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ARIMA-Based Forecasting of Rice Area Changes in Mindanao

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A B S T R A C T

The rapid economic growth and urbanization of the country, especially in the regions of rice farming, land use in Mindanao has undergone tremendous transformation over time. Using the ARIMA model, which stands for the Auto-Regressive Integrated Moving Average, in predicting the foreseen coverage of areas covered with rice plants in Mindanao and other areas in the future. By utilizing this approach, the study analyzes the trend of the creation of commercial land spaces in place of agricultural acreage, particularly the area of rice fields, in order to ascertain the consequences that agricultural land loss has on rice production. What are shown are expected reductions in the acreage of the rice fields, which emphasizes the importance of changing or enacting laws and regulations aimed at the preservation of agricultural resources.

Keywords: ARIMA, rice area forecast, land-use change, urbanization impact, agricultural sustainability, Mindanao

1. Introduction

Rice is an essential crop that feeds half of the world's population and contains a constant and vital source of nutrition in peoples' diets (Tang et al., 2022). For the Philippines, rice is not only the main staple food of most Filipinos but it also stands as the source of income for a broad network of stakeholders across both the demand and supply sectors (Mataia et al., 2020). Rice also contributes in a great way to job generation in the Mindanao province, especially in provinces that tend to be the poorest and have conflict histories. Additionally, most of these impoverished provinces are also the major rice-producing provinces for the region, accounting for one-third of Mindanao's total output for rice (Balgos & Digal, 2021) Climate variability, economic demand, urbanization, and government policies influence land use patterns in rice farming, such as those by Jamaludin et al. (2021), Mansaray & Jin (2020), and Yohandoko (2023). The capability to predict is the major function of decision-making and planning to minimize risks and maximize profit. Detection of changes in the cultivated rice areas is critically required in the reallocation of resources and to understand future trends such as change tendencies (Petropoulos et al., 2022). The Philippines is a Pacific country that experiences strong typhoons with strong winds and heavy rainfalls, which makes the region highly vulnerable to climate change impacts. Moreover, this increased number of such extreme climatic events hampers the country's ability towards severe vulnerability. Agriculture, especially rice production, is particularly exposed to the effects of climate change (Petropoulos et al., 2022). There are three main seasons: the wet season from June to November, the dry season from December to May, and the cool dry season from December to February. Its topography is very diversified and involves mountains, plateaus, lowlands, coastal areas, and islands; such diversity in topography creates different ecological zones that determine the crops that can be grown in each region. The array of such zones has a wide influence on the kind of crops that can be grown in a particular region (Ibañez & Monterola, 2023). As the population grows and expands into urban areas, the sustainability of rice production in Mindanao faces increased threats. The conversion of agricultural land to urban development is exerting pressure on available resources, reducing the amount of land under rice cultivation and jeopardizing food security and the livelihood of farmers (Cosrojas et al., 2022). Crop production predictions are important in the proper management of the food security and economic resilience of agricultural countries (Ibañez & Monterola, 2023). Time series analysis and forecasting analyze past relationships between variables through several models to enable accurate forecasting of future values. The Box-Jenkins ARIMA model is one of the highly utilized statistical tools in the time series analysis area of research, able to process a wide range of patterns, which include stationary, non-stationary, and seasonal data (periodic) (Singh et al., 2020). The capability of ARIMA to capture temporal patterns is critical for making informed production and pricing decisions in the agriculture sector. This is significant In the case of the Philippines since its agricultural yields are often affected by environmental factors in terms of changes in climate and weather disturbances (Dait, 2022). Although previous studies have explored some trends in agricultural production, few have pointed out the forecasting of changes in the regional allocation distribution of lands-for example, in rice-cropping areas. This study aimed to fill this gap by using ARIMA-based forecasting to understand the trends of rice area and finding the growth and decline patterns in different areas of Mindanao, providing valuable insights into the management of improving food security in agricultural productivity and livelihood of communities that mainly depend on rice farming for survival.

2. Theoretical Framework

The Autoregressive Integrated Moving Average model is known for time series forecasting over widespread application for predictions in agriculture. Box and Jenkins popularized the model in 1970, and since then it has been applied extensively to agricultural production and yield forecasting because it is capable of effectively modeling non-stationary data. Many examples illustrate the applicability of ARIMA in crop yield, cultivated area, and production forecasting. Similarly, Phuc et al. (2022) used ARIMA to forecast rice area, yield, and production in Vietnam, underlining its utility in risk reduction related to food insecurity through effective resource allocation and policy decision-making. On this basis, the current research employs the application of ARIMA in modeling and forecasting rice area changes in Mindanao. In this regard, the time series data for rice areas incorporate past values as well as random disturbances into the model to produce a good and accurate forecast. These forecasts are useful in framing strategies to resolve agricultural challenges and to ensure sustainable rice production.

3. Materials and Methods

3.1 Materials

The findings of the study were based on statistical data reported from the Philippines by the Philippine Statistics Authority (PSA) from the year 2015 to 2023. The research focused on the impacts of urbanization and land-use changes on rice farming in Mindanao, Philippines, with emphasis on the shrinking area dedicated to rice paddies. Employing the ARIMA model (Auto-Regressive Integrated Moving Average), projections concerning future trends in rice cultivation were estimated and evaluated concerning the impact of transitioning from agricultural to commercial land on rice production. Current statistics have shown some decline in rice-growing areas, threatening food security and the liveliest of the farmers. Increased urbanization and conversion of lands to other forms are truly identified in Mindanao. It will therefore require urgent needs for sustainable land policies and programs to conserve agricultural resources (Philippine Statistics Authority, 2024; IUCN NL, 2020). Climatic variability, characterized by events such as El Niño and the high frequency of typhoons, has a significant impact on rice cultivation. The interplay between these climatic changes and fast-paced urban growth has led to reduced arable land and increased risks against rice yield reduction. Studies point out that the risk can be mitigated if one understands the dynamics of land use and its impact on climate (PLOS ONE, 2024; IUCN NL, 2020). The research would aim to understand resource management techniques that can help enhance food security in Mindanao and similar agricultural regions. By focusing on participatory planning and incorporating SEA into the planning process, it is easier to balance urban development with the protection of priority agricultural lands (IUCN NL, 2020).

3.2 Methods

Significantly used in a lot of disciplines, the ARIMA (Auto-Regressive Integrated Moving Average) model was applied in this study to predict the change in rice acreage in Mindanao. In such a method, the ARIMA (p, d, q) algorithm, through the analysis of historical data, can predict trends concerning land use that can provide insight into how the patterns of urbanization and economic transformation affect agricultural sustainability and food security. Mathematically, the ARIMA model is given by:

$$Xt = \phi^7 X_{t-1} + \cdots + \phi_p X_{t-P} + at - \Theta 1at - 1 - \cdots - \Theta qat - q \quad (1)$$

Where Φ's (phis) represents the autoregressive parameters to be estimated, Θ's (thetas) are the moving average parameters to be determined, the original series is represented by X's, and the a.'s are the unknown random errors which are assumed to follow the normal probability distribution. Three were the steps undertaken for the prediction of acreage change of rice fields in Mindanao by following modules related to ARIMA. Three were the steps undertaken for the prediction of acreage change of rice fields in Mindanao by following modules related to ARIMA. For model identification, autocorrelation and partial autocorrelation analyses were performed to detect stationary, random, and seasonal effects from the time series data. Stationarity was obtained by differencing techniques, and plausible models were established using autocorrelograms and partial autocorrelograms. Parameter estimation and model testing followed, where a number of viable models were compared to select the most appropriate one for prediction. Predictive analysis was finally made to determine the trends of rice fields in the coming decade.

The paper used GRETL (Gnu Regression, Econometrics, and Time-series Library) software to generate graphs and work with data sets. Key findings of the study indicated a declining acreage of rice fields in Mindanao caused by increased urbanization and land-use transformations, calling for policy measures that protect agricultural resources. The results of the study underscore the fact that predictive models play a role in the formulation of sustainable agriculture strategies with secure food provision from this region. Figure 1 presents the architectural design in predicting rice area changes in Mindanao.

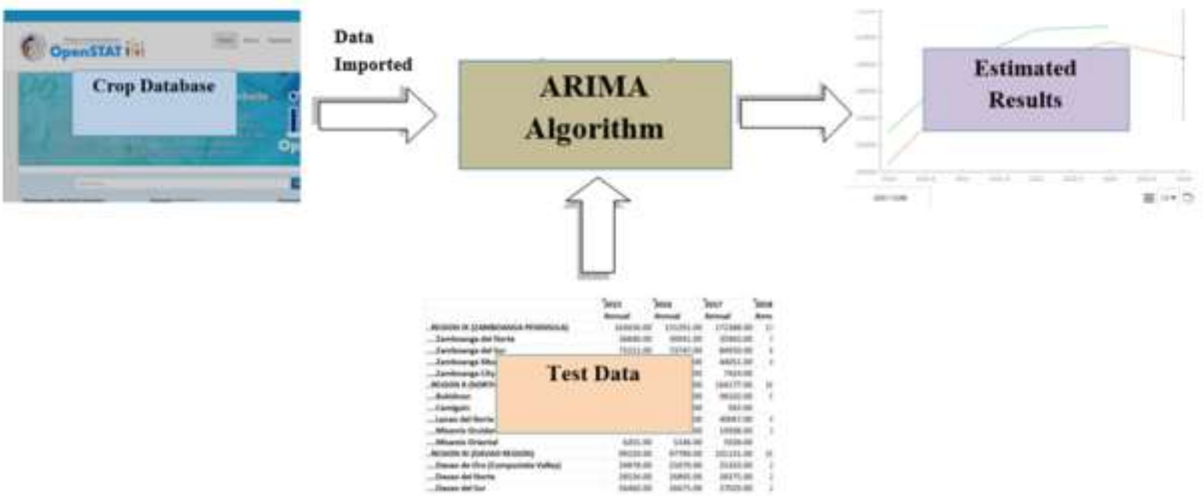

Fig. 1 – Predicting Area Changes

4. Results and Discussion

In the trend analysis of three key regions in Mindanao, focusing on historical data for rice/palay areas, the GRETL software was utilized for ARIMA modeling and trend visualization. Tables 1-2 present the raw data on rice area changes, covering the years 2014 to 2023.

4.1 Forecasting

The direction in the fluctuations area for rice or palay cultivation in Mindanao, which was utilized in its application, pushed the agricultural properties to turn commercial fast and projected such changes through the succeeding fourteen years based on historical data. Figures 2-7 further illustrate the intended trend of expected change in rice cultivation areas for the key provinces of Mindanao from 2024 to 2034 with a 95% confidence interval. The projected data exhibited a slow but timely decline of rice cultivation areas in most regions, consistent with the ongoing mainstream process of agricultural land conversion. These conclusions indicate the important need for specific land-use management strategies aimed at softening the decline of agricultural zones that ensure food supply. According to Talirongan et al. (2021), the model that used ARIMA to project health trends in the Philippines explained the complexity and dynamic nature well of time series, making it the apt choice for making scenarios across varying fields, especially in places where downward trends are already manifesting, and intervention strategies need to be undertaken. Example policies include those that incentivize sustainable agriculture and constrain land conversion, which could stabilize the rice area. However other provinces sometimes have tendencies towards stages of stability or slower declines which might suggest current efforts at mitigation, in the way of government support for irrigational systems and farm modernization, have positive localized effects.

The results are thus consistent with Talirongan et al such that continuing mitigation strategies will mitigate long-term problems. However, the ARIMA-based forecasts reveal further that the rates of change in land conversion hanged in fluctuated way over the years; such fluctuations may bear a correlation with shifts in the economy, urban priorities, and climate. Thus, there is an impetus for continuous observation and data-based policy formulation to respond to new challenges. This can then be integrated with other highly influential models of machine learning to allow policymakers to make much more accurate decisions in real time as mentioned and proposed in relevant studies (Talirongan et al., 2021). In conclusion, This study emphasizes that ARIMA modeling is important for understanding and addressing the impacts brought about by land conversion on rice production in Mindanao. These forecasts will then inform forward-looking strategies in land management as ways of saving agricultural resources amidst persistent developmental challenges.

Table 1 – **2014-2018 Raw data on palay area harvested in hectares for Mindanao Regions**

Regions of Mindanao	2014	2015	2016	2017	2018
Region IX Zamboanga Peninsula	163096.00 ha	163636.00 ha	155291.00 ha	172388.00 ha	177540.31 ha
Region X Northern Mindanao	161414.00 ha	163755.00 ha	160209.00 ha	164177.00 ha	164769.00 ha
Region XI	103822.00 ha	99220.00 ha	97789.00 ha	101131.00 ha	106550.00 ha

Davao Region					
Region XII SOCCSKSARGEN	346906.00 ha	339938.00 ha	315690.00 ha	351177.00 ha	348480.25 ha
Region XIII CARAGA	174170.00 ha	155129.95 ha	150076.00 ha	155203.00 ha	160282.00 ha
BARMM	217422.00 ha	194349.00 ha	212927.00 ha	221192.00 ha	226335.00 ha

Table 2 – **2019-2023 Raw data on palay area harvested in hectares for Mindanao Regions**

Regions of Mindanao	**2019**	**2020**	**2021**	**2022**	**2023**
Region IX Zamboanga Peninsula	164939.10 ha	157626.59 ha	161900.53 ha	162368.67 ha	170566.65 ha
Region X Northern Mindanao	163687.50 ha	167115.00 ha	165870.00 ha	173403.60 ha	173969.00 ha
Region XI Davao Region	103139.00 ha	102918.70 ha	108013.58 ha	110572.69 ha	110834.34 ha
Region XII SOCCSKSARGEN	324172.77 ha	334686.80 ha	346475.70 ha	340823.88 ha	338688.96 ha
Region XIII CARAGA	145366.95 ha	156073.05 ha	147878.00 ha	159519.02 ha	162990.00 ha
BARMM	208461.00 ha	233336.44 ha	236775.82 ha	241977.45 ha	258177.62 ha

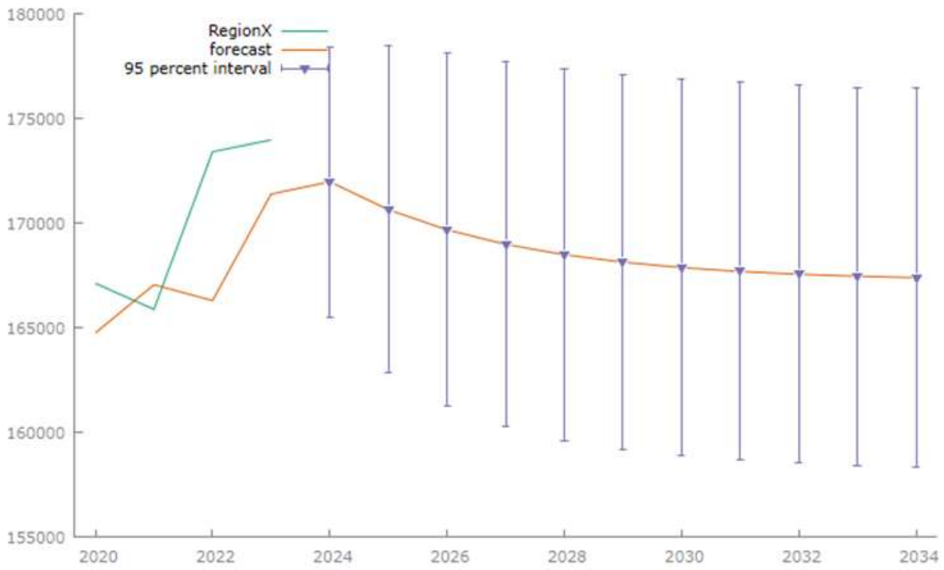

Fig 2 – Forecasted Rice Area Change in Hectares in Region IX from 2024 to 2034.

The forecasted change in rice area for Region IX from 2020 to 2034 exhibits a gradual increase up to 2024, followed by stabilization. The historical data shows slight fluctuations until 2023, aligning closely with the forecasted trend. Beyond 2024, the forecast indicates a stable trajectory in rice cultivation area, with predictions remaining within the 95% confidence interval. This interval widens over time, highlighting increasing uncertainty in long-term projections. The observed trends suggest that without significant external factors or interventions, the rice cultivation area may stabilize, but with a notable degree of variability. Such patterns reflect common challenges seen in agricultural regions impacted by urbanization, climate variability, and environmental pressures.

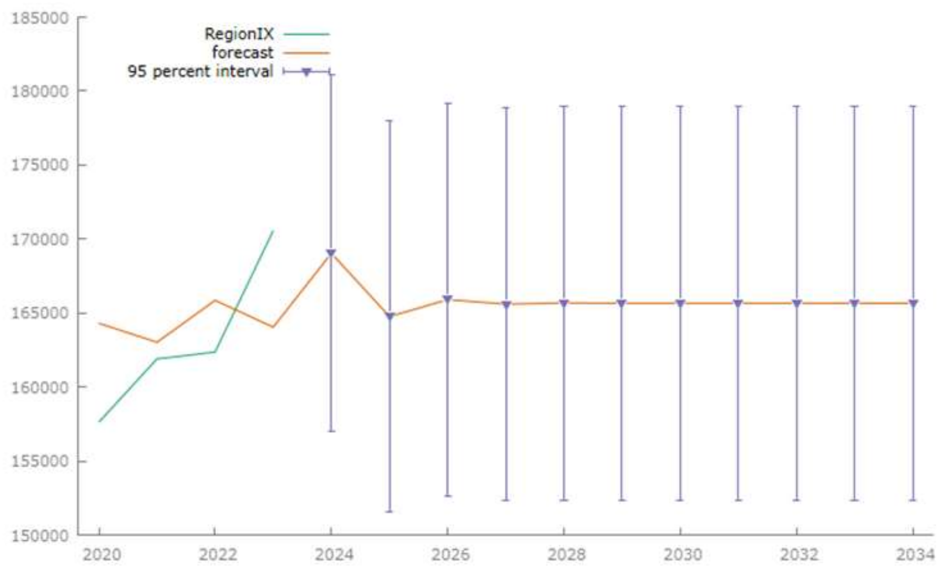

Fig 3 – Forecasted Rice Area Change in Hectares in Region X from 2024 to 2034.

The forecasted change in rice area for Region X from 2020 to 2034 shows an initial increase until around 2024, followed by a gradual decline and eventual stabilization. The historical data, represented by the green line, exhibits a rising trend until it transitions into the forecasted period. The forecasted values are depicted by the orange line, with the 95% confidence interval shown as blue vertical lines. These intervals widen over time, illustrating increasing uncertainty in long-term projections. This trend indicates that without significant interventions, the rice cultivation area may experience a modest decrease before stabilizing, though with a considerable range of variability. These patterns align with challenges like urbanization, environmental change, and evolving agricultural practices impacting rice-growing regions.

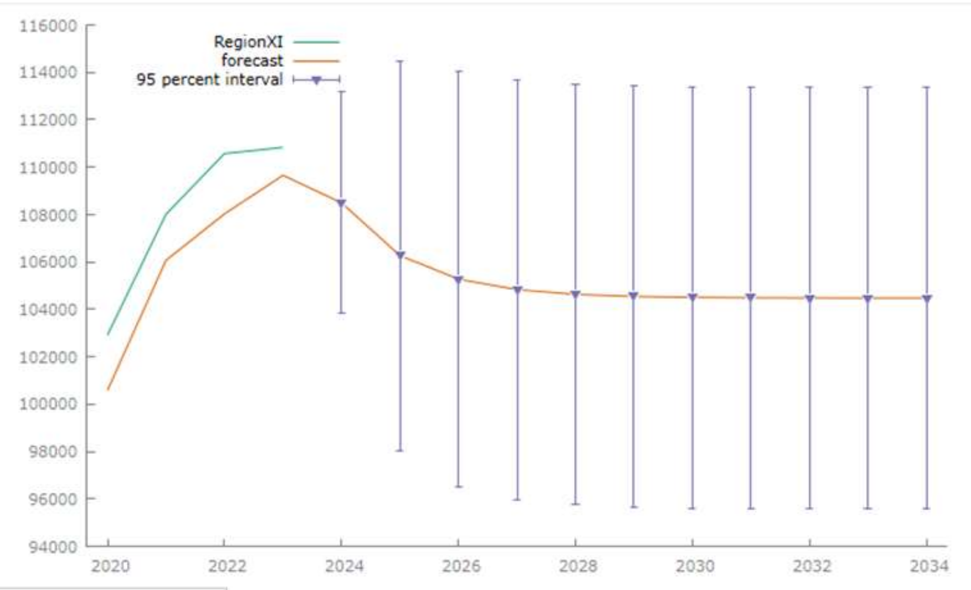

Fig 4 – Forecasted Rice Area Change in Hectares in Region XI from 2024 to 2034.

The forecasted change in rice area for Region XI from 2020 up to 2030 is somewhat of a declining trend. The forecasted data falls in the same range provided by the historical data. This pattern continues with other regions, where each of them duplicates the same tendencies observed in agricultural land, showing the sector is still facing loss due to mainly urban expansion and aspects of the environment.

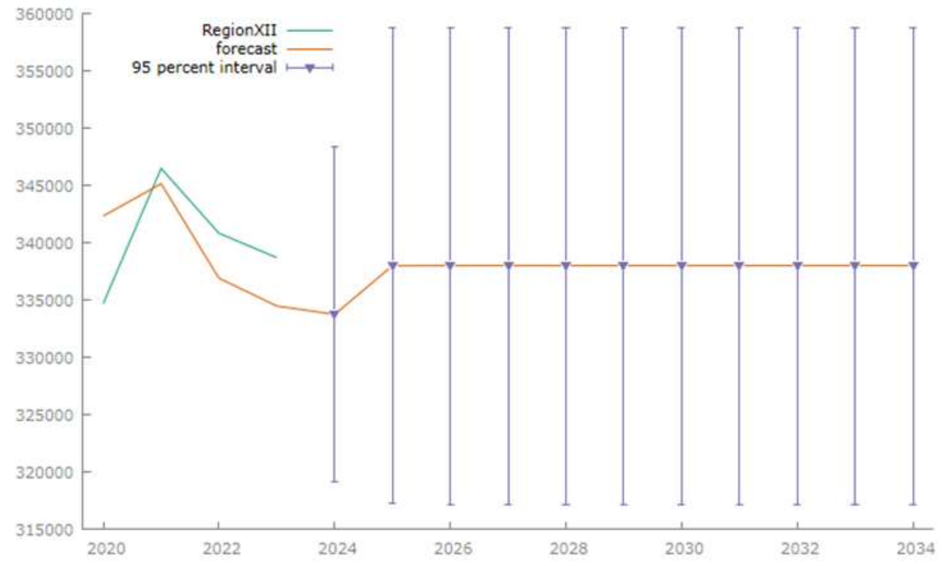

Fig 5 – Forecasted Rice Area Change in Hectares in Region XII from 2024 to 2034.

The forecasted change in rice area for Region XII from 2020 to 2034 shows an initial increase until around 2024, followed by a steady decline and eventual stabilization. The historical data, depicted by the green line, exhibits a rising trend up to 2023, transitioning into the forecasted data represented by the orange line. The 95% confidence interval, shown as blue vertical lines, widens over time, reflecting growing uncertainty in long-term predictions. This trend suggests that without substantial interventions, the area under rice cultivation may decline slightly before stabilizing, with variability influenced by external factors such as urban development, environmental challenges, and climate change.

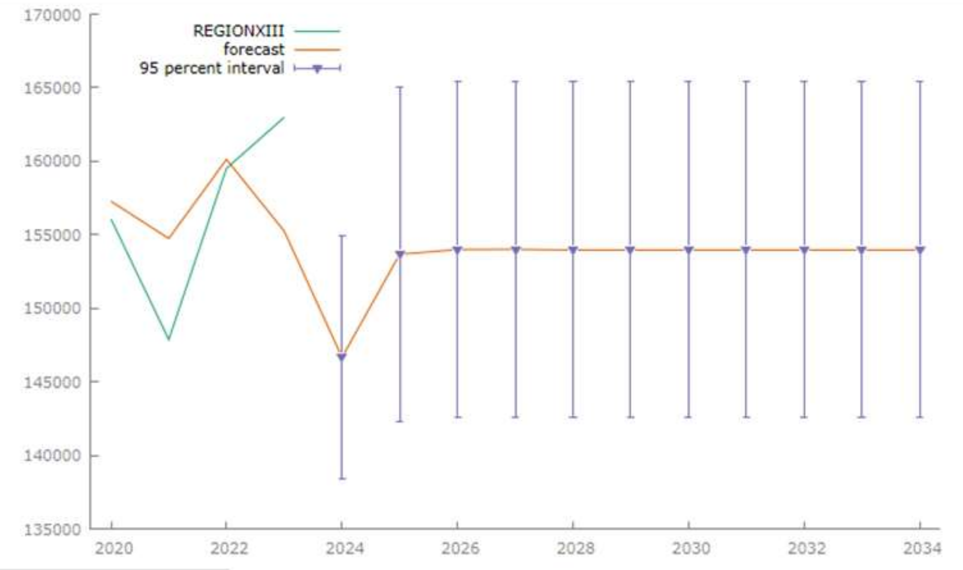

Fig 6 – Forecasted Rice Area Change in Hectares in Region XIII from 2024 to 2034.

The graph shows the actual and forecasted rice cultivation area in Region XIII from 2020 to 2034. Between 2020 and 2023, the area fluctuates, with a slight decrease evident in the actual values. From 2024 onward, the forecast predicts stabilization at approximately 155,000 hectares, contrary to an earlier assumption of stabilization at 165,000 hectares. The 95% confidence interval error bars indicate variability and uncertainty in the projections. Despite stabilization, a degree of uncertainty persists as reflected in the range of the error bars.

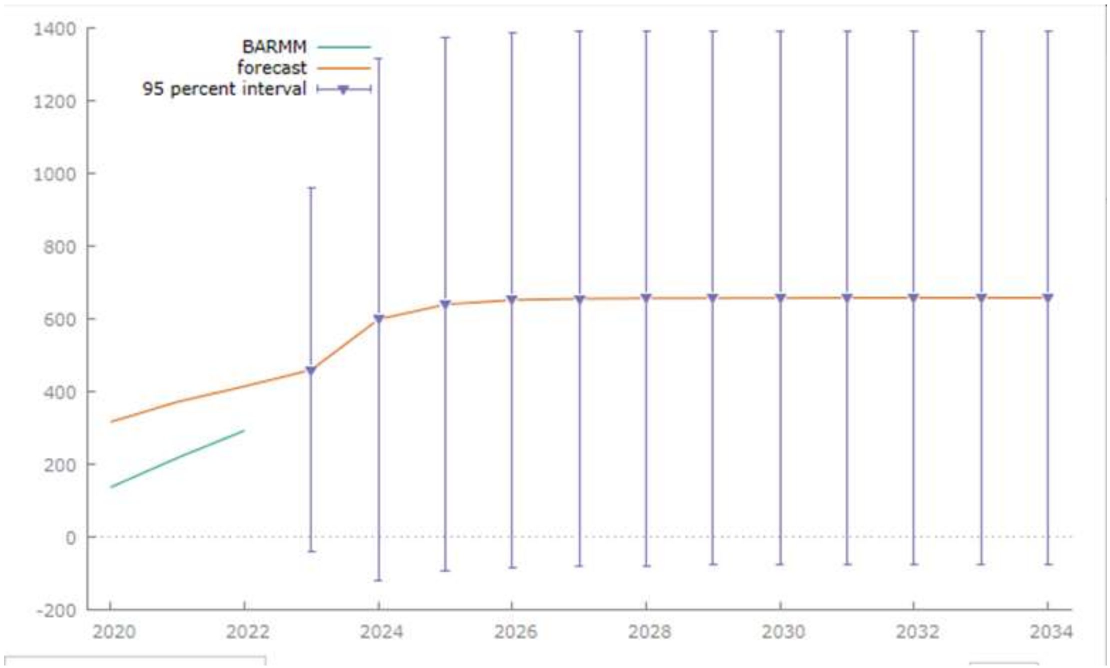

Fig 7 – Forecasted Rice Area Change in Hectares in Region BARMM from 2024 to 2034.

The graph illustrates the actual and forecasted rice cultivation area for BARMM from 2020 to 2034. Between 2020 and 2023, the area increases, followed by a slight decline up to 2030, after which it stabilizes. The error bars representing the 95% confidence interval highlight the variability around the forecast values. While fluctuations are evident, the projections remain within a predictable range, reflecting confidence in the forecast despite inherent uncertainties.

5. Conclusion and Recommendations

5.1 Conclusion

The ARIMA model is also useful for this study because it assists in resolving and comprehending concerns that revolve around land cover change and its impact on rice production specifically in Mindanao as a result of urbanization. More to the point the research notes that there has been a gradational increase in the rice area in the different regions in Mindanao largely due to the changes in agricultural land to that of urbanization and commercialism. The ARIMA models also contribute to estimating the future changes in rice area demanding policies to curb such losses of arable lands. These processes of land use change are not only examined in this study but the significance of sustaining agricultural systems that can ensure food and farmer livelihoods in Mindanao was also emphasized. In this sense, ARIMA forecasts are models of great importance for the achievement of policymakers sustenance agriculture objectives.

5.2 Recommendations

Based on the results of this study, the following recommendations are proposed to address the challenges posed by urbanization and preserve rice farming in Mindanao; First, Policy Interventions and Land Use Regulation, the government should enact policies regulating land conversion, particularly in areas crucial for rice production.

Stricter zoning laws must be established that protect agricultural lands, and incentives for sustainable land use practices must be encouraged to reduce encroachment of urbanization into farmland. Support to Agricultural Innovation and Farmers Increased support must be given by the government to rice farmers, especially in areas where land-use change is significant. This may include modern technologies of farming, subsidies, sensitization on sustainable farming practices, and investments in agricultural infrastructure such as irrigation systems. Third, Sustainable Urban Planning, Urbanization must be managed in a way that doesn't compromise agricultural land. Local governments should integrate agricultural land protection into urban planning through strategies such as mixed-use zoning and urban farming solutions like vertical farming that would minimize the loss of productive land. Fourth, Climate Adaptation Strategies, Since rice production is vulnerable to climate change, adaptive measures should be implemented. These might comprise climate-resilient rice varieties, improving weather forecasting systems, and other risk-reduction strategies that secure rice crops against extreme weather occurrences. Fifth, Continuous monitoring and data-informed policy making, the policymakers must also invest in good data-gathering systems to track the dynamic changes in land use as well as trends in rice production. The application of ARIMA and other forecasting models can help give insights in real-time, hence intervention is made early. Collaboration with local farmers and communities ensures that the policies will be more relevant and responsive to the issues at hand, not just superficially. In taking such recommendations, Mindanao can help in developing a healthier balance between urbanization and agricultural development to sustainably ensure the continued viability of rice farming and food security of the population in the region.

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