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HealthSentry: Design and Development of Municipal Health Condition Monitoring Using Spatio-Temporal Analysis and Geo-Mapping

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RESEARCH ARTICLE INFORMATION

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ABSTRACT

To prevent the spread of communicable illnesses and improve general health conditions, it is essential to have a better understanding of the health status of the community. Using historical data from the Rural Health Unit, this project aimed to develop a mechanism for anticipating health concerns. By predicting health concerns, decision-makers may develop better plans and tactics to prevent unhealthy circumstances. This endeavor used data-driven methodology and machine learning and deep learning approaches to improve monitoring accuracy. Graph neural networks (GNNs) were used in this research to handle graph-based forms, which are more ideal for predicting health concerns than convolutional neural networks (CNN), and were previously used to represent the city as a grid. The main goal was to provide a system that is simple to deploy and that provides a framework for future enhancements to track municipality natality, mortality, and morbidity rates. Using spatiotemporal analysis and geospatial mapping, the Municipal Health Condition Monitoring and Forecasting System was developed to monitor and manage the health status of the municipality's residents. The Rapid Application Development (RAD) technique was used to design and create the system. HTML, CSS, Javascript, and Node.js were used in the system's development for the user interface, whereas Phyton 3, TensorFlow, Keras, NumPy, and Pandas were utilized for data analysis. The technology may be used by decision-makers to keep track of geographic and temporal links, which are crucial for predicting health conditions and helping them take preemptive action to halt the spread of illnesses. Overall, this study is a valuable resource for those who want to build the same kind of study concept. Above all, this study could assist policymakers and medical experts in monitoring and anticipating rural health difficulties once they are implemented in their municipality.

Keywords: *decision support system, natality, mortality, mobility, spatio-temporal, geo-mapping*

Introduction

Health services and programs offered by the Rural Health Unit (RHU) are among the most important projects provided by the Philippine government to have standard healthcare for everyone (Aytona et al., 2022). Better awareness of the health conditions of people who live in an area is crucial for disease prevention and occurrence due to the area's rapid population expansion and the potential spread of communicable illnesses (Connolly et.al, 2021). The chance of illnesses in every household decreases with the help of the Rural Health Unit as it exercises its role to provide general consultations, dental services, maternal health, family planning, nutrition, immunization, examinations, health promotion/education, environmental sanitation services, communicable/noncommunicable disease control, and community-based rehabilitation services in the municipality (Labrague et al., 2019). However, to be able to intervene in the spread of diseases and to solve other health-related problems before they become huge and cost a lot of money (Abdel-All, 2019), a tool for forecasting the health conditions in every barangay based on the necessary historical data that the Rural Health Unit (RHU) have will greatly help the decision makers formulate a better plan and strategies to prevent poor health conditions (Currie et al., 2020).

Graph neural networks (GNNs) have emerged as the cutting edge of deep learning research in recent years, demonstrating cutting-edge performance in a variety of applications (Jiang & Luo, 2022). Spatiotemporal Graph Neural Networks (STGNN), also known as GNNs with spatiotemporal dimensions, are simple GNNs that can handle graphs that vary over time (Wu et al., 2020). Due to its capacity to capture both spatial and temporal dependency which are represented using non-Euclidean graph structures, this is particularly well-suited for problems involving the monitoring of health conditions. Several GNN-based models had been shown to perform better than earlier methods on tasks like traffic systems and social networks when given graphs as the input (Brimos et al., 2023).

This research focused on the terms natality which refers to birth rates, mortality which refers to death rates, and morbidity which refers to disease rates (Center for Disease Control and Prevention, 2020) to assess the citizens' health situation in the municipality. Thus, based on the problem and technology stated above, the researcher came up with developing a system that could be used to manage and monitor health conditions of the residents in Jones, Isabela. With the said system, the study specifically aimed to design and develop a system that could monitor municipality health conditions with the application of spatio-temporal analysis.

Methods

This research used the research development type, which is the systematic analysis of the design, development, and evaluation of educational programs, processes, and products that must meet internal quality and efficiency criteria. Developmental research is particularly significant in the area of instructional technology (Ritchie, 1994).

Rapid Application Development (RAD) was the method used by the researchers. It is a method of software development technique that prioritizes rapid prototyping over thorough preparation. Writing the program itself and using RAD to prepare for software development went hand in hand (Rouse,2016).

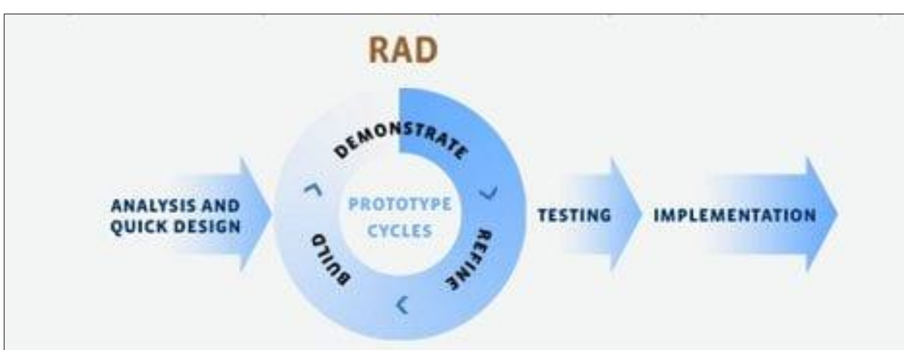

Figure 1. *Rapid Application Development*

To provide the municipality with a graphical representation of morbidity, mortality, and natality, the system also used GIS technology. The reports' data helped conduct the geographic data analysis. The study also used the location mentioned in the reports to plot the data's location coordinates on a map. The Municipal District Unit would have a visualization of natality, mortality, and morbidity.

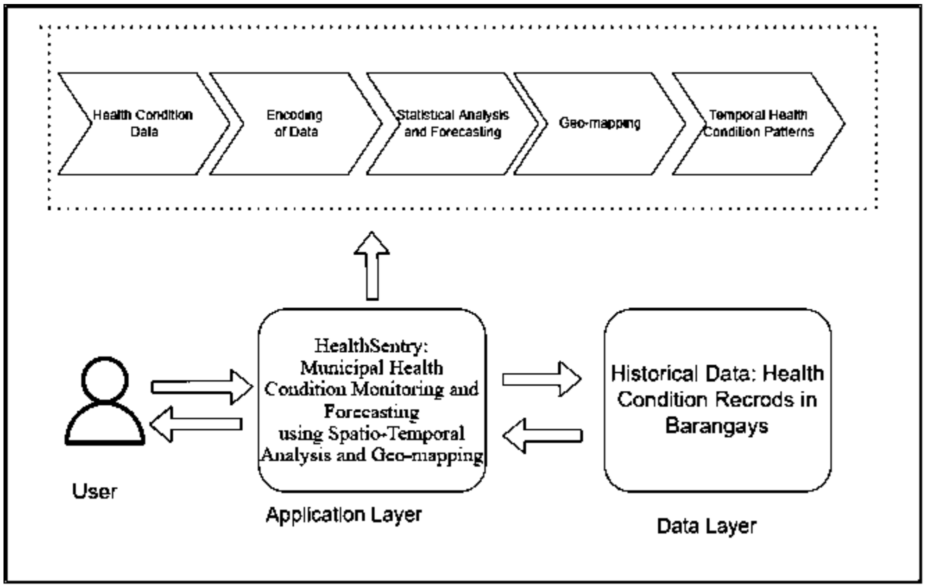

Figure 2. *Project Framework*

Technologies Used

Hypertext Markup Language (HTML): The preferred markup language for documents intended to be viewed in a web browser is HTML, often known as hypertext markup language (Krause, 2016). The system's presentation layer was built using HTML.

To offer a better visual representation of the system, CSS (Cascading Style Sheet) was used (Wilson et al., 2022). This aids in improving user interface (UI) design.

Cascading Style Sheet (CSS): Along with HTML and CSS, the programming language JavaScript is one of the foundational elements of the World Wide Web (Edler & Vetter, 2019). JavaScript gives the system features. The technology used for the application layer was the issue.

Node.jsl: JavaScript can be used by developers to create command-line tools and server-side scripts, which construct dynamic web page content before the page is transmitted to the user's web browser (Herron, 2020). Node.js facilitates communication between the application and data layer.

Python 3: High-level, interpreted Python 3 is a general-purpose programming language (Saabith, 2019). This project makes use of this programming language as a starting point for the creation of a machine-learning model and the provision of statistical evaluations of the obtained historical data.

TensorFlow: It is a free and open-source software library for machine learning and artificial intelligence (Ramchandani, 2022). The researchers utilized TensorFlow library to create the model for spatiotemporal analysis.

Keras: Artificial neural networks can be accessed using Python with the open-source software library Keras (Hung, 2020). The TensorFlow library has a Keras interface. For modeling, the system used Keras which is a part of TensorFlow.

NumPy: Large, multi-dimensional arrays and matrices are supported by NumPy, a library for the Python programming language, coupled with a substantial number of high-level mathematical operations that may be performed on these arrays (Park et al., 2020). To modify and perform calculations on the collected numerical data, NumPy was employed.

Pandas: To manipulate and analyze data, the Python programming language has a software package called Pandas (Lemenkova, 2019). Data was collected, cleaned, and then processed using the Pandas library to produce a training and test dataset.

System Testing Method

The researchers' approach to software testing was unit testing. It entails testing each class, component of software, or module's distinctive approaches and functionalities. An automated continuous integration server may run unit tests very quickly and inexpensively (Zhao, 2019).

Ethical Considerations

Informed permission, data accuracy, and data privacy were all guaranteed by the rigorous ethical guidelines the researchers followed. To safeguard the respondents' identity, personal identifiers were anonymous. Throughout the study, the goal was to promote fairness, transparency, openness, and ethical technology usage while also benefitting the community without establishing harm

Results and Discussion

To design and develop HealthSentry, the municipal health condition monitoring and forecasting was done using spatio-temporal analysis and geo-mapping. The system collected residents' information using the profile information form as shown in Figures 4 and 5. This form served as a tool to collect data and store it in the database to generate useful information. Upon collection of data, the system had another functionality of using a heat map to identify the barangay. The color of the map changed depending on the average rate or status in the area. The status was divided into low, medium, high, and critical conditions which could be used in decision-making on what will be their action for the area or the entire barangay. Another feature of the system being developed is the statistical analysis which shows the consolidated rate of natality, mortality, and mobility in the municipality. This feature provides a clear understanding of the rural health unit officials and staff of the current situation of rate which is a big help for faster and easier decision-making.

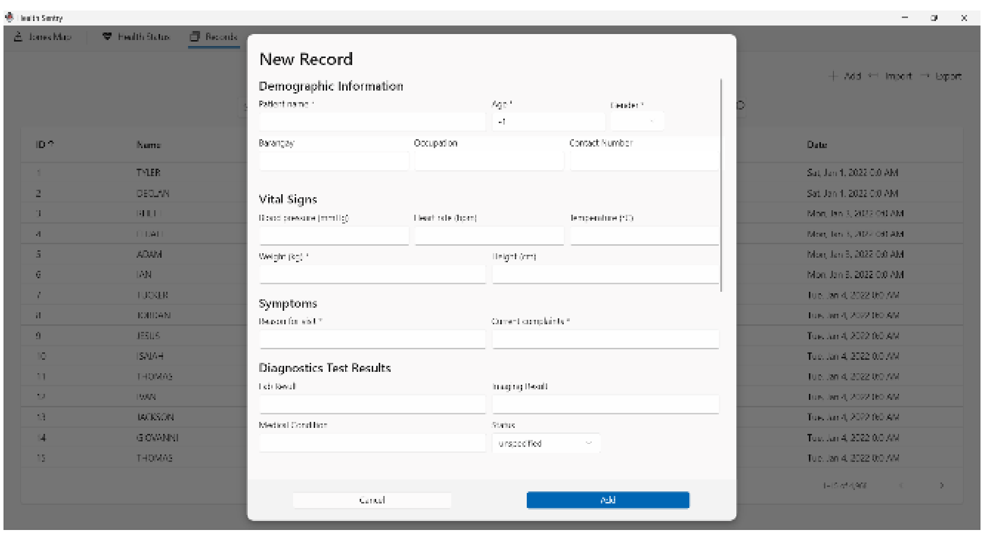

Figure 4. *Managing Residents' Profile*

Figure 4 shows the management of residents' profiles where users would be able to add new records using a form.

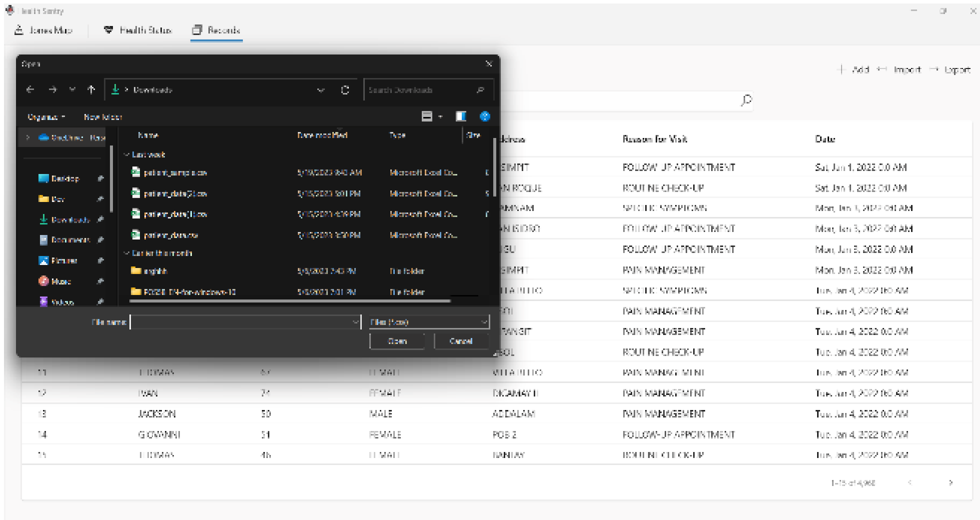

Figure 5. *Importing Residents' Records*

Figure 5 shows the feature of the system where the user can import records from a csv file containing the residents' profiles to easily store files.

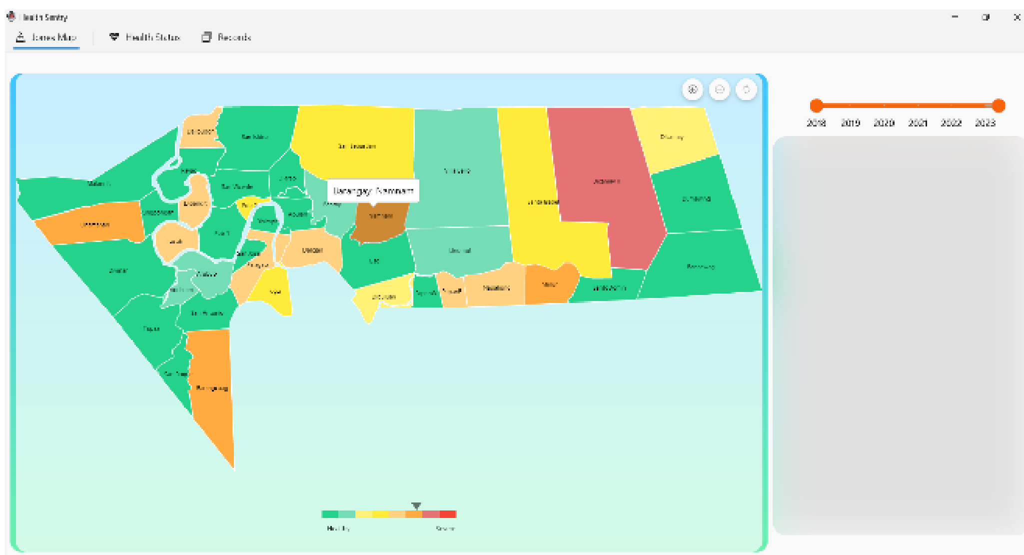

Figure 6. *Health Heatmap*

The creation of a heatmap is a vital element included in the developed HealthSentry system that is essential for portraying the health status of various areas within the municipality visually. Municipal health authorities can assess and analyze the general state of health in various barangays using this heatmap as a powerful tool. The heatmap capability makes use of the residents' data that has been gathered, including their health-related data that is kept in the system's database. The information covers a range of subjects, including disease prevalence, mortality rates, natality rates, and mobility trends. The technique uses the average levels or conditions of health-related variables in each barangay to produce the heatmap. The indicators fall into various levels, including low, medium, high, and critical situations. The municipality's overall health condition may be easily visualized and interpreted because each level is given a unique color. Municipal health officials can easily locate regions that need immediate attention or intervention by evaluating the heatmap. For instance, if a certain barangay is highlighted in a hue that denotes a critical state, it means that there is an urgent need for treatment for a serious health issue there. Conversely, regions with lower color intensity levels indicate better health. Municipal health authorities can make data-driven decisions with the help of HealthSentry's heatmap feature. Based on the determined health state of each barangay, they can prioritize resource allocation, deploy healthcare personnel, and implement preventive measures. It also enables the tracking of health trends over time, revealing regions in need of long-term interventions or focused health campaigns. Municipal health authorities are empowered by the heatmap feature of HealthSentry, which provides a potent visual picture of the municipality's health state. By utilizing this capability, decision-makers may effectively allocate resources, prioritize interventions, and address the various health needs across various barangays.

The necessary mapping features for rendering the heatmap on the system's user interface are provided by the integration of the syncfusion_flutter_maps library. This library has a wide range of options for showing the heatmap overlay on the map of the municipality and viewing geographic data. The system's general functioning is significantly improved by the heatmap feature, which also helps to provide a thorough picture of the municipal health landscape.

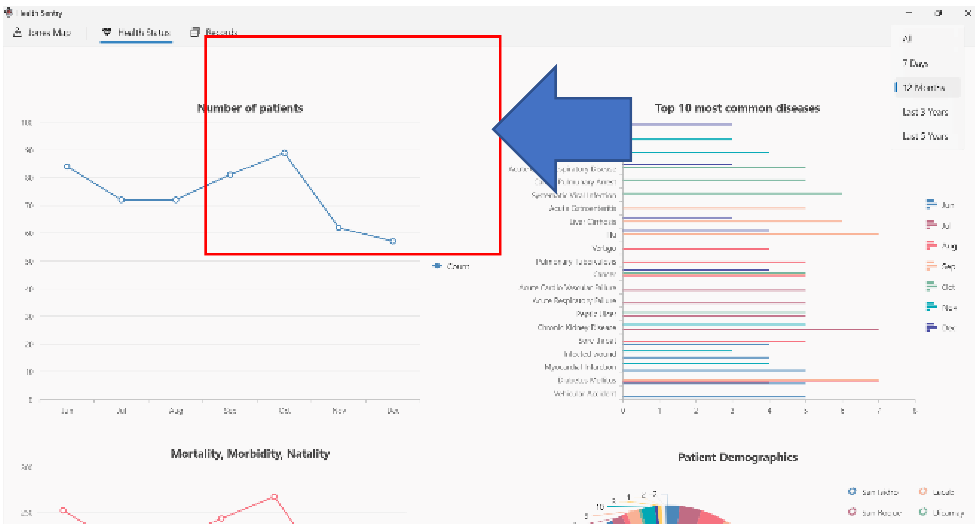

Figure 7. *Statistical Analysis of the Number of Patients on a Monthly Basis*

Using a line graph, the HealthSentry system's function offers a statistical analysis of the number of patients on a monthly basis. By gathering and storing pertinent information from locals, such as patient demographics and medical records, the system is equipped to generate in-depth statistical reports that highlight the monthly distribution of patients. This feature enables health authorities to gain comprehensive insights into the patient load and identify trends and patterns in healthcare utilization over time. The line graph provides a clear and intuitive visualization of the patient data, displaying the monthly patient counts on the vertical axis and the corresponding months on the horizontal axis. The line graph effectively visualizes the fluctuations in patient numbers, allowing health authorities to observe variations and trends in healthcare utilization across different months. Health officials may quickly comprehend the monthly fluctuations in healthcare demand as well as the overall patient load by looking at the graphical representation. By looking at the line graph, they can spot seasonal variations, peak times, and prospective trends in patient visits. This data is essential for resource allocation, capacity planning, and ensuring the best healthcare services are offered during times of high demand. Additionally, it aids in locating potential stumbling blocks or places that might need more assistance.

The line graph form of the statistical analysis feature enables health authorities to make data-driven decisions based on a thorough understanding of healthcare consumption patterns. The overall quality of healthcare delivery and patient experience are ultimately improved. It facilitates evidence-based planning, resource allocation, and service enhancements. HealthSentry's statistical analysis feature, displayed as a line graph, offers helpful insights into the number of patients on a monthly basis. By utilizing this feature, health authorities can track trends, patterns, and variations in how people use healthcare over time, allowing them to make well-informed decisions, optimize their use of resources, and create plans that are practical for the ever-changing needs of patient care.

By enabling the creation of interactive line graphs, the syncfusion_flutter_charts library integration improves the statistical analysis capability. This library provides a variety of charting options, including the ability to alter the line graph's look, feel, and interactivity. The line graph is now a useful tool for displaying and analyzing the monthly patient data as a result of this integration.

Figure 7. *Statistical Analysis of the Common Diseases*

The HealthSentry system has an effective function that uses an educational bar graph to display the most prevalent illnesses in the municipality. Health authorities can identify and rank the diseases based on their prevalence and influence on public health using this function. The system is able to produce thorough statistical reports that highlight the frequency and prevalence of various ailments by gathering and preserving pertinent data from inhabitants, including their medical records and disease diagnoses. Each ailment is displayed as a separate bar on the bar graph format, which effectively visualized the data. Health authorities may immediately recognize and comprehend the most prevalent diseases impacting the community since the height of each bar correlates with the frequency or prevalence of each condition. Health professionals can learn more about the disorders that provide the highest health hazards and need specialized attention by looking at the bar graph. They can use the information to set priorities for resource distribution, create focused interventions, and put preventative measures in place for the most prevalent diseases in the municipality. By enabling the creation of interactive and customizable bar graphs, the syncfusion_flutter_charts library integration improves the feature. The library's numerous formatting, stylistic, and interactive options let health authorities customize the representation to suit their own requirements. A useful tool for assessing and visualizing the most prevalent diseases in the municipality is the resulting bar graph. Health authorities can use the statistical analysis function to make data-driven decisions for public health planning, resource allocation, and illness management. It displays the most prevalent diseases in bar graph form. To successfully address the population's health requirements, they can concentrate their efforts on focused interventions, public health initiatives, and healthcare services by identifying the diseases with the highest prevalence.

The HealthSentry feature that uses a bar graph to display the most prevalent diseases gives useful information on the incidence and effects of diseases in the municipality. In order to control and prevent the most prevalent diseases, health authorities can use this feature to prioritize their efforts, distribute resources wisely, and execute focused initiatives. The bar graph visualization supports evidence-based decision-making for better public health outcomes and improves data interpretation.

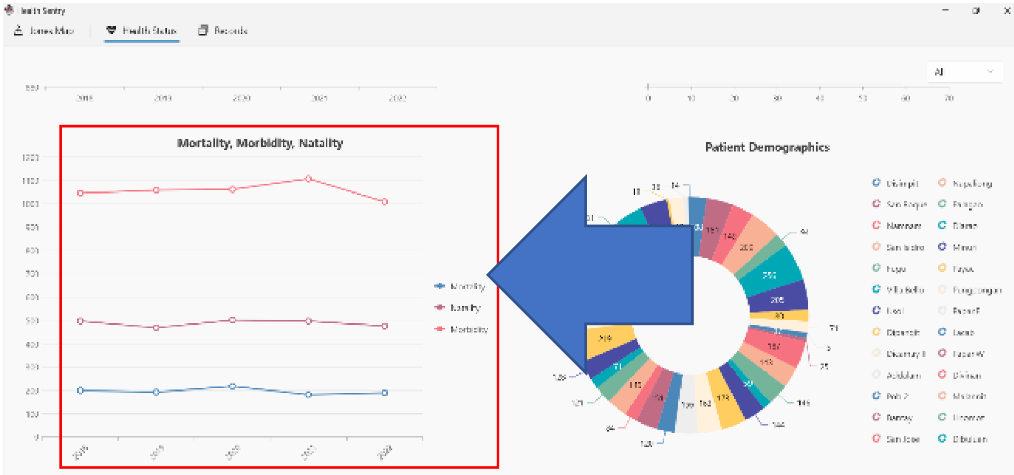

Figure 8. *Statistical Report of Mortality, Morbidity, and Natality*

The HealthSentry system included a thorough statistics report feature that compares the rates of death, illness, and natality in the municipality using a line graph. The health authorities were able to comprehend and keep track of the dynamics of these important indicators which offer insightful information about the population's health patterns. The system created statistical reports that indicate the trends and changes in mortality, morbidity, and natality rates over time by gathering and analyzing pertinent data, such as mortality records, disease prevalence, and birth rates. Each indicator is displayed as a separate line on the line graph representation, which effectively visualizes the data. The vertical axis of the graph shows the rates of death, sickness, and natality, and the horizontal axis shows the corresponding period. Health authorities can compare and contrast the trends and patterns of various variables using graphical representation. Health officials can spot correlations, oscillations, and probable connections between mortality, morbidity, and natality rates by looking at the line graph. They can determine whether changes in one indicator were accompanied by changes in others, offering information on the general health status and demographics of the community. Health authorities can use the statistics report function to make data-driven decisions for public health planning, resource allocation, and policy creation. It displays mortality, morbidity, and natality rates as line graphs. They can pinpoint problem regions, evaluate the success of interventions, and create focused strategies to enhance population health by comparing the trends of various indicators.

This HealthSentry statistical report feature compared mortality, illness, and natality rates using a line graph and offered important insights into the dynamics of population health. Health authorities can use this tool to track trends, find connections, and make educated decisions to handle the unique health requirements of the municipality. The line graph visualization supports evidence-based decision-making for better public health outcomes and improves data interpretation.

Figure 8. *Statistical Report of Mortality, Morbidity, and Natality*

An insightful element of the HealthSentry system presents statistics data on patient demographics by barangay within the municipality using an eye-catching pie chart. Health authorities can use this function to comprehend how patients are distributed among various barangays and learn more about the demographics of the patient population. The system is able to produce thorough statistical reports that emphasize the patient distribution per barangay by gathering and storing pertinent data from residents, including their demographic information like age, gender, and domicile barangay. The data is efficiently visualized using a pie chart, where each barangay is represented by a different piece of the pie. The proportion of patients from each barangay is represented by the size of each section, giving a clear visual picture of the distribution of patients among the various locations. Health professionals can quickly identify the barangays with larger patient densities and comprehend the demographic makeup of each location by looking at the pie chart. This data aids in resource allocation, targeted healthcare interventions, and planning for each barangay's unique healthcare requirements. Health authorities are given the ability to make data-driven decisions for resource allocation, healthcare planning, and targeted treatments because of the statistical presentation tool, which shows the demographics of patients broken down by barangay in pie charts. They can more effectively meet the unique healthcare needs of various communities and offer healthcare services that are specifically customized to those needs by analyzing the patient distribution and demographic features within each barangay.

A pie chart used by HealthSentry's statistics presentation function to show patient demographics broken down by barangay provides important details about the distribution and makeup of the patient population. Health authorities can effectively allocate resources, organize targeted interventions, and deliver healthcare services that are adapted to the particular requirements of each barangay by utilizing this capability. The pie chart visualization helps evidence-based decision-making for better healthcare service within the municipality and improves data comprehension.

Figure 9. *Statistical Report of Age Distribution*

The statistics display function of HealthSentry uses a pie chart to show patient demographics split down by barangay, giving important details about the distribution and makeup of the patient population. Health authorities can efficiently allocate resources, design targeted treatments, and deliver healthcare services that are tailored to the particular needs of each barangay by employing this competence. The pie chart representation aids in data comprehension and decision-making for improved municipal healthcare. The bar graph layout of the data efficiently visualizes each age group as a separate bar. The length of each bar indicates the number or proportion of individuals who belong to a certain age group, providing a clear visual representation of the population's age distribution. By examining the bar graph, health professionals may rapidly determine the most prevalent age groups and understand the population's overall age distribution. To fulfill the specific healthcare needs of different age groups, this information is crucial for resource allocation, healthcare planning, and the development of focused therapies. The statistics report function allows health authorities to plan for public health, allocate resources, and provide healthcare using data-driven judgments. It shows the distribution of ages in a bar graph. By examining the age demographics of the population, they may identify age-specific health problems, carry out targeted treatments, and allocate resources effectively to satisfy the unique needs of different age groups.

Understanding the age distribution of the population may be done with the aid of the HealthSentry statistics report function, which shows the distribution of ages in a bar graph. This capability may be used by health authorities to efficiently manage resources, organize focused efforts, and provide healthcare services that are specifically catered to the needs of different age groups. The municipality may utilize the bar graph presentation to better understand the data and make evidence-based decisions for better public health outcomes.

Figure 9. *Statistical Report of Medication Usage*

The HealthSentry system has a statistics report tool that displays medication usage in a useful 2-D bar graph. By enabling health officials to identify patterns and trends in the municipality's use of specific medications like aspirin, paracetamol, ibuprofen, and antibiotics, this function provides crucial insights into the healthcare practices and pharmaceutical needs of the local community. The system collects and analyzes relevant data, such as medication records, prescription information, and patient profiles to provide statistical reports that highlight the use of these specific drugs. The graph's use of different bars to represent each drug (aspirin, paracetamol, ibuprofen, and antibiotics) effectively visualizes the data. The length and breadth of each bar, which are correlated with the frequency or volume of medicine usage, give a clear visual picture of the relative consumption levels of these specific drugs. By examining the 2-D bar graph, health personnel may immediately ascertain the patterns of medication consumption for aspirin, paracetamol, ibuprofen, and antibiotics. Health authorities can use the statistical report function to make data-driven decisions for aspirin, paracetamol, ibuprofen, and antibiotic medication management, resource allocation, and healthcare planning. They are able to see how these drugs are used differently and understand the specific roles they play in treating the population's common health issues. A 2-D bar graph showing drug use is another element of this function. By examining patterns and trends on how these specific prescriptions are used, they can keep track of adherence to treatment regimens, identify potential issues like overuse or underuse, and ensure that the correct drugs are accessible to meet the population's healthcare requirements.

Furthermore, the statistics report function of HealthSentry also uses a 2-D bar graph to show medicine consumption for particular drugs like aspirin, paracetamol, ibuprofen, and antibiotics. This tool offers helpful insights into the municipality's medication trends and requirements. Health authorities may efficiently manage resources, monitor drug efficacy, and guarantee the supply of suitable pharmaceuticals to satisfy the population's healthcare requirements by utilizing this function. The 2-D bar graph display aids evidence-based decision-making for better healthcare service within the municipality and improves data comprehension.

Table 1. Library Used of the Study

Library	Description
syncfusion_flutter_maps (version 21.2.3)	mapping features
syncfusion_flutter_charts (version 21.2.3)	charting components
syncfusion_flutter_sliders (version 21.2.5)	select specific temporal intervals
Objectbox (version 2.0.0)	data storage
flutter_riverpod (version 2.3.6)	States management
fluent_ui library (version 4.6.1)	Interface design
csv library (version 5.0.2)	Processing csv file
window_manager library (version 0.3.0)	opening and closing of windows
file_picker library (version 5.3.0)	enabled the selection of files from storage

The use of the libraries listed above was made possible by the mapping functionality offered by syncfusion_flutter_maps (version 21.2.3), which allowed for the viewing and interaction of geographic data. Syncfusion_flutter_charts (version 21.2.3), which provides a full range of charting components, was used for data analysis and visualization. The syncfusion_flutter_sliders library (version 21.2.5) was used to enable range-based filtering, allowing users to choose particular temporal intervals. On the other hand, the objectbox library (version 2.0.0) was used to manage the application's database requirements, offering effective and dependable data-storing capabilities. Flutter_riverpod (version 2.3.6) was used to streamline state management and provide smooth control and exchange of application states across many displays. The researchers used the fluent_ui package (version 4.6.1) to create a user interface that is easy to use and pleasant to the eye. The csv library (version 5.0.2) was used to parse and analyze CSV files, allowing for the easy integration of external data sources. The window_manager library (version 0.3.0) made it easier to open and close windows, which improved the functioning of the program. To provide effective data entry, the file_picker library (version 5.3.0) made it possible to choose files from storage. The study was able to create a spatio-temporal application with geotagging capabilities by utilizing these libraries, giving clienteles a more beneficial and thorough user experience.

Conclusion and Future Works

HealthSentry system is a complete and effective instrument for tracking and forecasting municipal health conditions. To help in decision-making and resource allocation, it combined a number of features and functions that enable data collection, analysis, and display. The system used spatio-temporal analysis and geo-mapping methods to provide users with a comprehensive view of the municipality's health landscape.

The creation of a heatmap, which graphically depicted the health condition of various places within the municipality, was one of HealthSentry's primary features. The heatmap used information gathered from locals, such as their health-related data, and used different colors to represent the average rates or statuses in each barangay. The ability to swiftly identify regions with low, medium, high, or critical health conditions helped local health authorities to make data-driven decisions and target actions.

Additionally, the system had tools for statistical analysis that provide light on the combined rates of natality, mortality, and mobility within the municipality. In order to illustrate trends and patterns in healthcare consumption, prevalent diseases, patient demographics, age distribution, and medication use, these features use data from residents to create line graphs and bar graphs. Health authorities may make informed decisions for public health planning, resource allocation, and policy creation because of the visual representations that help them comprehend the dynamics of these important indicators, pinpoint problem regions, and indicate areas of concern.

To improve its mapping, charting, and data visualization capabilities, HealthSentry incorporated libraries like syncfusion_flutter_maps, syncfusion_flutter_charts, and syncfusion_flutter_sliders. These libraries offered a wide range of rendering options for heatmaps, line graphs, bar graphs, and interactive charts, enhancing the system's overall usefulness and usability.

In conclusion, HealthSentry is a useful tool for municipal health authorities to track and project local health situations. The system empowers decision-makers with actionable insights, supports data-driven decision-making, and supports effective resource allocation and targeted interventions to address the various health needs across various areas by utilizing spatio-temporal analysis, geo-mapping, and statistical analysis.

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