CRITICAL PATH ANALYSIS FOR DISASTER RELIEF EFFORTS IN TYPHOON HAIYAN-AFFECTED MUNICIPALITIES BASED ON MULTI-CRITERIA EVALUATION APPROACH

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ABSTRACT: The Philippines is traversed by an average of 20 tropical cyclones annually. This exposes communities to various hydro-meteorological hazards like strong winds, floods, rain-induced landslides, and storm surges. The delivery of relief services is crucial to ensure that affected communities can recover after these hazards. However, this may be hampered by roads that were damaged or deemed impassable in the said events. This study would map the critical facilities (evacuation centers, hospitals, and government buildings) and the road network. It will employ the use of a population density map generated from delineated built-up areas and the projected population estimates based from previous census results to integrate service area capacity of each critical facility. It would then employ a multi-criteria evaluation approach that considers accessibility, service coverage of critical facilities, and possible debris accumulation (ie. vegetation knocked down by strong winds, rubble from flood and storm surges, landslide deposits). Using network analysis in a Geographic Information System, critical and most efficient routes in transporting relief services will be determined. The identified critical path will be prioritized for clearing operations in times of disasters to ensure the effective facilitation of disaster response efforts. The outputs of the study can be used as a basis in improving disaster preparedness and resource prepositioning planning.

1. INTRODUCTION

Tacloban City is located at the northeastern part of Leyte within the Region VIII of the Philippines (Tacloban.gov.ph, 2015). It has a population of 221,174 (PSA.GOV.PH, 2015) as of the 2010 Census of Population and Housing. On November 8, 2013, Tacloban was heavily affected by Typhoon Haiyan or locally known as Typhoon Yolanda. It was battered by torrential rains and strong winds which then created storm surges that came deep inland. On November 11, 2013, an assessment was released by the European Commission Joint Research Centre (JRC Science Hub, 2013). The assessment indicated that more than 700 residential buildings were destroyed and more than 1200 were damaged by Typhoon Haiyan. Along with the damage in infrastructure, 18 roads were blocked at 113 different locations. As per the report, 70% of the built-up area was damaged and 65% of it was residential.

Days after the event, relief poured in both from local and foreign aid. Unfortunately due to the blocked roads, relief delivery was hampered which caused dismay and frustration to those who were affected (Hodal & Branigan, 2013). This therefore creates the need of a critical path analysis that would aid in the facilitation of disaster relief. Hazard maps have been extensively available through the efforts of Project NOAH (Nationwide Operational Assessment of Hazards) of the Department of Science and Technology but until now there is no study that would determine if our current road infrastructures will remain accessible or useable in times of flooding, landslides, and storm surge events.

2. METHODOLOGY

Road accessibility to critical facilities would be evaluated through the use of network analysis tools of ArcGIS. Service Area Analysis, Location-Allocation-Analysis, and Closest Facility Analysis will be performed with the aid of Project NOAH's flood hazard maps, landslide hazard maps, and storm surge hazard maps. Unpassable roads would be determined using the hazard maps by directly overlaying them with the existing road network data set acquired from OpenStreetMap. Roads that would fall under the hazard rating 2 or 3 were identified as the unpassable roads. Vegetation with heights 3 meters and up was extracted to create a tree fall scenario. Roads caught within the buffer zone of the tree would also be classified as unpassable. The identified roads would then be used to limit the accessibility to the critical facilities in all scenarios as physical barriers within the road network data analysis.

2.1 Service Area Analysis

Service Area analysis would be used to evaluate the current service area of each facility based on distance with 1000, 3000, and 5000 meter breaks to define their service area on a normal day to day scenario. The said analysis would then be re-run with flood, storm surge, and landslide scenarios. The difference between the two service areas would then be computed using the formula:

$$Service\ Area_{Remaining} = \frac{SA_{Hazard}}{SA_{NoHazard}} \quad (1)$$

2.2 Location-Allocation Analysis

In the said analysis, all residential buildings were considered as sources of demands or incident points. From each incident point, the closest facility that has the least impedance would then be calculated through network analysis. The Location-Allocation analysis would then project the existing demands on each critical facility to identify the indicative demand for each health facility.

2.3 Closest-Facility Analysis

Closest-Facility analysis would be used to identify roads which would be prioritized for clearing. In the said analysis, all residential and commercial establishments would be considered as incident points. With the analysis, the closest facility to the incidents would then be evaluated in terms of shortest travel time (STD) from each incident. STD stands for the total time that a moving object takes as it moves from one node to the other nodes in the network by choosing the shortest time spending route. The model expression for the STD (Gil & Steinbach, 2008) is:

$$A_i = \sum_{j=1}^{n} T_{ij}\left(i, j\ \mathrm{C}\ (l, n)\right) \quad (2)$$

A_i is the node accessibility value ranging from 0 to $+\infty$.
T_{ij} is the least travel time from node i to j.
n is the total number of road network nodes.

2.4 Critical Facility Evaluation

Critical facilities would also be evaluated based on their location with the existing hazards in the area to check if the said facilities are actually safe to use in such events. Each facility would capture the existing hazard rating per hazard type. Results where then tabulated to have an overview of the current situation of the said facilities.

2.5 Road Vegetation Analysis

Vegetation along roads was considered if they will post as causes of road blocks. Using the extracted vegetation data of Tacloban City, buffers were made to delineate the possible affected area of the tree in a scenario that they would be uprooted. The buffer for each tree was determined using the tree's height in the assumption that the tree would be completely uprooted. Roads that were covered by the buffers will be considered as non-passable and would later be considered in the critical path analysis.

2.5 Critical Path Analysis

With the use of the same incident points, used in the location-allocation analysis, closest facility analysis would be used to determine the shortest route from each incident point towards the critical facility (i.e. hospitals). Each incident point would then have a unique route which would be assigned a weight with a default value of 1. The road network would then be evaluated to determine the most used roads by each incident point by adding up the accumulated weight of each route that passes through it. The results will then be rendered as a map that would show the utilization of the roads which is indicative of its priority.

3. RESULTS AND ANALYSIS

Figure 1 shows the existing road network dataset of Tacloban City. The computed road length of the network is 389.187 KM. As seen on Figure 2, parts of the road network are no longer available due to flood as defined in the flood hazard map of Tacloban City, 32% of the road network is affected by floods and are unpassable.

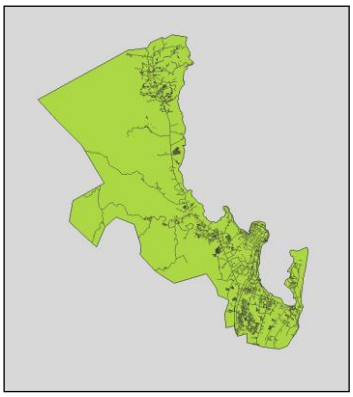


Figure 1. Tacloban Road Network Dataset

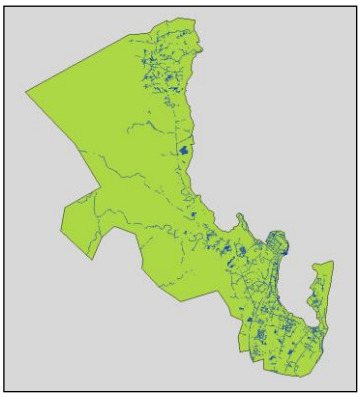


Figure 2. Tacloban Road Network Dataset Post-Flood Scenario

Figure 3 shows the post-storm surge scenario of the road network. In the post storm surge scenario, 50.30% of the road network is unpassable. 6.88% of the road network is made unpassable based on the post landslide scenario as shown on Figure 4. Figures 1, 2, 3 and 4 show that significant parts of the road network of Tacloban are cut-off which significantly paralyzes traffic movement.

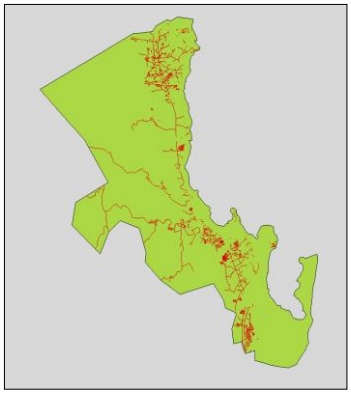


Figure 3. Tacloban Road Network Dataset Post-Storm Surge Scenario

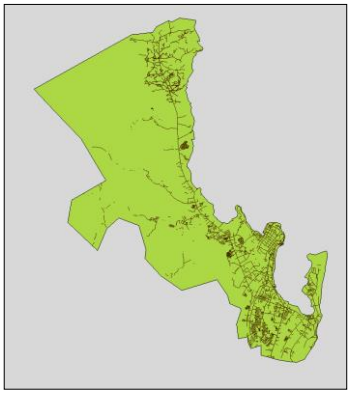


Figure 4. Tacloban Road Network Dataset Post-Landslide Scenario

Table 1 shows the remaining or available road network for each hazard scenario.

Scenario	Total Road Length (KM)	Percentage (%)
Day to day	389.1875	100
Landslide Scenario	362.3985	93.12
Flood Scenario	264.6243	67.99
Storm surge Scenario	193.4055	49.69

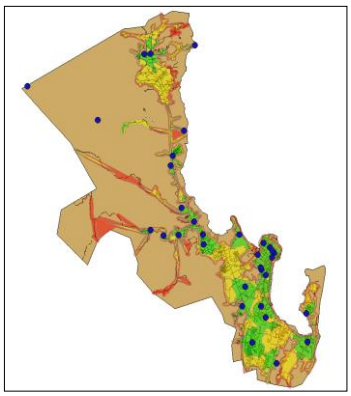


Figure 5. Service area of schools assigned as evacuation sites

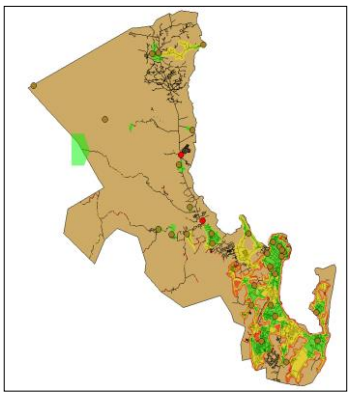


Figure 7. Service area of schools assigned as evacuation sites post-flood scenario

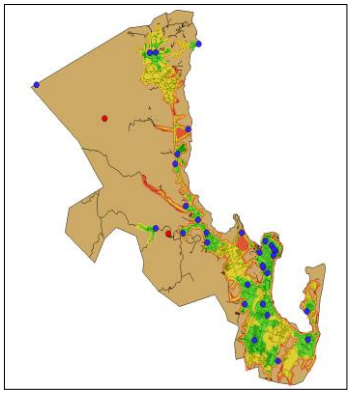


Figure 6. Service area of schools assigned as evacuation sites post-landslide scenario

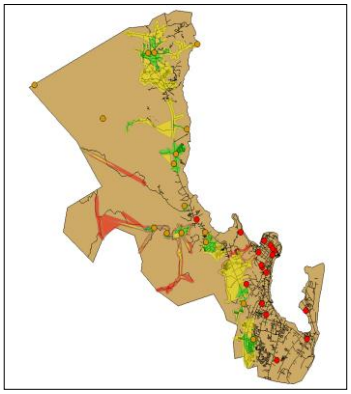


Figure 8. Service area of schools assigned as evacuation sites post-storm surge scenario

Figures 5 is the expected service area of the evacuation sites in a normal day to day scenario. Figures 6 to 7 shows the effects of the different hazards to the availability of the evacuation sites. Among the three hazard scenarios, the storm surge scenario had the greatest effect on the road network data set in terms of the service area of the evacuation sites with a yield of 91.38% decrease in the service area, followed by the flood scenario with a 61.99% decrease and the landslide scenario with a 20.44% decrease. (Please refer to table 1 for more details)

Table 1 shows the remaining or available service area for evacuation sites for each hazard scenario.

Scenario	Service Area (Sq. Km)	Remaining Service Area (%)	Decrease (%)
Day to Day Scenario	38.76	n/a	n/a
Storm Surge Scenario	18.66	48.14	51.86
Flood Scenario	21.26	54.85	45.15
Landslide Scenario	31.07	80.16	19.84

In the different hazard scenarios, some of the evacuation sites are also inaccessible due to floods caused by storm surges and rain or blocked by landslide debris.

Table 2 shows the number of evacuation sites that are accessible during the different hazard scenarios.

Hazard Scenario	Number of Accessible Evacuation Sites	Average Population per Evacuation Site
Storm Surge Event	16	13823
Flood Event	32	6912
Landslide Event	32	6912

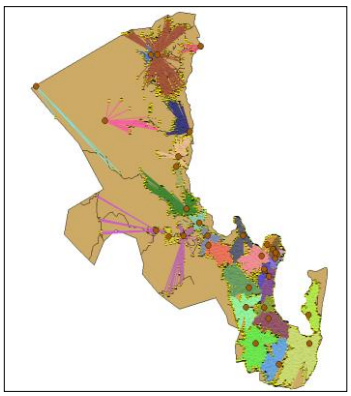


Figure 9. The illustration above shows the result of the location-allocation analysis.

As of 2008, there were 43,415 households with an average household size of 5.1. From the data which was taken from OpenStreetMaps, there were a total of 35,102 households. Figure 9 shows the result of the location –allocation analysis used to derive the current demand per evacuation site. The highest demand that was generated in one single evacuation site yielded 4,373 households which equates to a population of 22,302 while the lowest yielded only 4 households which caters to a population of 20. The average household among the evacuation sites is 1,010 households per evacuation site.

Table 3 shows the number of demands for each evacuation site using Allocation-Location Analysis solving a maximum attendance problem

Names of Schools being used as evacuation sites	Household Demand Count	Population	Percent Population as per Household
Cirilo Roy Montejo National High School (Panalaron NHS)	107	545	0.30
Leyte National High School	488	2488	1.39
Marasbaras National High School	2422	12352	6.90
Sagkahan National High School	2613	13326	7.44
Tacloban City National High School	940	4794	2.68
Tacloban City Night High School	43	219	0.12
Anibong Elementary School	1562	7966	4.45
B. Bulante Elementary School	248	1264	0.71
Bagacay Elementary School	194	989	0.55
Basper Elementary School	506	2580	1.44
Bliss Elementary School	1356	6915	3.86
Cabalawan Elementary School	282	1438	0.80
Cabolo-an Public School	4	20	0.01
Camansihay Elementary School	119	606	0.34
Don Vicente Quintero Elementary School	1329	6777	3.79
Fisherman's Village Elementary School	1423	7257	4.05
Kapangian Central School	1975	10072	5.63
Lucio Vivero Elementary School	1210	6171	3.45
Mercyville Elementary School	649	3309	1.85
Nula Tula Elementary School	990	5049	2.82
Old Kawayan Elementary School	126	642	0.36
Palanog Elementary School	227	1157	0.65
Palanog Resettlement ES	205	1045	0.58
Panalaron C Elementary School	220	1122	0.63
Remedios T. Romualdez Elementary School (Rizal Central Annex ES)	224	1142	0.64
Rizal CS	577	2942	1.64
Sagkahan Elementary School	1371	6992	3.91
San Fernando C Elementary School	1735	8848	4.94
San Jose Elementary School	4373	22302	12.46
Sto. Nino Elementary School	369	1881	1.05
Sto. Nino SPED Center	399	2034	1.14
Tigbao-Diit Elementary School	394	2009	1.12
Utap Elementary School	1678	8557	4.78
V & G Mem. Elementary School	3994	20369	11.38

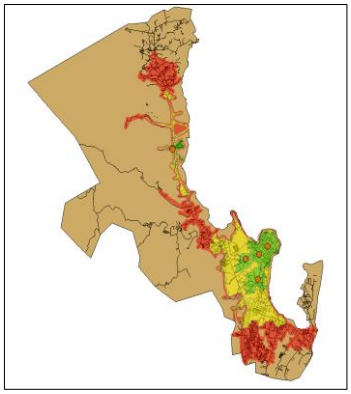


Figure 10. Service Area analysis for Hospitals

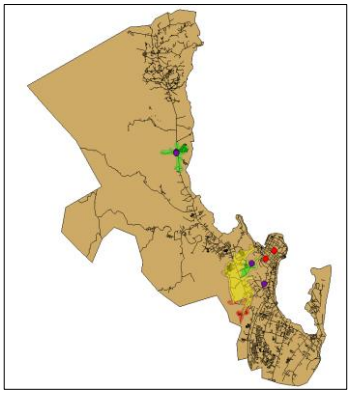


Figure 11. Service Area for Hospitals in Storm Surge Hazard Event

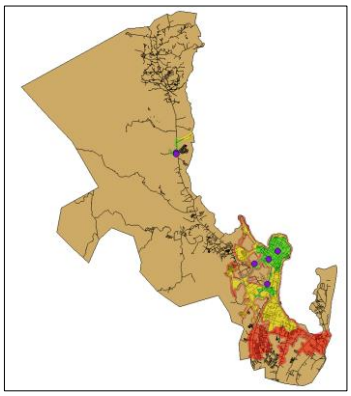


Figure 12. Service Area analysis for Hospitals with Flood Hazard Event

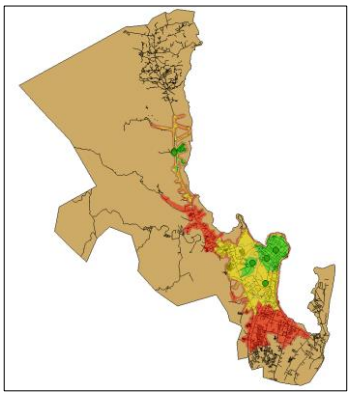


Figure 13. Service Area analysis for Hospitals with Landslide Hazard Event

Service area analysis was performed on the hospitals of Tacloban City. As seen from figures 10 to 13, hospital service areas were significantly degraded for each hazard event. As seen from the illustrations, a storm surge event greatly affected the service areas of the hospitals. Though as seen on Table 4, most of the hospitals remained accessible in the three hazard events.

Table 4 shows the remaining or available service area for hospitals in each hazard scenario.

Scenario	Service Area (Sq. Km)	Remaining Service Area (%)	Decrease (%)	Number of Accessible Hospitals
Day to Day Scenario	26.52	n/a	n/a	5
Storm Surge Scenario	4.40	16.59	83.41	4
Flood Scenario	14.32	54.00	46.00	5
Landslide Scenario	18.46	69.61	30.39	5

Location-Allocation Analysis was also done with the hospitals. Based on the data collected from OpenStreetMap, there are 5 hospitals that were located in the city. From the analysis, it was found that the Mother of Mercy Hospital had the highest demand based on its geographical location which yielded 100,842 of the population based on households. While a maternity hospital had the lowest demand of 8,180. With the 5 located hospitals, it can be said that the average demand for each hospital is at 44,234 in terms of the population (Please refer to table 5 for complete details of location-allocation analysis results).

Table 5 shows the number of demands for each hospital site using Location-Allocation Analysis solving a maximum attendance problem

Name of Hospital	Household Demand Count	Population (Household demand*Average Household Population)	Percent Population as per Household
Divine Word Hospital	3651	18620	10.63
Maternity Hospital	1604	8180	4.67

Mother of Mercy Hospital	19773	100842	57.60
Tacloban Doctor's Hospital	4098	20899	11.94
EVRMC	5204	26540	15.16

Critical facilities were also evaluated based on their spatial location with respect to the hazard maps. The critical facilities included hospitals, schools, schools used as evacuation sites, government institutions, and police stations. Results show that 7 of the 35 government institutions are hazard free (please refer to table 6 for complete details), 1 out of the 3 police stations is hazard free (please refer to table 7 for complete details), 2 out of 5 hospitals are hazard free (please refer to table 8 for complete details), and 10 out of 34 evacuation sites are hazard free (please refer to table 9 for complete details). Most of the critical facilities are susceptible to hazards.

Table 6. Hazard Rating of each Government Facility

Name	Flood Hazard Rating	Storm Surge Hazard Rating	Landslide Hazard Rating
DepEd Tacloban	2	1	0
NBI Office	0	2	0
Pag-Ibig Fund	0	2	0
COMELEC	0	2	0
Land Transportation Authority	0	2	0
Leyte Provincial Capitol	0	2	0
Department of Agrarian Reform RO 8	1	3	0
Bulwagan ng Katarungan	1	3	0
Department of Environment and Natural Resources	1	3	0
Tacloban City Division	1	3	0
Bulwagan ng Katarungan	1	3	0
Land Transportation Office RO 8	2	3	0
National Telecomunications Communication	2	3	0
Tacloban City Convention Center	0	3	0
Department of Budget and Management	0	3	0
Provincial Governor's Office	0	3	0
Provincial Engineer's Office	0	3	0
Legislative Office	0	3	0
Bangko Sentral ng Pilipinas	0	3	0
Civil Service Commission Provincial Office	0	3	0
Government Service Insurance System	0	3	0
National Housing Authority	0	3	0
DOLE	0	3	0
DSWD-RO8	0	3	0
Social Security System	0	3	0
CHED R08	0	3	0
Engineering Building	0	3	0
Department of Budget and Management	0	3	0
Tacloban City Hall	0	0	0
Engineering Building	0	0	0
PCSO	0	0	0
National Statistic Office	0	0	0
DILG Regional Office Region 8	0	0	0
Department of Agriculture Regional field Unit No	0	0	0
Sanguniang Panglungsod	0	0	0

Table 7. Hazard Rating of Police Stations

Name	Flood Hazard Rating	Storm Surge Hazard Rating	Landslide Hazard Rating
Sagkahan Police SubStation	0	3	0
PNP	0	3	0
Tacloban City Police Station	0	0	0

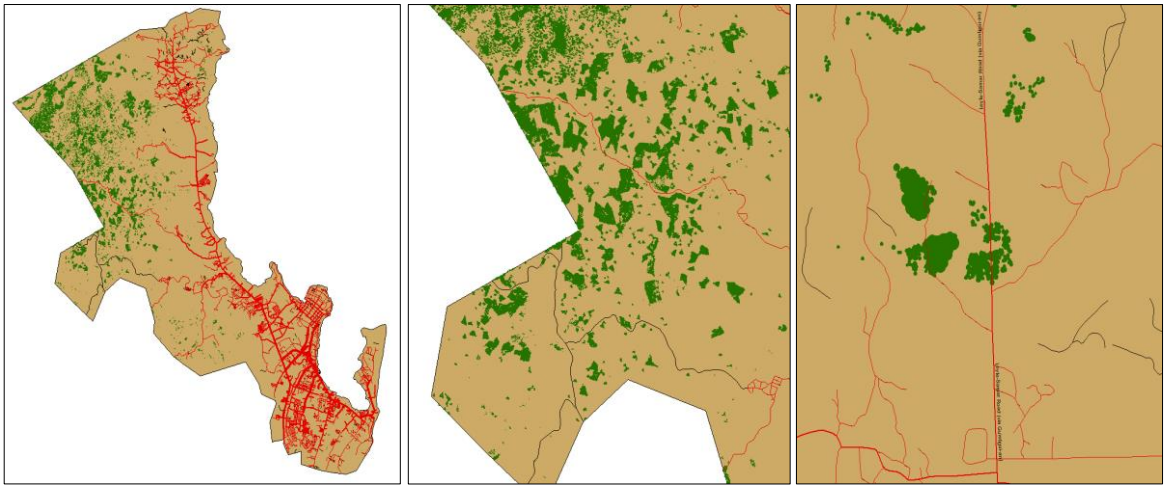
Table 8. Hazard Rating of Hospitals

Name	Flood Hazard Rating	Storm Surge Hazard Rating	Landslide Hazard Rating
Maternity Hospital	0	2	0
Mother of Mercy Hospital	0	2	0
Divine Word Hospital	0	3	0
Tacloban Doctor's Hospital	0	0	0
EVRMC	0	0	0

Table 9. Hazard Rating of schools functioning as an evacuation sites.

Name	Flood Hazard Rating	Storm Surge Hazard Rating	Landslide Hazard Rating
Cirilo Roy Montejo National High School (Panalaron NHS)	0	0	3
Leyte National High School	0	0	3
Marasbaras National High School	0	0	1
Sagkahan National High School	2	2	0
Tacloban City National High School	0	2	0
Tacloban City Night High School	0	2	0
Anibong Elementary School	0	2	0
B. Bulante Elementary School	1	3	0
Bagacay Elementary School	1	3	0
Basper Elementary School	1	3	0
Bliss Elementary School	1	3	0
Cabalawan Elementary School	1	3	0
Cabolo-an Public School	1	3	0
Camansihay Elementary School	2	3	0
Don Vicente Quintero Elementary School	2	3	0
Fisherman's Village Elementary School	0	3	0
Kapangian Central School	0	3	0
Lucio Vivero Elementary School	0	3	0
Mercyville Elementary School	0	3	0
Nula Tula Elementary School	0	3	0
Old Kawayan Elementary School	0	3	0
Palanog Elementary School	1	0	0
Palanog Resettlement ES	1	0	0
Panalaron C Elementary School	2	0	0
Remedios T. Romualdez Elementary School (Rizal Central Annex ES)	0	0	0
Rizal CS	0	0	0
Sagkahan Elementary School	0	0	0
San Fernando C Elementary School	0	0	0
San Jose Elementary School	0	0	0
Sto. Nino Elementary School	0	0	0
Sto. Nino SPED Center	0	0	0
Tigbao-Diit Elementary School	0	0	0
Utap Elementary School	0	0	0
V & G Mem. Elementary School	0	0	0

Figure 14 shows the debris coming from wind felled trees. It can be said that they do not severely hamper the road network system of Tacloban City but it blocks off alternate entry and exit points from the city specifically entry from and exit to Alangalang . Figure 14 (b) shows the entry and exit point to Alangalang, Leyte being possibly blocked by wind felled trees. Figure 14 (c) shows another possible scenario of wind felled trees blocking part of the Leyte-Samar Road going to Babatngon, Leyte. From the study, it was found that 24 roads that may be affected or blocked by the said wind felled trees.



(a) (b) (c)

Figure 14

Figure 15 shows the road utilization based on a closest facility analysis from possible incident points (residential houses) to health facilities (hospitals). The thicker the road representation entails a higher priority for road clearing for post disaster scenarios. The same can be said with relief operations, the same procedure can be done in terms of prioritizing road clearing operations. Priority was identified based on the number of routes that passed through a particular section of the road.

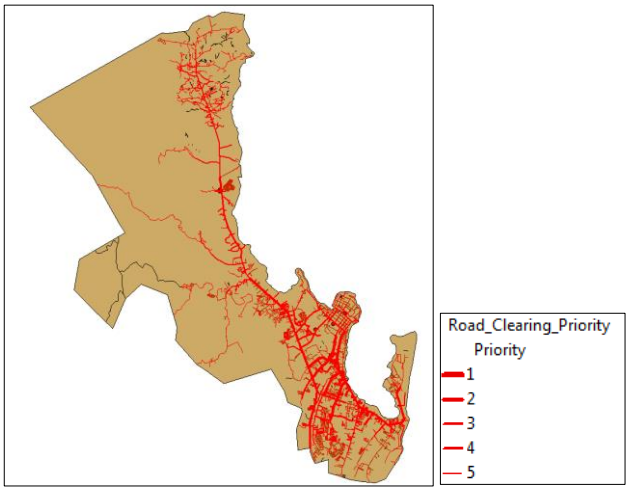


Figure 15. The figure above shows the most utilized roads from residential areas to hospitals.

4. CONCLUSIONS AND RECOMMENDATIONS

It can be said that the road network plays a critical role in the delivery of disaster relief. As it was previously illustrated, different hazards significantly impede the movement of people and disaster relief which would cause further loss in terms of lives and property. Thus, it is very important to identify parts of the road network that would be affected in the said scenarios so as to produce countermeasures for an effective disaster mitigation and response mechanism. Some solutions that may be considered to ensure the effective flow of disaster relief are to elevate the affected roads, construction of flood mitigation infrastructures and the like.

The study also shows that most of the critical facilities in Tacloban City are hazard prone most especially to storm surges. It is highly recommended therefore that they may either be made resilient to storm surges or worse be relocated. Hospitals and evacuation sites play an important role during pre- and post-disaster operation. It is utmost importance the Tacloban City should reconsider the choice of their evacuation sites since most of them are susceptible to flooding and storm surges which may entail more loss instead of relief to the evacuees.

It can also be said that some of the vegetation that are located along the roads of Tacloban should be monitored regarding their growth since they pose a threat of being possible blockades in a post-typhhon scenario. Relocation of the said trees can also be considered.

The same study may be recommended in other cities and municipalities that are located in the Yolanda Corridor to increase their disaster preparedness, to assess mobility in disaster events, and to ensure the effective delivery of disaster relief.

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