Modelling Disaster Response Route for Flood: A Geospatial Road Network Analysis Traversing the Vulnerable Zones of Candaba, Pampanga Through ArcGIS

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Abstract: - The municipality of Candaba in the Philippines, located near the Pampanga River, is widely recognized as the flood catch basin of the Northern and Central portions of Luzon. Barangays in the municipality continually face the perpetual challenge of flooding during heavy rains. From this, roads are becoming frequently impassable during the occurrence of typhoons. Due to the impacts of the flood on disaster response, this study aims to develop Disaster Response Route (DRR) choices for disaster response units through road network analysis using Arc Geographic Information System (ArcGIS). The study was carried out in the municipality's East River Side and Tagalog Region, with twenty-one (21) barangays under study. Furthermore, flood hazard maps with 5-year, 25-year, and 100-year flood periods from the University of the Philippines Disaster Risk and Exposure Assessment for Mitigation (UP-DREAM) were utilized to plot the DRR. These DRRs were tested based on their Levels of Service (LOS) and total time delays. Results showed that during the 5-year flood period, sixteen (16) routes were identified and ranked accordingly. From this, three (3) Disaster Response Routes were developed. While thirteen (13) passable routes were identified for the 25-year flood period, and three (3) Disaster Response Routes were established. However, for the 100-year flood period, all road links within the area of consideration were already submerged with floodwaters, resulting in no passable routes during this flood period. Following the simulation and ranking of routes, disaster response units may decide which route to take for the 5-year and 25-year flood periods. Accordingly, the said municipality is recommended to activate the Disaster Response Routes as necessary during an emergency or after the provincial or local state emergency declaration.

Key Words: — *Road Network Analysis, ArcGIS, Level of Service, Flooding, Disaster Response Routes.*

I. INTRODUCTION

Road networks are the most vulnerable to be affected by flooding. (Papilloud, 2021) Floods are among the most destructive natural disasters and are predicted to rise in frequency, prevalence, and severity. Furthermore, floods continue to cause significant property damage, costing billions of dollars (Zhang et al., 2016). With this, blocked and impassable roads caused by flooding lead to deliberate traffic flow. According to Abad and Fillone (2020), public transportation highlights the importance of running smoothly and accommodating passengers' travel. However, transportation systems are susceptible to catastrophes ranging from natural disasters to deliberate attacks, making them comparable to any other system. It has been demonstrated by He et al. (2021) that the effects of flooding on urban transportation systems and the local economy are more severe in developing countries. Regular flood events have a negative influence on several developing countries that are situated in

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flood-prone locations. The pavement serviceability of roads is crucial in examining the vulnerability of critical road links (Ballijepalli, 2014).

Additionally, any changes and the range of subsequent effects influence this transformation. Flood's influence has recently expanded due to their rising frequency and magnitude, the concentration of people and economic activity along river basins, and economic interdependence due to globalization.

Flood catastrophes inflict significant damage, including the loss of lives, property, and livelihoods. This natural disaster is especially dangerous in underdeveloped nations (Shrestha et al., 2014). In addition to that, Hilly et al. (2018) stated that urban floods can have a wide range of effects including the loss of life, damage to infrastructure and property, as well as other types of annoyance and discomfort to urban life, can all fall under this category.

In order to counteract the massive effects of flooding, rivers act as catch basins of rainfalls. In the Philippines, the Pampanga River, the second-largest drainage basin on Luzon, frequently experiences major flood events due to monsoon rains and typhoon hits. Nagumo and Sawano (2016) stated that residents along the zones of the Pampanga River Basin need to be aware of the deeper and more prolonged flooding during the start to middle occurrences, while people in the other zones need to be cautious of relatively powerful flood flows or severe floods. In line with this, areas near the Pampanga River experience extreme floods, making public roads inaccessible during calamities. Floodwaters tend to concentrate in the lower portion of the alluvial plains, especially in the lowest elevation point of the province of Pampanga – the municipality of Candaba.

Candaba is a known catch basin of flood from the terrain portion of Northern and Central Luzon. Roads within the barangays of the municipality are usually flooded, which later on become impassable roads, directly affecting the speed and causing delays. Barangays located in the East River Side and Tagalog Region are greatly affected by floods when typhoon occurs. In fact, eight barangays from the said region having residential areas were rated 100% prone to flooding (Local Disaster Risk Reduction and Management Plan 2023-2025 of Candaba, 2022). These places have moderate-high flood levels. High levels of flood greatly affect the transportation system. Worse, these blocked routes decrease the quality of the place's disaster response during heavy rains and typhoons.

Aside from the natural disaster, causes of flooding were significantly seen to be driven by (a) overflowing water in the river, (b) insufficient practices in garbage disposal, and (c) limited knowledge of flood control development programs (De Vera et al. 2020). Since then, the region has been a yearly victim of massive typhoon destruction, especially in its agricultural industry, which is its residents' primary income source. Due to its geographic location, disaster management, and mitigation should be highly imposed in these areas, given their situation. Thus, vulnerability assessments are conducted to determine affected roads, as networks are the most vulnerable during natural disasters, which later affects people's travel conditions (Fillone, 2017).

Thereafter, from the induced effects of flooding to the state of disaster response operations, this study proposed a disaster response route plan to alleviate the transportation above engineering problem by mapping an alternative network of disaster response routes crossing the twenty-one (21) barangays of the East Riverside and Tagalog Region, as well as the entry-exit points of the study area. This objective was carried out through the (1) utilization of ArcGIS software, a microscopic cloud-based mapping and analysis geographic information system where the 5-year, 25-year,

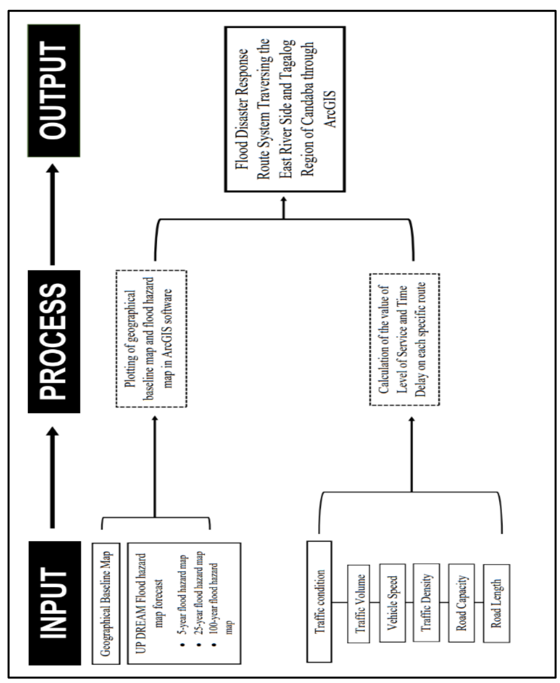

Fig. 1. Model on the Input-Process-Output Conceptual Approach

and 100-year flood hazard map retrieved from the University of the Philippines (UP) Disaster Risk and Exposure Assessment for Mitigation (DREAM) Project were

embedded. These flood hazard maps were modeled using the Digital Elevation Models (DEMs), Digital Terrain Models (DTMs), Classified LAZ, Resource Maps, and Orthophotos. (2) Geographical baseline map, and (3) traffic volume data. Levels of service were (LOS) calculated from the tabulation of the alternative routes identified. While the actual modeling of the disaster response route was simulated using the ArcGIS software. Considerations such as the Level of Service (LOS) and time delay were taken into account in the analysis and evaluation of the data procured.

II. Methodology

The primary goal of this research was to develop a disaster response route through road network analysis that could be used for the rescue operation, evacuation, conduct of medical social relief, and assistance of victims for rehabilitation. The following are the specific objectives:

a. Assess flood-prone areas in the municipality of Candaba and determine their flood susceptibility using flood hazard maps;

b. Establish disaster response route choices that connect the entry/exit point and the centroid through ArcGIS; and

c. Test the Level of Service (LOS) and estimated time delay of the disaster response routes through tabulation.

The illustrative Figure 1 shows the inputs considered such as the geographical baseline map that connects the true geographic location of substations that integrates the use of digital imagery, land use, and topographic data (Rantanen, 2018).

Additionally, data on traffic volume were considered as necessary input in determination of the volume and density of vehicles in Candaba. Moreover, the traffic volumes were significant in the identification of the most probable route with less traffic congestion that composes the disaster response route. In addition, the 5-year, 25-year, and 100-year flood hazard maps were selected as inputs since the 5-year return period has a 20%, while the 25-year has a 4% return period and the 100-year has a 1% return period. With this, the researchers examined the roadways' availability when plotted in a 5-year, 25-year, and 100-year flood hazard map.

The secondary data procurement on traffic condition, which includes the traffic volume, vehicle speed, traffic density, road capacity, and road length, were performed and calculated through the characterization of the abovementioned parameters. Consequently, the plotting of geographical baseline map, traffic volume data, and flood hazard map in the ArcGIS software for the simulation of flood effects in traffic volume and time delay were performed. After this, the values for LOS and time delay were derived. Furthermore, after the values had been determined, the routes were ranked based on their LOS and time delay, and the ranked routes were plotted in ArcGIS software for the determination of the route choices containing the modelled disaster response routes. Upon the processing of all inputs, the goal to map a flood disaster response route obtaining the selected parameters along the East River Side and Tagalog Region of Candaba, Pampanga, was attained.

This study is designed to be inductive in approach. Interpretations were directly based on the results reflected from the ArcGIS software and the initial findings and observations from the qualitative records, including the geographical location and topographic data of Candaba, its traffic condition, and traffic volume. From then, theories were formulated depending on the characteristic of the developed disaster response route. As such, no existing theories were applied within the initial analysis and conduct of the study. Additionally, the research objectives which were previously formulated are not based on any theories. Rather, this study aimed to identify patterns, and from these, relationships between variables were concluded. The researchers selected to conduct an inductive approach, the explanatory one since the study is localized within a specific part of the municipality. If theories were initially applied, some of the criteria might not apply to the study area. Thus, the inductive approach is much more suited to the philosophy of this study. Additionally, this approach gives the researchers the liberty to re-direct the flow of the research once the conduct has commenced (Goddard & Melville, 2004).

Moreover, this study used the mixed method methodology type of research as this study was experimental in approach, and qualitative data were analyzed to support the experimental results. Specifically, this study followed the Explanatory Sequential Design, which determined what quantitative results need further explanation. This starts with quantitative data analysis followed by qualitative data analysis (Creswell et al., 2003).

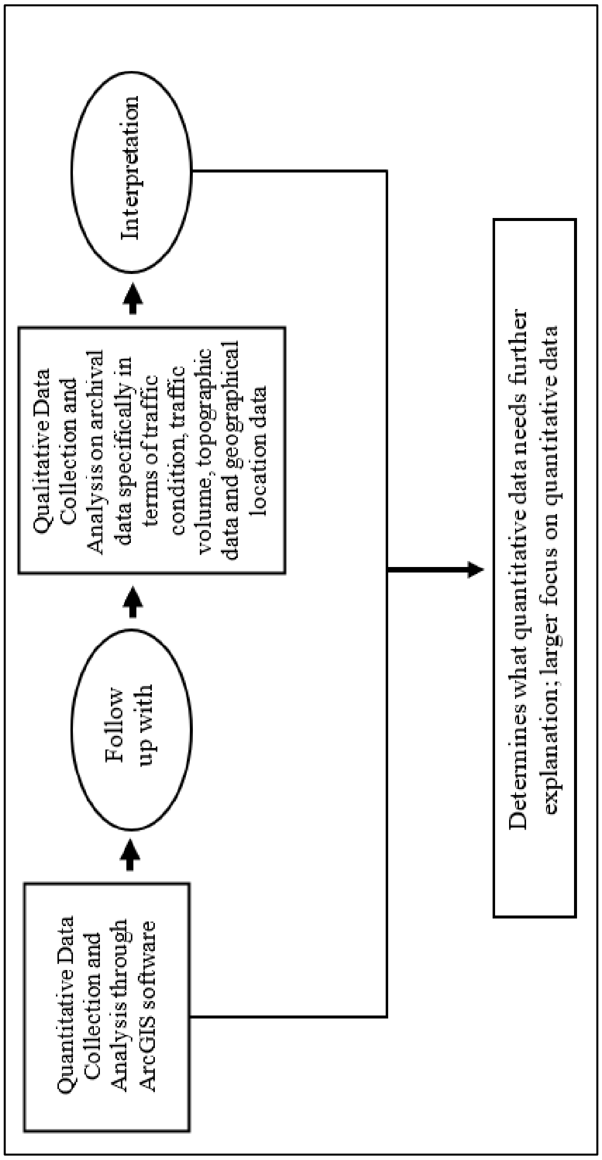

Fig. 2. Explanatory Sequential Mixed Method Design

To ascertain the effects of flooding on traffic volume and time delay in the building of disaster response route, quantitative data were first gathered and analyzed using ArcGIS software. For this data to be credible enough, results were supported by the qualitative data from existing database records on topography and geographical location. Along with the inductive approach, mixed methods methodology is applicable since the study is localized and concentrated in a specific point in the country.

It creates a stronger research output than individual methodologies (Malina et al., 2010). Since the researchers have a strong desire to come up with greater insights of credible findings supported by factual qualitative data, mixed methods helped the proponents explore the deeper aspects of the nature of the study area and how flooding affects the variables being tested. It also provided a wide range of flexibility in choices to incorporate for the betterment of the results (Terell, 2011).

The study was carried out in the municipality of Candaba, Pampanga. Specifically, within the East River Side and Tagalog Region of the said municipality. The barangays included in the region were considered in the route modeling. A total of twenty-one (21) barangays were included in the area of study, which includes barangays in Bahay Pare, Bambang, Barit, Buas (Poblacion), Gulap, Mangga, Paligui, Pangclara, Paralaya (Poblacion), Pescadores (Poblacion), Dalayap, Pulong Gubat, Pulong Palazan, Dulong Ilog, San Agustin (Poblacion), Santo Rosario, Talang, Tenejero, Vizal San Pablo, Vizal Sto. Cristo and Vizal Sto. Nino.

Table 1. Tabulation of the number of individuals that may be affected by flooding

BARANGAYS	NUMBER OF AFFECTED INDIVIDUALS
Bahay Pare	7146
Bambang	3352
Barit	216
Buas	2045
Gulap	4856
Mangga	125
Paligui	1842
Pangclara	920
Paralaya	6115
Pescadores	1856
Dalayap	490
Pulong Gubat	1826
Pulong Palazan	3544
Dulong Ilog	420
San Agustin	5671
Sto. Rosario	1634
Talang	150
Tenejero	51
Vizal San Pablo	814
Vizal Sto.Cristo	1232
Vizal Sto. Nino	52
Total	**44357**

Table 1 reflected the probable number of affected individuals due to flooding released by the Candaba Municipal Disaster

Risk Reduction Management Office (MDRRMO, 2022). From the data, about 44,357 individuals are anticipated to be affected by the occurrence of flood.

To procure the appropriate data needed, this study necessitated adapting the methodology presented by Othman and Hamid (2014), from which the effects of flooding on traffic volume, traffic flow, road capacity, and time delay will be calculated from the adapted method in consideration with the impacts of flooding to traffic routes choices.

Moreover, this study utilized the ArcGIS software, a Geographical Information System (GIS) program that handles and analyzes geographic information by visualizing geographical statistics such as climatic data or trade flows through layer-building maps.

To identify the flood disaster response route system traversing the municipalities and entry-exit points of Candaba, Pampanga, first, the researchers have gathered information about the flood hazard map from the website of UP-DREAM project.

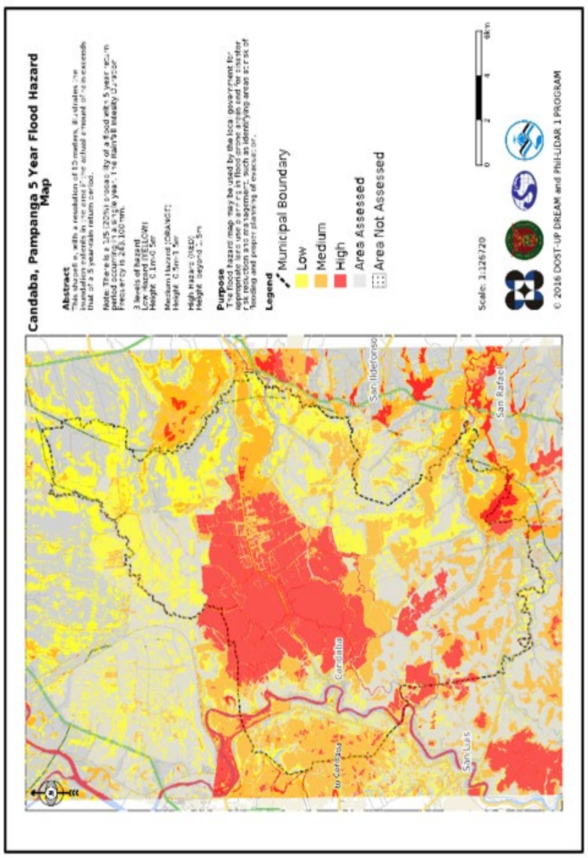

Fig. 3. A 5-year flood hazard map of Candaba, Pampanga from UP DREAM Project

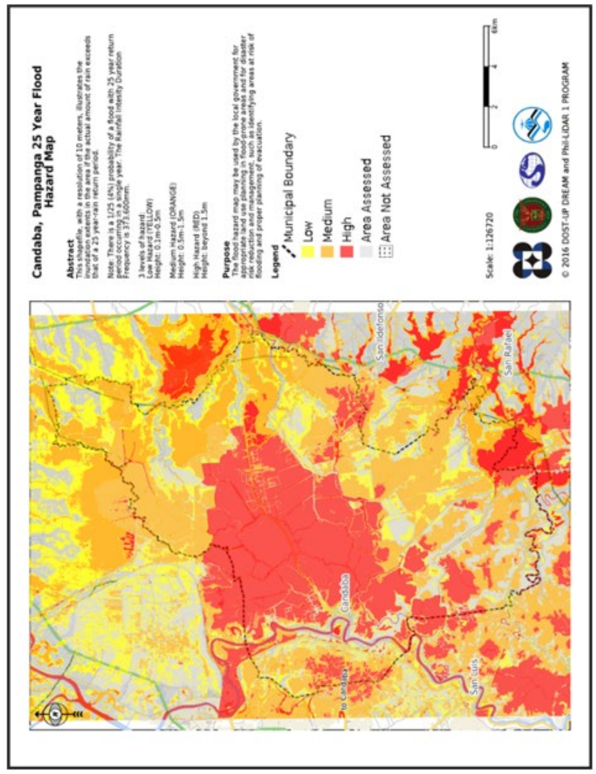

Fig. 4. A 25-year flood hazard map of Candaba, Pampanga from UP DREAM Project

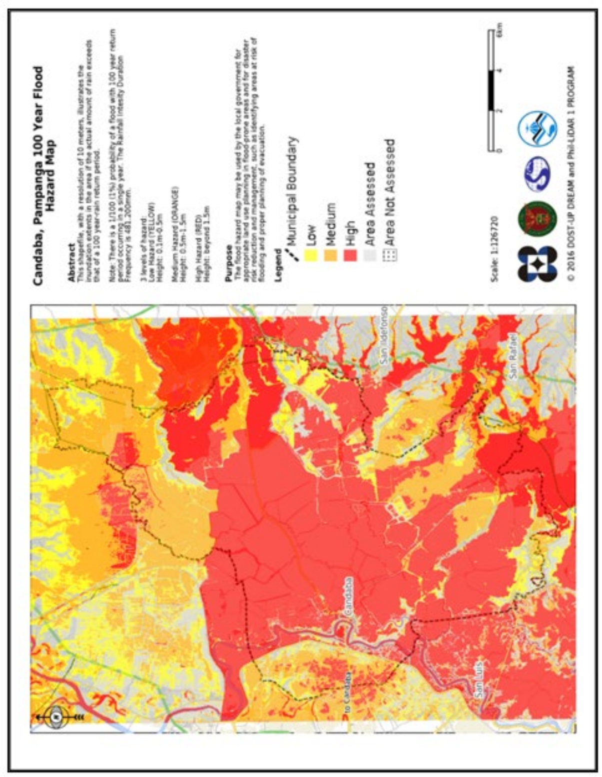

Fig. 5. A 100-year flood hazard map of Candaba, Pampanga from UP DREAM Project

Meanwhile, Figure 6 below demonstrates the typhoons from 2017-2022 that severely damaged the Municipality of Candaba.

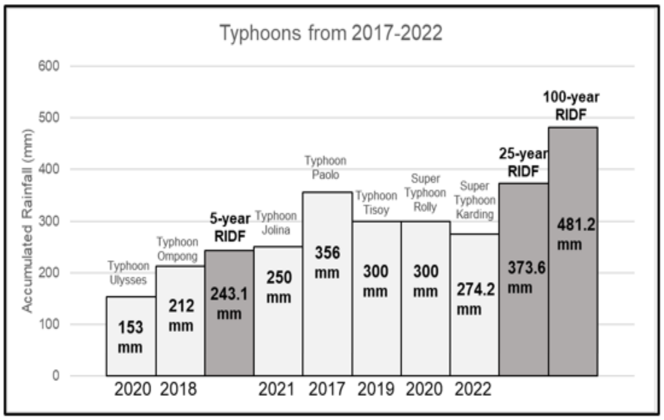

Fig. 6. Comparison between the amount of rainfall of typhoons (2017-2022) and flood periods

Additionally, the probable number of affected individuals in historical records of the flood is presented in Table 2. Meanwhile, shown above is the comparison of different typhoon events in a graphical manner in order to compare what flood year period of flood hazard maps should be used in a certain amount of rainfall. As seen from Typhoon Ulysses and Typhoon Ompong's rainfall amount, the 5-year flood hazard map could be used since this Rainfall Intensity Duration (RIDF) of this hazard map is greater than that of Ulysses and Ompong's. Meanwhile, the 25-year RIDF could be used for typhoons with the approximate amount of rainfall as Jolina, Paolo, Tisoy, Rolly, and Karding's, since the rainfall released from these typhoons is in a lower value than that of the 25-year flood period. This proves that the flood hazard maps' projection is acceptable in terms of the actual rainfall recorded from the typhoons and super typhoons.

Second is procuring traffic conditions (vehicle and road classification) from DPWH. Traffic volume, road capacity, and vehicle speeds prior to flooding the adjacent barangays of the boundary of Candaba, Pampanga were obtained and performed by this study's proponents. Third, all the values were calculated to determine the fastest and safest route that composes the disaster response route. Lastly, the acquired Arc Geographic Information System data were applied and plotted.

This study utilized a Geographical Baseline Map to visualize the geographical information through map layers. The topographical data of Candaba which are readily available on the existing data on records, were considered. To compare the acquired figures, the use of secondary data collection (topographic data, and geographical data) was applied. Additionally, the selection of road links was limited to roads characterized under Low Hazard Category with flood height ranging from 0.1 to 0.5m, and Medium Hazard Category ranging from 0.5-1.5m flood height.

This study concentrated on creating a flood catastrophe response route system. More precisely, the procedures of this study were focused on the following: (1) Selection of the routes based on their risk category, primarily road links classified under low and medium risk categories were selected to compose the alternative routes. (2) Measurement of traffic volume of roads under normal traffic conditions using the 15-minute flow rate. (3) Calculation of the level of service of the alternative routes. (3) Identification of vehicle speeds using the overall speed/journey speed method. (3) Mapping a disaster response route system traversing the East River Side and Tagalog Region of Candaba, Pampanga, with the evacuation centers as its centroids, and (4) Mapping entry and exit points along the boundaries of East River Side and Tagalog Region of Candaba, Pampanga through ArcGIS modeling software.

Additionally, when the road link is flooded, as indicated by its flood level hazard, its serviceability is decreased. For this analysis, three flood scenarios— 5-year, 25-year, 100-year flood—were considered, and various capacity restrictions were implemented throughout the transportation network based on the threat level on each road. Two scenarios were compared: (1) the normal condition of road networks in Candaba and (2) the roads' condition during flooding. The 5-year, 10-year, and 100-year flood hazard map were used to analyze the flooded condition networks using ArcGIS software. The alternative routes were ranked based on their LOS and time delays in a tabular manner. Following the analysis of network links using the data acquired, a flood catastrophe route map is built using ArcGIS to re-route the course of cars to less risky network links. The disaster route map was provided as the data have been processed and further evaluated. For the analysis of data, the two-directional traffic flow was identified. The vehicle speed, traffic density, road capacity, LOS, average LOS, road length, and time delay were tabulated and computed to determine the foremost route to be adapted.

To be able to calculate the variables needed to be tested, possible routes were first determined. These routes are comprised of different links in each barangay being considered. After the identification of the possible routes. The vehicle speed in kilometer per hour prior to the occurrence of flood were obtained by the researchers by dividing the total distance of the road link over the total time travelled excluding all delays. Meanwhile, Hourly Traffic Flow is obtained from two-directional traffic volume of each location, Direction 1 and 2, D1 and D2 respectively. Data for traffic flow for the local and national roads were measured using the 15-minute flow rate. In here, the number of vehicles in both lanes were counted for 15 minutes. Meanwhile, this 15-minute volume was then converted to a flow by multiplying the volume by four (4). Traffic flow is obtained from a 7-day observation.

On the other hand, the traffic density was calculated as traffic flow over the speed of the vehicle. Moreover, to assess the consistency of the flow of vehicles, Peak Hour Factor (PHF) was also calculated. Consequently, followed by the calculation of actual flow rate. [5] While the road capacity was calculated as the Passenger Car Unit (PCU) multiplied by the number of vehicles passing the roadway. PCU factors were derived from the Indian Road Congress (IRC) codes, this is described in terms of pcu/hr. Demonstrated below are the formulae for each variable being tested. Listed below are the formulas used to determine the Disaster Response Routes.

$$\text{Hourly Traffic Volume} = (\text{max. V1} + \text{max no. V2})$$

where:

V1 = vehicles in direction 1

V2 = vehicles in direction 2

$$\text{Traffic density} = \frac{\text{traffic flow}}{\text{vehicle speed}}$$

$$\text{Peak Hour Factor} = \frac{\text{Volume of two lanes}}{(4 \text{ x peak } 15 - \text{minute interval})}$$

$$\text{Actual Flow Rate} = \frac{\text{Peak Hour Volume}}{\text{PHF}}$$

$$\text{Road Capacity} = \Sigma(\text{No. of vehicles x PCU factor})$$

Meanwhile, the Level of Service (LOS) was determined as the traffic flow over the road capacity. After calculating the LOS of each link, the mean LOS of the whole links was calculated.

Lastly, the time delay which is defined as the relationship between the road length and the vehicle speed was also computed. Afterwards, route choices were developed according to their LOS values and total time delays.

$$\text{Level of service} = \frac{\text{traffic flow}}{\text{road capacity}}$$

$$\text{Time delay} = \frac{\text{road length}}{\text{vehicle speed}}$$

For Levels of Service (LOS), the farther the value to 1.0 the lesser the traffic congestion. In application to flooding, when the roads are subjected to flood, it is anticipated that lesser volume of vehicles will be able to pass through the roads, thus, giving a lesser congested road for the vehicles, since LOS deals with the condition of traffic, thus, referring to the presence of vehicles.

Table 2. Level of Service Criteria

Level of Service	Traffic Situation	Volume-Capacity Ratio
Level A	free flowing traffic	< 0.20
Level B	relatively free flowing traffic	0.21 and 0.50
Level C	moderate traffic	0.51 and 0.70
Level D	moderate/heavy traffic	0.71 and 0.85
Level E	heavy traffic	0.86 and 1.00
Level F	Saturation traffic volumes	> 1.0

With this, disaster response vehicles will be able to traverse the roads in accordance to the LOS of the routes they are taking. Table 4 shows the different levels of service with the traffic situation indicator in correspondence with the volume-capacity ratio. The higher the factor of the LOS the more problematic and congested the route is. Nevertheless, Levels of Service C or D are traditionally considered as the acceptable LOS which most design or planning efforts use (Highway Capacity Manual, 2010). Level of Service C is suggested for the implementation of Roads and Transport Authority (RTA) while Level of Service D is suggested for weekends and recreational peaks (Clark, 2008). With this, for disaster response obtaining a LOS higher than Level C indicates that there will more or less moderate to free-flowing traffic.

III. Results and Discussion

In order to extract the number of vehicles passing through every road, observations were conducted by observers standing at the roadside of the boundaries of each barangay and recording all the passing vehicles on a form during a pre-determined period (Bangladesh Roads and Highways Department, 2001). For barangays with intersections as entry points, observers were positioned along the intersection to count the number of vehicles entering the said zones through turning movement count. The hour interval with the highest number of vehicles for both directions of traffic was selected as the PHF. The peak hour volume was calculated from both directions of the lane, and the hourly traffic flow was derived by summing up the 15-minute interval with the highest number of recorded vehicles multiplied by four. The Peak Hour Factor (PHF) is necessary to assess if the number of vehicles in each barangay road varies or not.

The formula for the calculation of traffic flow is given below. Table 3 shows the summary of the hourly traffic flow of each barangay in terms of a number of vehicles per hour. Hourly traffic flow is given by the formula:

$$Hourly\ Traffic\ Flow = 4\ x\ (max\ no. of\ vehicles\ D1 + max\ no.\ of\ vehicles\ D2)$$

Table.3. Summary of barangays and their traffic volumes

Road Name	Hourly Traffic Flow
Tenejero	1512
Pulong Palazan	2064
Vizal Sto. Cristo	448
Buas	2112
Mangga	1512
Pangclara	448
Gulap	708
Paralaya	1284
Dulong Ilog	1512
Vizal San Pablo	448
Bahay Pare	2064
Sto. Rosario	708
Barit	1512
Vizal Sto. Nino	448
San Agustin	1896
Dalayap	1512
Paligui	2064
Pulong Gubat	488
Talang	1512

PCU values were based on the Highway Capacity Manual (HCM) in 1994 and were determined on three variables: grade length, percentage of vehicles along a specific thoroughfare, and highway grade. However, due to the differing circumstance of the variables in the Philippines, this study adapted the PCU factors from the standards set by the Department of Public Works and Highways (DPWH). Other vehicle types that are not present in the DPWH standards were supplemented based on the factors used by Mendi & Reddy (2020) in a study entitled "Forecasting Future Traffic Trend by Short-Term."

Table.4. Vehicle types with Passenger Car Unit (PCU) factors

Vehicle Type	PCU factors
2-wheeler	2.5
3-wheeler	2.5
Car/Van/Jeepney	1
Bus/Truck	2
Minibus	1.5
2-3 Axle	3
Multi-axle	4.5
Auto Rickshaw	2.5
Tractor	1.5
Tractor with trailer	4.5
Long Combination Vehicle (LCV)	1.5
Mini-LCV	1

The East River Side and Tagalog Region are commonly dominated by 2-wheelers, 3-wheelers, tractors, and trucks. 2-wheelers: PCU = 2.5 due to the slow-moving vehicles. Motor-tricycles (together with jeepneys and buses) limit road capacity when they halt on the highway. Bus/Trucks: PCU = 2.0 for busses and rigid trucks, 3.0 for 2-3 axle and 4.5 for multi-axle or trailer-truck combination. Manual counting was carried out to determine traffic data. For seven (7) consecutive days, the researchers observed vehicles passing by on each road link every 15 minutes in one hour. The table below shows the tabulation of the resulting road capacities in pcu/hr of each barangay.

For the calculation of road capacities, the formula is given by:

$$Road\ capacity = \Sigma(No. of\ vehicles\ x\ PCU\ factor)$$

Table.5. Road Capacities in pcu/hr of each barangay

Barangay	Road Capacity (pcu/hr)
Tenejero	3532
Pulong Palazan	4892
Vizal Sto. Cristo	1052
Buas	4680
Mangga	3532
Pangclara	1052
Gulap	1680
Paralaya	3032
Dulong Ilog	3532
Vizal San Pablo	1052
Bahay Pare	4892
Sto. Rosario	1680
Barit	3532
Vizal Sto. Nino	1052
San Agustin	4364
Dalayap	3532
Paligui	4892
Pulong Gubat	1052
Talang	3532

Road capacities were obtained by multiplying all the vehicles from 7-day observations with their corresponding PCU factors. The largest was adapted as the governing road capacity for each barangay, which was multiplied by four to reach the one-hour figure. On the other hand, vehicle speeds were also measured for each barangay road as this variable affects the process of identification of disaster response routes.

The vehicle speed was calculated using the overall speed journey method by dividing the total length of each barangay to the resulting time travelled which was derived by subtracting the time delays to the total time travelled. Time delays were subtracted in order to obtain the raw value for vehicle speed with no assumed road obstructions.

The formula for the calculation of vehicle speed is given by:

$$= \frac{total\ length\ of\ barangay}{resulting\ time\ travelled}$$

where

$$\text{resulting time travelled} = total\ time\ travelled - time\ delays$$

Table.6. Calculated vehicle speeds

Road Name	Veh. Speed (m/s)	Veh. Speed (km/hr)
Buas	5.749	20.697
San Agustin	7.169	25.808
Paligui	15.661	56.381
Bahay Pare	8.339	30.019
Pulong Palazan	11.212	40.362
Mangga	12.504	45.016
Dalayap	6.863	24.706
Tenejero	7.489	26.962
Talang	11.702	42.128
Barit	8.884	31.982
Dulong Ilog	2.690	9.683
Paralaya	10.488	37.757
Vizal San Pablo	4.976	17.912
Vizal Sto. Nino	6.002	21.609
Vizal Sto. Cristo	6.863	24.707
Pangclara	4.386	15.789
Pulong Gubat	2.104	7.574
Gulap	5.502	19.808
Sto. Rosario	9.284	33.424

The selection of disaster response routes in Candaba, Pampanga was based on the road networks in the municipality's East River Side and Tagalog Region. The number of links used was 284, excluding road links for barangay Pescadores and Bambang. Figure # shows the mapping of the routes all interconnected in one centroid. Schools and covered courts with low-to-medium flooding susceptibility were also mapped.

The official evacuation centers in Candaba—the Candaba Evacuation Center, Municipal Action Center Covered Court Evacuation Center, and Candaba North Municipal Extension-Salapungan—are also included in Figure #. For disaster response routes to be effective, rescue units are recommended to travel these evacuation legends, as stated above, in order to accomplish their purpose.

The researchers selected routes from the road networks that best qualified for the criterion. These routes were evaluated based on their susceptibility to flood hazards, with high hazard classified routes removed and dead ends excluded. All of the identified routes were included as disaster response route choices, passing through schools, covered courts, and staging areas to deliver emergency responses to residents.

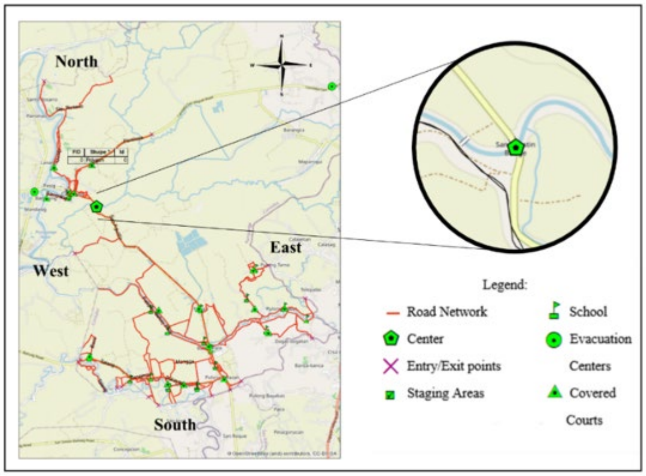

Fig. 7. Identified routes connected at the assigned centroid

Table.7. Routes' LOS and Total Time Delays

Route	Direction	Average LOS	Total Time Delay (mins)
1	North	0.38	51.80
2	North	0.17	47.30
3	West	0.44	3.92
4	West	0.23	20.86
5	West	0.43	22.2
6	East	0.35	89.60
7	East	0.35	188.06
8	East	0.35	51.38
9	South	0.42	16.35
10	South	0.32	32.12
11	South	0.43	17.09
12	South	0.43	24.39
13	South	0.42	23.59
14	South	0.43	23.48
15	South	0.43	24.59
16	South	0.43	29.93

Route 1 consists of seven road links, of which six have no flood hazard. Barangay Sto. Rosario is categorized as medium flood hazard, reducing traffic flow and vehicle speed. Disaster response vehicles can reach the centroid in 51.80 minutes, passing by all interconnected links with an LOS of 0.38 and free-flowing traffic (Level B).

Route 2 has a relatively higher value of average LOS than route 1, of which 0.17 is classified as Level A, indicating that there is free-flowing traffic as the number of vehicles is reduced according to their hazard classification above. Traversing this route, it will take 47.30 minutes to reach the centroid originating in Barangay Paralaya.

Route 3 consists of only two (2) road links with entry/exit

point in barangay Buas, with an average LOS of 0.44 with relatively free-flowing traffic (Level B). Since, this route has a relatively shorter road length, it will only take 3.92 minutes to reach the centroid.

Similar to Route 3, Route 4 route has only two (2) interconnected road links. From barangay Paligui to the centroid, disaster response vehicles will reach the centroid in 20.86 minutes, observing relatively free-flowing traffic at Level B of LOS originating in barangay Paligui.

Route 5 has nine interconnected road links with no flood hazard, resulting in 0.43 LOS, indicating free-flowing (Level B) traffic. Entering from Barangay Barit, it will take 22.20 minutes to reach the centroid.

Route 6 is made up of five (5) road links. Three (3) of the identified links are classified as national roads, of which road length, carriageway width, and number of lanes are greater than that of the local roads. Through the calculation, route 6 gives a 0.35 value of LOS at Level B. However, despite the higher LOS indicator, it will take 89.60 minutes or about 1 hour and 29 minutes to reach the centroid with entry/exit point in barangay Pangclara.

Having a similar average LOS of 0.35 at Level B with the previous route, route 7 has a longer total time delay of 188.06 minutes or about 3 hours and 8 minutes to reach the centroid. This was primarily affected by the difference in entry/exit points and the rate of vehicle speed given that the two links are classified under medium flood hazard. Route 6 originates from Pangclara with reduced vehicle speed of 2.368 km/hr while route 7 originates from Pulong Gubat which has a longer road length and slower reduced vehicle speed of 1.136 km/hr, which indicates a very little to no vehicle movement due to flooding.

Route 8 shows the least value of total time delay with relatively free-flowing traffic among the previously identified routes in the East of East River Side and Tagalog Region. With 0.35 value of LOS at Level B, entering from barangay Vizal Sto. Cristo, disaster response units are capable of reaching the centroid in 51.38 minutes.

Route 9, 10, and 11 have the same barangay of entry/exit, Pulong Palazan, but vary in the road links inside Pulong

Palazan, which were utilized to compose the whole route. Route 9 and 11 have four (4) interconnected road links, all of which are free of flood hazards, including the entry/exit point, as shown in the table. This simply means that all of the road links along this route are located in elevated regions enough to be passable. As a result, there is no reduction in traffic flow or vehicle speed. Thus, a value of 0.42 and 0.43 LOS was calculated, respectively. Having very little discrepancy in LOS, disaster response units may choose what route to take depending on their objective, as these routes' total time delays are already calculated above.

On the other hand, route ten road link's entry/exit point in barangay Pulong Palazan is classified under the medium flood hazard category, which is further reduced in terms of traffic flow and vehicle speed. This gives a higher indicator of LOS at 0.32 compared to routes 9 and 11. Utilizing this route, it will take 32.12 minutes to reach the centroid. All three routes being categorized under Level B, disaster response units, may choose what route to take depending on their objective as these routes' total time delays are pre-determined. Road links in three routes have no determined flood hazards, indicating that despite flooding from nearby barangays, there are road links within Pulong Palazan to the centroid that are still accessible for carrying out disaster response operations.

A close difference in average LOS values and total time delays were observed for routes 12 and 13 with an entry/exit point at barangay Tenejero. If disaster response units choose to take route 12, it will take them 24.39 minutes to reach the centroid passing seven (7) barangays. Meanwhile, if disaster response units desire to take route 13, still passing through seven (7) barangays, the route will take 23.59 minutes to reach the centroid. Road links in both routes have no flood hazard identified, indicating that despite flooding with neighboring barangays, there are still road links within Tenejero to the centroid which are passable to deliver disaster response operations.

Routes 14, 15, and 16 have the same barangay of entry/exit but use different road links within barangay Talang to complete the route. Having the same value of 0.43 for LOS at Level B, disaster response units may choose what route to take to accommodate ten (10) barangays from barangay Talang to the centroid. Route 14 takes 23.48 minutes to reach the centroid. Route 15 travels 24.59 minutes to the centroid. While route 16 takes 29.93 minutes. Road links in the three routes are free of flood hazards, indicating that regardless of the presence of floods within the surrounding barangays, there remain road links within Talang to the centroid that is accessible for carrying out operations for disaster response.

To determine the effectiveness of each route option in an emergency evacuation during a flood, a total of sixteen (16) routes were developed and analyzed. Reflected below is the summary of the sixteen (16) identified routes. The map of the 5-year flood hazard was utilized to pinpoint accessible routes. Only those routes that were assessed to have low-to-moderate susceptibility to flooding or no occurrence of flooding at all were included in the selection of these routes. Since all of the these achieve the criteria for selection, all 16 routes were included as disaster response routes choices during flooding.

Additionally, the flood hazard classifications of each road links were also identified as the primary basis of the reduced traffic flow and reduced vehicle speed during low and medium flood flooding. Reduction factors in Table # were based from the depth of the flood adapted from the flood hazard maps utilized. For low flood hazard classification with 0.1m to 0.5m of flood depth, traffic flow is reduced by 90% by multiplying 0.10. While for medium flood hazard classification with 0.5m to 1.5m flood depth, traffic flow is reduced by 95% by multiplying 0.05. These reduction percentages were based from the analysis and simulation of Othman & Hamid (2014) on their study entitled "Impact of Flooding on Traffic Route Choices". Re-aligning the flood depth utilized in the reference study in application to the flood depth provided by the UP-DREAM, the researchers of this study arrived in the aforementioned reduction factors applicable in the area of study.

Table.8. Reduction factors according to flood hazard classification

Flood Hazard Classification	Traffic Volume Reduction Factors	Vehicle Speed Reduction Factors
Low	0.10	0.30
Medium	0.05	0.15
High	0	0

Identified routes were divided based on their location in the topographic map. Routes from different entry/exit points will intersect at the common centroid. This was done to create a disaster response route composed of different routes from four (4) directions. The routes located in the North are R1 and R2. Moreover, the routes R3, R4 and R5 are located in the West. And then, R6, R7, and R8 are in the East. Lastly, the routes in the South portion include R9, R10, R11, R12, R13, R14, R15, and R16. Table # shows the ranking of the routes with their entry/exit points in the nearby municipalities of Candaba.

Table.9. Ranking of routes for 5-year flood period

5-YEAR DISASTER RESPONSE ROUTES					
Loc.	Route	Entry/Exit Point	Ave. LOS	Time Delay in mins	Final Ranking *(Based on total time delay)*
North	R2	San Miguel, Bulacan	0.17	47.30	1
West	R3	Sta. Ana, Pampanga	0.44	3.92	1
East	R8	San Rafael, Bulacan	0.35	51.38	1
South	R9	Baliuag, Bulacan	0.42	16.35	1
North	R1	Arayat, Pampanga	0.38	51.80	2
West	R4	San Luis, Pampanga	0.23	20.86	2
East	R6	San Ildefonso, Bulacan	0.35	89.60	2
South	R11	Baliuag, Bulacan	0.43	17.09	2
West	R5	San Luis, Pampanga	0.43	22.20	3
East	R7	San Ildefonso, Bulacan	0.35	188.06	3
South	R14	San Luis, Pampanga	0.43	23.48	3
	R13	San Luis, Pampanga	0.42	23.59	4
	R12	San Luis, Pampanga	0.43	24.39	5
	R15	San Luis, Pampanga	0.43	24.59	6
	R16	San Luis, Pampanga	0.43	29.93	7
	R10	San Rafael, Bulacan	0.32	32.12	8

Finalized routes, or the *Disaster Response Routes (DRR),* were selected through rankings. All of the routes that ranked first in every category were connected to become the first final route. As well as that of those routes that either ranked second or third will be the second or third final route. The routes ranked 4th to 8th will all be distributed in every DRR route to further utilize road serviceability. The objective of accommodating disaster operations for a greater number of residents during flooding also equates to accommodating a greater number of routes. Thus, routes that unmatched ranks 1,2,3 were included as part of the 1st – 3rd disaster response routes. Expanding the scope of DRR increases life efficiency.

Table.10. Summary of DRR for 5-year with average LOS

DRR-1 - 5Y	DRR-2 - 5Y	DRR-3 - 5Y
R2, R3, R8, R9, R10, R12, R13, R15, R16	R1, R4, R6, R11, R10, R12, R13, R15, R16	R5, R7, R14, R10, R12, R13, R15, R16
Average LOS: 0.38	*Average LOS 0.38*	*Average LOS 0.41*
Level B	Level B	Level B

In summary, when a 5-year flood occurs, R2, R3, R8 and R9 are the fastest routes to travel from the entry points to San Agustin (centroid) regardless of their distances. Therefore, these routes were included in the Disaster Response Route 1 (DRR-1). Being the second in rank, R1, R3, R8, and R11 were concluded to be the Disaster Response Route 2 (DRR-2).

While, the Disaster Response Route 3 (DRR-3) consists of will be the R5, R7 and R14. Then, distributing R10, R12, R13, R15, and R16 to all DRR developed are unmatched routes from ranks 1, 2, and 3, as shown above. Lastly, the average LOS of each of the final routes was computed. From Table 11, DRR-1 and DRR-2 are identical regarding their average LOS. Their average LOS was classified as Level B. Where there is relatively free-flowing traffic for DRR-1 and DRR-2. While, DRR-3's average LOS is greater than that of DRR-1 and DRR-2. Thus, it indicates that the first two routes have better service levels than the DRR-3.

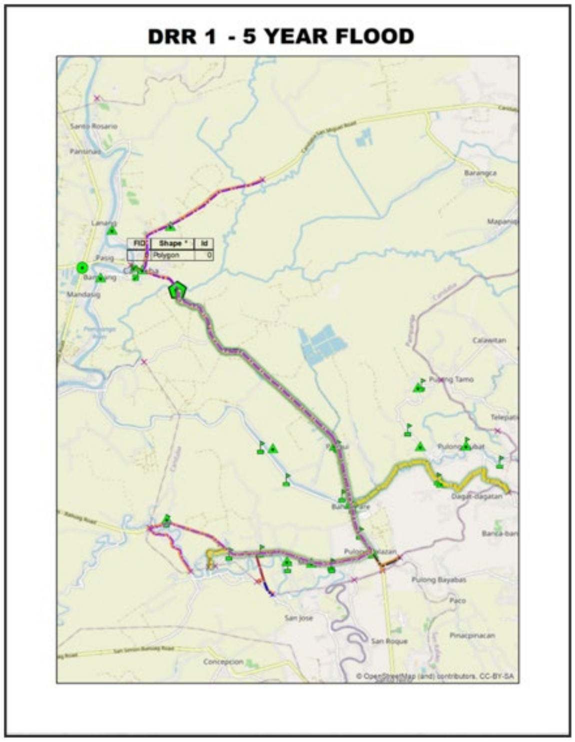

Fig.8. Disaster Response Route 1 for 5-year flood period

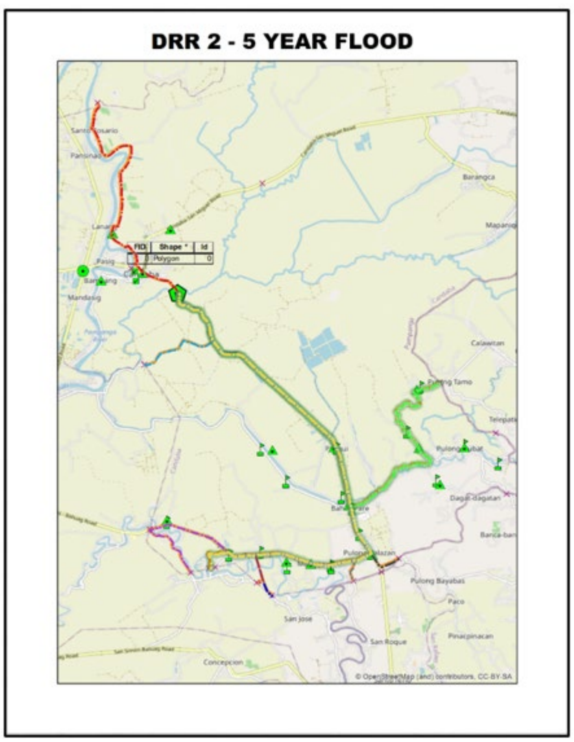

Fig.9. Disaster Response Route 2 for 5-year flood period

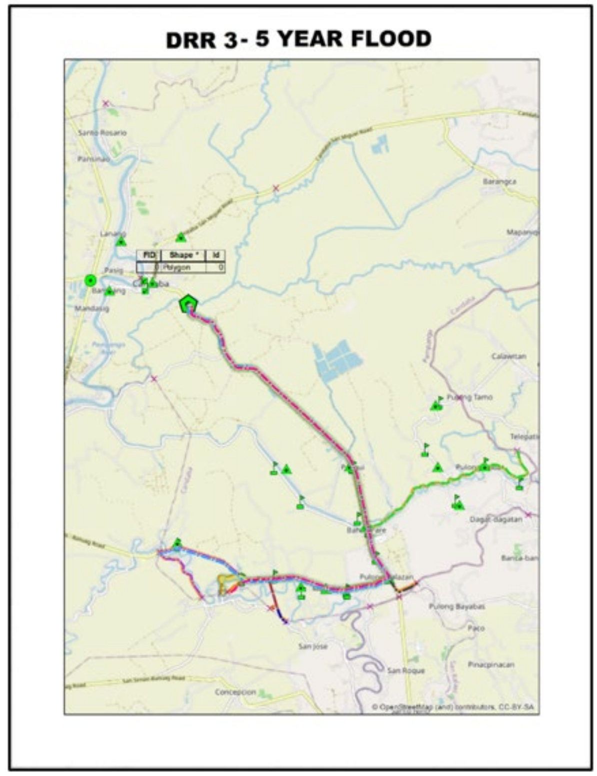

Fig.10. Disaster Response Route 3 for 5-year flood period

On the other hand, in the 25-year flood hazard map flooding scenario, routes 2, 4, and 10 have been removed from the map. The decision to exclude these routes was based on the fact that some of their links were already classified as highly susceptible to flooding. These routes are not safe to pass when a 25-year flood occurs in the municipality (see Table 11).

Table.11. Ranking of routes for 25-year flood period

25-YEAR DISASTER RESPONSE ROUTES					
Loc.	Route	Entry/Exit Point	Ave. LOS	Time delay in mins	Final Ranking *(Based on total time delay)*
North	R1	Arayat, Pampanga	0.26	26	**1**
West	R3	Sta. Ana, Pampanga	0.24	0.14	**1**
East	R8	San Rafael, Bulacan	0.19	29.04	**1**

South	R9	Baliuag, Bulacan	0.32	16.35	**1**
West	R5	San Luis, Pampanga	0.34	26.72	**2**
East	R6	San Ildefonso, Bulacan	0.19	36.07	**2**
South	R11	Baliuag, Bulacan	0.22	17.09	**2**
East	R7	San Ildefonso, Bulacan	0.19	46.41	**3**
South	R14	San Luis, Pampanga	0.33	23.48	**3**
South	R13	San Luis, Pampanga	0.25	23.59	**4**
	R12	San Luis, Pampanga	0.25	24.39	**5**
	R15	San Luis, Pampanga	0.29	24.59	**6**
	R16	San Luis, Pampanga	0.35	29.93	**7**

When a 25-year flood occurs, R1, R3, R8, and R9 were the shortest distances between the entry locations and San Agustin (centroid). As a result, these routes were incorporated into DRR-1. R5, R6, and R11 were determined to be in the DRR-2 since they ranked second. Lastly, R7 and R14 compose the Final Route 3 (DRR-3).

Table.12. Summary of DRRs for 25-year with average LOS

DRR-1 - 25Y	DRR-2 - 25Y	DRR-3 - 25Y
R1, R3, R8, R9, R12, R13, R15, R16	R5, R6, R11, R12, R13, R15, R16	R7, R14, R12, R13, R15, R16
Average LOS: 0.27	*Average LOS: 0.27*	*Average LOS: 0.28*
Level B	Level B	Level B

From Table 12, all computed average LOS is also classified as Level B. According to the findings, DRR-1 and DRR-2 had a lower average LOS than DRR-3.

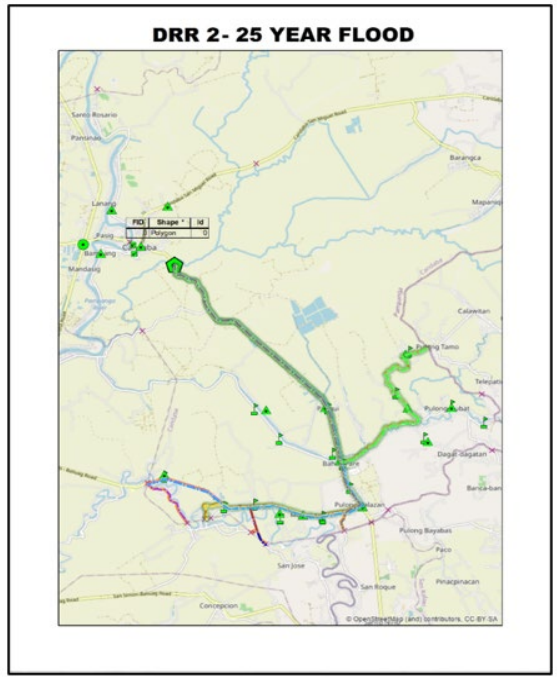

Fig.11. Disaster Response Route 1 for 25-year flood period

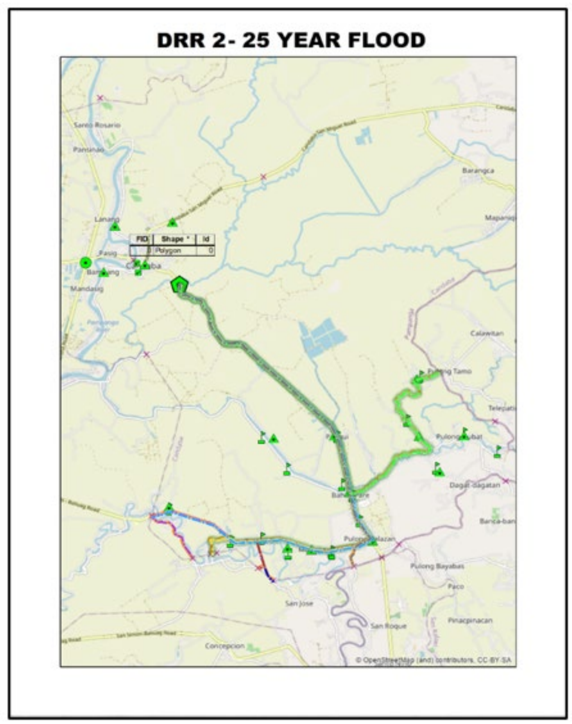

Fig.12. Disaster Response Route 2 for 25-year flood period

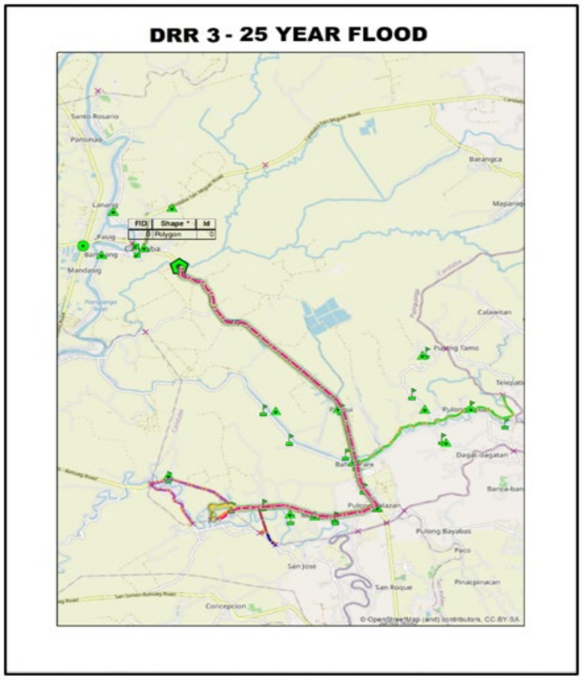

Fig.13. Disaster Response Route 3 for 25-year flood period

Meanwhile, for 100-year flood, as shown in the figure, majority of the routes identified are already submerged to flood and are classified under high flood hazard category. Thus, no routes can be developed as no road links for all the barangays are passable at flood depth beyond 1.5 meters (see Figure 13).

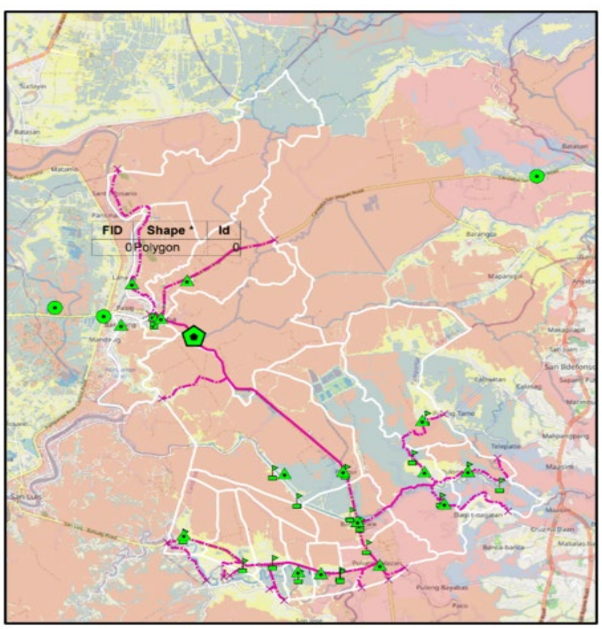

Fig.14. East river side and Tagalog Region under 100-year flood period

IV. Summary of Findings

Table 13 shows the tabulation of the completed Disaster Response Routes under 5-year and 25-year flood period. Meanwhile, no routes were identified during the 100-year flood period since all the previously identified routes were submerged to flood with 1.5m depth (see Table 13).

Table 13. Summary of Disaster Response Routes

5-YEAR FLOOD PERIOD		
(DRR-1)	**(DRR-2)**	**(DRR-3)**
R2, R3, R8, R9, R10,R12, R13, R15, R16	R1, R4, R6, R11, R10, R12, R13, R15, R16	R5, R7, R14, R10,R12, R13, R15, R16
Average LOS: 0.38 Level B	*Average LOS* 0.38 Level B	*Average LOS* 0.41 Level B
25-YEAR FLOOD PERIOD		
(DRR-1)	**(DRR-2)**	**(DRR-3)**
R1, R3, R8, R9, R12, R13, R15, R16	R5, R6, R11, R12, R13, R15, R16	R7, R14, R12, R13, R15, R16
Average LOS: 0.27 Level B	*Average LOS* 0.27 Level B	*Average LOS* 0.27 Level B
100-YEAR FLOOD PERIOD		
All road links considered were submerged to flooding at 1.5m flood depth		

V. Conclusion

Synthesis on Objective 1: To assess flood-prone areas in the municipality of Candaba and determine their flood susceptibility

Through collecting qualitative data from the Candaba MDRRMO and simulation of flood hazard maps in ArcGIS, barangay roads that are safe and prone to flooding were identified. Moreover, the flood susceptibility of these areas was also identified. This motivated the researchers to exclude the barangays, which are not usually affected by low-to-medium levels of the flood. Areas classified under the high flood hazard levels are automatically excluded in the route selection as it is not possible to access these road links with flood depth beyond 1.5 meters.

Due to this, the area of study was limited to the barangays located in the East River Side and Tagalog Region of Candaba, which apparently are the regions with the greatest number of road links with low-to-medium flood hazard levels. Additionally, the number of affected individuals in the two selected regions is the greatest compared to the remaining ones in the municipality. In total, twenty-one (21) barangay road networks were analyzed but road links in barangay Pescadores and Bambang were also excluded during the simulation since these two (2) barangays are already submerged in a 5-year flood period.

*Synthesis on Objective 2***:** To establish disaster response route choices that connects the entry/exit point and the centroid through network analysis

Analyzing the road networks between the 21 selected barangays, entry/exit points assigned in North, West, East, and South directions were identified, and these were all connected to one centroid mapped in barangay San Agustin. With this, about sixteen (16) routes were identified during the 5-year flood period and ranked accordingly. From which three (3) Disaster Response Routes have been developed. On the other hand, three (3) routes were removed from the 5-year flood period, resulting in the routes for 25-year flood period. The removed routes were found to be submerged with flood water during this flood period, giving only thirteen (13) routes passable. These remaining routes were ranked, and another three (3) Disaster Response Routes have been established for a 25-year flood period. However, for a 100-year flood period, all road links within the area of consideration are already submerged with a flood, resulting in no routes passable during this flood period.

Synthesis on Objective 3: To test the Level of Service (LOS) and estimated time delay of the disaster response routes

Eventually, after the simulation and ranking of routes, disaster response units may choose what route to take for 5-year and 25-year flood period given their levels of services (LOS) and total time delays. The length of each route was also calculated along with the number of barangays included in each route, location of evacuation centers, staging areas, schools, and covered courts which are commonly used for disaster operations.

RECOMMENDATIONS:

Flooding may occur drastically and affect a vast number of individuals, but through proper mitigation and prevention at early stages, more lives can be saved. Thus, further action is recommended to deliver faster and more efficient response operations.

For the local government, it is recommended to fully designate or assign the mapped routes for disaster response vehicles only in times of flooding. The municipality is recommended to activate the Disaster Response Routes as necessary during an emergency or after the provincial or local state emergency declaration. With this, rescuers can quickly navigate the roads and provide assistance and transportation for affected individuals. Moreover, disaster response routes make it possible for emergency services and supplies to reach areas rapidly where they are most needed. In response to this, the transportation engineering sector is recommended to provide alternative routes whenever the Disaster Response Routes are closed for public and private vehicles.

Furthermore, future researchers are highly encouraged to use current flood hazard maps available in their studies and rainfall data recorded in the study area. Maps and data illustrating the potential impact of floods and the locations at risk of flooding are made possible using flood hazard information and rainfall data. Updated maps can offer vital information for efficient risk management and disaster planning. Flood risk may change quickly as the climate changes and development proceeds. The efficiency of flood mitigation measures can also be evaluated by researchers using updated flood hazard maps, which can also be used to pinpoint areas that require additional focus. Researchers may guarantee that their conclusions are founded on the most accurate and up-to-date information by using the most recent flood danger maps available, producing more trustworthy and significant results. Moreover, since there are no passable routes identified in a 100-year flood period, future researchers are then recommended to provide supplementary procedures on which disaster operations would still be possible during this flood period.

For evacuation planning, the established disaster response routes are recommended as a basis for evacuation planning in the area of study. The developed DRR map can be used for the innovation of future disaster management plans and as a reference for the local government and MDRRMO of Candaba, in terms of performing relief and rescue operations.

Additionally, since there are no nearby official evacuation centers in the area under consideration, it is advised to construct official evacuation centers inside the East River Side and Tagalog Region for engineering purposes. In places that are susceptible to flooding, evacuation facilities are essential infrastructure for disaster risk reduction and management. Having a designated evacuation center in the case of a flood will assist and make sure that affected people and their families have a safe and secure location to stay while waiting for the floodwaters to subside. Most importantly, these facilities can give people access to essential resources such as food, water, and medical care from disaster response units, which can save lives during a disaster especially flooding.

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