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# Predictive Policing Through Integrated Crime Mapping Analysis Using Geographical Information System: A Convergent Mixed Method Study

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**Abstract: This study developed a predictive policing model through integrated crime mapping and Geographic Information System (GIS) analysis in Region XI, Philippines. Using a convergent mixed-methods design, the study integrated quantitative crime data from 2013 to 2023 with qualitative insights from law enforcement practitioners, crime analysts, and GIS personnel to examine the temporal and spatial patterns of major index crimes and the factors influencing crime incidence. Quantitative findings revealed a significant decline in murder, rape, physical injury, robbery, and theft over time, while regression and time-series forecasting analyses showed strong temporal patterns suitable for predicting future crime trends from 2024 to 2028. GIS hotspot mapping identified urbanized and densely populated areas as persistent crime hotspots. Qualitative findings revealed that GIS-supported predictive policing enhanced hotspot monitoring, strategic police deployment, crime prevention, and evidence-based decision-making despite challenges related to data quality and technical capability. Data integration showed convergence between statistical forecasting, spatial crime concentration, and practitioner experiences, confirming that recurring crime patterns were concentrated in identified hotspot areas. The study concluded that integrating statistical forecasting, GIS mapping, and practitioner-based insights strengthened proactive and data-driven policing strategies in Region XI.**

***Keywords:*** *Criminology, Predictive Policing, Crime Mapping, GIS, Convergent Mixed-Methods, Time-Series Forecasting, Philippines.*

***SDG Indicator:*** *# 11 – Sustainable Cities and Communities # 16 – Peace, Justice, and Strong Institutions.*

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## I. INTRODUCTION

The integration of Geographic Information Systems (GIS) in crime mapping and predictive policing has emerged as a significant advancement in contemporary law enforcement; however, it is accompanied by several critical empirical and theoretical concerns that necessitate further investigation. Empirical literature has revealed that predictive crime mapping systems heavily depend on historical crime data, which are often affected by issues such as underreporting, data inaccuracies, and systemic bias. These limitations may result in distorted spatial analyses and the unintended reinforcement of disproportionate policing practices in already vulnerable communities (Lee, 2024; Ugwudike, 2024). Moreover, studies have emphasized that reliance on incomplete or biased datasets can compromise the validity of predictive outputs and weaken the reliability of GIS-based crime forecasting models (Andresen & Malleson, 2020; Davies & Bishop, 2021).

Moreover, the quality and reliability of spatial outputs depend on the integrity of the input data, raising concerns about the validity of the predictive models used in operational decision-making. From a theoretical standpoint, frameworks

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such as Routine Activity Theory and Environmental Criminology posit that crime is spatially patterned and influenced by environmental opportunities; however, emerging studies argue that crime patterns are dynamic and subject to rapid social, economic, and environmental changes that static or inadequately integrated GIS models may fail to capture (Ristea & Leitner, 2020; Hu et al., 2020). In addition, the increasing reliance on algorithm-driven GIS systems has raised concerns about transparency, interpretability, and accountability, as law enforcement practitioners may rely on predictive outputs without fully understanding the models' underlying mechanisms or limitations (Carbonell, 2024). These gaps highlight the need for stronger, context-sensitive, and theoretically grounded approaches in the application of GIS for predictive policing.

The importance of studying GIS-supported crime prediction lies in its potential to significantly enhance evidence-based policing, improve crime prevention strategies, and optimize the allocation of limited law enforcement resources. Empirical studies have consistently demonstrated that spatial and spatial-temporal analyses enable police agencies to identify crime hotspots, detect emerging patterns, and implement targeted interventions that contribute to crime reduction and increased operational efficiency (Hu et al., 2020; Ristea & Leitner, 2020). Theoretically, the application of Environmental Criminology and Routine Activity Theory has reinforced the understanding that crime is not randomly distributed but concentrated in specific locations and influenced by situational opportunities, thereby validating the use of spatial analysis as a critical tool in criminological research and practice (Brantingham & Brantingham, as cited in Ristea & Leitner, 2020). These studies collectively underscore the relevance of GIS-based approaches in advancing both theoretical discourse and practical policing frameworks.

Despite these contributions, previous works also highlight significant limitations that justify the present study. Many existing studies have predominantly focused on quantitative spatial modeling while overlooking the experiential insights of law enforcement practitioners who directly engage with crime data and operational realities. Furthermore, there is a lack of integrative approaches that combine spatial, environmental, and socio-demographic variables with practitioner-based perspectives to produce a more comprehensive understanding of crime dynamics. These gaps suggest the need for a convergent mixed-methods approach that not only analyzes spatial crime patterns but also incorporates qualitative insights to validate, explain, and contextualize quantitative findings. Thus, the present study was conducted to address these limitations by integrating GIS-based crime mapping with practitioner perspectives, ultimately contributing to the development of a more holistic, reliable, and context-sensitive framework for predictive policing.

However, existing studies also reveal limitations that shape the rationale and purpose of the current research. Prior works often focus on isolated crime types, static datasets, or single analytical techniques, which may limit the predictive accuracy and operational usefulness of GIS-based crime analysis systems (Hu et al., 2020). Additionally, scholars have highlighted concerns regarding data quality, algorithmic transparency, and ethical implications, indicating that predictive outcomes may be unreliable or inequitable if GIS models are not properly integrated and theoretically grounded (Ugwudike, 2024). These gaps suggest the need for further investigation into more integrated, systematic crime-mapping approaches that combine multiple data sources and analytical methods. Consequently, the current study is justified in seeking to strengthen the empirical reliability, theoretical alignment, and practical relevance of GIS-supported crime prediction, thereby contributing to more accurate, ethical, and actionable crime prevention strategies.

Several studies and institutional reports highlighted the use of Geographic Information Systems (GIS)-based crime mapping and spatial analysis by the Philippine National Police (PNP) as a critical tool for improving crime prevention and law enforcement decision-making. Empirical research demonstrated that GIS, predictive analytics, and hotspot analysis were utilized to support police resource allocation and strategic patrol deployment, significantly enhancing operational efficiency and situational awareness among officers (Davies & Bishop, 2021; Kurland et al., 2022). Official reports and transparency platforms of the Philippine government further showed that geospatial datasets and crime hotspot mapping were integrated into crime monitoring and intelligence systems, indicating that GIS had become an essential component of modern policing practices (Philippine National Police, 2023; Department of the Interior and Local Government, 2023). Moreover, criminological studies emphasized the implementation of crime information systems and spatial dashboards that enabled law enforcement agencies to analyze crime trends, identify peak crime periods, and adjust patrol strategies accordingly; however, challenges such as incomplete datasets, limited technical expertise, and infrastructural constraints remained evident (Davies & Bishop, 2021; Solymosi et al., 2022). In addition, empirical studies demonstrated that GIS-enabled crime analysis improved the identification of crime hotspots and supported predictive forecasting, with significant implications for both policing operations and community safety initiatives (Solymosi et al., 2022). Collectively, these studies indicated that GIS-based crime mapping not only strengthened policing effectiveness but also provided a robust empirical foundation for further research aimed at optimizing predictive policing strategies.

This era is a data era. The private and public sectors are required to build and update their policies based on data. Even in many situations categorized as wicked problems, where the optimal solution is challenging (Veenstra & Kotterink, 2017), data are needed to guide the solution. Data-driven policy is becoming inevitable and is expected to become standard practice across organizations. Organizations must have goals that their members aim to achieve (Niati et al., 2021). Leadership success is partly determined by a leader's ability to develop their organizational culture (Arif, 2019). Despite the growing popularity and adoption of predictive policing techniques, a significant research gap remains in the

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integrated analysis of crime mapping using GIS. This gap stems from the lack of comprehensive studies that effectively integrate crime-mapping data, GIS capabilities, and predictive modeling techniques to develop robust, accurate predictive policing models.

Data has increasingly become integral to police science and policy, shaping contemporary approaches to crime prevention and law enforcement decision-making. In recent years, the field has been influenced by various data-driven methodologies, particularly predictive policing. The existing literature highlights predictive policing as a technique grounded in data science, primarily applied at the micro-level of technical crime prevention. For instance, Tayebi and Glässer (2016) defined predictive policing as the use of data science to identify potential targets for criminal activity with the goal of preventing crime. Similarly, Egbert and Leese (2021) emphasized that predictive policing extends beyond algorithms and data, encompassing everyday police practices such as briefings, patrol operations, and decision-making processes influenced by both analytical outputs and human judgment. These perspectives illustrate that predictive policing is not solely a technological innovation but also a socio-technical practice embedded in routine law enforcement activities.

Development, in this context, refers to a systematic and continuous process of improvement aimed at enhancing existing systems and practices. It involves effectively mobilizing human resources, knowledge, and technological capabilities to achieve desired outcomes. Moreover, development is influenced by various factors, including the availability of resources that support growth and innovation (Shah et al., 2020). Given the increasing complexity of crime and the demand for more efficient policing strategies, the integration of Geographic Information Systems (GIS) into predictive policing represents a critical advancement. The use of GIS in crime mapping enables a more precise understanding of spatial crime patterns, thereby supporting the development of more accurate, efficient, and equitable crime prevention strategies. Consequently, studying predictive policing through integrated crime-mapping analysis using GIS is essential to strengthen evidence-based policing and enhance public safety outcomes.

Police work is currently undergoing a significant transformation as law enforcement agencies face increasing demands for efficiency, accountability, and equity. In this context, predictive policing has gained prominence as a data-driven approach that utilizes advanced technologies to anticipate potential criminal activity. Unlike earlier methods that relied heavily on officer intuition and basic statistical tools, modern predictive policing systems integrate big data, machine learning, and geospatial analysis to produce more accurate, timely crime forecasts. As noted by Mohler et al. (2020) and Wheeler and Steenbeek (2021), contemporary predictive policing models can identify spatial and temporal crime patterns, enabling law enforcement agencies to proactively allocate resources and prevent crime before it occurs.

The evolution of predictive policing reflects a shift toward more sophisticated and technology-driven frameworks. Recent studies emphasize that predictive systems now operate as part of a broader analytical process that includes data collection, processing, modeling, and operational deployment (Lum et al., 2022). These systems aim to produce actionable forecasts, akin to early warning systems, enabling police to intervene before crimes materialize. However, scholars such as Richardson et al. (2021) caution that while predictive policing offers significant advantages, it also raises concerns related to data bias, fairness, and ethical decision-making. This highlights that predictive policing is not purely a technical innovation but a socio-technical system that must balance efficiency with accountability.

Place-based predictive policing remains one of the most widely adopted approaches, grounded in the principle that crime is spatially concentrated and can be forecasted within specific geographic areas. Recent empirical evidence supports the idea that deploying police resources to identified hotspots can significantly reduce crime rates (Braga et al., 2020; Wheeler & Steenbeek, 2021). These findings reinforce the argument that crime prevention can be enhanced through targeted interventions informed by spatial analytics. Moreover, predictive policing shifts law enforcement's focus from reactive responses to proactive strategies, emphasizing prevention, deterrence, and efficient resource allocation.

Despite its potential, the effectiveness of predictive policing depends on the visibility of results and its practical application within police operations. Studies indicate that for predictive models to succeed, they must be integrated into routine policing practices and supported by trained personnel and reliable data systems (Koper et al., 2021; Lum et al., 2022). Without these conditions, predictive outputs may remain underutilized or ineffective. Additionally, while predictive policing aims to reduce human bias by relying on algorithmic decision-making, recent research suggests that biases embedded in data can still influence outcomes, challenging the notion of purely objective “automated justice” (Richardson et al., 2021).

Overall, contemporary literature suggests that predictive policing represents a critical evolution in law enforcement, combining technological innovation with strategic crime prevention. However, its success depends on integrating accurate data, implementing ethical safeguards, and building organizational capacity. As such, predictive policing should be understood not only as a forecasting tool but as a comprehensive policing strategy that requires continuous evaluation, adaptation, and alignment with broader social and institutional goals.

Predictive policing has emerged as a powerful approach that uses data analytics and geographic information systems (GIS) to anticipate criminal activity before it occurs. Studies have shown that integrating GIS into predictive models allows law enforcement agencies to visualize spatial and temporal crime patterns effectively. For example, Mohler et al. (2021) emphasized that predictive algorithms combined

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with geospatial analysis help identify high-risk areas, enabling better resource allocation. Similarly, Zhang and Zhao (2020) demonstrated that spatial clustering techniques improve the detection of evolving crime hotspots in urban environments. This integration of technology and spatial data represents a shift from reactive to proactive crime prevention strategies.

The use of GIS-based crime mapping has significantly enhanced the understanding of crime dynamics across temporal and spatial dimensions. According to Kurland et al. (2022), GIS applications enable visualization of crime density through hotspot analysis, allowing authorities to identify areas requiring immediate attention. Additionally, studies by Adeyemi and Balogun (2023) revealed that combining socioeconomic variables, such as poverty levels and population density, with spatial data provides deeper insight into the causes of crime. These findings highlight the crucial role of environmental and contextual factors in shaping patterns of criminal behavior. Consequently, integrating GIS with predictive analytics offers a more holistic view of crime distribution.

Machine learning models have also become integral to predictive policing. Research conducted by Yadav and Singh (2021) used Random Forest and Support Vector Machine algorithms to predict future crime occurrences based on spatial and temporal data. The study found that combining GIS layers with historical crime datasets yielded higher prediction accuracy than traditional models. In another study, Hossain et al. (2022) used deep learning frameworks integrated with GIS to analyze spatiotemporal data and effectively forecast potential crime hotspots. These findings underscore the value of computational intelligence in modern crime prevention systems.

Moreover, predictive policing through GIS fosters evidence-based decision-making among law enforcement agencies. Kim and Lee (2023) explained that spatial prediction models not only optimize police patrol routes but also reduce operational costs by prioritizing high-risk zones. The integration of big data, urban analytics, and GIS enables continuous learning, where models adapt to new patterns over time. According to Shanmugam and Kumar (2022), this adaptability is essential for addressing the dynamic nature of crime influenced by urban growth and demographic changes. Thus, predictive policing enhances efficiency, transparency, and strategic deployment of policing resources.

This study was primarily anchored on Crime Pattern Theory developed by Brantingham & Brantingham (1981). The theory explains that crime is not randomly distributed but tends to occur in predictable locations where offenders encounter opportunities within their routine movement patterns and activity spaces. Crime Pattern Theory emphasizes that criminal incidents are influenced by geographic locations, environmental opportunities, and the movement of individuals within urban and social environments. The theory further posits that crimes commonly occur in areas frequently visited by offenders, such as commercial centers, transportation routes, residential areas, and other activity nodes.

According to this perspective, individuals create a cognitive map of their familiar spatial environment through their routine activities. The action space of an individual consists of (a) nodes, the destinations of travel, such as work, home, and entertainment locations, and (b) paths, the travel routes that individuals take to move from one node to another. Through repeated movement along paths to various nodes, individuals develop an awareness of space consisting of the areas in a city with which they are familiar. The theory strongly supports the present study because it explains the spatial concentration and temporal movement of crime incidents examined through Geographic Information Systems (GIS), hotspot analysis, and predictive policing. Since the study focused on identifying crime-prone areas, analyzing spatial crime distribution, and forecasting future crime trends in Region XI, Crime Pattern Theory provided a relevant theoretical basis in understanding how crime patterns emerge and cluster in specific geographic locations over time. The theory also supports the use of GIS-based crime mapping and predictive analytics to help law enforcement agencies anticipate potential crime occurrences and strengthen evidence-based policing strategies.

Furthermore, the Routine Activities Theory, developed by Cohen and Felson (1979), has been widely applied to research on the spatial patterns of crime and is significant. To Cohen and Felson, crime is a predatory activity and, as such, can subsist only near patterns of legitimate activity. Therefore, it is necessary to understand the patterns of conventional routine activities around which crime is organized to comprehend crime patterns. As a supporting theory, the Environmental Criminology Theory (Brantingham & Brantingham, 1993) complements this framework by focusing on how physical environments influence criminal opportunities. This theory emphasizes the role of spatial patterns in crime, asserting that the built environment, street layout, and land use affects offender behavior. By using GIS to map these environmental characteristics, predictive policing aligns with the principles of environmental criminology, offering empirical tools to analyze and forecast spatial crime risks.

The conceptual framework presented in Figure 1 illustrates the convergent mixed-method design employed in the study. The framework demonstrates the integration of quantitative and qualitative approaches to provide a more comprehensive understanding of crime patterns, predictive policing, and crime hotspot dynamics in Region XI.

In the quantitative phase, the study focuses on crime incidents and crime hotspots as the primary variables for analysis. Using predictive policing techniques, the study examines crime trends and forecasts future crime occurrences. The quantitative component also incorporates geographical, environmental, and socio-demographic factors as explanatory variables influencing crime concentration and spatial distribution. These factors help identify the underlying

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determinants of crime hotspot emergence and support the development of data-driven crime prevention strategies.

Meanwhile, the qualitative phase centers on themes derived from interviews with key informants and participants. This phase aims to explore stakeholders' perceptions, experiences, and insights on crime occurrence, hotspot formation, and the implementation of predictive policing practices. The qualitative findings provide contextual explanations that cannot be fully captured through numerical and spatial analyses alone. The framework further shows that both the quantitative and qualitative findings converge in the "*Compare and Connect*" stage. In this process, the results from statistical forecasting, hotspot mapping, and explanatory factor analysis are compared and integrated with the themes generated from interviews. This allows the researcher to determine areas of convergence, divergence, and complementarity between the two datasets. Finally, the integrated findings lead to the data integration and interpretation stage, where the combined results are synthesized to generate a holistic understanding of predictive policing and crime hotspot analysis. Through this convergent mixed-method framework, the study strengthens the validity and depth of the findings by combining empirical statistical evidence with real-world perspectives and experiences.

Despite the growing international attention to predictive policing and GIS-based crime analysis, current literature still reveals significant limitations and underexplored areas. Most existing studies have been conducted in technologically advanced countries where crime data systems and digital infrastructures are already well-established. In contrast, there remains a scarcity of localized studies in developing countries, particularly in the Philippines, where crime databases are fragmented, spatial analytics remain underutilized, and predictive policing models have not yet been fully institutionalized. Furthermore, previous studies have primarily emphasized quantitative approaches such as visual crime mapping and statistical forecasting, with limited integration of qualitative perspectives that explain the underlying causes of crime hotspots. Although some studies have explored.

In studies of spatial and temporal crime patterns, few have incorporated Explanatory Factor Analysis (EFA) alongside qualitative thematic inquiry to identify the latent environmental, socioeconomic, and contextual factors influencing crime variation. Hence, the absence of an integrated, convergent mixed-methods approach limits a more comprehensive understanding of how statistical crime trends and lived experiences jointly shape crime hotspots and predictive policing strategies.

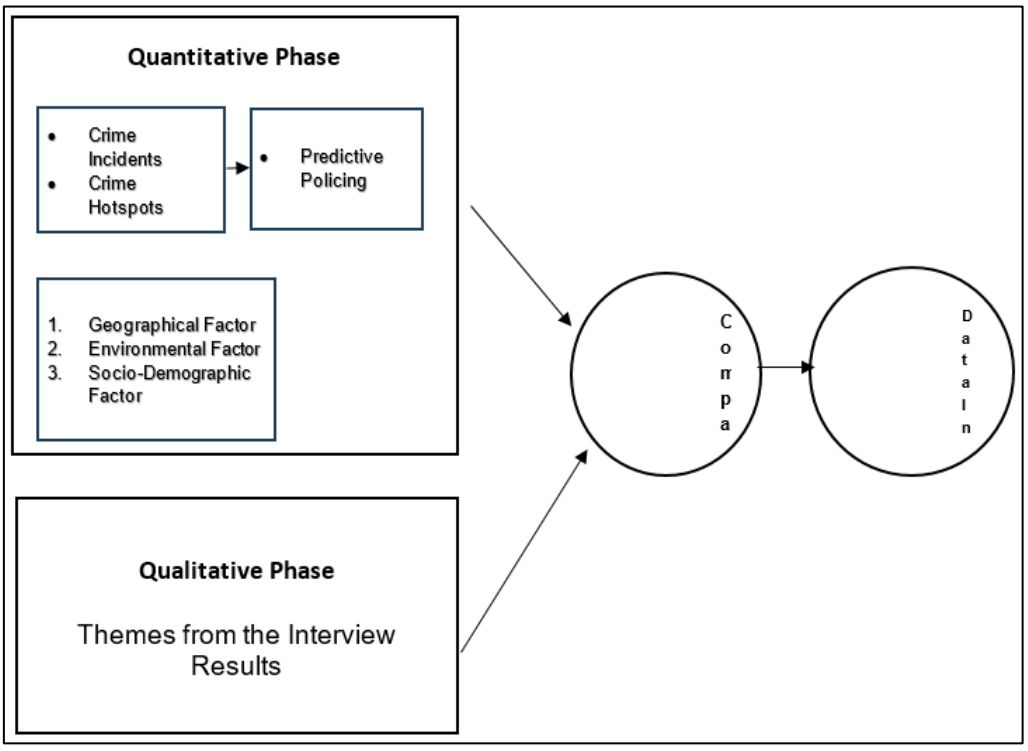


Fig 1 Conceptual Paradigm of the Study

The uniqueness of this study lies in its combined use of GIS and EFA to develop a predictive framework that identifies both the spatial distribution and the underlying causal structures of crime. Unlike traditional hotspot mapping, which merely visualizes concentration areas, this study aims to uncover the root explanatory factors, such as environmental vulnerability, socioeconomic pressure, and law enforcement accessibility, that contribute to crime emergence. This analytical integration advances existing methodologies by providing a data-driven approach that connects statistical modeling with real-world spatial contexts. Through this, the study not only enhances predictive accuracy but also contributes new insights to the disciplines of criminology and geographic information science.

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The urgency of conducting this study in the local context stems from the persistent challenges law enforcement agencies in the Philippines face in crime management and resource allocation. Despite technological advancements, policing strategies in many areas remain reactive, relying heavily on incident reports rather than predictive intelligence. The absence of spatially integrated analytical tools limits local police forces' capacity to anticipate and prevent crime effectively. Implementing a GIS-based predictive model tailored to the Philippine setting is, therefore, crucial for modernizing policing practices, optimizing deployment, and enhancing community safety through evidence-based decision-making.

Moreover, the increasing urbanization and population density in many Philippine cities have led to complex spatial patterns of crime that require advanced analytical intervention. The study's focus on predictive crime mapping directly addresses the need for strategic urban governance and aligns with national initiatives promoting digital transformation and public safety. By generating localized predictive insights, the research provides timely and actionable knowledge for law enforcement, local government units, and policy planners. Its urgency lies in supporting data-driven crime prevention and enhancing community resilience in the face of evolving social and environmental conditions.

Despite the increasing adoption of predictive policing and Geographic Information Systems (GIS) in crime analysis, existing studies are predominantly centered in developed countries and urbanized contexts, with limited attention to their application in regional settings in developing nations such as the Philippines. There is a scarcity of research on the Davao Region (Region XI) that integrates quantitative crime mapping with the qualitative perspectives of law enforcement practitioners. Previous studies often emphasize advanced predictive models but overlook the localized realities of policing, including resource constraints, data limitations, and socio-spatial dynamics unique to the region. This highlights the gap that the present study aims to address by providing a context-specific analysis that combines geospatial data with practitioner insights. The urgency of conducting this study in Region XI lies in the need to develop more responsive, evidence-based policing strategies that reflect the distinct geographic, environmental, and socio-demographic characteristics of the area, thereby enhancing the effectiveness and sustainability of predictive policing in the local context.

The study aimed to advance crime analysis in PNP Region XI by leveraging crime mapping and Geographic Information Systems (GIS) for predictive criminality assessment. Anchored on a convergent mixed-methods design, the research integrated quantitative spatial analysis and qualitative insights from law enforcement practitioners to explore the transformative potential of predictive policing through integrated crime mapping.

Specifically, the study sought to obtain and analyze secondary geospatial crime data from PNP Region XI covering the period from 2013 to 2023, including records of crime incidents and identified crime hotspots. Using GIS-based mapping and statistical analysis, the study examined spatial distribution patterns and crime trends in the region to identify the top five most prevalent or high-impact criminal cases within the specified period. It further analyzed how geographic, environmental, and socio-demographic factors influenced the occurrence and distribution of crime, ultimately leading to the development of a predictive model capable of forecasting potential crime hotspots and future crime trends. This quantitative component provided a data-driven foundation for enhancing proactive law enforcement strategies, particularly in decision-making and resource allocation.

Concurrently, the qualitative component of the study explored law enforcement practitioners' perspectives and insights on the role of geospatial data and crime incidents in predictive policing using GIS. Specifically, 1.) What are the perspectives and insights of law enforcement practitioners on the role of geospatial and crime incidents in predictive policing using GIS? It examined how practitioners interpreted and utilized spatial data in their operational contexts, particularly in crime prevention, planning, and deployment of resources. 2.) How do geographic, environmental, and socio-demographic factors influence and predict the incidence of crime as experienced by law enforcement practitioners? By integrating these qualitative insights with the quantitative results, the study ensured convergence, validation, and a more comprehensive understanding of crime dynamics in Region XI.

Overall, the study contributed to the growing body of literature on predictive policing and spatial crime analysis by demonstrating the value of integrating quantitative geospatial analysis with qualitative practitioner-based insights within a convergent mixed-methods framework. It bridged existing gaps in research by combining spatial, temporal, and socio-demographic data with experiential knowledge from law enforcement personnel. The findings provided an evidence-based, context-sensitive framework for data-driven policing and strengthened the application of criminological theories, particularly Routine Activity Theory and Environmental Criminology, by illustrating how spatial and experiential data could be operationalized in real-world law enforcement settings to enhance crime prevention.

Globally, this study contributes to the growing body of literature on predictive policing and spatial crime analysis by integrating advanced analytical techniques, such as the Convergent Mix Method Design, with Geographical Information Systems (GIS). While prior research has separately explored predictive models and spatial mapping, this study bridges the gap by combining spatial, temporal, and socioeconomic variables to identify underlying crime determinants. The findings will enrich international criminological research by providing an evidence-based framework for data-driven policing. This also strengthens the theoretical link between Routine Activity Theory and Environmental Criminology, demonstrating how spatial data can operationalize these frameworks in real-world contexts for crime prevention.

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In terms of social value, this study promotes a proactive approach to public safety by allowing communities and law enforcement to anticipate potential crime hotspots before incidents occur. Through GIS-integrated prediction models, local governments can optimize resource allocation, reduce crime rates, and improve community trust in policing institutions. By identifying environmental and socioeconomic factors that increase crime risk, the study can guide urban planners and policymakers toward more inclusive, safer urban designs. Ultimately, this empowers communities to participate in data-informed crime prevention initiatives, fostering transparency and collaboration between citizens and authorities.

This study particularly benefited law enforcement institutions, such as the Philippine National Police (PNP) and other global policing agencies, that aimed to adopt technology-driven approaches. The criminal justice sector benefited from enhanced investigative efficiency and evidence-based resource deployment. Local government units (LGUs) and urban planning departments utilized the spatial findings to improve public safety infrastructure, including lighting systems, surveillance mechanisms, and community policing initiatives. Additionally, academic institutions and research centers found value in the study as it provided a model framework for integrating statistical and geospatial methodologies within a convergent mixed-methods approach in criminological research.

For future researchers, this study served as a foundation for exploring advanced predictive mechanisms using artificial intelligence, deep learning, and big data analytics in crime analysis. It offered a methodological contribution by demonstrating that integrating quantitative spatial analysis with qualitative practitioner insights can provide a more comprehensive understanding of crime patterns and their underlying determinants. Future studies could replicate or refine this framework across different geographic settings or types of crimes. Thus, the study not only contributed to theoretical development and empirical knowledge but also advanced methodological innovation in criminology and data science.

Finally, this research aligned with the United Nations Sustainable Development Goals (SDGs), particularly SDG 16 (Peace, Justice, and Strong Institutions), by promoting effective, accountable, and transparent law enforcement systems. It also supported SDG 11 (Sustainable Cities and Communities) by fostering safer, more resilient, and data-informed urban environments. By enabling evidence-based policing and spatial crime prevention, the study contributed to sustainable governance and the protection of human security. Integrating these SDGs ensured that the research not only addressed local safety challenges but also resonated with global efforts to achieve peace, justice, and sustainable urban development.

## II. METHOD

This section presents the methods used in the study, including the study participants, materials and instruments, and the design and procedure.

- *Data Sources*

For the quantitative phase, the study utilized secondary data obtained from the Philippine National Police (PNP) Regional Office XI and its affiliated provincial and city police offices. The dataset consisted of officially recorded crime incidents extracted from the Crime Information Reporting and Analysis System (CIRAS), e-Blotter, and other authorized police crime databases maintained by the law enforcement organization. The crime data covered the period from 2013 to 2023 and included index crimes such as murder, rape, physical injury, robbery, and theft. These official records served as the primary quantitative data source for conducting trend analysis, forecasting, and Geographic Information System (GIS)-based spatial analysis. The use of secondary data from an official law enforcement agency ensured the reliability, authenticity, and consistency of the information, as the records were collected and maintained in accordance with the Philippine National Police's standard crime reporting procedures.

For the qualitative phase, the primary data were obtained through interviews with the participants of the study, who comprised professionals in crime analysis, Geographic Information Systems (GIS) expertise, and law enforcement personnel from PNP Region XI. Crime analysts in the Davao Region were typically trained to analyze crime data, patterns, and trends, often with backgrounds in criminology, statistics, or data analysis. Similarly, GIS experts specialized in geographic information systems and spatial analysis, demonstrating proficiency in mapping and interpreting geospatial data. These participants provided relevant and experience-based insights necessary for the study.

For this research, a total of seven (7) participants were selected and successfully interviewed through In-Depth Interviews (IDIs). The selection process involved a combination of purposive sampling and snowball sampling. Initially, key participants were purposefully identified based on their recognized expertise in GIS, crime analysis, and law enforcement. These individuals served as the primary data sources. Subsequently, a snowball sampling technique was used, in which initial participants recommended other individuals with relevant knowledge and experience related to the research topic.

The sample size was determined by the principle of data saturation in qualitative research. Data saturation was achieved when no new information or themes emerged from subsequent interviews, indicating that the number of participants was sufficient to address the research objectives (Creswell & Poth, 2018). Qualitative research methodologies emphasize the importance of saturation rather than a fixed sample size (Morse, 2000). In this study, the relatively small number of participants enabled a more in-depth exploration of experiences and perspectives, facilitating rich, detailed

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data collection (Patton, 2002). Additionally, smaller participant groups enabled more meaningful engagement and ensured that each participant's insights were thoroughly captured (Morgan, 1996).

The use of purposive sampling was appropriate, as it enabled the selection of participants with specific knowledge and expertise relevant to the study (Patton, 2002). Meanwhile, snowball sampling proved valuable in identifying additional qualified participants who might not have been easily accessible through conventional sampling methods, thereby enhancing the depth and diversity of perspectives (Berg, 2009). The integration of these sampling techniques enabled the study to achieve a comprehensive understanding of GIS's role in crime analysis and predictive policing.

In terms of inclusion criteria, participants were required to be actively employed as crime analysts, GIS experts, or law enforcement officers and to have at least 2 years of professional experience in their respective fields to ensure adequate expertise. Conversely, individuals who did not meet these criteria or were unwilling or unable to participate in the interviews were excluded from the study. Participants were also informed of their right to withdraw from the study at any point without providing a reason. The study locale was selected based on the prevalence of crime-related issues, the availability of qualified participants, and its relevance to the research objectives.

Table 1 Profile of the Participants

| Participant Code Name | Role/Assignment | Years of Service | Area of Assignment |
|---|---|---|---|
| Alpha | Crime Data Encoder/Crime Registrar | 5 years | Police Station |
| Bravo | CIRAS Operator/Crime Registrar | 7 years | City Police Office |
| Charlie | Crime Registrar | 10 years | Police Station |
| Delta | Mapping Assistant/Crime Registrar | 4 years | Police Station |
| Echo | Data Analyst Staff | 8 years | Police Station |
| Foxtrot | Administrative Staff/Crime Registrar | 3 years | Police Station |
| Golf | CIRAS Operator | 14 years | Police Station |

- *Materials and Instrument*

This section describes the materials and instruments used to collect and analyze both quantitative and qualitative data, consistent with the study's convergent mixed-methods design. For the quantitative component, secondary data were obtained from the Philippine National Police (PNP) Regional Office XI. These included geospatial datasets of crime incidents and official crime hotspot or crime mapping records covering the period from 2013 to 2023. The data were obtained through formal requests and used as the primary inputs for Geographic Information Systems (GIS)-based spatial analysis, trend analysis, and predictive modeling.

For the qualitative component, the primary instrument was a researcher-designed semi-structured interview guide for conducting In-Depth Interviews (IDIs). The interview guide consisted of open-ended questions and probing prompts that facilitated in-depth exploration of participants' experiences, perspectives, and insights regarding the implementation of predictive policing through GIS-based crime mapping. The guide was structured around the central research questions, focusing on the perspectives and insights of law enforcement practitioners on the role of geospatial and crime incidents in predictive policing using GIS, and how geographic, environmental, and socio-demographic factors influence and predict the incidence of crime as experienced by law enforcement practitioners.

- *Design and Procedure*

The study employed a convergent mixed-methods research design, in which both quantitative and qualitative data were collected and analyzed concurrently and then integrated to provide a comprehensive understanding of the research problem. This approach is supported by recent literature, which emphasizes that convergent designs enable researchers to collect and analyze both data strands simultaneously, then merge the results to achieve a more holistic and validated interpretation of the findings (Dawadi et al., 2021; Rana, 2025). In this design, integrating quantitative and qualitative data enhances the depth, validity, and overall explanatory power of the study by enabling comparisons and corroborations across multiple data sources. This design was appropriate for the study as it combined GIS-based crime mapping and spatial analysis with qualitative insights from law enforcement practitioners to examine crime patterns and predictive policing practices in Region XI. From a governance and public safety perspective, this approach enabled a more comprehensive and context-sensitive understanding of spatial crime dynamics and their practical implications in law enforcement decision-making.

For the quantitative phase, the study employed a quantitative non-experimental descriptive and predictive research design using secondary crime data obtained from the Philippine National Police (PNP) Region XI. The descriptive component was used to examine the distribution, frequency, and trends of crime incidents, while the predictive component utilized time-series forecasting and Geographic Information System (GIS)-based spatial analysis to identify crime patterns and forecast future crime occurrences. This design was appropriate because it enabled the researcher to analyze existing crime records without manipulating any variables and to generate evidence-based predictions to support strategic law enforcement planning.

For the qualitative phase, the study adopted a qualitative descriptive research design using in-depth interviews (IDIs) with selected law enforcement personnel, crime analysts, and

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GIS practitioners from PNP Region XI. The qualitative descriptive approach was appropriate because it sought to obtain rich, straightforward descriptions of participants' experiences, perceptions, and practices regarding the use of GIS in crime mapping and predictive policing. This design enabled the researcher to explore operational realities, contextual factors, and implementation challenges that could not be adequately explained through quantitative crime statistics alone.

In terms of research typology, the study employed a convergent mixed-methods design, combining quantitative and qualitative approaches to achieve a comprehensive analysis of predictive policing and GIS-based crime mapping in Region XI. The study was descriptive-exploratory, describing existing crime trends and exploring the underlying factors influencing crime occurrence and hotspot formation. It was also cross-sectional in the time dimension, as crime data and interview responses were collected within a specific timeframe for a one-time analysis and interpretation.

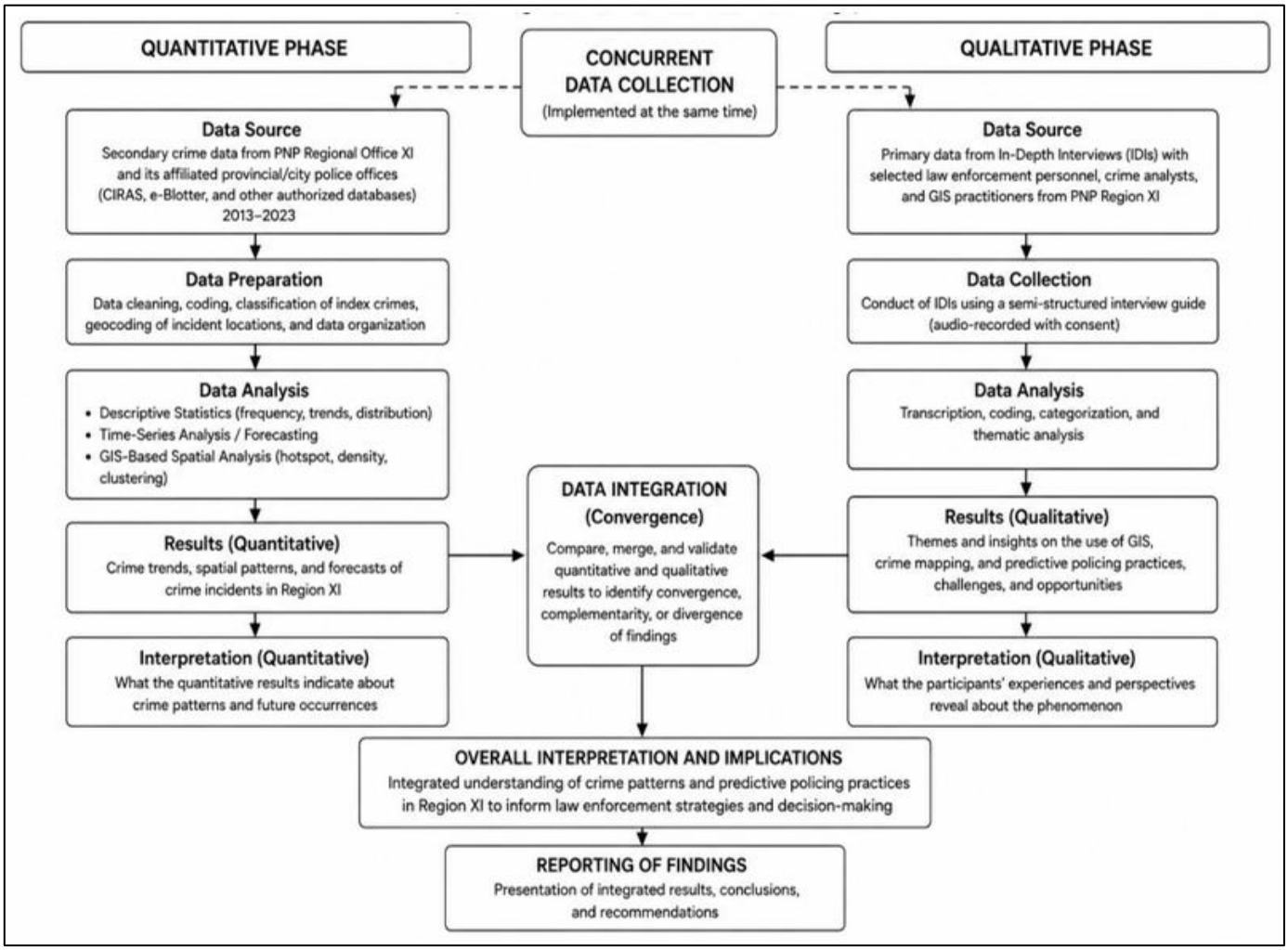


Fig 2 Model Procedure Diagram for the Conduct of Two Phases

For the quantitative phase, the study used descriptive statistics, linear regression, time-series forecasting models, and GIS hotspot analysis to examine the spatial and temporal patterns of major index crimes from 2013 to 2023. Specifically, regression analysis was used to determine the relationship between year and crime incidence, while forecasting techniques, including Winters' Additive and Multiplicative models, were employed to predict future crime incidence from 2024 to 2028. Forecasting model fit statistics, including R-Squared, RMSE, MAPE, MAE, and Normalized BIC, were likewise utilized to evaluate the predictive accuracy and reliability of the forecasting models. Meanwhile, GIS-based crime mapping was applied to identify crime hotspots and spatial concentrations of criminal activities within Region XI.

For the qualitative phase, thematic analysis was used to examine participants' interview responses regarding predictive policing, crime hotspots, and GIS implementation in law enforcement operations. The quantitative and qualitative findings were analyzed separately and subsequently integrated during the interpretation phase to compare, connect, and validate the study's results. The researcher assumed the role of crime analyst, responsible for collecting crime datasets, conducting GIS mapping, performing statistical and forecasting analyses, facilitating interviews, and interpreting the integrated findings. This active involvement contributed to the credibility, consistency, and depth of the study by ensuring accurate data collection, systematic analysis, and comprehensive interpretation of both numerical and thematic findings.

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Prior to conducting the study, the researcher obtained clearance from the University Multi-Disciplinary Ethics Review Committee (UMERC) and secured permission from relevant agencies, including the PNP Regional Office XI. Upon approval, official crime data related to index crimes (e.g., murder, rape, robbery, and theft) were collected and processed using GIS software to identify crime clusters and spatial trends. Concurrently, key informant interviews were conducted with purposively selected participants, such as crime analysts and police officers, to gather insights into operational challenges and the practical application of predictive policing strategies.

The data collection was conducted between March and April 2026, and data analysis followed two parallel tracks consistent with the convergent mixed-methods design. Quantitatively, GIS-based spatial analysis was performed to examine crime distribution, hotspot patterns, and trends. Qualitatively, interview transcripts were analyzed using Braun and Clarke's (2006) thematic analysis framework, which involved data familiarization, coding, theme development, and interpretation. This process aimed to uncover key themes that complemented and explained the quantitative findings.

The study adhered to established ethical principles to protect the rights, welfare, and dignity of all participants. Ethical clearance was obtained from the University of Mindanao Ethics Review Committee (UMERC) under UMERC Certificate No. UMERC 2026-084 prior to data collection. Participation was voluntary, with written informed consent obtained after participants were fully informed of the study's purpose, procedures, and their right to withdraw at any time without penalty. Privacy and confidentiality were maintained through participant anonymization and secure data storage in compliance with the Philippine Data Privacy Act of 2012 (Republic Act No. 10173). The study also upheld credibility, dependability, confirmability, and transferability through systematic qualitative procedures while maintaining academic integrity by avoiding plagiarism, fabrication, falsification, and conflicts of interest. Formal permission was secured from PNP Region XI, and proper academic authorship and acknowledgment were accorded to Dr. Rowela Cartin Pecson for her scholarly guidance, in accordance with institutional and international ethical standards for research involving human participants.

## III. RESULTS AND DISCUSSIONS

This section presents the quantitative and qualitative findings of the study on predictive policing, conducted through integrated crime-mapping analysis using Geographic Information Systems (GIS) in Region XI. The presentation of results follows the study's convergent mixed-methods design, in which quantitative and qualitative data were analyzed separately and then integrated to provide a more comprehensive understanding of crime trends, forecasting patterns, hotspot distribution, and law enforcement perspectives on predictive policing and GIS implementation.

➢ *Quantitative Findings*

This section presents the quantitative findings of the study derived from crime trend analysis, time-series forecasting, regression analysis, and GIS hotspot mapping of major index crimes in Region XI from 2013 to 2023. Statistical and predictive models were used to examine temporal patterns in crime incidence, identify hotspot areas, and forecast future crime trends within the region. The findings provide empirical evidence on the spatial and temporal behavior of crime and on the applicability of predictive policing and GIS-based crime analysis to strengthen evidence-based law enforcement operations.

- *Crime Trend Analysis of Murder Records in Region XI (2013–2023)*

The time series plot of murder records in Region XI from 2013 to 2023 showed a generally decreasing trend across the provinces included in the study. Davao City consistently recorded the highest number of murder cases throughout the ten-year period; however, a continuous decline was observed from approximately 275 cases in 2013 to around 170 cases in 2023. Similarly, Davao del Norte, Davao del Sur, and Davao de Oro also demonstrated gradual reductions in murder incidents over time. The observed downward trend may indicate the effectiveness of intensified anti-criminality campaigns, law enforcement visibility, intelligence-driven operations, and community-based crime prevention initiatives implemented within the region. The findings suggest that peace and order conditions in Region XI have improved over the years, despite variations in crime rates across provinces.

On the other hand, Davao Occidental exhibited noticeable fluctuations in murder incidents during selected years, particularly between 2016 and 2020, before declining again in succeeding periods. Although the province recorded fewer murder cases than Davao City, the fluctuating pattern may indicate the influence of localized social, economic, environmental, or demographic conditions on criminal activity within the area. These fluctuations further suggest that crime incidents are dynamic and may vary with situational factors and policing conditions. Nevertheless, the overall regional trend still reflected a decline in murder records, indicating that law enforcement interventions and regional crime prevention strategies may have contributed to reducing violent crimes throughout Region XI.

These findings agree with Mugari and Obioha (2021), who emphasized that predictive policing and historical crime trend analysis are essential in improving crime prevention and law enforcement operations. The use of historical crime data enables police agencies to identify recurring crime patterns, forecast possible criminal incidents, and implement proactive policing strategies in high-risk areas. This supports the present findings, as the decreasing trend of murder incidents in Region XI demonstrates the importance of data-driven policing and crime analysis in strengthening public safety and supporting evidence-based law enforcement interventions.

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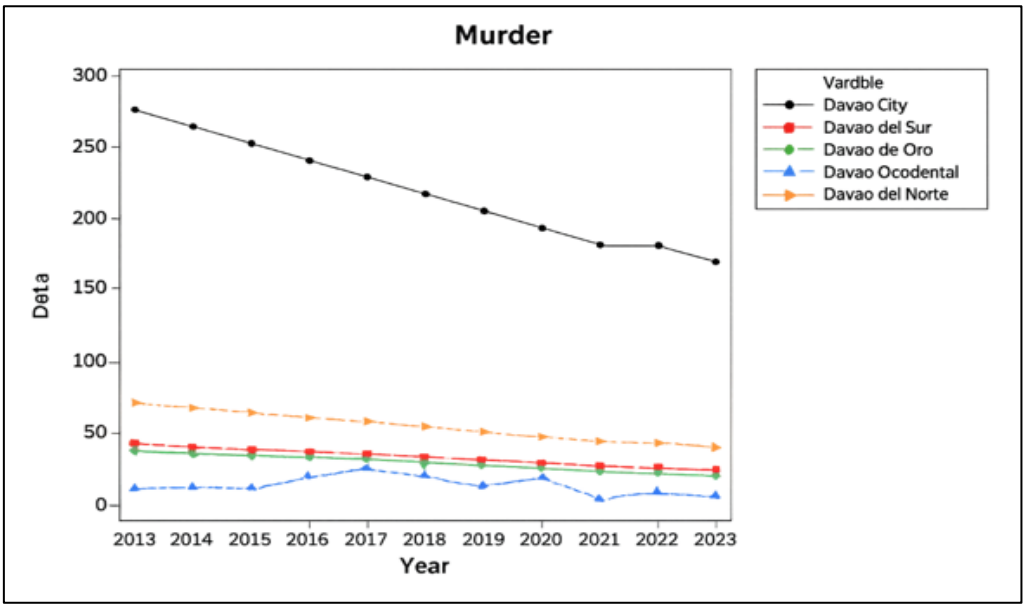


Fig 3 Time Series Plot of Trend of Murder Records in Region XI from Year 2013 to 2023

- *Crime Trend Analysis of Physical Injury Records in Region XI (2013–2023)*

The time series plot of physical injury records in Region XI from 2013 to 2023 revealed a generally decreasing trend across most provinces included in the study. Davao City consistently recorded the highest number of physical injury incidents throughout the observed period, although a continuous decline was evident from approximately 148 cases in 2013 to around 90 cases in 2023. Likewise, Davao del Norte, Davao del Sur, and Davao de Oro also demonstrated gradual reductions in physical injury cases over the ten-year period. The declining trend may indicate the effectiveness of strengthened law enforcement efforts, public safety campaigns, conflict-prevention programs, and community-based interventions implemented in the region. The findings suggest that preventive policing measures and improved peace and order initiatives may have contributed to a reduction in incidents of physical injury in Region XI.

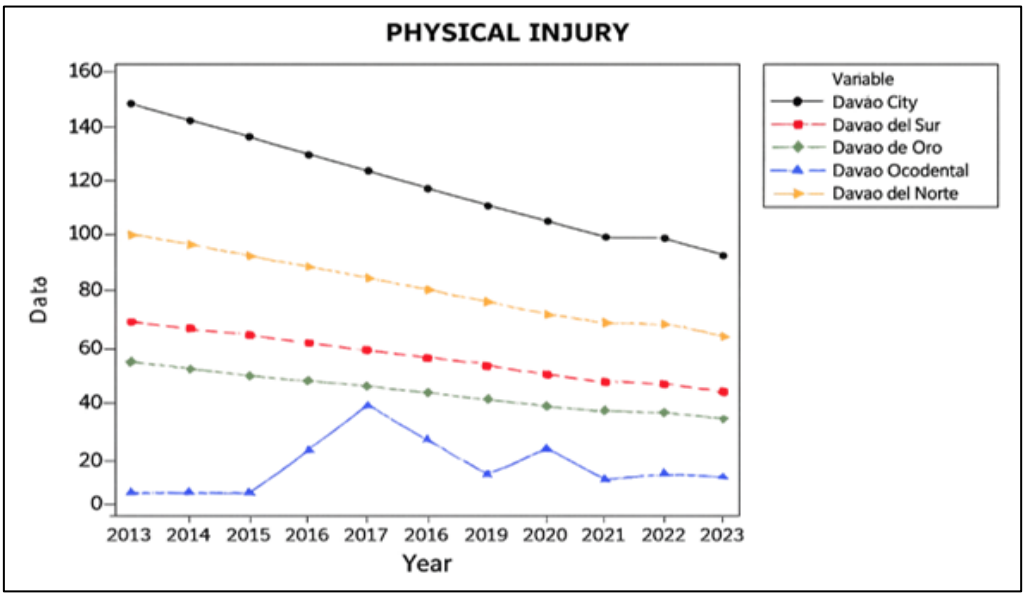


Fig 4 Time Series Plot of Trend of Physical Injury Records in Region XI from year 2013 to 2023

In contrast, Davao Occidental exhibited fluctuating physical injury records during selected years, particularly from 2016 to 2020, where sudden increases and decreases were observed. Despite recording comparatively lower incident rates than other provinces, fluctuations may reflect the influence of localized disputes, socio-economic factors, environmental conditions, or inconsistencies in crime reporting and law enforcement presence. Nevertheless, the overall pattern in the region continued to show a downward trend in physical injury cases. This implies that while some areas may experience temporary increases in crime incidents, sustained policing operations and coordinated crime prevention efforts remain significant in maintaining public safety and minimizing violent offenses across the region. The result is consistent with the findings of Mojica et al. (2017), who found that incidents of physical injury and other violent

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crimes in Metro Manila were strongly influenced by demographic and spatial factors such as population density, migration, and the concentration of young male populations. These findings support the present study, as the observed decline in physical injury cases in Region XI may reflect the effectiveness of intensified law enforcement initiatives, proactive crime prevention programs, and strategic policing interventions implemented within the region.

- *Crime Trend Analysis of Rape Records in Region XI (2013–2023)*

The time series plot of rape records in Region XI from 2013 to 2023 revealed a generally decreasing trend across most provinces included in the study. Davao City consistently recorded the highest number of rape incidents throughout the ten-year period, although a gradual decline was observed from approximately 160 cases in 2013 to around 98 cases in 2023. Similar downward patterns were also evident in Davao del Norte, Davao del Sur, and Davao de Oro, indicating a reduction in reported rape cases over time. The decreasing trend may suggest the effectiveness of strengthened law enforcement operations, gender-sensitive policing, public awareness campaigns, and violence prevention initiatives implemented within the region. The findings imply that ongoing crime-prevention efforts and victim protection programs may have contributed to improved public safety and reduced sexual offenses in Region XI.

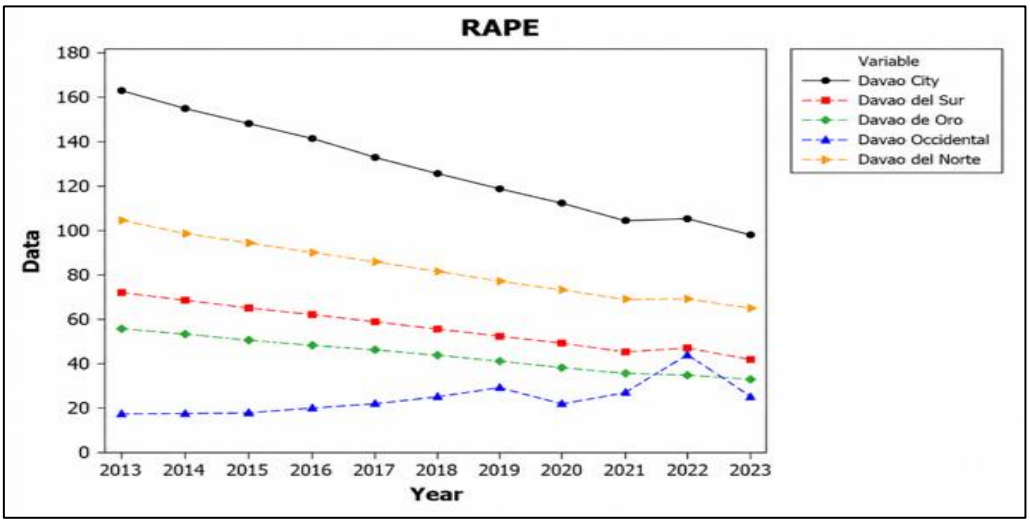

Fig 5 Time Series Plot of Trend of Rape Records in Region XI, year 2013-2023

In contrast, Davao Occidental demonstrated noticeable fluctuations in rape records, particularly from 2018 to 2022, where sudden increases in incidents were observed before declining again in 2023. Although the province recorded comparatively lower rape incidents than Davao City, the fluctuating pattern may reflect the influence of localized socio-economic conditions, reporting behavior, population dynamics, or environmental factors affecting crime occurrence. These variations indicate that rape incidents remain dynamic and may change depending on community circumstances and law enforcement conditions. Nevertheless, despite these fluctuations, the overall regional trend still reflected a decline in rape incidents, suggesting improvements in crime monitoring, law enforcement responsiveness, and community-based intervention programs throughout the region.

The findings of the study reinforce the observations of Dalton et al. (2022), who emphasized that improved policing strategies, specialized investigations, victim-centered approaches, and strengthened law enforcement responses contribute to better handling and prevention of rape cases. The study explained that enhancing police investigative procedures and community engagement can influence reporting patterns and crime reduction. Bautista (2022) highlighted that rape and sexual violence in the Philippines remain influenced by cultural, social, and reporting-related factors. The study emphasized that increased awareness campaigns, advocacy movements, and reporting mechanisms contribute to changes in rape reporting trends and public response to sexual violence.

- *Crime Trend Analysis of Robbery Records in Region XI (2013–2023)*

The figure illustrates the trend in robberies in the provinces of Region XI from 2013 to 2023. Among the five provinces, Davao City consistently recorded the highest number of robbery incidents throughout the observed period. However, despite having the highest crime volume, the data showed a steady decline in robbery cases from 2013 to 2023, from approximately 94 incidents in 2013 to about 58 in 2023. Similarly, Davao del Norte, Davao del Sur, and Davao de Oro also showed gradual downward trends over the years, suggesting possible improvements in crime prevention and law enforcement initiatives across the region. In contrast, Davao Occidental showed fluctuating robbery incidents, with a noticeable increase from 2015 to 2017, followed by a significant decline afterward.

The declining robbery trend across most provinces may suggest the effectiveness of intensified police visibility, anti-criminality campaigns, hotspot policing, and community-based crime prevention programs implemented in Region XI. The reduction in robbery incidents could also be associated

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with strengthened coordination between law enforcement agencies and local government units, as well as the increasing use of crime-mapping and surveillance systems to identify high-risk areas. Furthermore, the consistently higher robbery incidence in Davao City may be attributed to its larger population, higher urbanization rate, economic activities, and concentration of commercial establishments compared to other provinces in the region. Urban centers commonly experience higher property-related crimes due to greater opportunities for offenders and increased movement of people and goods.

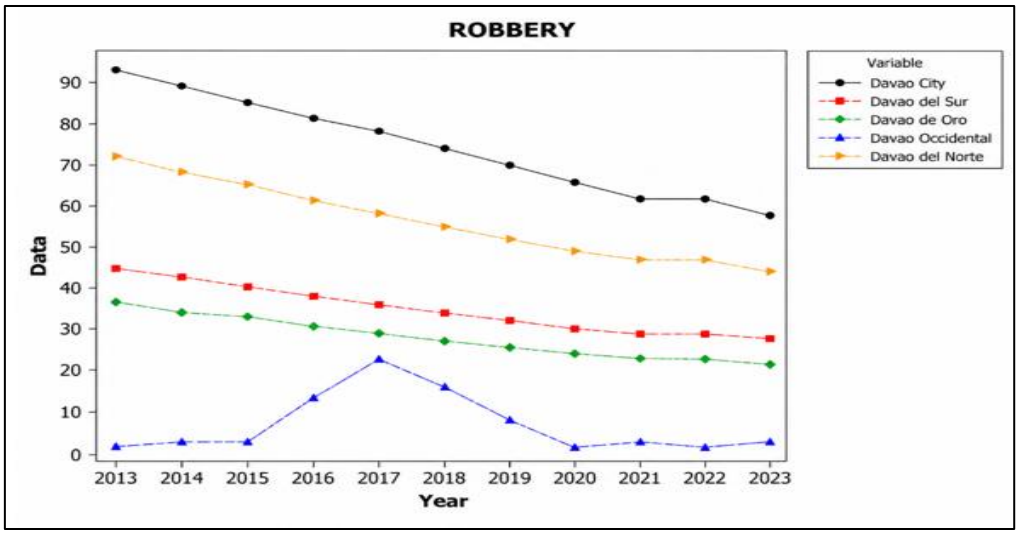


Fig 6 Time Series Plot Trend of Robbery Records in Region XI from year 2013 to 2023

A study conducted in Sorsogon Province by Barreda found that property-related crimes, particularly robbery and theft, were comparatively lower in municipalities where law enforcement agencies and community stakeholders worked together to implement crime prevention initiatives. The study emphasized that public information campaigns, community participation, and continuous police operations played significant roles in maintaining peace and order and minimizing crime incidents (Barreda, 2022). These findings support the present study, as the decreasing robbery trend observed in Region XI may likewise indicate the effectiveness of collaborative efforts among local government units, police authorities, and community members in strengthening crime prevention and enhancing public safety.

- *Crime Trend Analysis of Theft Records in Region XI (2013–2023)*

The figure illustrates the trend of theft incidents in the provinces of Region XI from 2013 to 2023. Among the provinces, Davao City consistently recorded the highest number of theft cases throughout the observed period. However, despite having the highest incidence, theft cases in the city gradually declined from 2013 to 2023. Similar decreasing patterns were also observed in Davao del Norte, Davao del Sur, and Davao de Oro, indicating a steady reduction in theft incidents across most provinces in the region. Meanwhile, Davao Occidental showed slight fluctuations in some years before eventually declining toward the latter part of the study period.

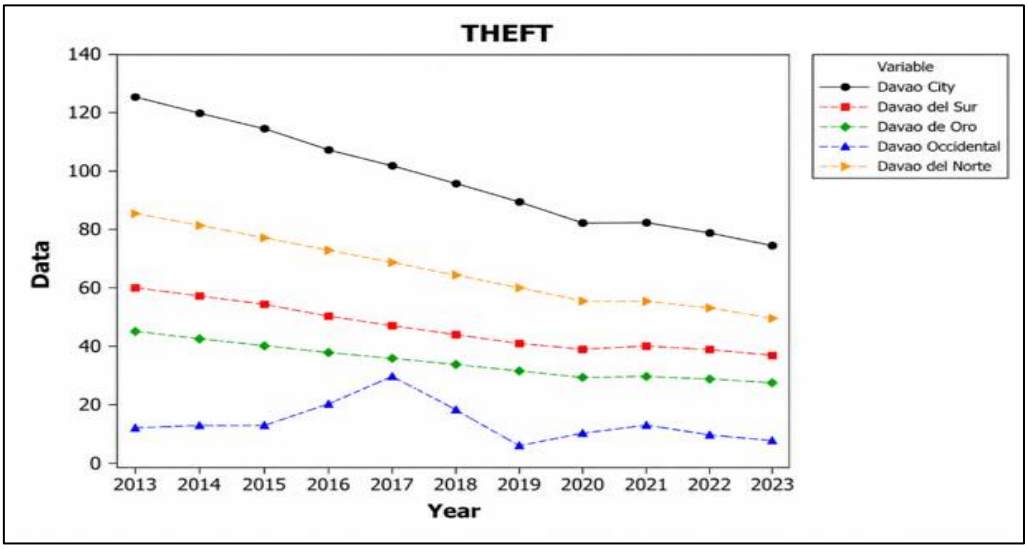


Fig 7 Time Series Plot of Trend of Theft Records in Region XI from year 2013 to 2023

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The declining trend of theft incidents may suggest the effectiveness of intensified anti-criminality campaigns, increased police visibility, and strengthened community-based crime prevention efforts implemented across Region XI. Since theft is commonly associated with urbanization, business activity, and population concentration, the consistently higher number of cases in Davao City may be influenced by its status as the region's major urban and commercial center. Nevertheless, the gradual decrease in theft cases over the years may indicate improvements in law enforcement response, strategic police deployment, and public cooperation in crime prevention activities. The findings support the study of Ortega (2025), which emphasized that increased police visibility and proactive policing strategies contribute significantly to crime prevention and public safety. The study explained that visible police presence, regular patrol operations, and stronger community-police partnerships help deter crime and enhance community security.

➢ *Historical Crime Trend Analysis in Region XI*

This section presents the historical trend of major index crimes in Region XI from 2013 to 2023. The analysis focused on murder, rape, physical injury, robbery, and theft using the monthly and yearly crime datasets. The purpose of the analysis was to determine the temporal movement and behavioral patterns of crime incidence within the region.

- *Historical Crime Incidence in Region XI (2013–2023)*

Table 2 presents the historical crime incidence in Region XI from 2013 to 2023, focusing on the five major index crimes, namely murder, rape, physical injury, robbery, and theft. The findings revealed a generally decreasing trend in crime incidence throughout the eleven-year period despite observable yearly fluctuations. Total crime incidence declined from 4,782 cases in 2013 to 2,934 in 2023, indicating a reduction in crime over time within the region.

Table 2 Historical Crime Incidence in Region XI (2013–2023)

| Year | Murder | Rape | Physical Injury | Robbery | Theft | Total Crime |
|---|---|---|---|---|---|---|
| 2013 | 612 | 844 | 1120 | 904 | 1302 | 4782 |
| 2014 | 628 | 861 | 1134 | 918 | 1318 | 4859 |
| 2015 | 601 | 826 | 1096 | 874 | 1267 | 4664 |
| 2016 | 617 | 842 | 1112 | 896 | 1288 | 4755 |
| 2017 | 566 | 781 | 1018 | 778 | 1175 | 4318 |
| 2018 | 528 | 746 | 956 | 721 | 1104 | 4055 |
| 2019 | 503 | 719 | 914 | 673 | 1057 | 3866 |
| 2020 | 548 | 768 | 982 | 744 | 1188 | 4230 |
| 2021 | 521 | 734 | 941 | 691 | 1114 | 4001 |
| 2022 | 447 | 648 | 806 | 556 | 914 | 3371 |
| 2023 | 391 | 579 | 701 | 462 | 801 | 2934 |

The results showed slight increases in crime incidence in 2014 and 2016, followed by a gradual decline from 2017 to 2019. A temporary increase was again observed in 2020, with total crime incidence rising to 4,230 cases from 3,866 in 2019. This increase may be associated with the social and economic disruptions brought about by the COVID-19 pandemic, including mobility restrictions, unemployment, economic instability, and operational challenges faced by law enforcement agencies during the pandemic. However, crime incidence gradually declined again from 2021 to 2023, suggesting improvements in public safety conditions and stabilization of police operations after the height of the pandemic.

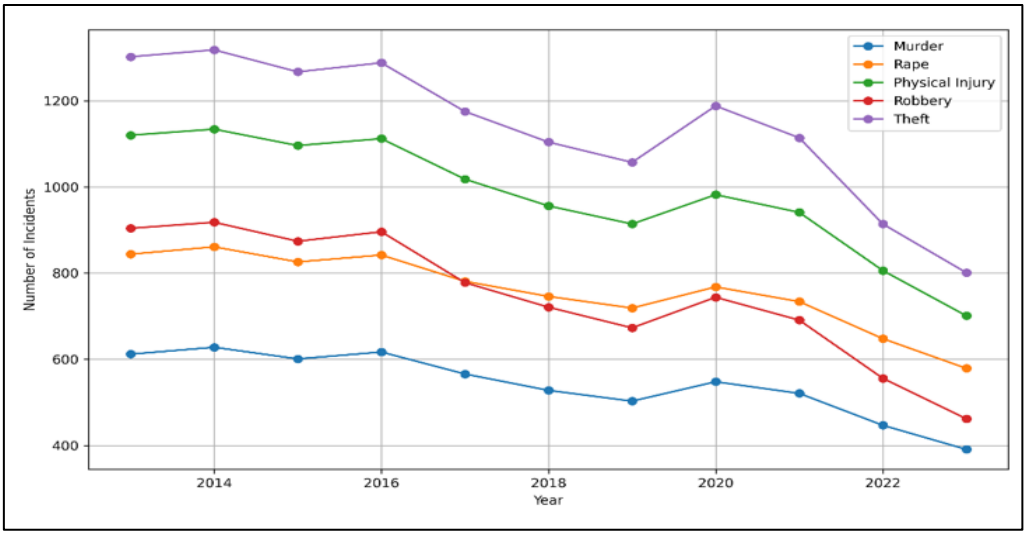


Fig 8 Trend of the Five Major Index Crime in Region XI (2023-2023)

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Among the five major index crimes, theft consistently recorded the highest number of incidents throughout the study period, followed by physical injury and robbery. In contrast, murder consistently recorded the lowest incidence among the five crime categories. Theft decreased from 1,302 cases in 2013 to 801 in 2023, while robbery declined from 904 to 462 during the same period. Similarly, murder, rape, and physical injury also demonstrated substantial reductions over time.

Overall, the findings indicate that although crime incidence experienced temporary fluctuations and pandemic-related increases, the long-term trend remained decreasing across all major crime categories. The observed reduction may suggest the effectiveness of predictive policing initiatives, hotspot-focused patrol deployment, GIS-based crime monitoring, intensified anti-criminality campaigns, and data-driven law enforcement strategies implemented within Region XI. A systematic review conducted by Lee et al. (2024) explained that data-driven predictive policing contributes to crime reduction by enabling police agencies to anticipate high-risk areas and implement targeted interventions. The study further noted that predictive policing improves operational efficiency by analyzing historical crime trends and spatial crime concentrations.

➢ *Predictive Modeling and Forecasting Analysis*

This section presents the predictive modeling and forecasting analysis of major index crimes in Region XI using Linear Regression and SPSS Time Series Forecasting Models. Monthly crime datasets from 2013 to 2023 were analyzed to forecast future crime incidence from 2024 to 2028.

- *Linear Regression Analysis Model Summary*

Table 3 presents the Linear Regression Analysis Model Summary of major index crimes in Region XI. The regression analysis revealed a very strong relationship between the independent variable (year) and the dependent variable (crime incidence), as reflected by the R-value of .977. This indicates a strong correlation between temporal progression and changes in crime incidence within the region. The R-squared value of .954 indicates that approximately 95.4% of the variation in crime incidence can be explained by the regression model.

Table 3 Linear Regression Analysis Model Summary

| Model | R | R Square | Adjusted R Square | Std. Error |
|---|---|---|---|---|
| 1 | .977 | .954 | .954 | 12.043 |

This suggests that temporal changes significantly influenced crime incidence and the reliability of the regression model, even after accounting for the number of variables included in the analysis. The relatively low standard error of the estimate (12.043) further indicates that the regression model's predicted values closely approximate the observed crime values, suggesting acceptable predictive accuracy and model fit. Overall, the findings imply that crime incidence in Region XI exhibits a strong temporal pattern suitable for predictive modeling and forecasting. The results support the applicability of regression analysis, predictive policing, and GIS-integrated crime analysis in examining crime trends and forecasting future crime occurrence within the region.

- *Analysis of Variance (ANOVA) for the Linear Regression Analysis*

Table 4 presents the ANOVA for the linear regression analysis used to determine whether the regression model significantly explains the relationship between year and crime incidence in Region XI. The findings reveal that the regression model is statistically significant, with an F-value of 2716.836 and a significance value of .000, which is lower than the standard alpha level of 0.05. This indicates that the regression model effectively explains the changes in crime incidence over time.

Table 4 ANOVA Results of Linear Regression Analysis

| Model | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Regression | 394060.037 | 1 | 394060.037 | 2716.836 | .000[b] |
| Residual | 18855.683 | 130 | 145.044 | | |
| Total | 412915.720 | 131 | | | |

The results suggest that temporal progression, or the passage of years, significantly influenced the temporal trend in crime incidence in Region XI from 2013 to 2023. In simpler terms, the analysis confirmed that crime incidence changed significantly over time and that the regression model was reliable for predicting crime trends. The relatively small residual value further indicates that only a minimal amount of unexplained variation remained after the model accounted for the observed crime patterns. Overall, the findings support the applicability of linear regression analysis in examining crime trends and forecasting future crime incidence within the region.

- *Coefficients of Linear Regression Analysis*

As observed in Table 5, the coefficients of the linear regression analysis used to determine the effect of year on crime incidence in Region XI are presented. The results reveal that the variable "Year" has a negative coefficient (B = -17.278), indicating that crime incidence generally decreased over time. This means that for every increase in the year, crime incidence tended to decline.

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Table 5 Coefficients of Linear Regression Analysis

| Model | B | Std. Error | Beta | t | Sig. |
|---|---|---|---|---|---|
| Constant | 35185.664 | 668.935 | | 52.599 | .000 |
| Year | -17.278 | .331 | -.977 | -52.123 | .000 |

The standardized beta coefficient (Beta = -.977) further indicates a very strong negative relationship between year and crime incidence. This suggests that temporal progression strongly influenced the decline in crime rates within the region. Moreover, the computed t-value of -52.123 and significance value of .000 indicate that the relationship is statistically significant, meaning the decrease in crime incidence over time was not due to chance. The findings show that crime incidence in Region XI generally declined from 2013 to 2023. The results support the effectiveness of predictive policing strategies, hotspot-focused patrol deployment, and data-driven crime prevention initiatives implemented within the region. Overall, the regression coefficients confirm that the model is suitable for forecasting future crime trends and examining long-term crime movement in Region XI.

The findings support Mohler et al. (2020), who explained that predictive policing models help identify spatial and temporal crime patterns, enabling police agencies to allocate resources strategically and prevent crime proactively. Similarly, Koper et al. (2021) emphasized that predictive policing models become more effective when integrated into routine police operations and supported by reliable crime data systems, supporting the applicability of regression analysis and predictive modeling in examining crime trends in Region XI.

➢ *Time Series Forecasting Analysis*

Table 6 illustrates the forecasting model used to analyze the major index crimes in Region XI. The findings reveal that different forecasting models were applied depending on the movement and behavior of each crime variable over time. Specifically, the Winters' Multiplicative model was utilized for murder, robbery, and theft, while the Winters' Additive model was applied to rape and physical injury cases. This indicates that crime incidents in Region XI followed varying temporal and seasonal patterns, requiring different forecasting approaches to obtain more accurate and reliable crime predictions.

Table 6 Forecasting Model Description

| | | | Model Type |
|---|---|---|---|
| Model ID | Murder | Model_1 | Winters' Multiplicative |
| | Rape | Model_2 | Winters' Additive |
| | Physical Injury | Model_3 | Winters' Additive |
| | Robbery | Model_4 | Winters' Multiplicative |
| | Theft | Model_5 | Winters' Multiplicative |

The use of the Winters' Multiplicative model for murder, robbery, and theft suggests that fluctuations in these crimes changed proportionally with the overall trend of crime incidence. In simpler terms, increases and decreases in crime became more noticeable as crime trends changed across the years. Meanwhile, the Winters' Additive model applied to rape and physical injury indicates that these crimes demonstrated relatively stable and consistent variations over time. The findings imply that major index crimes in Region XI followed identifiable temporal patterns that can be forecasted using time-series models. This further supports the applicability of predictive policing and data-driven crime analysis to help law enforcement agencies anticipate potential crime occurrences, improve hotspot monitoring, and strengthen proactive policing operations within the region.

The findings substantiate the statement of Mugari and Obioha (2021), who explained that predictive policing and crime forecasting models enable law enforcement agencies to identify recurring crime patterns, anticipate future criminal incidents, and improve police deployment strategies through data-driven analysis. The study emphasized that forecasting techniques strengthen proactive policing by examining historical crime trends and temporal crime behavior to support operational decision-making and crime prevention initiatives. Similarly, Gu et al. (2021) emphasized that spatial-temporal crime forecasting has become an important component of predictive policing, enabling law enforcement agencies to analyze historical crime patterns and forecast future crime risks using statistical and forecasting models. The study further explained that time-series forecasting models contribute to more effective crime prevention strategies, more effective hotspot identification, and more efficient allocation of police resources through predictive analytics.

- *Forecasting Model Fit Statistics*

As shown in Table 7, the forecasting model fit statistics are used to evaluate the accuracy and reliability of the time-series forecasting models used to predict major index crimes in Region XI. The findings reveal that the forecasting models demonstrated strong predictive performance and acceptable model fit. Specifically, the Stationary R-Squared value of .707 indicates that approximately 70.7% of the variation in the stationary crime data was explained by the forecasting models, suggesting substantial predictive capability in capturing the movement of crime trends over time.

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Table 7 Forecasting Model Fit Statistics

| Statistic | Mean Value |
|---|---|
| Stationary R-Squared | .707 |
| R-Squared | .960 |
| RMSE | 2.059 |
| MAPE | 2.553 |
| MAE | 1.460 |
| Normalized BIC | 1.553 |

Moreover, the R-Squared value of .960 indicates that about 96.0% of the variation in crime incidence was explained by the forecasting models. This indicates a strong model fit and suggests that the forecasting models were highly effective at analyzing and predicting crime patterns in Region XI. The low Root Mean Square Error (RMSE = 2.059), Mean Absolute Percentage Error (MAPE = 2.553), and Mean Absolute Error (MAE = 1.460) further indicate minimal forecasting errors between the predicted and actual crime values. In simpler terms, the forecasted crime incidents closely matched the observed crime data, indicating high predictive accuracy and reliability of the forecasting models. Additionally, the relatively low Normalized Bayesian Information Criterion (BIC = 1.553) suggests that the forecasting models achieved good model fit while maintaining model simplicity and efficiency. Overall, the findings imply that the forecasting models used in the study were statistically reliable and suitable for predictive policing and crime forecasting analysis in Region XI.

The findings are in agreement with Wheeler and Steenbeek (2021), who explained that predictive policing models become more reliable when forecasting models demonstrate high explanatory power and low forecasting errors. The study emphasized that strong forecasting performance allows law enforcement agencies to better identify temporal crime trends, anticipate future crime risks, and improve operational planning through evidence-based policing strategies. Similarly, Mohler et al. (2021) emphasized that accurate forecasting models are essential to predictive policing, as they enhance law enforcement agencies' ability to identify emerging crime patterns and allocate police resources more effectively. The study further noted that forecasting models with high predictive accuracy and low error values contribute significantly to proactive crime prevention and strategic policing operations.

- *Forecasted Crime Incidence in Region XI (2024–2028)*

The forecast results in Table 8 show the time-series forecast of major index crime incidence in Region XI from 2024 to 2028. The findings reveal that major index crimes are generally expected to decline over the five-year forecast period despite slight fluctuations observed in selected crime categories. The total forecasted crime incidence is projected to decrease from 2,682 cases in 2024 to 2,290 cases in 2028, indicating a gradual improvement in peace and order conditions within the region. Theft consistently recorded the highest forecasted crime incidence throughout the forecast period, followed by physical injury and rape, while murder and robbery recorded comparatively lower projected cases.

Table 8 Forecasted Crime Incidence in Region XI (2024–2028)

| Year | Murder | Rape | Physical Injury | Robbery | Theft | Total Forecast |
|---|---|---|---|---|---|---|
| 2024 | 347 | 536 | 654 | 417 | 728 | 2682 |
| 2025 | 355 | 545 | 661 | 425 | 597 | 2583 |
| 2026 | 331 | 514 | 621 | 389 | 632 | 2487 |
| 2027 | 314 | 486 | 593 | 362 | 633 | 2388 |
| 2028 | 296 | 463 | 567 | 341 | 623 | 2290 |

The forecast also shows slight increases in some crime categories in 2025, followed by gradual declines in the succeeding years. Specifically, murder increased from 347 cases in 2024 to 355 cases in 2025, rape from 536 to 545 cases, physical injury from 654 to 661 cases, and robbery from 417 to 425 cases. These temporary increases may indicate the influence of socio-economic conditions, population movement, environmental opportunities, law enforcement operational adjustments, and variations in crime reporting within the region. However, despite these short-term increases, the following years show a sustained decline across all crime categories. By 2028, murder cases are forecasted to decline to 296 cases, rape to 463 cases, physical injury to 567 cases, robbery to 341 cases, and theft to 623 cases.

The findings suggest that crime incidence in Region XI follows identifiable temporal trends that can be forecasted using predictive models and time-series analysis. The observed fluctuations further imply that crime occurrence remains dynamic and influenced by changing social, environmental, and operational factors. Nevertheless, the overall downward trend indicates that predictive policing initiatives, GIS-based hotspot monitoring, intensified anti-criminality campaigns, and evidence-based policing strategies may continue to contribute to the gradual reduction in crime incidence within the region. The results further support the importance of predictive analytics in helping law enforcement agencies improve operational planning, strategic deployment, and proactive crime prevention initiatives.

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The findings align with Dakalbab et al. (2022), who emphasized that predictive analytics and crime forecasting techniques are valuable tools in modern policing, enabling law enforcement agencies to analyze historical crime patterns and forecast future crime risks through statistical and machine-learning approaches. The study explained that forecasting models improve operational efficiency, hotspot identification, and evidence-based crime prevention strategies. Moreover, Walczak (2021) explained that forecasting models and predictive analytics contribute significantly to law enforcement decision-making by identifying spatial and temporal crime patterns using historical crime data. The study further emphasized that predictive crime models enhance proactive policing by enabling police agencies to anticipate potential crime and allocate resources more effectively.

- *Time Series Forecasting Model Fit for Major Index Crimes in Region XI*

As shown in Figure 9 presents the comparison between the observed crime incidence and the fitted values generated by the time-series forecasting models for murder, rape, physical injury, robbery, and theft in Region XI. The red lines represent the actual or observed crime data, while the blue lines represent the fitted values produced by the forecasting models. The figure shows that the fitted lines closely tracked observed crime trends across all five crime categories, indicating that the forecasting models captured the general pattern and direction of crime incidence over time.

A noticeable pattern in the figure is the gradual downward movement of crime incidence across all major index crimes. Although occasional spikes and fluctuations were observed in some periods, the overall trend continued to reflect a decline in crime over time. Theft and physical injury consistently recorded the highest incidence among the crime categories, while murder showed comparatively lower values throughout the observed period. The slight fluctuations in the graphs suggest that crime incidence in Region XI remains influenced by various situational factors, including population movements, economic conditions, law enforcement operations, and environmental factors. Despite these variations, the fitted models remained closely aligned with the actual crime data, suggesting that the forecasting models were reliable in estimating crime trends.

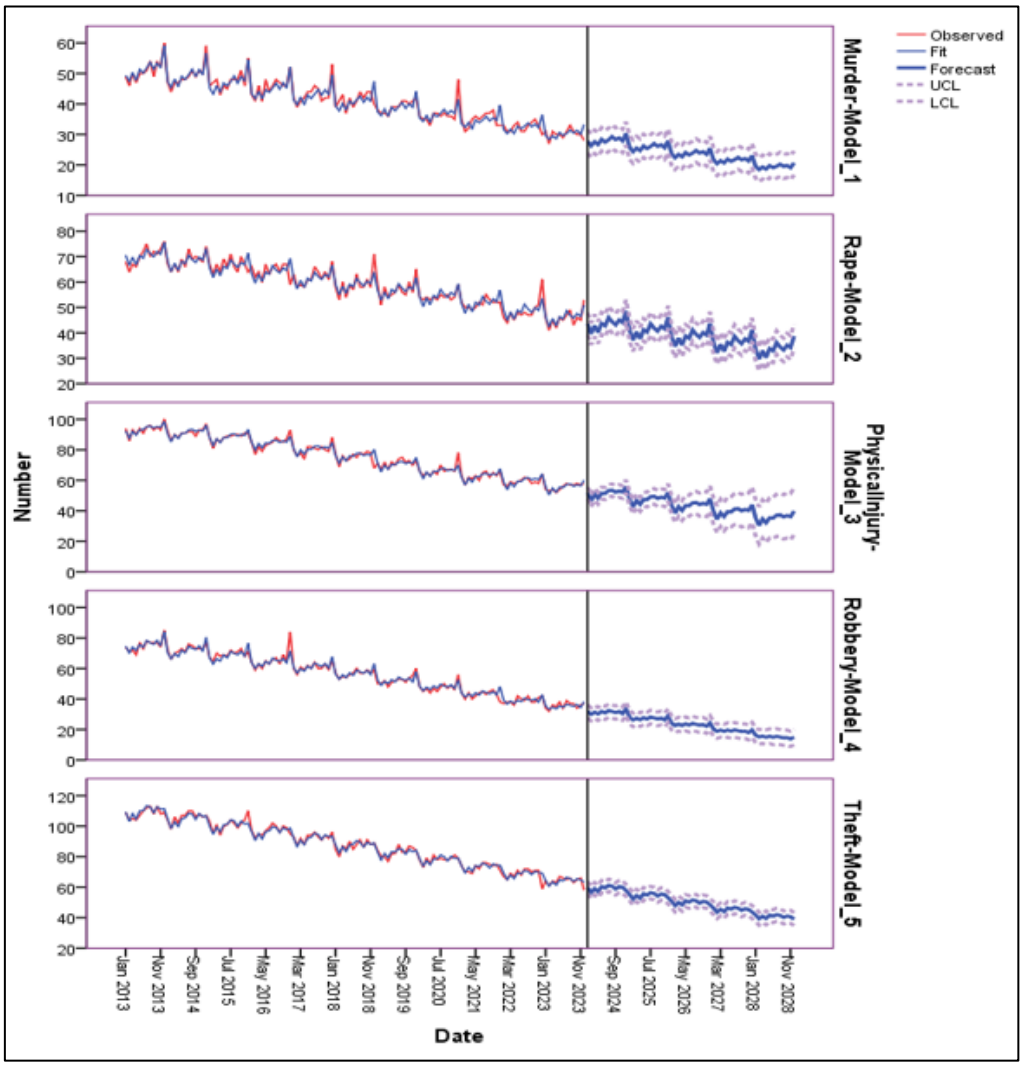


Fig 9 Forecast Trend of Major Index Crimes in Region XI (2013–2028)

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The close relationship between the observed and fitted values further indicates that the forecasting models demonstrated good predictive capability and strong model fit. In simpler terms, the forecasting models estimated crime movement with minimal differences between actual and predicted values. This implies that historical crime patterns in Region XI followed identifiable temporal trends that can be analyzed and forecasted using predictive analytics and time-series modeling. The findings also support the usefulness of predictive policing and GIS-based crime analysis in helping law enforcement agencies improve hotspot monitoring, operational planning, and evidence-based crime prevention strategies.

The findings are consistent with Chand et al. (2021), who explained that crime forecasting models become effective when predicted values closely match actual crime patterns, indicating strong forecasting reliability and improved predictive performance. The study emphasized that predictive analytics helps law enforcement agencies identify temporal crime patterns and enhance proactive policing strategies through data-driven analysis. Similarly, Yu and Chen (2022) stated that time-series forecasting, and predictive crime analysis contribute significantly to modern policing by helping law enforcement agencies anticipate crime fluctuations, identify crime-prone periods, and improve resource allocation strategies. The study further highlighted that forecasting models with strong alignment between observed and predicted values provide more reliable support for operational decision-making and crime prevention planning.

## IV. CONCLUSION, IMPLICATION, AND CONCLUDING REMARKS

Based on the study's findings and conclusions, it is recommended that the Philippine National Police (PNP) institutionalize the implementation of Geographic Information Systems (GIS)-based predictive policing by integrating crime mapping, hotspot analysis, and forecasting models into routine police operations, crime prevention programs, and strategic planning activities. Given that the quantitative findings demonstrated identifiable temporal trends and the spatial concentration of crime incidents in urbanized areas, the adoption of GIS as a standard operational tool may further enhance proactive policing, optimize police deployment, and improve evidence-based decision-making.

Considering that the effectiveness of predictive policing depends largely on the quality of crime data, law enforcement agencies are encouraged to strengthen crime database management by ensuring the accuracy, completeness, timeliness, and reliability of crime reports. Establishing standardized data collection, encoding, validation, and reporting procedures across police stations may improve the quality of predictive analytics, increase the reliability of forecasting models, and support more informed operational decisions.

In response to the qualitative findings highlighting operational and technical limitations, the Philippine National Police should provide continuous capability-building programs and specialized training in GIS applications, spatial analysis, crime mapping, and predictive analytics for police personnel, crime analysts, and operational units. Likewise, investments in modern GIS software, technological infrastructure, and information systems are recommended to maximize the operational benefits of predictive policing and strengthen the technical capacity of law enforcement agencies.

Recognizing that crime patterns are influenced by geographic, environmental, and socio-demographic conditions, local government units are encouraged to collaborate closely with law enforcement agencies in supporting technology-driven crime prevention initiatives through sustainable funding, technological infrastructure, interagency data-sharing mechanisms, and community-based public safety programs. Such collaborative efforts may further improve hotspot intervention strategies and strengthen localized crime prevention initiatives.

Consistent with the study's theoretical and practical implications, policymakers are encouraged to formulate policies, standards, and operational guidelines that promote the ethical, transparent, accountable, and evidence-based implementation of predictive policing technologies. These policies should include safeguards for data privacy, information security, responsible data governance, and mechanisms to minimize algorithmic bias while ensuring that predictive policing remains a decision-support tool rather than a substitute for professional police judgment.

Future researchers are encouraged to expand the present study by integrating machine learning, artificial intelligence, remote sensing, and advanced spatial analytics into predictive policing models to improve forecasting accuracy, hotspot detection, and operational efficiency. Comparative studies involving other regions of the Philippines and longitudinal evaluations of predictive policing implementation are likewise recommended to further validate and refine predictive policing models under different geographic and operational contexts.

Finally, academic institutions offering criminology and public safety programs are encouraged to strengthen interdisciplinary research and instruction by integrating Geographic Information Systems (GIS), data science, environmental criminology, predictive analytics, and intelligence-led policing into their curricula and research initiatives. Such efforts will contribute to developing future law enforcement professionals equipped with the analytical competencies needed to advance evidence-based policing and enhance public safety in the Philippines.

- *Implications for Practice*

The study's findings have important implications for law enforcement practice, particularly for implementing predictive policing and GIS-based crime analysis. The study implies that law enforcement agencies may strengthen crime prevention initiatives by integrating GIS-based hotspot mapping and predictive analytics into routine police

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operations. By using spatial analysis and forecasting models, police agencies can improve patrol deployment, monitor high-risk areas, and implement proactive interventions before crimes occur.

The findings also imply the importance of enhancing data management systems within police agencies. Since predictive policing relies heavily on accurate and reliable crime data, improving crime reporting systems, database integration, and geospatial information management is necessary to strengthen forecasting accuracy and operational effectiveness.

Furthermore, the study highlights the need for continuous capability-building programs among law enforcement personnel. Specialized training in GIS operations, spatial analysis, predictive analytics, and crime forecasting may enhance police personnel's technical competence and maximize the effectiveness of predictive policing initiatives. The findings likewise imply that local government units and policymakers may support GIS-based policing initiatives through technological investments, inter-agency collaboration, and community-based crime prevention programs. Strengthening institutional support for predictive policing may contribute to safer communities, improved police responsiveness, and more efficient public safety management.

➢ *Implications for Future Research*

The study's findings have several implications for future research on predictive policing, crime mapping, and Geographic Information Systems (GIS). Future researchers may replicate the study in other regions of the Philippines to determine whether similar spatial crime patterns and predictive policing outcomes exist across different geographic settings.

Future studies may also incorporate advanced analytical techniques such as machine learning, artificial intelligence, deep learning, and big data analytics to improve the predictive accuracy of crime forecasting models. Integrating more sophisticated computational approaches may further strengthen predictive policing frameworks and contribute to more precise crime prevention strategies.

Moreover, future researchers may examine additional environmental, economic, and socio-demographic variables that may influence the occurrence of crime. Expanding the scope of explanatory factors may provide a deeper understanding of the underlying causes of the spatial concentration of crime and criminal behavior. Future investigations may likewise focus on specific crime categories, longer time-series datasets, or comparative studies between urban and rural settings. Qualitative studies exploring community perceptions, ethical concerns, and public trust regarding predictive policing may also contribute to a more holistic understanding of technology-driven policing systems. Overall, the study serves as a foundation for future criminological and spatial research aimed at improving predictive policing methodologies and strengthening evidence-based law enforcement practices.

## RECOMMENDATIONS

Based on the study's findings and conclusions, it is recommended that the Philippine National Police (PNP) strengthen the institutional implementation of GIS-based predictive policing by integrating crime-mapping and forecasting systems into routine police operations, crime-prevention programs, and strategic planning activities. Police agencies may also improve crime database management by ensuring the accuracy, completeness, and reliability of crime reports, thereby enhancing the effectiveness of predictive analytics and forecasting models. Furthermore, law enforcement agencies may provide ongoing capability-building programs and specialized training in GIS operations, spatial analysis, and predictive analytics for police personnel, crime analysts, and operational units to improve technical competence and maximize the operational use of GIS technologies.

It is further recommended that local government units collaborate closely with law enforcement agencies to support technology-driven crime prevention initiatives by providing funding, developing infrastructure, and supporting community-based public safety programs. Policymakers may also formulate policies and operational guidelines that promote the ethical, transparent, and accountable use of predictive policing systems, while protecting data privacy and minimizing algorithmic bias. Future researchers are encouraged to explore integrating machine learning, artificial intelligence, and advanced spatial analytics into predictive policing to improve forecasting accuracy and operational efficiency. Likewise, academic institutions may strengthen interdisciplinary criminological research by integrating GIS, data science, environmental criminology, and predictive analytics to further advance evidence-based policing and public safety research in the Philippines.

➢ *Concluding Remarks*

The completion of this study enabled the researcher to realize the growing importance of integrating technology, data analytics, and human experience in modern policing and crime prevention. The findings demonstrated that crime analysis is no longer limited to traditional reactive policing but has evolved into a proactive and evidence-based approach supported by predictive analytics and Geographic Information Systems (GIS).

The study further highlighted that effective crime prevention requires not only statistical forecasting and technological innovation but also the operational insights, experiences, and commitment of law enforcement practitioners. By integrating quantitative and qualitative findings, the researcher gained a deeper understanding of how spatial analysis, crime forecasting, and practitioner-based knowledge collectively contribute to safer communities and more responsive policing systems.

Ultimately, the study reinforced the importance of balancing technological advancement with ethical responsibility, operational readiness, and community-centered policing. It is hoped that the findings of this research

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may contribute to strengthening predictive policing initiatives, improving public safety, and advancing criminological research and practice in the Philippines and beyond.

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