order of the moving average seasonal part of the model.

Z_t is a white noise following a normal (Gaussian) distribution $\mathcal{N}\ (0,\sigma^2)$

$$\begin{cases} E(Z_t) = 0 \\ Var(Z_t) = \sigma^2 \\ Covar\ (Z_t, Z_{t+k}) = \begin{cases} \sigma^2 & if\ k = 0 \\ 0 & if\ k \neq 0 \end{cases} \end{cases} \quad (7)$$

For the case $D = 0$ the model is an $ARIMA\ (p,d,q)$. It is this kind of model that is sometime called ARIMA model. In fact, the general model $ARIMA\ (p,d,q)\ (P,D,Q)^S$ described above is sometimes called SARIMA (Seasonal ARIMA) model.

We may also remark that for $d = 0$, the ARIMA model $ARIMA\ (p,d,q)$ becomes an ARMA model $ARMA(p,q)$.

The relation (1) can be written in a more simple form and directly as a relation between the series X_t and the white noise Z_t particularly for lower values of the parameters p,q,d,P,Q,D.

For instance, for an $ARIMA\ (1{,}1{,}1)\ (1{,}1{,}1)^S$ and with a mean value of the series equal to zero($\mu = 0$), the relation (1) becomes

$$\begin{cases} Y_t = (1-B)(1-B^S)X_t - \mu \\ (1+\phi_1 B)(1+\Phi_1 B^S)Y_t = (1+\theta_1 B)(1+\Theta_1 B^S)Z_t \\ Z_t \propto \mathcal{N}(0,\sigma^2) \end{cases} \quad (8)$$

So we have for the direct relation between X_t and Z_t

$$[(1+\phi_1 B)(1+\Phi_1 B^S)][(1-B)(1-B^S)X_t - \mu] = (1+\theta_1 B)(1+\Theta_1 B^S)Z_t$$

The common approach for fitting and using an ARIMA model is to follow the Box-Jenkins methodology[13,14]. According to this methodology, the main steps are briefly: i. The model identification and parameters estimation: use of plots and summary statistics to identify trends and seasonality and to estimate the values of the parameters p,d,q,P,D,Q,S of the appropriate model. The study of some statistical parameters and functions characterizing the data, like ACF (Autocorrelation Function) and PCF (Partial Autocorrelation Function) are generally useful for these steps. ii. The model checking and forecasting.

Establishment of the ARIMA models: As described in Table-1 and Table-2, the data have been subdivided in 13 groups corresponding to each month of the year and the 13th group is the annual average. The ARIMA model corresponding to each group was established with the XLSTAT software, through the

XLSTAT / Time Series Analysis / ARIMA command. According to the results shown in the Tables-1 and 2 and the Figures-4 and 9, all of the time series corresponding to these groups of data can be fitted in a model of the form $ARIMA(1,1,1)(1,1,1)^S$. This kind of model is described by the relation[9].

A logarithmic transformation was done for the modeling of precipitation time series to deal with eventual apparition of negative values in the forecast (Table-2).

The second column of the Tables-1 and 2 gives the notations chosen to label each time series. The third column refers to the parameters of the corresponding ARIMA models. The fourth and fifth columns show the number of years used for validations and forecasts.

Table-1: ARIMA model parameters for Ranohira average annual temperature.

Temperature	Time series	Model parameters	Validation	Forecast
January	T_t^1	$(1,1,1)(1,1,1)^{22}$	8	50
February	T_t^2	$(1,1,1)(1,1,1)^{22}$	9	50
March	T_t^3	$(1,1,1)(1,1,1)^{22}$	6	50
April	T_t^4	$(1,1,1)(1,1,1)^{14}$	15	50
May	T_t^5	$(1,1,1)(1,1,1)^{20}$	10	50
June	T_t^6	$(1,1,1)(1,1,1)^{14}$	10	50
July	T_t^7	$(1,1,1)(1,1,1)^{20}$	10	50
August	T_t^8	$(1,1,1)(1,1,1)^{14}$	6	50
September	T_t^9	$(1,1,1)(1,1,1)^{21}$	10	50
October	T_t^{10}	$(1,1,1)(1,1,1)^{21}$	10	50
November	T_t^{11}	$(1,1,1)(1,1,1)^{21}$	10	50
December	T_t^{12}	$(1,1,1)(1,1,1)^{23}$	6	50
Average	T_t^{13}	$(1,1,1)(1,1,1)^{21}$	10	50

Results and discussion

Trends and forcast in temperature: Figure-2 represents the temporal variation of the average annual temperature of Ranohira during the period from 1961 to 2016. The overall observation shows an increasing trend. The year 1964 was the coldest year, 2006 and 2010 were the warmest years of the observation period.

The linear trend equation of the average annual temperature of Ranohira is

$$\langle T \rangle = 0.0204t - 18.835 \quad (10)$$

The homogeneity test shows that the year 1996 is a rupture date distinguishing two trends. Between 1961 and 1996, the mean of the average annual temperature is 21.53°C against 22.19°C, between 1997 and 2016 (Figure- 3).

Table-2: ARIMA model parameters for the neperian logarithm of Ranohira annual precipitation.

Precipitation	Time series	Model parameters	Validation	Forecast
January	$ln(P_t^1)$	$(1,1,1)(1,1,1)^{23}$	6	50
February	$ln\ (P_t^2)$	$(1,1,1)(1,1,1)^{23}$	6	50
March	$ln\ (P_t^3)$	$(1,1,1)(1,1,1)^{23}$	6	50
April	$ln(P_t^4)$	$(1,1,1)(1,1,1)^{23}$	6	50
May	$ln(P_t^5)$	$(1,1,1)(1,1,1)^{21}$	10	50
June	$ln\ (P_t^6)$	$(1,1,1)(1,1,1)^{21}$	6	50
July	$ln(P_t^7)$	$(1,1,1)(1,1,1)^{21}$	6	50
August	$ln\ (P_t^8)$	$(1,1,1)(1,1,1)^{21}$	6	50
September	$ln(P_t^9)$	$(1,1,1)(1,1,1)^{23}$	6	50
October	$ln(P_t^{10})$	$(1,1,1)(1,1,1)^{23}$	6	50
November	$ln\ (P_t^{11})$	$(1,1,1)(1,1,1)^{23}$	6	50
Décember	$ln(P_t^{12})$	$(1,1,1)(1,1,1)^{21}$	6	50
Average	$ln(P_t^{13})$	$(1,1,1)(1,1,1)^{23}$	6	50

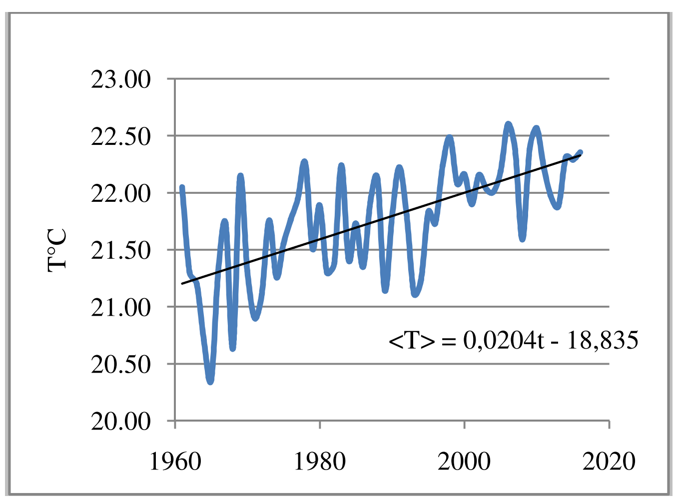

Figure-2: Trend in average annual temperature of Ranohira.

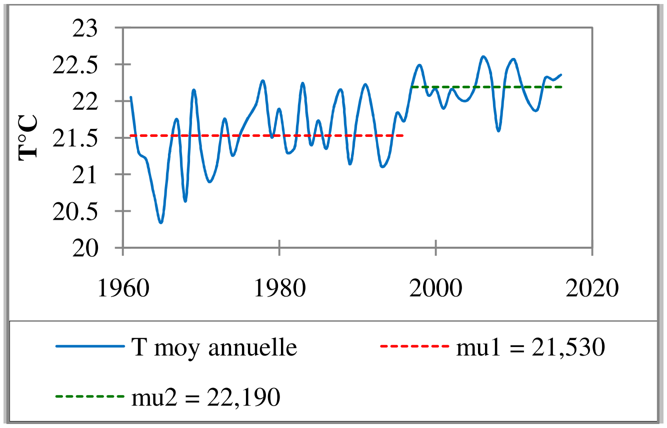

Figure-3: Average annual temperature homogeneity test.

Table-3 gives the linear trends equations and linear growth rate for the 12 months of the year. The last three months, October, November and December, and June were the months most affected by climate change with linear growth rate of 0.3°C per decade. The February temperature was the most stable with a very small linear growth rate of 0.01°C per decade. The temperature values for the remaining months had almost the same linear growth rate of about 0.2°C per decade.

Figure-4 shows the results obtained from the ARIMA modeling of the temperatures of the twelve months of the year and the annual temperature. The ARIMA models corresponding to each curve are given in Table-1. The blue curves refer to the observed data, those in red refer to modeled data, and those in black are the forecasts. The green curve are lower and upper bounds of errors corresponding to a confidence interval of 95%.

The forecast curves show an increasing trend for all of the temperatures time series. Figure-5 shows the differences between the average of monthly temperatures for the 50 years corresponding to the observed data (1961 to 2016) and the 50 years of forecast (2017 to 2066). The months of June, April and November are predicted to be the most affected by the warming process (Figure-5).

In 2066, the monthly temperature is predicted to be between 18.6°C (July) and 27.6°C (November, Figure-6. From the diagram corresponding to the average annual temperature (13th graphic), it is predicted that for the next 50 years, i.e. between 2017 and 2066, the mean of the average annual temperature will be equal to 22.8°C against 21.7°C for the 50 years corresponding to observed data (1961 to 2016). It corresponds to an increase of about 1°C. The average temperature would be 23.94°C in 2066 against 22.4°C for 2016, indicating a significant increase.

Trends and forcast in precipitation: The linear trend in Ranohira's average annual rainfall between 1961 and 2016 is shown in Figure-7. It shows a decreasing trend with a rate equal to 47.2 mm per decade. 1982 was the rainiest year and 1988 was the driest year. A deficit period is observed between 1985 and 1995. The homogeneity test shows a rupture date corresponding to a sharp decrease, which occurred in 1985. The first trend (1961 to 1985) has an average annual rainfall of 985.6 mm and for the second (1985- 2016) it is equal to 832mm (Figure-8).

Figure-9 shows the results of the ARIMA modeling. Orange curves refer to observed data; blue curves refer to modeled and predicted data. The Forecast shows a decreasing trend for all of the precipitation time series. The deficit is more important for the dry season.

Table-4 gives the average of annual precipitation for the next 50 years (2017 to 2066) compared to the 50 years corresponding to the observed data (1961 to 2016). It shows that the duration of dry season will increase. In fact, it would start around March, with an average rainfall less than 50mm, and end only in October. A very dry period is expected to occur between April and September. The month of July would be the most affected with a deficit equal to 99%. Overall, the global deficit for the annual average rainfall would be equal to 22.19%. In 2066, the annual precipitation should reach 470 mm while it was 605 mm in 2016.

Table-3: Linear regressions equations and increase of the annual temperatures for the twelve months of the year between 1961 and 2016.

Month	Equation of the linear trend	linear growth rate
January	$T^1 = 0{,}009t + 24$	0,09°C/decade
February	$T^2 = 0{,}001t + 24$	0,01°C/decade
March	$T^3 = 0{,}019t + 23$	0,19°C/decade
April	$T^4 = 0{,}02t + 21$	0,20°C/decade
May	$T^5 = 0{,}017t + 19$	0,17°C/decade
June	$T^6 = 0{,}033t + 16$	0,33°C/decade
July	$T^7 = 0{,}012t + 17$	0,12°C/decade
August	$T^8 = 0{,}019t + 18$	0,19°C/decade
September	$T^9 = 0{,}019t + 20$	0,19°C/decade
October	$T^{10} = 0{,}031t + 22$	0,31°C/decade
November	$T^{11} = 0{,}03t + 23$	0,30°C/decade
December	$T^{12} = 0{,}027t + 23$	0,27°C/decade

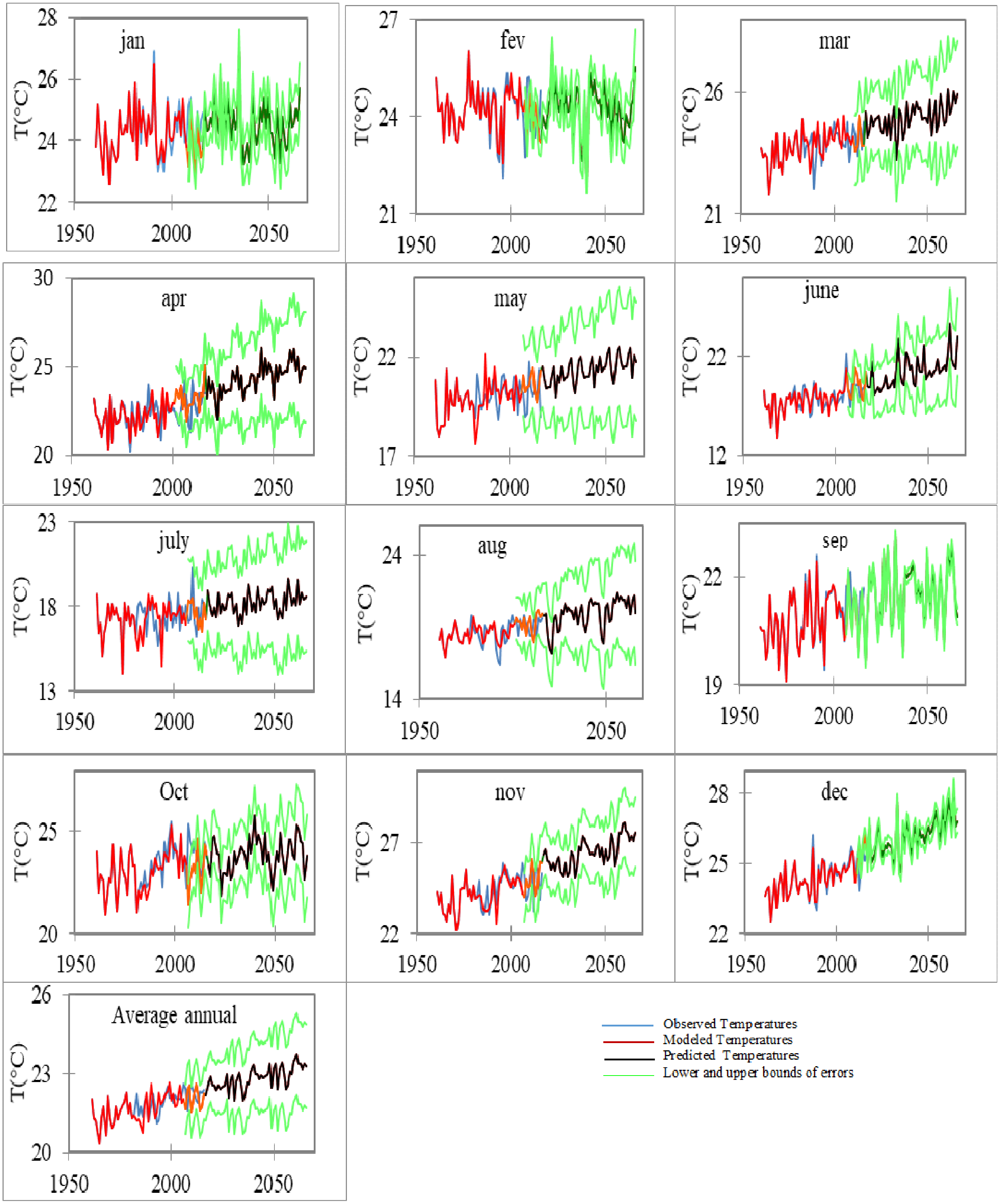

Figure-4: ARIMA modeling results for temperatures.

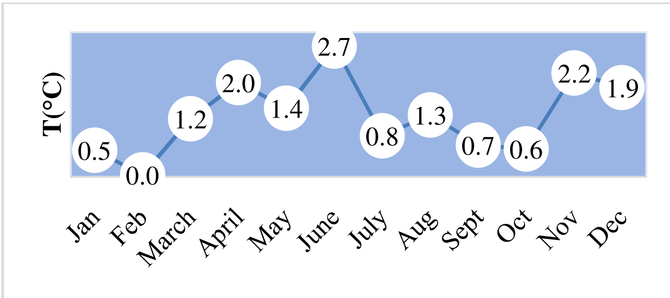

Figure-5: Differences between the average of monthly temperatures for the 50 years corresponding to observed data (1961 to 2016) and the 50 years of forecast (2017 to 2066).

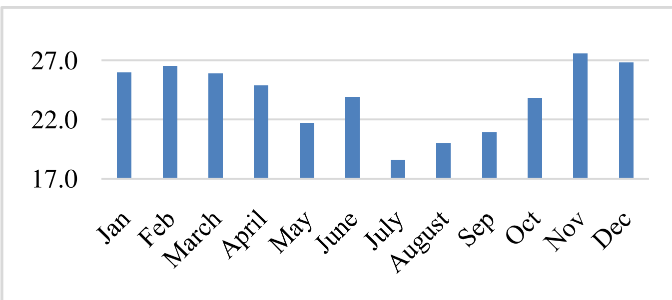

Figure-6: Expected monthly temperatures for 2066.

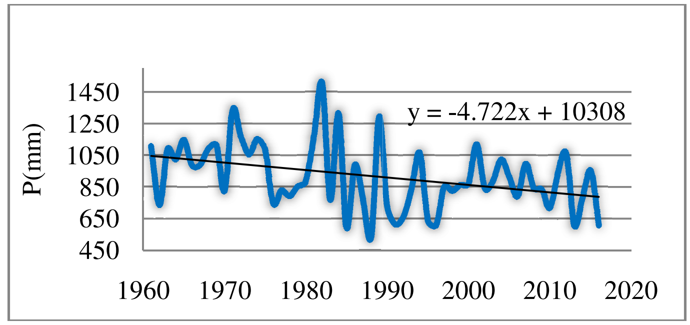

Figure-7: Linear trend of Ranohira annual precipitation between 1961 to 2016.

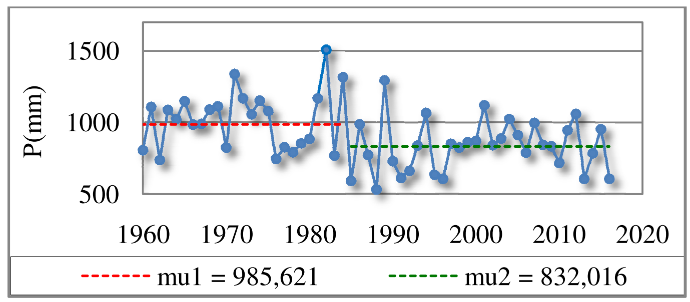

Figure-8: Homogeneity test of Ranohira annual precipitation between 1961 and 2016.

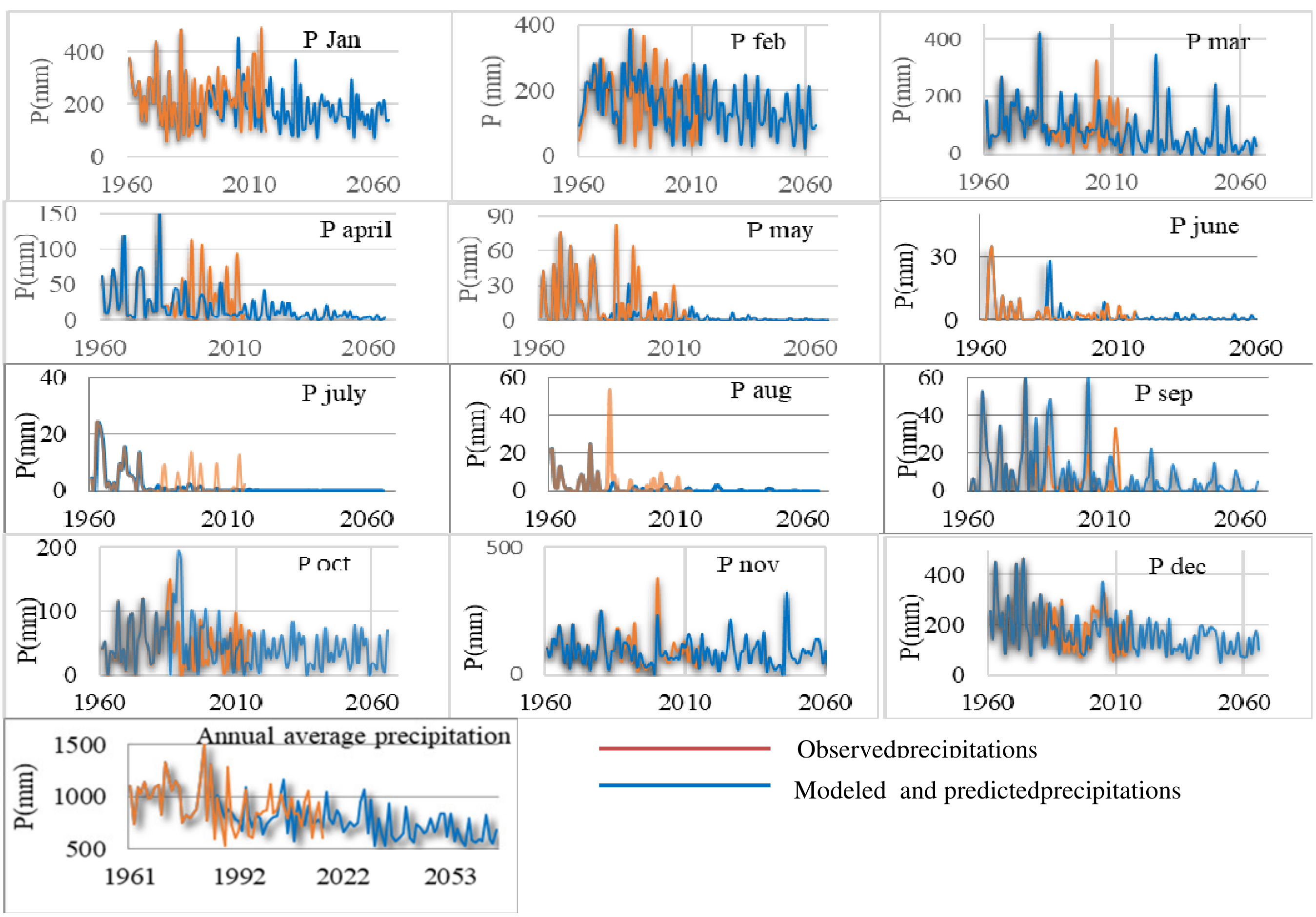

Figure-9: ARIMA modeling results of annual and monthly precipitation in Ranohira.

Table-4: Precipitation averages for observation years and forecast years.

Mois	1961-2016 (mm)	2017-2066 (mm)	Déficit (%)
January	227,56	166,58	26,82
February	173,5	129,3	25,48
March	108,5	55,99	48,4
April	32,26	7,17	77,71
May	14,98	0,95	93
June	3,05	0,59	80,58
July	3,77	0,03	99
August	3,84	0,28	92
September	9,25	3,14	66
October	46,91	35,28	24
November	95,56	83,04	13
Décember	198	129	54
Annual	917	713,6	22,19

Conclusion

The statistical analysis and modeling of the climatic data of Ranohira makes it possible to know the trend and the temporal variations of the temperatures and the precipitations of the region, and to perform predictions. In this work, we have shown how linear regression and ARIMA modeling can be used for this purpose. Analytical results and forecasts indicate a potential significant warming and a drought trend in the future.

Annual temperature data from 1961 to 2016 show a growth rate of 0.2°C per decade and modeling permits to predict warming up to 23.9°C in 2066. Analysis of annual rainfall averages show a decrease of 47.2mm per decade and permits to predict a decrease of 22.19% within 50 years.

This study contributes to the evaluation of impacts of climate change in the Ihorombe region. It may be considered as important and great interests for the future of the southern part of Madagascar regarding climate issue. In fact, it can be applied in the anticipation of consequences of future climate behavior and variations. As these variations could have significant impact on water cycle, water resources, environment, economic and social life, public health and the development of the region, it is vital to have some knowledge about the latter parameters in advance. As Mr David SAGARA, Minister of Environment and Sanitation, said in a speech delivered at the opening ceremony of the 1st session of National Steering Committee of the Global Alliance against Climate Change project (AGCC) in Mali on November 19, 2012 "The time has come for the country to move from awareness and political statements to the design and effective implantation of a coherent response to climate change"[15].

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