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The development of the Geographical Information System (GIS)-based Mapping of Infectious Diseases using Spatial Data Analysis

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ABSTRACT

The study provides real-time surveillance and consolidation of reported cases of infectious diseases from the different health agencies down to the barangay level. A Web-based Decision Support System with Android Mobile Support, Mapping and Short Message Service (SMS) was developed and used. The system intended to assist the health authorities' in making a decision in resolving problems related to infectious diseases.

The system contains functionality such as mapping the diseases using Spatial Data Analysis, Graphical and Tabular Analysis in monitoring real-time disease data. It also contains mobile support using an Android Application to connect users using mobile devices. Short Message Service (SMS) for notification of the possible disease outbreak in a specific location. The system also generates reports with comparative analysis of the top 10 affected areas per province, municipality and barangay levels. In developing the project, the Rapid Application Development (RAD) model was used. The system was evaluated using ISO 25010 Software Quality Standard instrument by the Information Technology (IT) Experts in the academe and the end-users. In analyzing the result of the survey the researcher used Frequency Distribution, Weighted Mean, and Independent Sample T-test.

The developed system was used as a decision-support system that facilitated health authorities to gather information and solving problems and decisions making related to prevention, control, and eradication of Infectious Diseases. The developed system has a strong potential to do Spatial Mapping and surveillance of infectious diseases. It can greatly constitute the solution to addressing the spread of infectious diseases in the community.

Key words: Android Application, GIS, Infectious Diseases, Mapping, Mobile Support, Spatial Data, SMS

1. INTRODUCTION

Geographical Information System (GIS) is an effective tool in mapping geographical distributions of the manifestations of infectious diseases and how the disease was transmitted, and the graphical representation of infectious disease occurrences [1], [2], [3], [4]. More, the Geographical Information System was used for mapping infectious diseases and to monitor the environment in order to mitigate the spread of infectious diseases and improve the delivery of health services [5].

According to Philippine Integrated Disease Surveillance and Response (PIDSR) [6], to ensure the enhancement of coverage of reporting, there must be an institutionalized community -based surveillance technique that must be used. Health agencies are urged to report cases or events seen or detected from clinics, airports, ports, hospitals, and other health facilities should be reported. In this approach, the sources of reports shall be coming from the Disease Reporting Units (DRU). However, it is difficult to determine the outbreak of the disease in a specific area due to untimely generation reports from the different levels of concerned agencies. Awareness, prevention, and control served as a bigger challenge for the different health agencies.

The legal basis of this study is the Republic Act 3573 otherwise known as the "Law on Reporting of Communicable Diseases". As mandated by this law, all persons and health agencies must report occurrences of infectious diseases to Municipal, City, Provincial, Regional, and National health agencies. The development of GIS-based Mapping of Infectious Diseases using Spatial Data Analysis is instrumental to address the existing problems of the health agencies.

The purpose of this research is to design and develop a Geographical Information System (GIS) Mapping of infectious Diseases. In this study, the GIS used as a repository of data of patients diagnosed with infectious diseases from the different health agencies in the region. The information from the different health agencies was consolidated from the Municipalities, Cities, Provinces, and Region. The data from different sources were stored to the GIS database for analysis, evaluation, and interpretation to determine the type of infectious diseases, the time the infectious diseases were detected, the geographic location of the disease and the person infected with the disease. Spatial Analysis was used in analyzing those data from GIS. The GIS system is providing health information available for the public through the Internet. The public can also view this information using Google Maps API as a graphical interface. [7].

Moreover, the system provides a web-interface that allows the health agencies to collect and consolidate real-time data in the Municipal/City, Province, and Regional levels. The system also generates reports for monitoring real-time data from local to national levels. The data after consolidation provides the mapping of the areas where diseases are prevalent using spatial data analysis. When the level of outbreak is reached the system automatically sends alert to the different agencies involved. The community where the diseases are prevalent also receives alert through short messages (SMS).

1.1 Geographical Information System (GIS)

GIS is computer software used for recording data, location mapping, modifying, data retrieval, organized enquiring, and analyzing the occurrences and the difference of various incidence including infectious diseases and non-infectious diseases across the globe with reference to various time periods. The Geographical Information System facilitated the mapping of infectious diseases necessary to identify the location of the disease and the infected person, transmission of the disease, and the type of the disease.

The Geographical Information System was traditionally used in modifying and mapping infectious diseases. It was also used for disease surveillance and mapping the transmission and location of the disease. GIS became an effective tool for disease investigation, disease mapping, monitoring of health conditions, organized surveying, and disease mitigation program.

The predominance of infectious diseases can also be mapped using GIS including environmental occurrences of disease, mode of diffusion, and the spatial modeling of environmental aspects of disease occurrence [8], [1], [9], [10]. The GIS was also used for spatial analysis, spatial modeling, sequential analysis, and cause and effect analysis. It was also used in monitoring programs related to disease control, studying and mapping replacement information related to disease transmission, and disease surveillance.

1.2 Concepts of Epidemiology

Epidemiology focuses on the regularity and design of health events in a population. Geographical Location patterns dealt with environmental disparity, municipal or city differences, and location of work or health facility. Epidemiology also fucoses on demographic characteristics in relation to age, sex, marital status, and socio-economic status, as well as behaviors and environmental conditions. The data in the epidemiology were based on time elements, place or location, and person or patient. This is also called Triad Principles of Epidemiology, which are considered as activities in descriptive epidemiology. Epidemiology is also used to determine the causes and factors that influence the presence of disease and other events related to health. To determine these factors and causes, epidemiologist utilized logical epidemiology or epidemiologic studies to answer the questions "Why" and "How".

The concepts of Epidemiology specifically the Triad - Time, Place and Person are used in mapping infectious diseases. This is done based on the systematic collection and evaluation of mortality reports and other related information. There are several tasks involved in epidemiology public health surveillance, field investigation, analytics studies, evaluation, and linkages. Presently, another task was included which is policy development [11].

1.3 Geospatial technologies for infectious disease surveillance

Geospatial technology maps are used to show the distribution of infectious diseases of a population and the health condition and allow health authorities to interconnect about the spreading of infectious disease, disease regulation, and retrieval effort. The Geographic Information System (GIS) is an essential tool in illustrating the nature of exposure from infectious diseases by doing reconnaissance along with environmental and population demographic data. Geographical Information System can also be utilized to show differences in access to health care by calculating the average distance traveled by an infected person that was presented in clinics where the patient was detected with infectious disease. The health authorities shall be able to determine the cause of infection or whether it is class, ethnic, or racial lines [12]. GIS can be used to spatially determine through analysis of health data and identify deficiencies geographically [13].

The ability of GIS in terms of scalability and analytics responds well to the need for municipal, city, provincial, regional, and international infectious disease surveillance and control. Static and dynamic maps from GIS can be a useful tool for monitoring and surveillance for municipal, city, provincial, regional and international health agencies, access to services, and disease database pathways. This can eradicate problems pertaining to the outbreak and mitigating the effects of infectious diseases. It provides a common operating picture for authorities to effectively respond to health emergencies.

With the continuous developments of web application tools, health authorities can improve disease surveillance across the different levels of geographic locations. Web-based GIS assists the different levels of health organizations access relevant information with respect to infectious diseases. This information allows health agencies to exchange ideas and knowledge and enable them to create policies and guidelines that empower policymakers to eliminate differences in basic or universal health care. The application of the Web-based GIS in relation to surveillance of infectious diseases and eradication provides solutions in the existing environmental problems by different health agencies with speedy access to

sources of data. Web application GIS is an effective tool used in surveillance to quickly identify immediate domestic dangers, including foreign health emergencies like SARS or pandemic influenza by impeccably assimilating surveillance data from the national government for fast analysis and decision-making [14]. The application of Web-GIS enables evidence-based decision-making would minimize duplication and conflicting actions by diverse agencies in responding to an epidemic.

In analyzing spatial data there are three types of operations involved, the attribute query, special query, and generation of new datasets from the local database. The coverage of spatial analysis includes a simple query about the spatial incidents to complex variation of attribute queries, spatial queries, and alteration of original data.

2. METHODOLOGY

2.1 Software Development Model

In developing the system, the researchers used Rapid Application Development (RAD) as a development model. The different phases of RAD include Identification of project requirements, Building Prototypes, User feedbacks, Testing, and System deployment.

2.2 Web GIS Framework

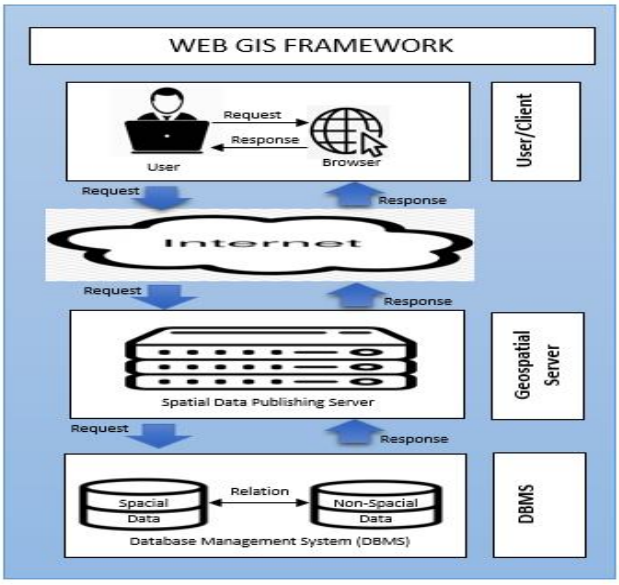


Figure 1: Web Geographic Information System Framework

Figure 1 shows the web GIS system with the standard webserver/browser. Basically, a web GIS system consists of three main components, the D**atabase**, **Map,** and **Web servers**. The server database served as the repository of data and data management. Map server provides maps based on users' requests in the application server-side and web server acts as provider of web services to the users. Users can have access to the system with the compatible browser with different web applications tools; zoom, pan, identify, visualize maps, query data and visualize data in tabular or graphical forms.

2.3 Mapping Framework

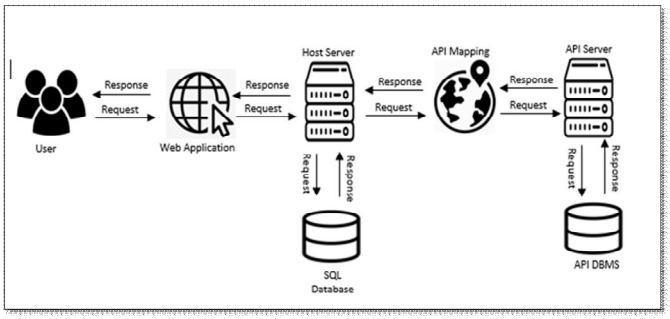


Figure 2: Mapping Framework

The following resources were used in this Map Framework:

- **User.** The user performs a query request by accessing the Web Application System. The Web Server processes the query and passed it through the SQL database. Once the query request is satisfied, the SQL database generates the data as a response to the query. The result of the query is projected to an API Map. The API Server processes the API request by sending it to the API Database.
- **Web Application.** Web Application is the front end of the developed Epidemiological Mapping and Surveillance System using Spatial Data Analysis that serves as the User Interface of the user.
- **Host Server**. The host server serves as the third party repository of GIS data consolidated by the system from the health agencies. In this research, the dedicated host server of the Municipal Health Office was used.
- **MySQL**. It is considered as the back-end of the system where the data resides. All the data infected patients were gathered from the different health agencies and stored it in the database of the system for spatial analysis of data.
- **API Map.** Google map API was used as the geographical interface of the system where the number of cases of infectious disease can be viewed in a specific location in the barangay, municipality, city, province, and the region.
- **API Server**. The API Server is the source of the API map based on the query request of the user. The user specifies to its query what specific location and the type of disease to monitor and projected on the map.

2.4 Development of the Web-based System with GUI

The following were the software used in designing the interface and developing the system:

- PHP. PHP is a scripting language used in constructing the web-based dynamic component of the system.
- XAMPP. XAMPP is a development tool that allows the user to test their work on their own computer without any access to the Internet.
- **MySQL.** MySQL is an open-source database management system used to develop the back-end component of the system as the repository of data.
- Browser. The Google Chrome browser was used for accessing the developed system using the Internet.
- Adobe Photoshop. Adobe Photoshop was used for cropping and resizing images, and for making the banner of the system presentable and elegant.
- Sublime Text. Sublime Text was used as a source code editor.
- Bootstrap. Bootstrap was used by the researchers in designing the webpages of the system.

2.5 Datasets

The consolidated dataset was used in analyzing the occurrence of Infectious diseases using Spatial Data Analysis in mapping the disease from the 64 Barangays in the Municipality of Echague. The datasets were consolidated using Microsoft Excel from the year 2013 to 2018 from the different health agencies.

2.6. Spatial Data Analysis

In analyzing the consolidated data of the GIS, the researchers used three types of operations Attribute Query also known as non-special query, Spatial Query, and Generation of new datasets from the original database [14]. The coverage of the spatial analysis ranged from simple to complex combinations of attribute queries, spatial queries, and modification of the original data. Using the Attribute query, the user can search and retrieve records in the database using a specific attribute value. The result of the query is used as part of handling and analyzing GIS data. The user can perform this query using a criteria-based query language or Structured Query Language.

3. RESULTS AND DISCUSSION

3.1 Description of the Web-based Portal with a graphical user interface

The system provides a web portal for the end-users to access the system. The portal requires unique security and identity in accessing it. No users are allowed to use the system without its unique security identity. The system was designed as a web-based application system that allows the user to use the system with or without an internet connection. Barangay/CHT and HF, the internet connection must be present during the surveillance and data gathering since they will be using Mobile phones or Tablets.

The system is a Web-based system designed to consolidate cases of infectious Diseases from different health facilities. These health facilities submit reports of the occurrence of infectious diseases to their corresponding Rural Health Unit. The Rural Health Unit then consolidated the reported cases and submit them to the Provincial Health Unit and the Provincial Health Unit forwards the reported cases to Regional Health Unit and to the Department of Health at the National Level respectively. The modules of the system are User Management, Profile of infected Patient, Disease Management, Mapping, and Report Module. The system also provides a graphical and tabular presentation of consolidated reports. The system provided mapping of infectious diseases from the different Barangays in the Municipality of Echague. The system is also capable of identifying an outbreak of the disease. SMS notification is sent to the area where the disease is prevalent.

User's Login Interface: Administrator

Figure 3: User's Login Interface

3.2. Local Disease Surveillance

In this level, the reports are coming from different health facilities are being consolidated. The consolidated reports are forwarded to the Provincial and Regional Levels for consolidation. The system automatically consolidates the reports coming from the CHT/HF. The system provides a graphical representation of the consolidated data. When there is an outbreak detected the Local Disease Surveillance Team can send an alert to the residents in the areas. The alert is either in SMS or Email. The residents can upload the alert using social media. The consolidated reports provide real-time monitoring from the Municipal, Provincial and Regional levels in a graphical, tabular and graphical format and view the areas where the diseases are prevalent using maps.

3.3 System Functionalities and Features

The developed system possessed the following major functionalities and features:

1. Users' Login. There are six authorized users of the system. Each user handles different levels of functionality in the system.

2. The system contains Interfaces such as Administrator Panel, Regional Level, Provincial Level, Municipal Level, Rural Health Unit, Disease Reporting Unit (DRU), Field Officer User, Short Message Service (SMS) Interface, and Mobile User Interface
3. The system contains the following functionalities: Administrator, User Management, Manage Disease, Manage Provinces, Manage Municipalities, Manage Barangay, Patience Profile, Disease Management, Mapping, and Report Module.
4. The residents are notified when an outbreak is detected using the SMS notification
5. The system can identify the location and the information of the infected person in different areas.
6. The location of the infected person is identified on the map.
7. The system monitors Real-time data from different health agencies.
8. The system automatically consolidated the occurrences of infectious diseases are by the system from different health agencies.
9. The system can generate reports from the municipal, city, provincial and regional levels.
10. The system provides tabular, graphical and geographical data as a graphical user interface.

3.4. Spatial Data Analysis Results

The developed system has a strong potential to do Spatial Mapping and surveillance of infectious diseases. It can greatly constitute the solution to addressing the spread of infectious diseases in the country.

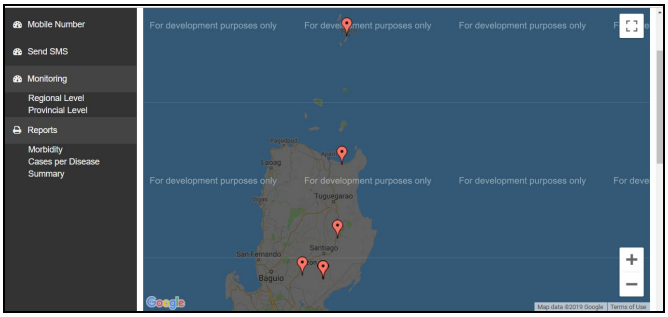


Figure 4: Monitoring Regional Level Interface

Figure 4 shows the Regional Level Monitoring Interface. The interface is divided in two columns. The first column contains the functionality the Regional Health Officer handles which are the following: Dashboard, Monitoring, and Reports. The function monitoring contains sub-functions which are the Regional Level and Provincial Level. While the Report functionality also contains 3 sub-functions which include Morbidity, Cases per Disease and Summary.

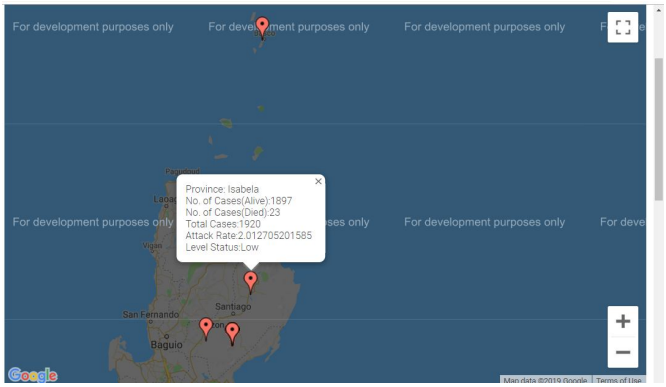


Figure 5: Spatial Analysis of Data Regional Level

Figure 5 shows the Map showing the location of the Provinces under Region II. The specific location of the Provinces is represented on the map using the map marker. When Map Marker is clicked using a mouse pointer an Information Window appears exactly right on the location marker. Information Window on the Map contains information about the name of the Province, Number of Alive Cases, Number of Death Cases, Total Number of Cases, Attack Rate, and Level of Status of specific infectious disease.

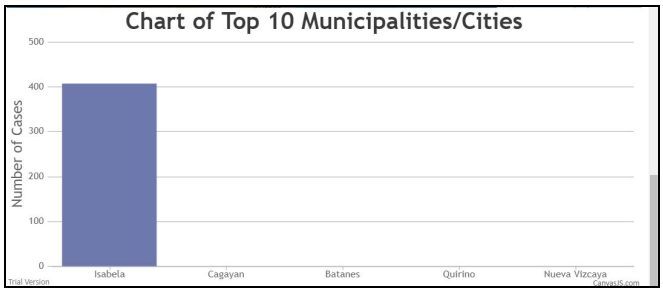


Figure 6: Graphical Analysis of Data Regional Level

Figure 6 shows the **Graphical Representation** of the data using a Bar graph. The system automatically generates a chart based on the data from the database. The Regional Health Officer can easily identify an area that has holds the highest case among the Provinces based on the data projected on the Chart.

#	Province	Alive	Died	Total	CFR(%)	Attack Rate
1	Batanes	0	0	0	0	0
2	Cagayan	0	0	0	0	0
3	Isabela	399	8	407	1.97	0.43
4	Nueva Vizcaya	0	0	0	0	0
5	Quirino	0	0	0	0	0

Showing 1 to 5 of 5 entries Previous 1 Next

Figure 7: Tabular Analysis of Data Regional Level

Figure 7 shows the Tabular Data that contains vital information about the occurrences of infectious diseases among the Provinces. This information includes Names of the Provinces, Number of Alive Cases, Number of Death Cases, Total Number of Cases, Case Fatality Risk (CFR%) and the Attack Rate.

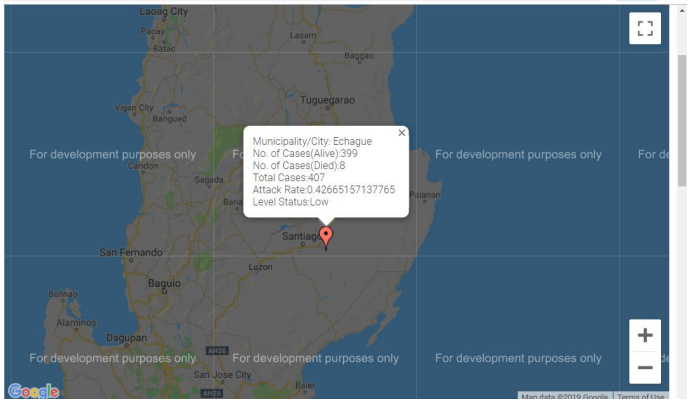


Figure 8: Spatial Analysis of Data Provincial Level

Figure 8 shows the Google Map showing the location of the Municipalities under specific Province. The specific location of the area is represented by a Map Marker. When Google Map Marker is accessed an Information Window appears exactly right on the location marker. Information Window on the Map contains information about the name of the area the Google Map Maker represents, Number of Alive Cases, Number of Death Cases, Total Number of Cases, Attack Rate, and Level of Status of specific infectious disease.

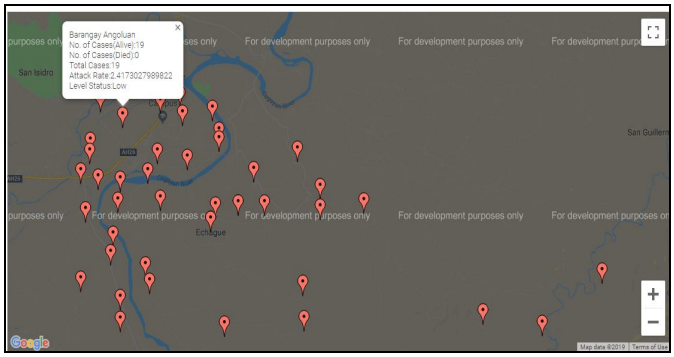


Figure 9: Spatial Analysis of Data Municipal Level

Figure 9 shows the spatial analysis of data at the municipal level. The location of the different Barangays in the municipality is located on the map. Each Barangay contains an information window containing the following information: Number of Cases Alive, Number of Cases Died, Total Cases, Attack Rate and Level Status.

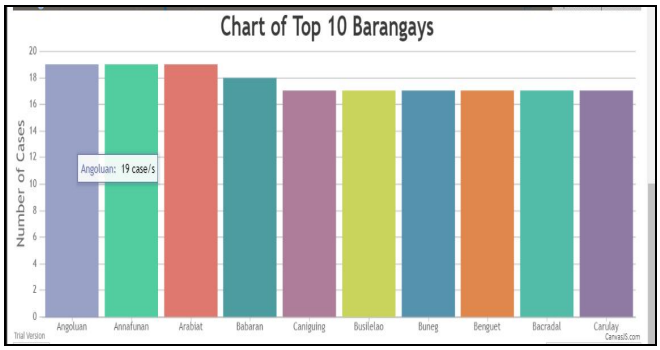
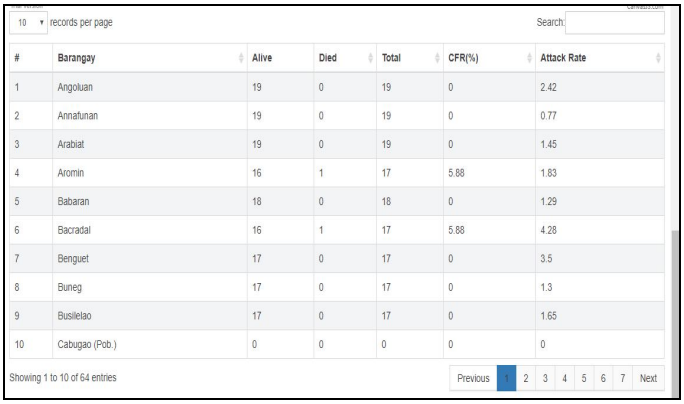


Figure 10: Graphical Analysis of Data Municipal Level

Figure 10 shows the graphical analysis of the data on the Municipal level. The graph shows the top ten Barangays with the most number of cases of specific infectious diseases.



10 records per page — Search:

#	Barangay	Alive	Died	Total	CFR(%)	Attack Rate
1	Angoluan	19	0	19	0	2.42
2	Annafunan	19	0	19	0	0.77
3	Arabiat	19	0	19	0	1.45
4	Aromin	16	1	17	5.88	1.83
5	Babaran	18	0	18	0	1.29
6	Bacradal	16	1	17	5.88	4.28
7	Benguet	17	0	17	0	3.5
8	Buneg	17	0	17	0	1.3
9	Busilelao	17	0	17	0	1.65
10	Cabugao (Pob.)	0	0	0	0	0

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Figure 11: Tabular Analysis of Data Municipal Level

Figure 11 shows the tabular analysis of the data Municipal Level. The tabular data shows the list of Barangays that obtained the most numbered cases to the least ones. It also contained Case Factor Risk Analysis in percent form and Attack Rate.

Figure 12: Spatial Analysis of Data Barangay Level

Figure 12 shows the Spatial Analysis of the Data Barangay Level. The location of the different barangays in the municipality are reflected in the Map. Each Barangay contains an information window containing the following information: Number of Cases Alive, Number of Cases Died, Total Cases, Attack Rate and Level Status.

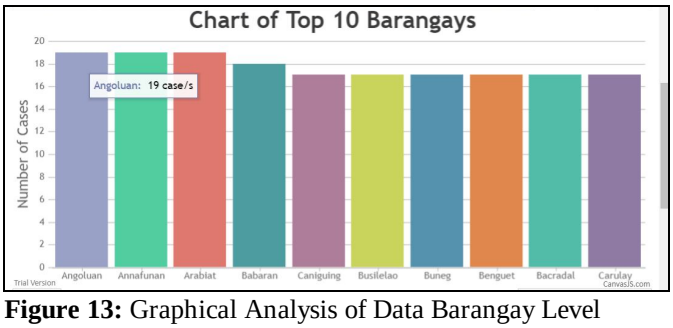

Figure 13: Graphical Analysis of Data Barangay Level

Figure 13 shows the graphical analysis of the data municipal level. The graph shows the top ten Barangays with the most numbered cases of specific infectious diseases.

4. CONCLUSION

Based on the findings of this research, the following conclusions were drawn:

The developed system was used as a tool in monitoring occurrences of infectious diseases from the different health agencies in the Municipal, City, Provincial and Regional Levels. The consolidated information on infectious diseases gathered from the different health agencies were used in the decision-making of the higher health authorities in preventing the spread of infectious diseases and improving the delivery of health services to their clientele.

Moreover, the developed system has a strong potential to do Spatial Mapping and surveillance of infectious diseases. It can greatly constitute to the solution of addressing the spread of infectious diseases in the community.

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