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Temperature Forecasting as a Means of Mitigating Climate Change and Its Effects: A Case Study of Mali

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Temperature forecasts and trend analyzes were carried out for several locations in Mali as an important tool for warning of potentially threatening weather events such as severe heat waves, storms, droughts and floods, which could pose a great risk to humans and their environment. Five locations (Segou, Sikasso, Kayes, Gao and Taoudenni) across Mali (170 00'N – 40 00'W) were chosen for this research work. Satellite data of annual temperature obtained from the European Centre for Medium-Range Weather Forecast (ECMWF) database for 35 years (1985-2019) was used for this work. The Mann-Kendall trend test was carried out for various locations to observe and study the trend. Four Models including Auto Regressive and Integrated Moving Average (ARIMA), Exponential smoothening (ETS), TBATS (Trigonometric seasonality, Box-Cox transformation, ARMA errors, Trend and Seasonal components) and the linear model were employed to forecast average temperature for 10 years for all the locations. The model that produces the best forecast at the 95% confidence level is expected to have the lowest Root Mean Square Error (RMSE) value. The results showed that no significant trends were recorded at the considered locations. The linear model produced the best forecast for Segou, Kayes and Taoudenni, while the TBATS model produced the best forecast for Gao and the ARIMA model produced the best forecast for Sikasso.

Keywords: Trend Analysis; Forecast; Temperature; Mali; Mann-Kendall; Models

Introduction

Temperature is a physical quantity that expresses quantitatively the perceptions of hotness and coldness of a body or a place [1]. Increase in temperature are strongly associated with the changes in the earth's climate and tends to have negative effects on live and livelihood [2]. This has made it very important to study the trends and forecast the parameter thereby providing a clear picture of the climate of a location. Temperature forecasts are crucial because Mali's economy, which is heavily reliant on mining and agriculture, would expand if favorable climate circumstances were to occur [3]. Long-term variations in temperature and precipitation are important in defining the current and future changes seen in nature [4]. Monthly precipitation distortions may be desirable or undesirable in various months of the year, as crop growth period can be disrupted by

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heating from high temperatures [5]. Crop production and water-use efficiency are expected to be very inefficient due to reduced precipitation during this period, leading to increased demand for water at high temperatures [6].

Changes in surface temperature also tend to increase due to rapid land use conversions and modifications, which may present greater potential for climate-related hazards such as flooding, erosion, and any other relevant environmental hazards [7]. These harsh conditions are expected to double in the future due to increased levels of migration due to favorable socioeconomic, agricultural, political and natural factors, which pose a major threat to water resources, agricultural activities and ecosystem services [8]. These temperature variations are a strong indicator that the future of any place depends on it, and weather forecasting is in high demand for a variety of applications in areas such as agriculture, air traffic services, flooding, energy and environmental control [9].

The changes in the trends of temperature contribute greatly to the increase in global warming of any location. According to the Intergovernmental Panel on Climate Change (IPCC), emitted greenhouse gases are the main contributor to the increase in temperature, making global warming longer than expected unless the release of greenhouse gases is strictly controlled [10]. Daramola *et al.* [11] in their analysis of temperature over the climatic zones across Nigeria used data from ten Global Circulation Models (GCM) re-grided to a 1° x 1° spatial resolution. His analysis showed the standardized temperature forecast and anomaly over the different climatic zones in Nigeria from 2011-2100. From the summary statistics of the temperature anomaly for the zones, he concluded that positive anomaly exceeds the negative anomaly across all the zones, indicating more warm years than colder years.

Yusuf *et al.* [12] investigated the temperature trend in Nigeria using a network of ground based Automatic Weather Stations (AWS) installed at different locations in Nigeria. The results reveal a continuous variability that is seasonally dependent in each of the years. It was also seen that the results showed a steady increase in temperature recorded in the locations under study. This temperature increase is connected to the climate change observed in the locations under study as a result of increase in the concentration of greenhouse gases.

Short term predictions of temperature have failed to give a clear picture on future climate conditions, thereby creating the need to engage multiple models to forecast temperature [13]. The ideal model will be the one that forecasts temperature for that location with the lowest root mean square error [14]

Materials and Methods

For the purpose of this research work, the atmospheric data were satellite remote sensing data obtained from the archives of the European Centre for Medium-Range Weather Forecasts (ECMWF) Website. This dataset represents one of the best systematic estimates of the average annual temperature anomalies of the Earth’s surface, taking all land and sea surfaces together, based on historical observations. The dataset is regularly updated and is freely available.

The meteorological data which was in degree Celsius were obtained using the geographical coordinates of each of the locations for the period of 35 years (1985 – 2019) covering 5 different locations across Mali. The locations are Segou, Sikasso, Kayes, Gao and Taoudenni. Using the Anaconda software created and maintained by Anaconda, Inc. Austin, Texas, USA, which was established by Peter Wang and Travis Oliphant in 2012, the data that were initially griddled in NetCDF format were converted to readable format. The hourly data were further averaged to daily, monthly and yearly data using the same software to reduce the data, to obtain smoother profiles for easy analysis.

Data Analysis

Mann-Kendall trend analysis was carried out using the R programming language in all the locations to understudy and observe the trend of the parameter so as to compare with the forecasted values. Four different models were employed to run a decadal forecast of the parameter using the already obtained set of data for each of the locations. These models are Auto regressive integrated moving average (ARIMA), Exponential smoothing (ETS), TBATS (Trigonometric seasonality, Box-Cox transformation, ARMA errors, Trend, Seasonal components) and the linear regression models. The best model was selected using the root mean squared error (RMSE). The root mean square error is commonly used to evaluate quality predictions, because it measures the differences between predicted values and the observed or recorded values. Root mean square error can be expressed as:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(p_i - o_i)^2}{n}} \quad (1)$$

where P = predicted values, O = Observed values, n = sample size or number of data points, and Pi – Oi = the residual.

In machine learning, it is extremely helpful to have a single number to judge a model's performance, whether it be during training, cross-validation, or monitoring after deployment. Root mean square error is one of the most widely used measures for this. It is a proper scoring rule that is intuitive to understand and compatible with some of the most common statistical assumptions. The RMSE indicates the absolute fit of the model to the data by telling us how close the observed data points are to the models forecasted values. RMSE is a perfect measure of how accurately a model predicts the response, and it is the most important fit criterion if the primary purpose of the model is prediction. The lower values of RMSE portrays a better fit [15].

Results and Discussion

From the Mann-Kendall trend analysis, the parameters obtained include the Z-value, the Mann-Kendall statistic (S), the probability value (p-value) and the tau (τ). These parameters were computed for the period of study which covers all locations in the scope. The Mann-Kendall parameters for all the locations in Mali are presented below in Table 1.

Table 1 shows the Mann-Kendall trend analysis parameters for Segou, Sikasso, Kayes, Gao and Taoudenni. Results shows there are no significant Mann-Kendall trends recorded in the considered locations. This is because the p-values obtained in all the locations are greater than the set alpha value of 0.05. The positive z-value as well as the positive tau value becomes insignificant since there is no trend.

Table 1. Mann-Kendall trend test parameters for locations in Mali

MALI	Z-value	Sens's slope	p-value	tau(τ)	Trend Status
Segou	1.050906	0.012757	0.29330178	0.12605	No Trend
Sikasso	0.454446	0.005117	0.649507976	0.055462	No Trend
Kayes	1.704172	0.019308	0.08834899	0.203361	No Trend
Gao	-0.02865	-0.00025	0.97734084	-0.00504	No Trend
Taoudenni	-1.29666	-0.01854	0.20120399	-0.15294	No Trend

SEGOU

From Figure 1, average annual temperature was observed to vary over the years in Segou with the highest value at 24.073°C in 2006 and the lowest value of 20.632°C in 1989.

For the Arima Model, temperature was forecasted at the 95% confidence level and the forecast can go as high 22.67°C as and as low as 20.98°C.

For the ETS model, temperature was forecasted at the 95% confidence level and the forecast could go as high 22.75°C as and as low as 21.05°C.

For the linear regression model, temperature was forecasted at the 95% confidence level and the forecast could go as high 22.24°C as and as low as 21.21°C.

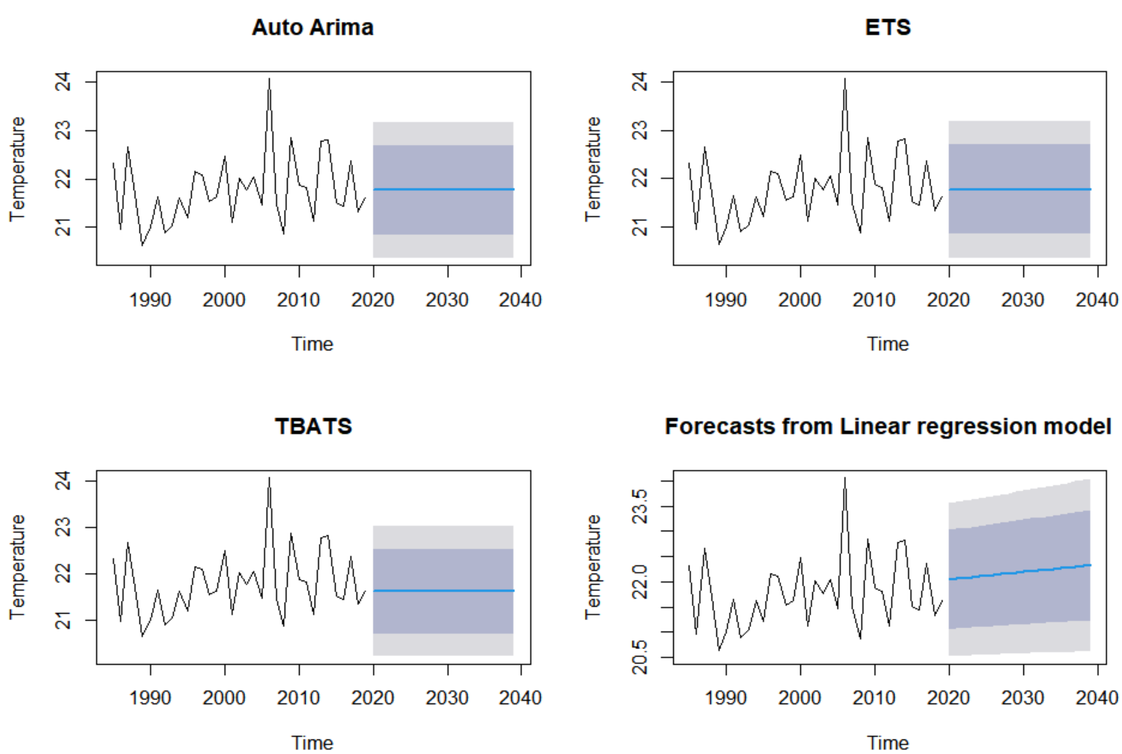

Fig. 1. Graphs showing temperature variations between 1985 and 2019 and forecast between 2020 and 2030 for Segou using the different models.

For the TBATS model, temperature was forecasted at the 95% confidence level and the forecast could go as high 22.65°C as and as low as 20.82°C.

From Table 7, the model that made the best forecast was the linear model since it recorded the lowest Root Mean Square Error value of 0.690 for the location with a forecast range of 21.21°C – 22.24°C. The average observed value was 22.35°C and the forecast value is 21.73°C with a percentage anomaly of -2.7%.

Below is a table showing the forecast coefficients for Segou.

Table 2: Forecast coefficients for Segou.

SEGOU	AIC	AICC	BIC	MEAN	R^2	SE	P value	INTERCEPT	ACF
ARIMA	79.04	79.41	82.15	21.7719	-	0.1195	-	-	-0.134
ETS	106.1503	106.9245	110.8163	-	-	-	-	-	-0.134
LINEAR	-	-	-	-	0.01734	0.24556	0.2148	21.50101	-0.204
TBATS	105.0908	-	-	-	-	-	-	-	-0.126

SIKASSO

From Figure 2, average annual temperature was observed to vary over the years in Sikasso with the highest value at 22.50°C in 2006 and the lowest value of 20.04°C in 1989.

For the Arima Model, temperature was forecasted at the 95% confidence level and the forecast can go as high 21.75°C as and as low as 20.44°C.

For the ETS model, temperature was forecasted at the 95% confidence level and the forecast could go as high 21.65°C as and as low as 20.31°C.

For the Linear regression model, temperature was forecasted at the 95% confidence level and the forecast could go as high 22.29°C as and as low as 20.53°C.

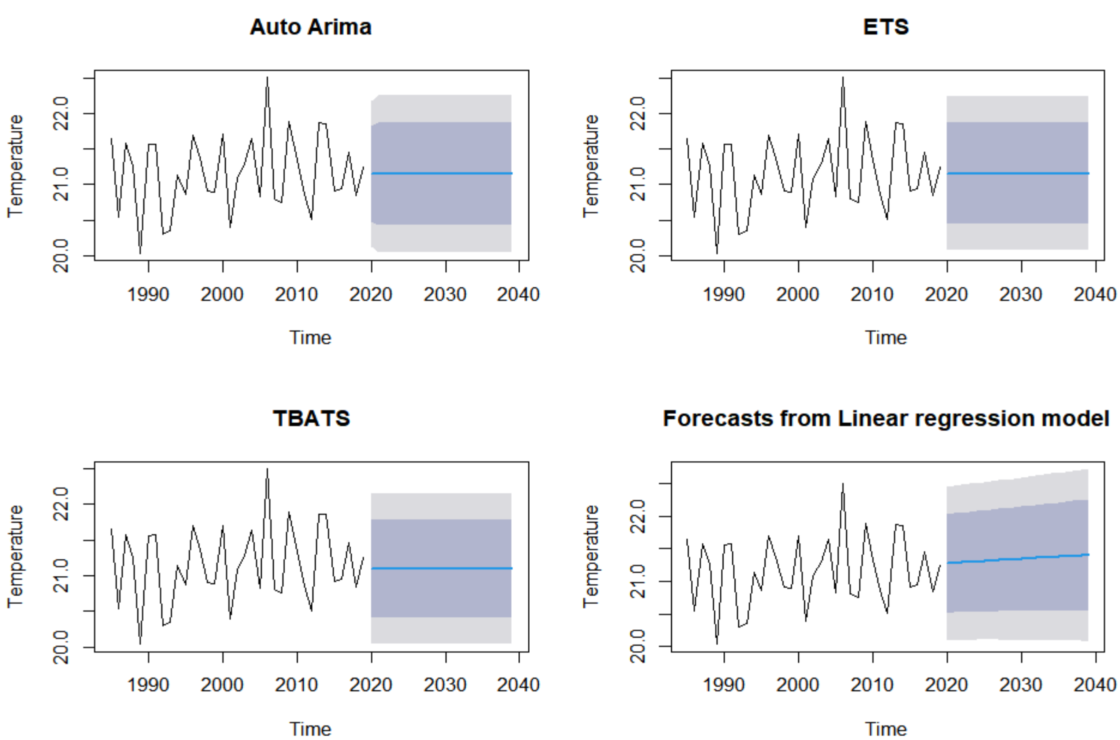

Fig. 2. Graphs showing temperature variations between 1985 and 2019 and forecast between 2020 and 2030 for Sikasso using the different models.

For the TBATS model, temperature was forecasted at the 95% confidence level and the forecast could go as high 21.72℃ as and as low as 20.41℃.

From table 7, the model that made the best forecast was the Arima model since it recorded the lowest Root Mean Square Error value of 0.507 for the location with a forecast range of 20.48℃ – 22.4℃. The average observed value was 21.27 and the forecast value is 21.40℃ with a percentage anomaly of 0.6%.

Below is a table showing the auto correlation function coefficients for Sikasso.

Table 3: Forecast coefficients for Sikasso.

SIKASSO	AIC	AICC	BIC	MEAN	R^2	SE	P value	INTERCEPT	ACF
ARIMA	58.01	58.78	62.67	21.1531	-	0.1601	-	-	0.042
ETS	86.78310	87.55730	91.44915	-	-	-	-	-	-0.225
LINEAR	-	-	-	-	-0.01359	0.189119	0.466	21.035041	-0.252
TBATS	84.80428	-	-	-	-	-	-	-	-0.223

KAYES

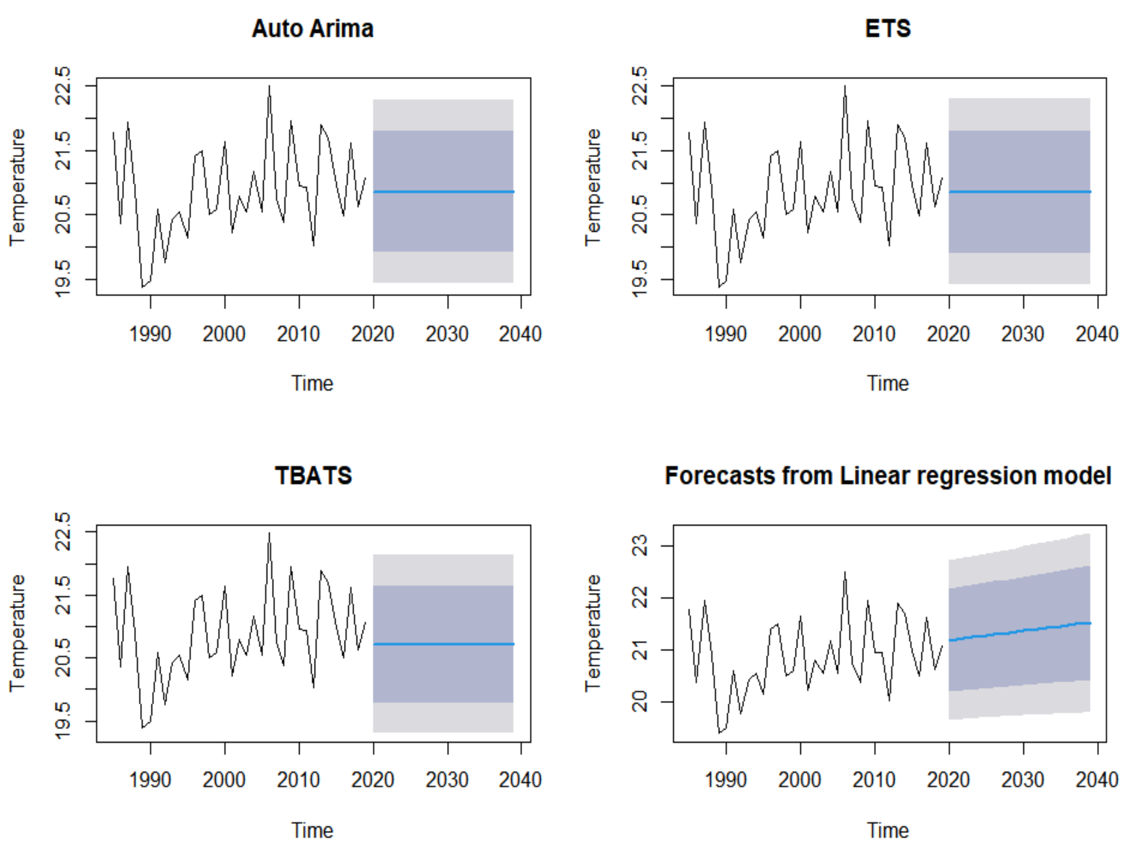

Fig 3: Graphs showing temperature variations between 1985 and 2019 and forecast between 2020 and 2030 for Kayes using the different models.

From Figure 3, average annual temperature was observed to vary over the years in Kayes with the highest value at 22.49℃ in 2006 and the lowest value of 19.38℃ in 1989. For the Arima Model, temperature was forecasted at the 95% confidence level and the forecast can go as high 21.87℃ as and as low as 20.16℃.

For the ETS model, temperature was forecasted at the 95% confidence level and the forecast could go as high 21.93℃ as and as low as 20.31℃.

For the linear regression model, temperature was forecasted at the 95% confidence level and the forecast could go as high 22.66℃ as and as low as 20.63℃.

For the TBATS model, temperature was forecasted at the 95% confidence level and the forecast could go as high 21.61℃ as and as low as 19.73℃.

From Table 7, the model that made the best forecast was the linear model since it recorded the lowest Root Mean Square Error value of 0.69 for the location with a forecast range of 21.63℃ – 22.66℃. The average observed value was 20.94℃ and the forecast value is 21.64℃ with a percentage anomaly of 3.34%.

Below is a table showing the forecast coefficients for Kayes.

Table 4: Forecast coefficients for Kayes

KAYES	AIC	AICC	BIC	MEAN	R^2	SE	P value	INTERCEPT	ACF
ARIMA	79.98	80.35	83.09	20.8588	-	0.1211	-	-	-0.0006
ETS	107.0921	107.8662	111.7581	-	-	-	-	-	-0.0006
LINEAR	-	-	-	-	0.03475	0.24668	0.1454	20.53801	-0.087
TBATS	105.7442	-	-	-	-	-	-	-	0.006

GAO

From Figure 4, average temperature was observed to vary over the years in Gao with the highest value at 25.49℃ in 2000 and the lowest value of 19.38℃ in 1997.

For the Arima Model, temperature was forecasted at the 95% confidence level and the forecast can go as high 25.50℃ as and as low as 22.48℃.

For the ETS model, temperature was forecasted at the 95% confidence level and the forecast could go as high 25.49℃ as and as low as 22.50℃.

For the linear regression model, temperature was forecasted at the 95% confidence level and the forecast could go as high 25.37℃ as and as low as 22.08℃.

For the TBATS model, temperature was forecasted at the 95% confidence level and the forecast could go as high 25.29℃ as and as low as 22.49℃.

From Table 7, the model that made the best forecast was the TBATS model since it recorded the lowest Root Mean Square Error value of 0.791 for the location with a forecast range of 22.49℃ – 25.29℃. The average observed value was 22.43℃ and the forecast value is 23.89℃ with a percentage anomaly of 6.51%.

Below is a table showing the forecast coefficients for Gao.

Table 5: Forecast coefficients for Gao.

GAO	AIC	AICC	BIC	MEAN	R^2	SE	P value	INTERCEPT	ACF
ARIMA	87.14	87.52	90.25	23.9494	-	0.1341	-	-	-0.12
ETS	114.2597	115.0339	118.9258	-	-	-	-	-	-0.12
LINEAR	-	-	-	-	-0.028	0.282073	0.8084	24.009550	-0.125
TBATS	112.0242	-	-	-	-	-	-	-	-0.125

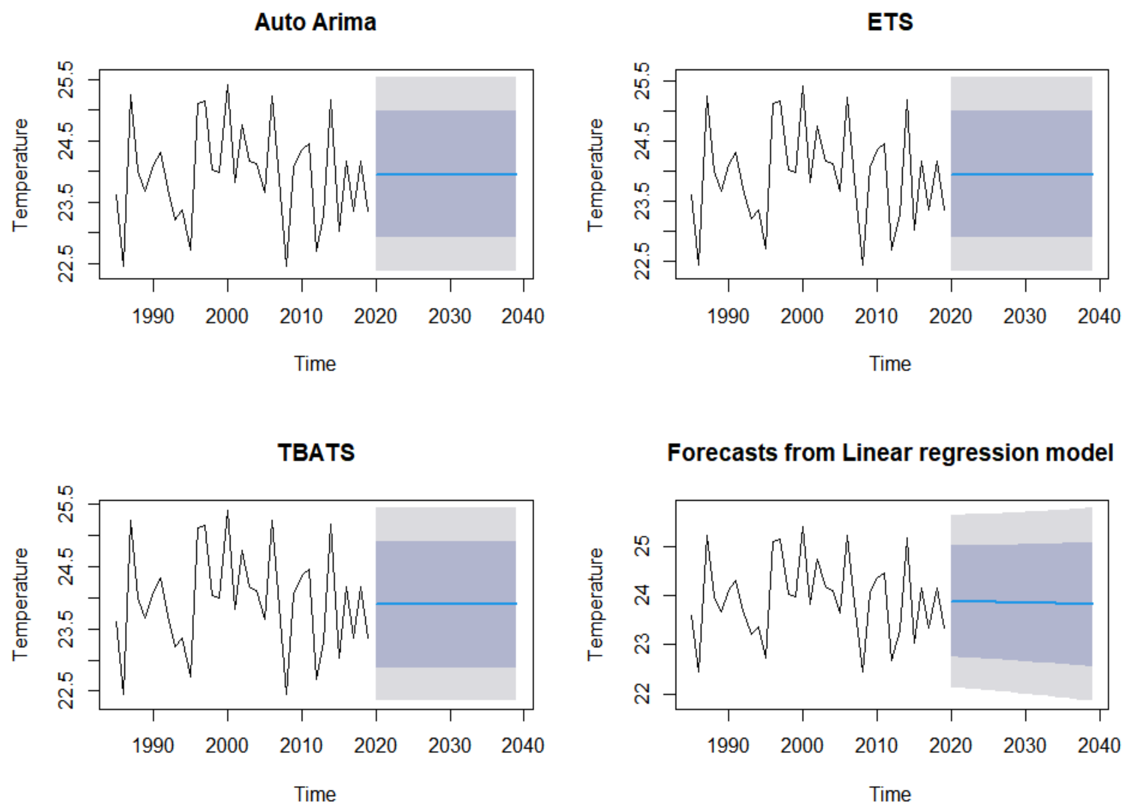

Fig. 4. Graphs showing temperature variations between 1985 and 2019 and forecast between 2020 and 2030 for Gao using the different models.

TAOUDENNI

From Figure 5, average temperature was observed to vary over the years in Taoudenni with the highest value at 21.29℃ in 1991 and the lowest value of 17.77℃ in 2008.

For the Arima Model, temperature was forecasted at the 95% confidence level and the forecast can go as high 21.25℃ as and as low as 17.97℃.

For the ETS model, temperature was forecasted at the 95% confidence level and the forecast could go as high 21.20℃ as and as low as 17.60℃.

For the Linear regression model, temperature was forecasted at the 95% confidence level and the forecast could go as high 20.64℃ as and as low as 16.82℃.

For the TBATS model, temperature was forecasted at the 95% confidence level and the forecast could go as high 21.15℃ as and as low as 17.71℃.

From Table 7, the model that made the best forecast for the location was the linear model since it recorded the lowest Root Mean Square Error value of 0.808 for the location with a forecast range of 16.822℃ – 20.64℃. The average observed value was 19.53℃ and the forecast value is 18.73℃ with a percentage anomaly of -4.1%.

Below is a table showing the forecast coefficients for Taoudenni.

Table 6: Forecast coefficients for Taoudenni.

TAOUDENNI	AIC	AICC	BIC	MEAN	R^2	SE	P value	Intercept	ACF
ARIMA	90.6	90.98	93.71	19.515		0.1409	-		0.040
ETS	117.7183	118.4925	122.384	-		-	-		0.040
LINEAR	-	-	-	-	0.060	0.8322	0.1536	19.88156	-0.023
TBATS	116.8273	-	-			0.2874	-		0.009

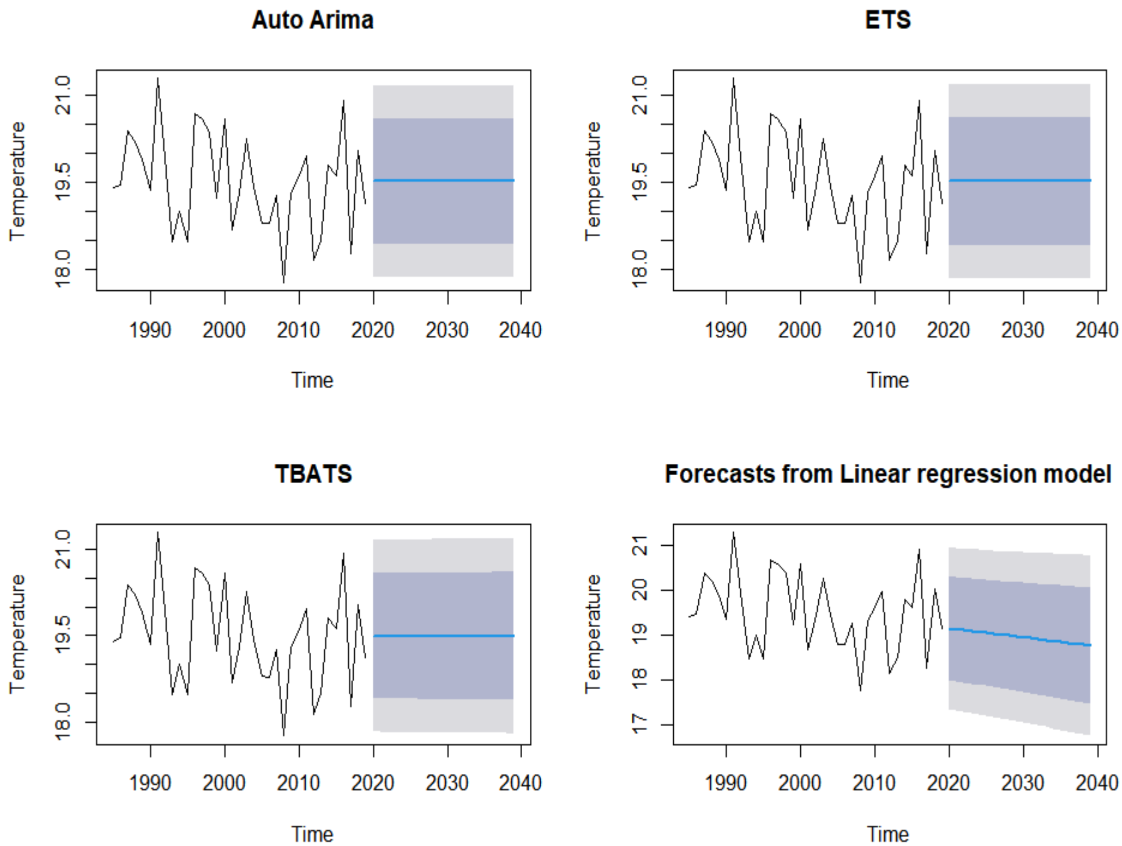

Fig. 5. Graphs showing temperature variations between 1985 and 2019 and forecast between 2020 and 2030 for Taoudenni using the different models.

Annual temperature variations from 1985-2019 and 10 year forecast for Segou is as shown in fig 1. Table 1 shows the Mann-Kendall trend analysis parameters for Segou and the results obtained exhibits no significant trend, making it difficult to assess the recent changes in temperature patterns in this location over the years considered. This is because the p-value of 0.293 is greater than the set alpha value of 0.05. The positive z-value of 1.05 recorded as well as the positive tau value of 0.126 becomes insignificant since there is no trend. The linear model produced the best forecast since it recorded the lowest Root Mean Square Error value of 0.69 for the location with a forecast range of 20.243℃ – 22.553℃. The average observed value was 21.06℃ and the forecast value is 21.73℃ with a percentage anomaly of 3.18%.

Annual temperature variations from 1985-2019 and 10 year forecast for Sikasso is as shown in fig 2. Table 1 shows the Mann-Kendall trend analysis parameters for Sikasso and the results obtained exhibits no significant trend, making it difficult to assess the recent changes in temperature patterns in this location over the years considered. This is because the p-value of 0.65 is greater than the set alpha value of 0.05. The positive z-value of 0.45 recorded as well as the positive tau value of 0.05 becomes insignificant since there is no trend. The ARIMA model produced the best forecast since it recorded the lowest Root Mean Square Error value of 0.51 for the location with a forecast range of 20.48℃ – 22.4℃. The average observed value was 21.27℃ and the forecast value is 21.40℃ with a percentage anomaly of 0.6%.

Table 7. Summary forecast Error Matrices for computer stimulated models for locations in Mali

COUNTRY	LOCATION	MODEL	FORECAST ERROR METRICS			
			RMSE	MAE	MPE	MAPE
MALI	SEGOU	ARIMA	0.7068015	0.5485527	-0.1025036	2.498599
		ETS	0.7068368	0.548575	-0.1019651	2.498689
		LINEAR	0.690267	0.5435422	-0.09763038	2.474713
		TBATS	0.7163979	0.5316598	0.4600906	2.407051
	SIKASSO	ARIMA	0.507526	0.4083713	-0.0391515	1.931589
		ETS	0.5359954	0.4477136	-0.0613197	2.117101
		LINEAR	0.5316043	0.4528471	-0.06303722	2.140672
		TBATS	0.5361576	0.4460023	0.1675978	2.104197
	KAYES	ARIMA	0.7163759	0.5798585	-0.1177178	2.776958
		ETS	0.7164117	0.5798236	-0.1160546	2.776747
		LINEAR	0.693391	0.5595368	-0.1099555	2.674297
		TBATS	0.7231157	0.5742113	0.3889485	2.735901
	GAO	ARIMA	0.7936096	0.6267157	-0.110006	2.620907
		ETS	0.793655	0.627	-0.09758923	2.621767
		LINEAR	0.7928921	0.6269887	-0.1098197	2.622059
		TBATS	0.7909886	0.6279222	0.1031281	2.620536
	TAOUDENNI	ARIMA	0.8338108	0.682474	-0.1832373	3.506958
		ETS	0.833853	0.6824711	-0.1796436	3.506819
		LINEAR	0.8081034	0.674337	-0.1719619	3.462911
		TBATS	0.8471683	0.7108771	-0.8564933	3.676114

Annual temperature variations from 1985-2019 and 10 year forecast for Kayes is as shown in Figure 3. Table 1 shows the Mann-Kendall trend analysis parameters for Kayes and the results obtained exhibits no significant trend, making it difficult to assess the recent changes in temperature patterns in this location over the years considered. This is because the p-value of 0.09 is greater than the set alpha value of 0.05. The positive z-value of 1.70 recorded as well as the positive tau value of 0.20 becomes insignificant since there is no trend. The linear model produced the best forecast since it recorded the lowest Root Mean Square Error value of 0.69 for the location with a forecast range of 21.63℃ – 22.66℃. The average observed value was 20.94℃ and the forecast value is 21.64℃ with a percentage anomaly of 3.34%.

Annual temperature variations from 1985-2019 and 10 year forecast for Gao is as shown in Figure 4. Table 1 shows the Mann-Kendall trend analysis parameters for Gao and the results obtained exhibits no significant trend, making it difficult to assess the recent changes in temperature patterns in this location over the years considered. This is because the p-value of 0.09 is greater than the set alpha value of 0.05. The negative z-value of 0.02 recorded as well as the negative tau value of 0.005 becomes insignificant since there is no trend. The TBATS model produced the best forecast since it recorded the lowest Root Mean Square Error value of 0.79 for the location with a forecast range of 22.49$^{℃}$ – 25.29℃. The average observed value was 22.43℃ and the forecast value is 23.89$^{℃}$ with a percentage anomaly of 6.51%.

Annual temperature variations from 1985-2019 and 10 year forecast for Taoudenni is as shown in Figure 5. Table 1 shows the Mann-Kendall trend analysis parameters for Taoudenni and the results obtained exhibits no significant trend, making it difficult to assess the recent changes in temperature patterns in this location over the years considered. This is because the p-value of 0.20 is greater than the set alpha value of 0.05. The negative z- value of 1.29 recorded as well as the negative tau value of 0.15 becomes insignificant since there is no trend. The linear model produced the best forecast since it recorded the lowest Root Mean Square Error value of 0.808 for the location with a forecast range of 16.822℃ – 20.64℃. The average observed value was 19.53℃ and the forecast value is 18.73℃ with a percentage anomaly of -4.1%.

CONCLUSIONS

Variations of air temperature have been observed in certain locations in Mali from 1985-2019 using satellite data from the European Centre for Medium-Range weather forecast (ECMWF) website and a 10-year forecast has been carried out using four different models (ARIMA, TBATS, ETS and the Linear model). The results reveal a continuous increase in temperature across most of the locations considered for this research. The Mann-Kendall trend test for the temperature trends at the various locations studied in the study showed that none of the locations showed a significant temperature trend. Temperature forecast results show that the linear model records the least RMSE, and is very effective in forecasting average temperature for Segou, Kayes and Taoudenni. Taking the anomaly percentage of 3.18% for the forecast point value of 21.73°C, 3.34% of the anomaly percentage for the forecast point value of 21.64°C and -4.1% of the anomaly percentage of the forecast point value of 18.73°C, using the 95% confidence interval, it is found that the RMSE It is effective.

The ARIMA model that recorded the smallest RMSE was found to be the best model for predicting Sikasso temperature. This is because it has a predicted point value of 21.40°C and an anomaly percentage of 0.6%. TBATS has the smallest high RMSE, the forecast point value is 23.89°C, and the anomaly percentage using the 95% confidence interval is 6.51%, so it is considered as the best model for temperature forecasting in this region.

Negative anomaly was recorded in Taoudenni while positive anomaly was recorded in Segou, Kayes, Sikasso and Gao. This suggests that cooler years are expected to be warmer in these regions, further suggesting that events associated with higher temperatures may increase, such as droughts.

These are in line with the Intergovernmental Panel on Climate Change projections that there will be "high likelihood of warming" ranging West Africa. This has wide-ranging implications for many economic sectors such as the health sector, aviation, agriculture, water resources, etc. Active steps by individuals, governments and companies will help mitigate the effects of climate change.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this paper.

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