Alqalam Journal of Medical and Applied Sciences. 2026;9(2):410-415
https://doi.org/10.54361/ajmas.269215

Original article

Impact of Climate Changes on Sheep Production in Marsa Matrouh Governorate in Egypt, using the Nardl Model Methodology

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Abstract
The study aimed to analyze the impact of positive and negative changes in the variables of maximum and minimum temperatures and rainfall on sheep production in Matrouh Governorate in Egypt. Nonlinear Autoregressive Distributed Lag (NARDL) modeling is used from 1998 to 2023. The results showed that negative changes in the maximum temperature (X1NEG) had a positive impact on sheep production, while positive changes in the rainfall variable (X3POS) hurt sheep production (Y) in the study area. Negative changes in the rainfall variable (X3NEG) had no impact. The error correction term coefficient (ECM (-1)) was -1.2490, a negative and statistically significant value. This indicates that sheep production returns to equilibrium after a short-term shock, with fluctuations occurring before stabilization due to excessive correction. In the matter of the long run, the positive changes in the variable X1 (maximum temperature) hurt sheep production. Changes in climatic factors, represented by positive and negative changes in maximum and minimum temperatures and rainfall, affect sheep production in the Marsa Matrouh region, and sheep production is affected by these non-linear and asymmetrical changes.
Keywords. Maximum Temperature, Minimum Temperatures, Rainfall, Sheep Production.

Introduction

The agricultural sector plays a pivotal role in the Egyptian economy. It supports and develops other economic sectors by increasing agricultural activity, meeting the population's food needs, and providing raw materials for primary industries. This has a significant impact on the growth of the industrial sector. In addition, it generates foreign currency through the export of agricultural products. Furthermore, it relieves pressure on land use by reducing unemployment. This involves transferring disguised unemployment from agriculture to non-agricultural sectors and creating more employment opportunities, as well as the agriculture contributing significantly to Egypt's GDP. Based on published data [1], the total volume of exports amounted to 52,115.7 million dollars, while agricultural exports amounted to 11,525.8 million dollars, which represents 22.11% of the total exports. Total employment reached 30,122 thousand workers, and agricultural employment amounted to about 5,268 thousand workers, representing 17.48% of the total workforce. As for the gross domestic product, it amounted to 409,306.89 million dollars, while the agricultural gross domestic product amounted to 44,801.72 million dollars, which represents 10.94% of the total gross domestic product.

Food security is a global priority, and a significant increase in demand for animal products is expected in the future. Production is directly dependent on climate and affected by long-run weather patterns [2]. Agricultural production is particularly vulnerable to climate fluctuations. These fluctuations lead to reduced production, deteriorating quality of animal products, and deteriorating animal health [3]. Besides that, it decreases expected returns, increasing anxiety among agricultural producers and limiting investment in the sector [4]. Sheep farming is affected by changes in temperature and rainfall, which in turn affect its adaptation to its environment, leading to fluctuations in production, weakening its role in increasing animal activity and its participation in the agricultural GDP, as it is one of the vital agricultural economic activities for an important segment of farmers. This research aims to identify the characteristics of sheep production in Matrouh Governorate, including temperature and minimum, by employing time series data from 1998 to 2023, leading to improved production and results that are realistic and were sought using the Nardl Model. Therefore, this study focuses on investigating the impact of climate change (temperature, rainfall) on sheep production in Marsa Matrouh Governorate, presenting findings that can contribute to increasing, achieving optimal conditions for improving sheep breeding, and assisting decision-makers in developing appropriate environmental policies.

Methods

Model specification

Numerous experimental studies have addressed the importance of agricultural production in general and livestock production in particular. This model examines the relationship between maximum and minimum temperatures, rainfall, and sheep production during the period 1998 to 2023. This relationship can be defined as follows:

$$Y = b0 + b1X1 + b\,2\,X2 + b\,3X3 + Ut \quad --(1)$$

where:

***Received**: 06-12-2025 - **Accepted**: 06-02-2026 - **Published**: 11-02-2026*

Sheep production (Y) is defined as the total annual sheep production in Marsa Matrouh Governorate in Egypt, during a specific period (year). Y is used as an indicator of sheep production and represents the dependent variable in the study. Sheep production is measured in thousands of heads. As for maximum temperatures, represents the annual average maximum temperature rate, which impacts the dependent variable, is denoted by X_1 and is measured in Celsius. The lowest temperature is denoted by the independent variable X_2, which represents the average annual minimum temperature rate, measured in degrees Celsius. The last independent variable that affects the dependent variable sheep production, is the annual rate of rainfall on the Earth's surface, which is measured in millimeters.
The equivalent parameters B_0, B_1, B_2, and B_3 are called the parameters, or the regression coefficients. B_0 represents the intercept of coefficient and B_1, B_2, and B_3 represent the slopes of the coefficients. The slope coefficient measures the rate of change in the (conditional) mean value of Y per unit change in each independent variable X. As for U_t is known as the stochastic, or random, error term or simply the error term. The error term is a random variable (r.v.), for its value cannot be controlled or known a priori and it represents the influence of those variables that are not explicitly included in the mode [5]. Accordingly, the NARDL model can be formulated as follows [6]:

$$\Delta Y = \mu - \rho yt - 1 + \theta^{+}x_{t-1}^{+} + \theta^{-}x_{t-1}^{-} + \sum_{j=1}^{\rho-1} a_j \Delta y_{t-j} + \sum_{j=0}^{q-1} (\pi_j^{+}\Delta x_{t-j}^{+} + \pi_j^{-}\Delta x_{t-j}^{-}) + \varepsilon t -- (2)$$

where:
θ^{+}; θ^{-} represents the long-run information for the symmetric relationship in the model, and π_j^{+}; π_j^{-} represents the short-run asymmetric coefficients.

Data of the Research
To estimate the specifications of Nardl model, this study employed secondary data from 1998 to 2023 from the Central Agency for Public Mobilization and Statistics in Egypt [7]. In addition, historical climate data from the Tutiempo Network website for Marsa Matrouh Governorate [8], as well as from published research.

Results and discussion
Statistical Descriptive of the Study Variables
The variables under study indicated that the highest value for sheep production as a dependent variable was 482,811 head of sheep, while the highest temperature was 27 °C and the lowest temperature was 17 °C. The mean annual rainfall was 263.1 millimeters. The arithmetic means of the results also indicated that the mean of variable Y is 397714.6, which is greater than the median of 395896, meaning that the distribution is slightly skewed to the right and that the data are not perfectly symmetrical. Conversely, a difference emerged between the mean (25.0683) and the median (25.00) for variable X1, reflecting a slight skewness in the distribution. For variable X2, the mean (15.89) was slightly larger than the median (15.85), thus confirming a slight positive skewness. Furthermore, the mean for variable X3 was observed to be larger than the median, and the distribution was skewed to the right due to the higher values. In terms of standard deviation of variable Y, which implies that a large dispersion far from the mean means there is a significant difference between the small and large values of the variable? Regarding the standard deviation of variable X1, which was 0.79, this suggests that the data are homogeneous, closely adjacent to the mean, and do not contain outliers. Analogously to the standard deviation of the variable X2, this pointing to the values is very contiguous to the mean, consistent, and has less dispersion. In relation to the X3, the standard deviation was 50.87, reflecting that the values are distant from the mean and not concentrated relative to it, thus implying far-apart dispersion. Concerning the values of all variables in the normal distribution test, it indicated that they were higher than the significance level of 5 percent; consequently, it accepted the null hypothesis and deduced that the data are normally distributed.

Unit Root Tests Results
To avoid obtaining statistically significant spurious regression results when using non-stationary time series for regression estimation, it is important to determine the nature of the time series, whether it is stationary or non-stationary. Therefore, the extended Dickey-Fuller (ADF) test was used to determine whether the data are stationary or non-stationary, meaning if the mean and variance are constant regarding time [9]. This test is a development of the Dickey-Fuller test (1979) [5] and involves the extra lagged terms of the dependent variable to eliminate the autocorrelations and has three forms, which can be written as follows:

$$\Delta y_t = \theta y_{t-1} + \sum_{i=1}^{p} \delta_1 \Delta y_{t-i} + \varepsilon_t \ldots (3)$$

$$\Delta y_t = \gamma_0 + \theta y_{t-1} + \sum_{i=1}^{p} \delta_1 \Delta y_{t-i} + \varepsilon_t \ldots \quad (4)$$

Received: 06-12-2025 - **Accepted**: 06-02-2026 - **Published**: 11-02-2026 https://doi.org/10.54361/ajmas.269215

$$\Delta y_t = \alpha_0 + \theta y_{t-1} + \alpha_2 t + \sum_{i=1}^{p} \delta_1 \Delta y_{t-i} + \varepsilon_t \ldots \ (5)$$

where:
α_0, γ_0 Constants: θ, Coefficient: a_2, Time Trend: p, Optimal Lag Length.

The findings of the unit root tests, the t-statistics, and the critical values at the 1% significance level indicated that three variables—annual sheep production, annual maximum temperature, and annual minimum temperature—are stationary at the first differences of order I(1). On the other hand, the annual rainfall variable was found to be stationary at the first level, I(0), as listed in Table 1. According to these findings, the difference in integration of the variable orders under study allows for the estimation of the NARDL model.

Table 1. Unit Root Test Results

Variables	At level		First differences		Decision
	t-Statistic	Prob	t-Statistic	Prob	
SP	- 2.434921	0.1429	- 7.647024	0.00	1(1)
X_1	- 1.391173	0.5694	- 9.846318	0.00	1(1)
X_2	- 2.220572	0.2046	- 10.54238	0.00	1(1)
X_3	- 4.183104	0.0034	-	-	1(0)

*Note: SP = Annual sheep production; X_1 = Annual maximum temperature; X_2 = Annual minimum temperature; X_3 = Annual rainfall amount. * Indicates the rejection of the null hypothesis at 1% level of significance.*

Optimal Lag order selection

By using model selection criteria, such as the Akaike Information Criterion (AIC), the optimal model suitable for a small sample can be selected. According to the AIC criterion, the optimal lag was 1, and the best model was 1010011. This gave the lowest value for the Akaike criterion of the Nardl model and the highest value for the adjusted coefficient of determination (Adj. R-sq), as demonstrated in (Figure 1).

Bound Test Approach

The bound testing procedure is used to verify the existence of long-term relationships between variables. The results in Table 2 showed a long-term relationship, as determined by comparing the calculated F-statistic with the critical values for bound testing. The F-statistic was 3.617240, which is greater than the upper bound critical value (3.361). This further illustrates that a long-run relationship exists. This indicates that there is cointegration between the variables.

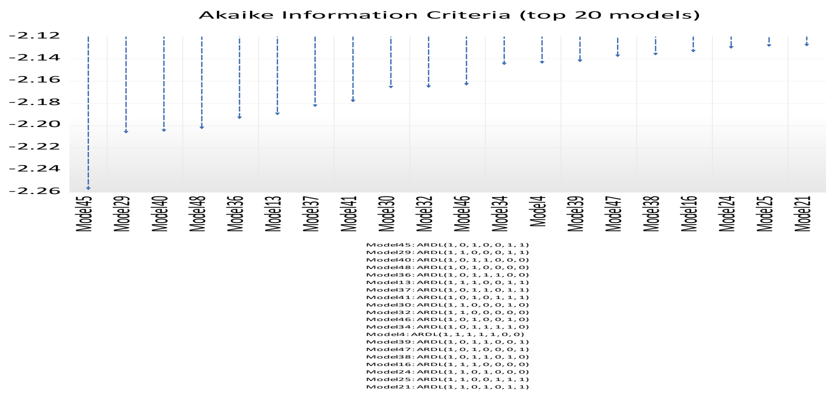

Figure1. Optimal model selection

The short and long-run parameters for the Nardl model

After dividing the independent variables into positive and negative values for each of them, the NARDL model was estimated based on the results of the ARDL model estimation, from which the results of the NARDL model estimation were obtained, as illustrated in Tables 2 and 3. In the short term, the results in Table 2 indicate that negative changes in the X1NEG variable have a positive and motivating impact on the dependent variable Y at a significance level of 5%. Conversely, X3NEG has no impact, as its t-values were greater than 5%. In contrast, positive changes in the X3POS variable had a negative impact on the dependent variable at a significance level of 1%. About the long run, there was one significant result, which is that positive changes in the X1 variable of maximum temperature had a negative impact on the dependent variable, which is sheep production. In connection with the results of short-term symmetry, it was found to be nonexistent because the positive and negative cumulative changes in the maximum temperature variable are unequal due to their different signs and values. However, the negative cumulative changes do have a positive impact.

***Received**: 06-12-2025 - **Accepted**: 06-02-2026 - **Published**: 11-02-2026*

As for the cumulative effect in the short term, it was found that reducing the negative cumulative changes of variable X1 by one unit led to an increase in sheep production by 1.61, in contrast to the positive cumulative changes of the same variable, which were found to have no effect. The same conclusion applies to the minimum temperature variable X2; whether the changes are positive or negative, they have no cumulative effect in the short term. In the third variable, rainfall (X3), the study indicated that positive cumulative changes in this variable negatively impact the dependent variable, reducing it by 0.1548. In contrast, negative cumulative changes in the same variable have a positive effect, increasing the dependent variable by 0.037. Therefore, it has been shown that the cumulative effect is asymmetrical for short-term response. On the other hand, the results indicated that the value of ECT (-1) was negative and significant (-1.249027) in the NARDL model, which indicates that the dependent variable was less than its long-run equilibrium level in the previous period. This deviation will be corrected through a negative error correction factor, with a corrective increase in the current period, which demonstrated the long-run equilibrium through the system's gradual return by explaining the behavior of the asymmetric response to negative versus positive deviations of the system.

Regarding the long run, the results indicated that all three variables are not asymmetrical, and the cumulative effect of negative changes (climate shocks) is greater than the cumulative effect of positive changes in most cases. Consequently, sheep production has become increasingly sensitive to adverse climate changes (negative shocks), such as decreased rainfall and increased temperatures. Reduced rainfall and heat stress have a significant negative impact on sheep, resulting in decreased production, reduced fertility and reproductive capacity, increased disease, and physiological disturbances (such as loss of appetite, panting, and rapid breathing). In addition, drought and fatal sunstroke may have a greater impact on high-producing animals that are less adapted to these extreme climatic changes.

Table2. ***The short and long-run parameters for the Nardl model***

The short-run parameters			
Variable	**Coefficient**	**t-Statistic**	**Prob**
D(X_1NEG)	1.610659	2.999435	0.0096
D(X_3POS)	- 0.154863	-3.713223	0.0023
D(X_3NEG)	0.037651	0.976158	0.3456
CointEq(-1)*	- 1.249027	-6.165807	0.0000
R-squared	0.6654	Adjusted R-squared	0.61767
The long-run parameters			
Variable	Coefficient	t-Statistic	Prob
X_1pos	-2.367849	-2.294236	0.0378
X_1neg	-0.381104	-0.301232	0.6777
X2pos	-0.663485	-0.976651	0.3453
X_2neg	-0.356717	-0.399852	0.6953
X_3pos	-0.018430	-0.422268	0.6792
X_3neg	-0.081061	-1.566143	0.1396
C	13.19402	171.0255	0.0000

Note: XNote: X_1pos refers to positive changes in maximum temperature, X_1neg refers to negative changes in maximum temperature, X_2pos refers to positive changes in minimum temperature, X_2neg refers to negative changes in minimum temperature, X_3pos refers to positive changes in rainfall, X_3neg refers to negative changes in rainfall, and Y refers to sheep production.

Diagnostic Tests for the NARDL Estimation

Table 2 presents the results of the diagnostic test statistics for the NARDL model. The Breusch-Godfrey Serial Correlation LM Test implies the probability corresponding to the Obs*R-squared statistical value of 0.0665 is greater than 0.05 at a significance level of 5%. Therefore, the null hypothesis is accepted, stating that the model is free from the serial correlation problem. The normality test indicates that the residuals are normally distributed. Besides that, the results of the ARCH test also indicated that there was no heteroscedasticity issue, since the Obs*R-squared statistical value of 0.6717 was greater than 0.05 at a significance level of 5%. Moreover, the RESET test implies the correctly specified NARDL model.

Table3. Diagnostic Tests for the NARDL Estimation

Test Statistics	**Value**	**Probability**
Ramsey Test	0.0656	0.8018
Serial Correlation LM Test	3.3684	0.0665
Heteroscedasticity (Breusch-Pagan Godfrey)	7.5603	0.6717
Heteroscedasticity (Arch test)	0.3847	0.5351
Normality	1.0795	0.5828

***Received**: 06-12-2025 - **Accepted**: 06-02-2026 - **Published**: 11-02-2026*

https://doi.org/10.54361/ajmas.269215

Furthermore, the results of the structural stability test for the Nardl model parameters in Figures 2 and 3 showed that plots for CUSUM and CUSUM of squares were within the critical boundaries at a significance level of 5%. This indicates that there is stability in the model between the short and long run.

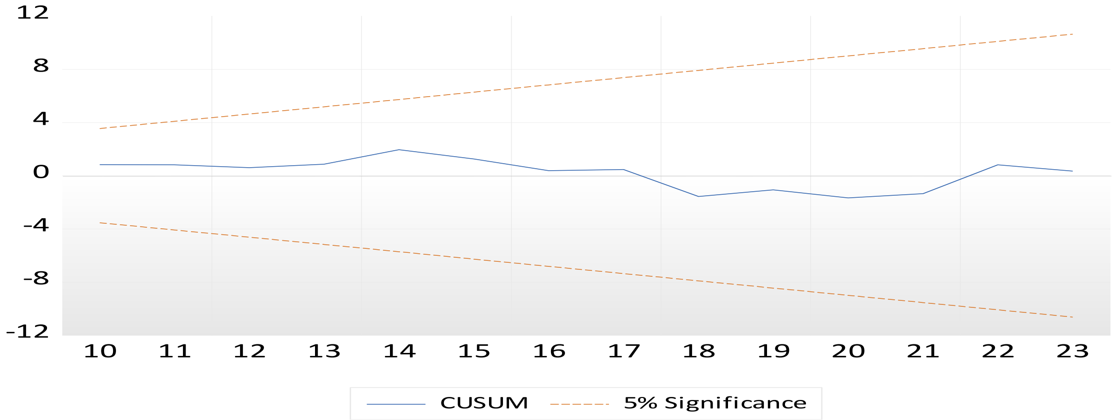

Figure2. CUSUM test for the Stability of the Parameter

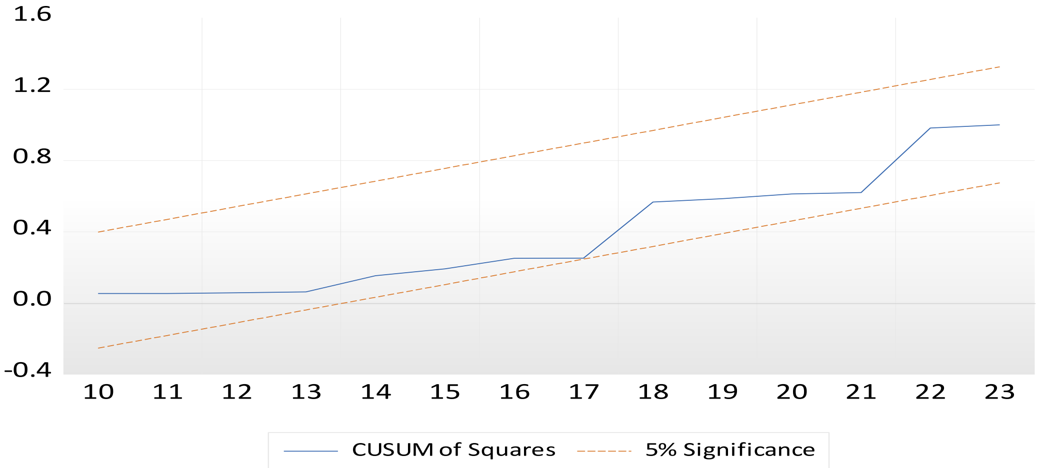

Figure3. CUSUMSQ test for Stability of Parameter

As regards the predictive performance of the Nardl model, it is observed that the value of the Theil inequality coefficient (0.002), bias proportion (0.00003), and variance proportion (0.049) are close to zero and less than one. It is also the value of the covariance. The proportion is close to one (0.951), which indicates that the model has good predictive power.

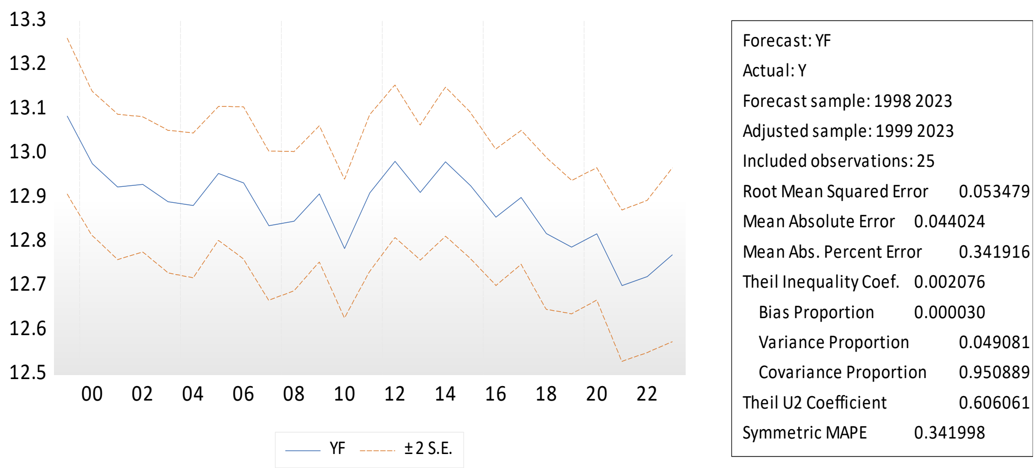

Figure4. The predictive performance of the Nardl model

Conclusion

This research aimed to determine the effect of maximum and minimum temperatures on sheep production in Marsa Matrouh Governorate using the NARDL methodology during the period (1998-2023). The results indicated that annual sheep production, annual maximum temperature, and annual minimum temperature were stationary at the first difference, while the variable of annual rainfall was stationary at the level. The

Received*: 06-12-2025 -* ***Accepted****: 06-02-2026 -* ***Published****: 11-02-2026*

bound test for cointegration illustrates that a long-run relationship exists. This indicates that there is cointegration between the variables when the F-statistic was 3.617240, which is greater than the upper bound critical value (3.361). As to the short-run of the variables, negative changes in maximum temperature (X1NEG) had a positive impact on sheep production, while X3NEG showed no impact. The variable of X3POS negatively impacted sheep production.

Recommendations

In regions affected by environmental degradation and recurring drought, it is essential to improve water availability while at the same time enhancing farmers' knowledge of agricultural practices and the appropriate timing for their application. Such measures will strengthen resilience and ensure more sustainable productivity. Equally important is the establishment of integrated farming systems that combine crop cultivation with livestock production. This approach not only supports adaptation to climate change but also promotes food security and resource efficiency within rural communities. Furthermore, involving farmers directly in policymaking processes is a vital step toward mitigating the effects of climate change. Their participation helps promote environmental improvement and ensures that production systems are both sustainable and responsive to local needs. By empowering farmers in this way, policies can be better aligned with practical realities, ultimately contributing to long-term agricultural stability and resilience.

Conflict of interest. Nil

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***Received**: 06-12-2025 - **Accepted**: 06-02-2026 - **Published**: 11-02-2026*