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Assessment of Climate Predictions for the Oued Laou watershed in Northern Morocco: A comparison of two predictive models

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Abstract. Focusing on the Oued Laou watershed, this study presents an innovative approach to simulate daily precipitation over a 35-year period in northern Morocco. We used the SARIMAX (AutoRegressive Seasonal Moving Average with Exogenous Variables) model and combined its potential with the Python programming language to achieve these Predictions. The SARIMAX model is an advanced time series analysis tool that integrates exogenous, autoregressive, seasonal and integrated variables. This model is capable of accurately predicting daily, monthly and annual precipitation averages for the study period. The climate projections obtained suggest that precipitation in the study area will decrease and it's accompanied by increasing temperatures. This could have significant impacts on ecosystems, water resources and the agricultural sector. This study provides essential information for a better understanding of the particular climatic trends in northern Morocco. It provides a sound basis for making informed decisions on the sustainable management of natural resources. This information will be essential in anticipating and mitigating the effects of climate change, particularly with regard to precipitation and its potential impacts it could have on the environment and agriculture.

1 Introduction

One of the most pressing issues facing the world today is climate change, which is having a major impact everywhere [1]. The Sixth Assessment Report (AR6) of the International Panel on Climate Change (IPCC) found that the Middle East and North Africa (MENA) region in particular is expected to become hotter and drier as a result of climate change [2]. This vulnerable region is highly susceptible to extreme weather events such as storms, heat waves, heavy rainfall, flash floods and rising sea levels, all of which are being exacerbated by climate change [1,2]. It should be emphasised that climate change is currently recognised as the world's biggest problem [3]. Due to the significant social, economic and environmental impacts of severe precipitation events, the effects of climate change on their frequency and severity have recently received much attention [4]. In order to manage risks responsibly, it is imperative to provide an accurate estimate of future changes in these catastrophic events [5]. One Mediterranean country that has experienced significant impacts from climate change is Morocco [6]. However, Morocco's very uneven rainfall distribution, with significant annual variability, is predicted to result in more intense precipitation events [7]. where there is a significant population vulnerability to major hydrological events. Morocco, which has an arid climate, has recently experienced a major change in its climate as a result of the worldwide phenomenon known as global warming. This change has had a significant impact on critical sectors [8], including agriculture, water resources and the general economy [9]. In order to properly plan and manage water resources, it is therefore imperative to study rainfall distribution and future trends, especially in areas where the population is particularly vulnerable to major hydrological events [10].

Forecasts of rainfall and temperature provide an excellent opportunity to learn about and prepare for the effects of climate change, both globally and in Morocco. This data can help decision-makers make informed choices about adaptation, risk reduction, infrastructure development and environmental protection. By establishing resilience measures tailored to climate projections, Morocco and the international community can prepare for a sustainable and prosperous future in the face of climate risks

Our main objective is to compare the SARIMAX model with the ETS model to see how well it is able to provide an accurate assessment of future climate projections. Using a spatialized methodology, we are also trying to develop a forecast for the next 25 years. The aim of this method is to simplify the combined management of water and soil resources and to manage

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future developments more effectively. Our study is based on a rigorous approach and aims to significantly advance knowledge of regional climate patterns while providing a solid basis for consideration of sustainable use of natural resources.

2 Methodology

The data used were sourced from the Loukous Hydraulic Basin Agency (LHBA).

For the simulation, we used the SARIMAX model in Python, which is a, short for "Seasonal AutoRegressive Integrated Moving Average with eXogenous variables," is a statistical model used to analyse and forecast time series data. It is an extension of the ARIMA model (AutoRegressive Integrated Moving Average) that incorporates seasonal components and exogenous variables to enhance forecast accuracy [11]. The SARIMAX model used to simulate future climate conditions at the regional level. We applied it in the study area to simulate the spatial variability of precipitation between 2022 and 2047.

2.1 Study area

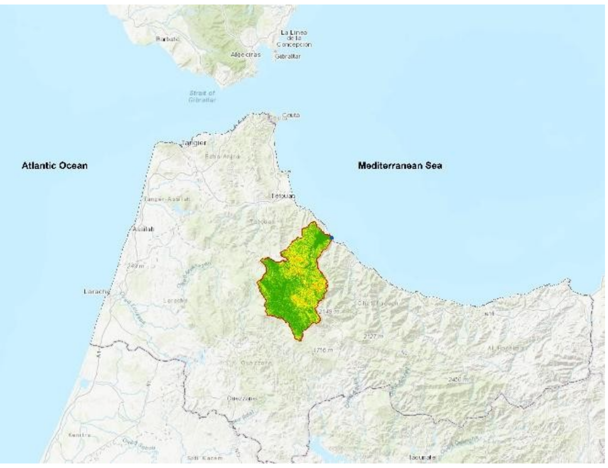

Fig. 1. Location of study area

The Oued Laou watershed is located in the north-western region of Morocco, on the Mediterranean coast and in the provinces of Tétouan and Chefchaouen (Figure 1). It lies in the central part of the Rif Mountain range, also known as the Haut Rif, between 5°04' and 5°19' W longitude and 35°27' and 35°12' N latitude, Covering an area around 928 km2, the south part of the site under study is mostly mountainous, marked by abrupt slopes and steep reliefs: the northern part is mainly flat at the central area and gently hilly at the borders, the altitude range between 0 and 2122 m above sea level. The climate is subhumid Mediterranean with 666.09 mm annual average rainfall with humid, relatively cold winter and dry, warm summer. The majority of precipitation occurs between November and March. The annual average temperature is 18.6°C. [12].

2.2 SARIMAX Model

The SARIMAX model, or Seasonal AutoRegressive Integrated Moving Average with eXogenous regressors model, is a type of time series model used to forecast future points in the series. Here's a brief overview of the SARIMAX model's components:
the algorithm of the SARIMAX model involves estimating the parameters that best fit the model to theobserved data. This estimation is typically done using Maximum Likelihood Estimation (MLE). Once the parameters are estimated, the model can be used for forecasting [13].
It's important to note that choosing the right orders for the AR (AutoRegressive), I (Integrated), MA (Moving Average), and seasonal components can be a complex task. It often involves the use of techniques like autocorrelation plots, partial autocorrelation plots, and grid search.
SARIMAX is a combination of AR, I, MA, seasonal, and exogenous components. The general form of the model can be written as follows:

$$Y_t = \mu + \Phi_1 Y_{t-1} + ... + \Phi_p Y_{t-p} + \Theta_1 \varepsilon_{t-1} + ... + \Theta_q \varepsilon_{t-q} + \Phi_P Y_{t-P} + ... + \Phi_{Pseasonal} Y_{t-Pseasonal} + \Theta_Q \varepsilon_{t-Q} + ... + \Theta_{Qseasonal} \varepsilon_{t-Qseasonal} + \beta * X_t + \varepsilon_t$$

Where
Y_t is the value of the time series at time t.μ is a constant term.
$\Phi_1, ..., \Phi_p$ are the parameters of theautoregressive part.
$\Theta_1, ..., \Theta_q$ are the parameters of the moving average part.
$\Phi_P, ..., \Phi_{P*seasonal}$ are the parameters of the seasonal autoregressive part.
$\Theta_Q, ..., \Theta_{Q*seasonal}$ are the parameters of the seasonal moving average part.
β is the parameter of the exogenous variable X_t. ε_t is the error term at time t, assumed to be white noise.

The parameters "d" and "D" in the SARIMAX model (p, d, q) (P, D, Q) m represent the order of differencing required to make the series stationary. If d or D is non- zero, then Y_t in the equation above represents the differenced series.

This is a simplified version of the SARIMAX model equation. The actual equation is much more complex, especially concerning seasonal and exogenous components. Additionally, the equation assumes that the series is stationary, which is not always the case in practice. Non-stationary series need to be differenced (i.e., subtracting the previous observation from the current observation) one or more times to make them stationary before applying the SARIMAX model [11].

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3 Results & Discussion

3.1 Dataset & overview

The Precipitation distribution (Figure 2) shows the evolution of annual rainfall in the Oued Laou catchment area from 1987 to 2022. The horizontal axis indicates the rainfall in millimetres, while the vertical axis is the date, from 1987 to 2022. Looking at this graph, we can see an interesting trend in annual precipitation.

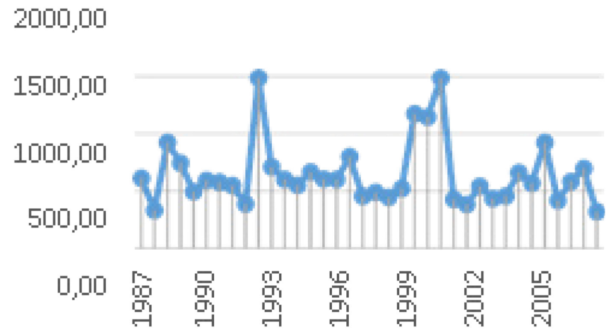

Fig. 2. Rainfall trends in the Oued Laou watershed

At the beginning of the graph (Figure 2), precipitation seems to be fairly constant over the years. However, as the years go by, the intensity of precipitation increases, especially during the winter season, while the other seasons have very little or no precipitation. Agriculture, local ecosystems and regional hydrological cycles may be significantly affected by this change.

In another study, precipitation patterns predicted in northern Morocco by the RegCM4.6 model for the years 2023-2099 were compared with historical data for the years 1970-2005, particularly in north-western Morocco. The mean winter precipitation predicted by the RegCM4.3 model was found to be significantly anomalous. This anomaly showed a clear negative bias over the entire northern area, indicating a significant decrease in the total amount of precipitation expected for the years 2023 to 2099. [3]

Forecasts of rainfall and temperature in the Dar Chaoui region of northern Morocco up to 2050 have produced some alarming results. In recent years, there has been a significant increase in temperature and a corresponding decrease in rainfall. [4]

Data analysis

The normalised residual, also known as the standardised residual, is a measure of the difference between the observed values of a variable and the values predicted by a statistical model. It is commonly used to test the fit of a model to the data.

The use of standardised residuals allows the detection of data points that deviate significantly from the model's predictions. Extremely high standardised residuals (positive or negative) may indicate outliers or influential points that can have a significant impact on the overall model fit.

In our case, (Figure 3, a) a negative standardised residual indicates that the observed value is lower than the predicted value.

The histogram plus estimated density graph combines a histogram and an estimated density to provide a more complete and accurate representation of the data distribution.

As a result, (Figure 3, b) the characteristics and shape of the data distribution are better understood.

In this case, it is clear that the kernel density estimate accurately captures the shape of the theoretical standard normal distribution for precipitation.

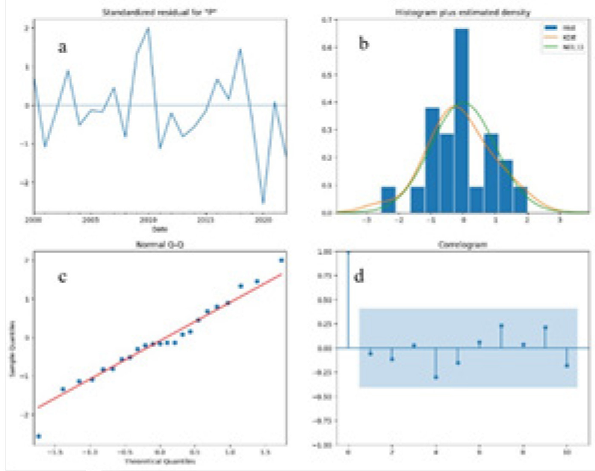

Fig. 3. Exploration of Data Distribution: Residuals (a), Density Histogram (b), Normal QQ Plot (c) and Correlogram (d)

The quantile-quantile (QQ) plot is a graphical tool used to compare the empirical distribution of a data set with a theoretical distribution, typically the normal distribution. It can be used to determine whether or not the data have a normal distribution.

In this case, (Figure 3, c) the points of the QQ plot are distributed at an angle of 45 degrees to the reference line, indicating a normal distribution for the data. In other words, the theoretical quantiles of the normal distribution correspond to the empirical quantiles. This supports the univariate normality of the data.

The correlogram displays bars or lines representing the correlation between observations at different time lags. Higher bars or lines indicate a stronger correlation between observations at that time lag, while lower bars or lines indicate a weaker correlation (Figure 3, d).

3.2 Results & Comparison

The research has progressed to a more sophisticated stage of analysis since the Python code was developed. Python, as a versatile programming language, allows for advanced data analysis, modeling, and simulations. It enables the incorporation of multiple libraries and packages that improve the research process.

While time series models are widely used for forecasting in the forest sector

Some researchers found that the six-month ARIMA forecasts were the most accurate in predicting beech sawlog prices in Central Europe compared to linear and multivariate exponential smoothing models. As a result, they recommended that this model be used to guide management and trade decisions [13].

this graph (Figure 4) illustrates the results of annual and monthly rainfall forecasts. It allows us to observe seasonal variations and long-term trends in precipitation, providing us with a comprehensive view of both annual and monthly precipitation forecasts.

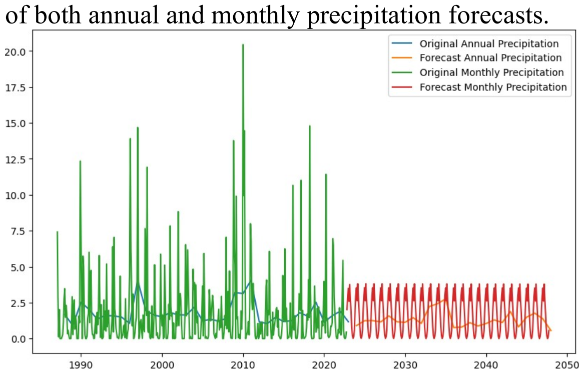

Fig. 4. Daily Average Precipitation Predictions

As the PBIAS is positive in (Table 1), it indicates that the model estimates are on average higher than the actual values, although the deviation from the actual values is relatively modest. A PBIAS score of 0.4213 is within an acceptable range, but it's important to consider and possibly adjust for this bias when interpreting the model's results to ensure accuracy in applications where precise estimates are required.

The Model performance is moderately good, as evidenced by the KGE score of 0.6295 (Table 1). KGE values closer to 1 and higher indicate better performance. This result shows that, when compared to the observed data, the model reasonably captures the variability, mean, and correlation of precipitation.

In the last column of (Table 1), The model is successfully lowering residual errors with an RSR of 0.7491; nevertheless, there is still a potential for improvement to produce an even better match with the observed data.

Table 1. Performance Metrics for Oued Laou Watershed

Measure	Value
PBIAS	0.4213072330938469
KGE	0.62946389127892377
RSR	0.7491351048051272

The graph in (Figure 5) shows the results of the Error- Trend-Seasonal (ETS) model, which is one of the most widely used time series forecasting models. Although the ETS model is a popular option for time series forecasting, some scenarios, such as the one I'm about to present, have performance measures that raise questions about its effectiveness.

Moreover, to shed further light on our findings, we delve into a deeper analysis of the results, seeking insights and implications.

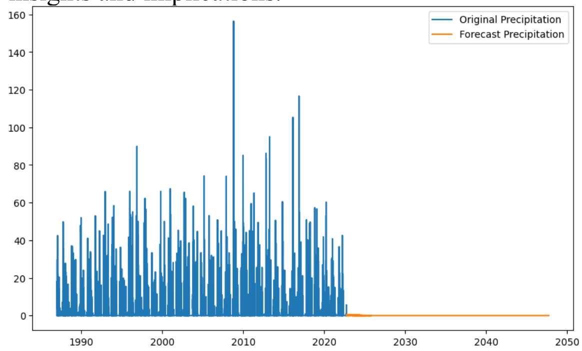

Fig. 5. Lack of Significant Results for ETS Model Performance

- -PBIAS (Percent Bias) for Precipitation: 0.8213
- -KGE (Kling-Gupta Efficiency) for Precipitation: 0.1255
- -RSR (Root Mean Square Residual) for Precipitation: 0.9491

A significant performance gap in precipitation forecasting is revealed by the data analysis, highlighting the need for more accurate models to improve forecasting skills. In this situation, the SARIMAX model outperforms the ETS model in terms of performance. SARIMAX is a useful tool for increasing the accuracy of precipitation forecasts (Figure 4), especially in difficult settings, due to its capacity to incorporate exogenous variables and capture complicated time series patterns. These findings highlight how crucial it is to take into account cutting-edge modeling strategies like SARIMAX in order to close the performance gap and improve the accuracy of precipitation forecasts.

4 Conclusion & perspective

The climate projections generated in this study using SARIMAX and Detailed graphs of the projected rainfall in Oued Laou BV are provide crucial information on the anticipated future changes and demonstrate that the Oued Laou watershed will receive a decrease in precipitation.

The ability of the SARIMAX model to reproduce observed climate data demonstrates its reliability and usefulness for future research. The identification of temperature and precipitation variations associated with climate change will be an asset in providing clearer results on future climate change, as this information is crucial for understanding climate change trends specific to the sites studied and historical data. Our aim is to improve soil management techniques by adding temperature as an additional element to the current model. This extension aims to improve resource management decisions and provide a more thorough understanding of soil dynamics.

References

1. AR6 Climate Change (2021) - Impacts, Adaptation, and Vulnerability, IPCC. url: Rapport de synthèse — GIEC (ipcc.ch).
2. Almazroui, Atmosphere 10, 675 (2019)
3. I. Boulahfa, M. ElKharrim, M. Naoum, M. Beroho, A. Batmi, R. E. Halimi, M. Maâtouk, and K. Aboumaria, Heliyon 9, e17473 (2023)
4. M. Beroho, H. Briak, R. El Halimi, A. Ouallali, I. Boulahfa, R. Mrabet, F. Kebede, and K. Aboumaria, Heliyon 6, e05094 (2020)
5. M. Beroho, H. Briak, E. K. Cherif, I. Boulahfa, A. Ouallali, R. Mrabet, F. Kebede, A. Bernardino, and K. Aboumaria, RemoteSensing 15, 1162 (2023)
6. L. Liuzzo and G. Freni, J. Hydrol. Eng. 20, 04015036 (2015)
7. A. Danandeh Mehr and E. Kahya, J. Hydrol. Eng. 22, 05016037 (2017)
8. N. S. Diffenbaugh and F. Giorgi, Climatic Change 114, 813 (2012)
9. J. Schilling, E. Hertig, Y. Tramblay, and J. Scheffran, Reg Environ Change 20, 15 (2020)
10. R. P. Allan and B. J. Soden, Science 321,1481 (2008)
11. J. Banaś and K. Utnik-Banaś, Forest Policy and Economics 131, 102564 (2021)
12. O. Amellah and K. El Morabiti, Soil Sci. Ann. 72, 1 (2021)
13. M. Gejdoš, M. Lieskovský, B. Giertliová, M. Němec, and Z. Danihelová, BioRes 14, 2995 (2019)