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ASSESSING VULNERABILITIES AND COSTS OF POWER OUTAGES TO EXTREME FLOODS IN SURIGAO CITY, PHILIPPINES

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ABSTRACT: Surigao city is a coastal community located in the north eastern part of the county. It is vulnerable to rain-induced floods and storm surges. Although direct flood damage to electrical infrastructure is rare, power outages are applied to prevent electrocution in communities. In this regard, the authors investigated several local districts in Surigao city to observe the vulnerability of households to power outages caused by flood events. This information will help the local network operator, Surigao del Norte Electric Cooperative (SURNECO), reduce power interruption and inconvenience. This study simulates flood events of 5,10,25 and 50-year 24-hour rainfall-flood event against a backdrop of an electrical distribution network and geotagged households in four urban coastal barangays. Results show that the estimated power loss for two (2) days is about US$ 8000 per day of outage. The depth and velocity (*d-v*) product also shows that about 22% of the households are affected specifically for a 50-year 24-hour rainfall-flood event. The cost model based on a two-day power loss duration analysis shows that the loss range is from US$7,781 to US$8,676 for the different return periods. The household survey also shows that the average inconvenience loss is about US$ 11/hour.

Keywords: Extreme flood, Power outage, Resilient community, D-v product

1. INTRODUCTION

Many countries in the world experience extreme flood inundations. Severe storms or typhoons generally bring heavy precipitation after making landfall. During extreme flooding, unfortunate situations happen such as loss of power, loss of functionality of lifelines, loss of medical services and often lead to deaths [1– 4]. The Philippines is no stranger to this phenomenon. Every year, about 20 to 30 typhoons enter the Philippine Area of Responsibility (PAR). After making landfall, these typhoons bring about heavy downpour and flooding over a wide area. In November 2020 Typhoon Ulysses (International name: Vamco) made landfall in the Philippines causing widespread power outage [5]. Raging flood waters (function of velocity and depth) also pose a risk to households and livelihood [6].

Electric power lifelines are indispensable systems in modern society. If this critical lifeline is damaged and becomes unavailable due to an extreme event, the power provider incurs losses, and end-use consumers are inconvenienced, and their activities are restricted. With the current trend to improve power reliability and resilience, power utility providers adapt measures to reduce outage and consequently money loss. This is good for the supply side. On the demand side, end-use consumers, can be at risk and be faced with considerable burden from power outage because of their geographic location.

Most of the fragility curves focus on structures; however, this study takes on a household-centric approach. Instead of focusing on lifeline structure, the authors propose to look at the vulnerability of the households to different flood depths leading to power outage. To illustrate the framework, the approach is applied to a small city in the Philippines. Flood modeling and simulation are used with geographic information system (GIS), and showed the vulnerability of the households to different flood heights, the corresponding monetary risk to the power producer and the inconvenience loss to the households.

2. METHODOLOGY

2.1 The Approach

The research focuses on quantifying power outage losses based on decisions by service provider to ensure life safety during extreme flooding. In this paper we consider flood hazard characteristics such as extreme depths and the *d-v* (depth-velocity) product and its effects on households. The approach to loss estimation involves three parts, namely: a) development of vulnerability curves for power loss due to extreme flooding of the power supplier, b) possible household damage due to the depth-velocity (d-v) product [7] and c) the estimated inconvenience loss of the households due to the power outage. Flood hazard vulnerability was quantified using the flood depth and velocity combinations (*d-v* product). Use of this product is useful to index vulnerability of community and its assets. Thresholds had been identified for indicating a) stability of people to walk [8] or drive [9] through a flood; b) potential damage to structures [10] and as c) constraints for land use planning. Ranges of products *d-v* < 2.0 unsafe for people and vehicles, *d*-v < 4.0 generally makes it unsafe for people and vehicles, and buildings vulnerable to structural damage. Increasing *d-v* > 4.0, generally indicates unsafe conditions for vehicles, people and all buildings are considered vulnerable to failure [11]. Figure 1 presents the framework of this research.

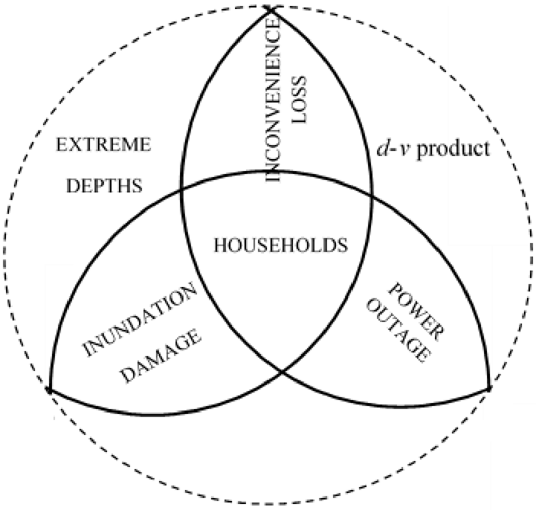

Fig. 1 The framework of the research

2.2 The Study Area

The study area is Surigao City (9°41'16" N, 125°29'30" E), the capital city of Surigao del Norte in the Philippines. The city falls under the Type II climate (with four main climate regimes) [23] thus has a pronounced maximum rainfall starting in November to January. Table 1 shows the average monthly rainfall in Surigao City. Based on the table, January has the highest rainfall (wettest), and August is the driest month (lowest rainfall).

The study areas of the research cover the urban barangays of San Juan, Washington, Taft and Canlanipa, and shown in Fig. 2. As of August 1, 2015, the population of these four barangays reached 62,093 [16]. The light-yellow dots in this figure are the 14,387 consumers in the urban barangays and gathered through a geo-tagging survey of households connected to the electrical power system managed by SURNECO (Surigao Del Norte Electric Cooperative). which is the local electric power provider. At present, it supplies power to 57,728 households and has an annual peak load demand of 25 MW [17].

Table 1 Average monthly rainfall in Surigao City (Source: weather-atlas.com)

Month	Monthly Average Rainfall (in mm)	Month	Monthly Average Rainfall (in mm)
January	582.3	July	137.8
February	389.2	August	113.3
March	283.5	September	122.4
April	196.3	October	216.0
May	123.5	November	378.3
June	114.2	December	429.4

2.3 Flood Modelling and Simulation

The two-dimensional flood inundation model was developed using HEC-.HMS 4.3 [18] for the flow model and the HEC-RAS 5.0 [19] for the inundation model. These models are based on ease of developing the 2-D model with a digital terrain model (DTM) of ten (10) meter grid resolution. The channel cross sections and alignments were derived from river bathymetry in 2011 and validated in 2018. Tide elevations were used for the outflow boundary condition. Flood canals and storm drainage were not integrated into the model due to lack of surveys on the sewers.

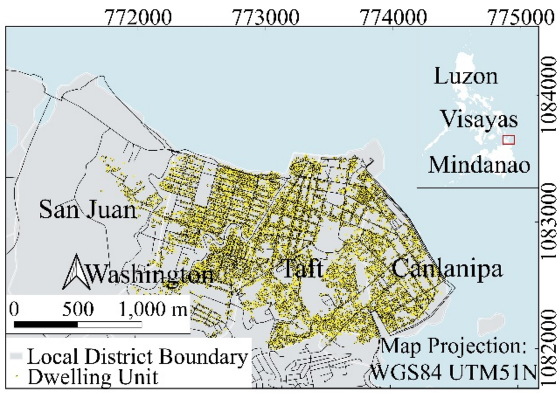

Fig. 2 Surigao city urban areas. The yellow dots are the consumers.

Four flood models, each representing a hypothetical rainfall flood event were constructed and shown in Table 2. Hyetographs for 5, 10, 25 and 50-year design rainfall return periods were based on the Rainfall Intensity Duration Frequency (RIDF) tables obtained from PAGASA weather station located in Surigao City [16]. The alternating block method [17] was applied on the RIDF data to produce the hypothetical 24-hour distribution rainfall with the maximum intensity occurring on the 12th hour (*i.e.* middle peak).

Table 2 Rainfall totals with Return Period (Source: PAGASA, 2017)

Return Period (yrs)	Rainfall Depth (mm)
5	308.9
10	377.8
25	464.9
50	529.5

Flood simulation provided information on flood characteristics in terms of water depth (*d*-[m]), flow velocity (*v*-[m/s]) and inundation time (*t*) under depth $d > 0.5$m. Based on simulation runs, the period of flooding for the different rainfall events was about 48 hours. The hazard for a consumer (here defined as equivalent to one household in one dwelling unit [DU]) was based on its location in the inundated area. This study uses the flood depth ($d \geq 0.5$m) and the product of flood depth and velocity *(d-v)* as *indicators* of threats to life safety and building vulnerability to failure. The water depth is measured by the difference between the flood elevation and the dwelling units' (DU) ground floor elevation. Here, a DU's ground floor elevation was taken to be same as the ground elevation. These were estimated using the digital terrain model values and were assumed accurate to within ± 0.2m. Elevation transects, taken in 2011 were also used to check precision of the DTM elevation. Figure 3 shows the extent and depth distribution of the flood depths for the different return periods.

2.4 Vulnerability and Risk Curves

2.4.1 Power loss vulnerability curves for households

To develop the vulnerability curves for power loss, three flood depth hazard ranges were considered, and the corresponding number of consumers affected were counted for each range:

- $0.5 \leq d < 1.5$ m
- $1.5 \leq d < 3.0$ m
- $d > 3.0$ m

The lower bound of the flood depth range was set at 0.5m to consider a typical height of the power outlet from the ground floor elevation of a dwelling unit. Using GIS tools, depth values from the flood map were extracted and assigned to each dwelling unit and were further categorized using the flood depth hazard ranges. A plot of the water depth d (*x*-axis) against the number of households (*y*-axis) over the flooding period and the total number affected based on the highest flood depth on grid (10m) was used to develop the vulnerability curve.

2.4.2 Risk curve for power for power producers

A risk curve for the [temporary] power outage was derived from the following parameters: (a) the number of affected households for each MRI; and (b) average residential electricity rate in Peso (or US$) per kWh. Their product results in the power loss in peso (or US$) in one hour. The risk curve is then a plot of the power loss on the *x*-axis against the inverse of the MRI on the *y*-axis.

2.5 Damage Possibility Based on *d-v* Value

To develop the safety and damage possibility table, categories using the criterion of Smith et al [10] and a distribution of *d-v* values over the inundated areas were categorized and interpreted as follows:

- $d\text{-}v < 2$ m^2/s means unsafe for people and vehicles;
- $2\text{m}^2/\text{s} \leq d\text{-}v < 4$ m^2/s means unsafe for vehicles and people, and buildings that are less robust are vulnerable to failure;
- $d\text{-}v \geq 4$ m^2/s means unsafe for vehicles and people, and all building types are considered vulnerable to failure.

2.6 Inconvenience Loss Due to Power Outage

A survey was conducted to estimate the monetary equivalence of the inconvenience experienced by a household during a power outage.

Table 3 Flood affected consumers ($d \geq 0.5$m)

	Consumers not affected				Consumers affected			
Barangays	5-yr MRI	10-yr MRI	25-yr MRI	50-yr MRI	5-yr MRI	10-yr MRI	25-yr MRI	50-yr MRI
Canlanipa	2,366	2,346	2,298	2,282	719	739	787	803
San Juan	193	192	192	192	47	48	48	48
Taft	6,189	6,178	6,135	6,098	428	439	482	519
Washington	4,110	4,110	4,110	4,110	335	335	335	335
	12,858	12,826	12,735	12,682	1,529	1,561	1,652	1,705

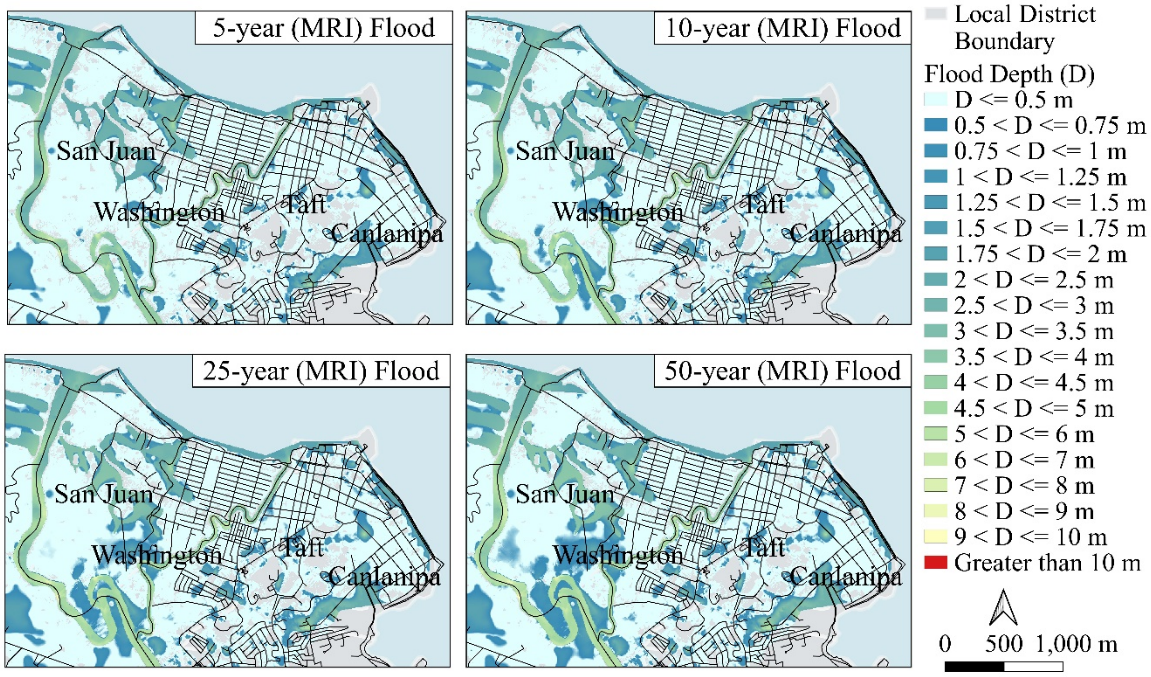

Fig. 3 Depth distribution under different return period floods

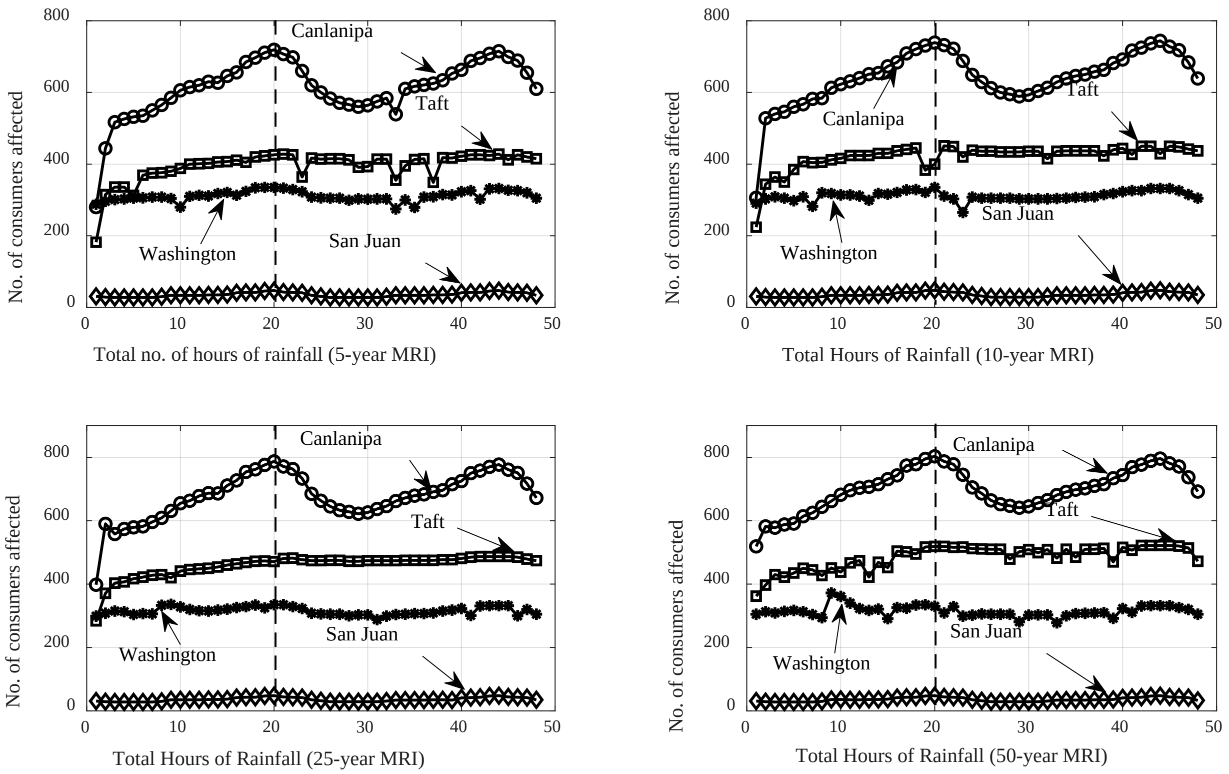

Fig 4. Hourly number of households affected for flood depths of different MRIs (in 48 hours)

A total of 1.021 households were surveyed, and respondents were asked to affirm the power losses during flood events, list the inconveniences it brought to them and rate each item (1 is least important and 4 is most important) listed according to importance to address the concern. Finally, respondents gave estimated costs of the inconvenience (in pesos) based on their responses in a one-hour power outage.

3. RESULTS AND DISCUSSION

3.1 Flood Simulated Results

The results of the flood modelling are extreme flood heights with the following mean recurrence intervals (MRIs): 5, 10, 25 and 50 years. Table 3 presents the flood affected consumers under $d \geq 0.5$m. It shows that barangays Taft, Canlanipa and Washington have the greatest number of consumers affected by flooding. Furthermore, the count under a five-year rainfall- flood event practically identifies the affected consumers. Figure 4 shows the hourly distribution of affected consumers under different MRIs. The number of affected persons peak during the 20th hour of the simulated flooding. An initial estimate of the length of time of power outage is 48 hours (2-days) based on the period of flood event with depth $d \geq 0.5$m.

3.2 Vulnerability Curve for Power Loss

A plot of the percentage of consumers affected with the three ranges is shown in Figure 5 and represents the depth-based vulnerability curves for power loss. A summary of the total number of consumers affected is shown again in Table 4. If a household consumes an average of 12 kWh/day [22] and the average household electricity rate is PhP 10.60 / kwh, then the estimated power loss for two (2) days is roughly 0.2 million pesos each day of outage.

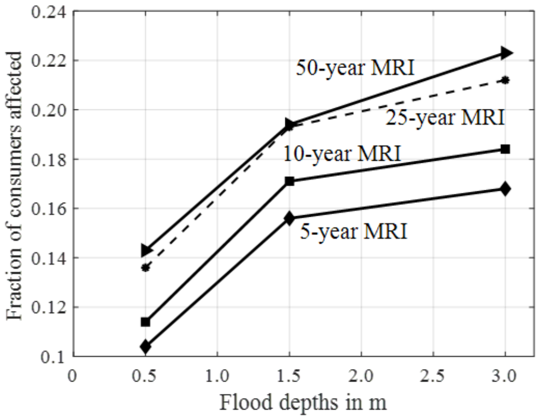

Fig. 5. Vulnerability curves for power loss

Table 4 provides a summary of the potential revenue loss for each hypothetical flood events. Figure 6 gives the risk curve. Annual expected revenue loss based on the three probabilities is US$ 1,447.5.

Table 4 Potential Revenue Loss during Flooding

Return Period	Consumers affected	Power Loss (PhP)	Power Loss (US$)*
5	1,529	389,027	7,781
10	1,561	397,169	7,943
25	1,652	420,322	8,406
50	1,705	433,807	8,676

*Exchange rate = 50 PhP/ US dollar

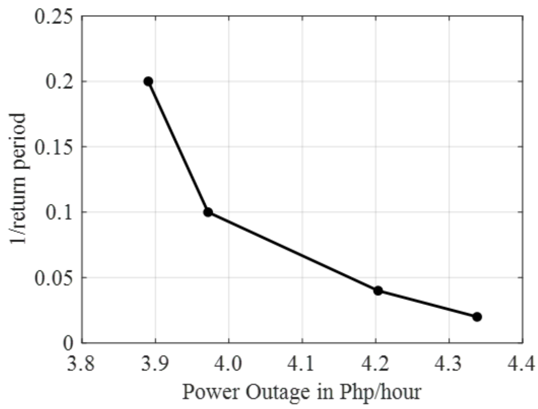

Fig. 6 Risk curve for power loss due to flooding

Based on the results, flood events under the 5-year MRI in Surigao city already gives an indication of the number of consumers affected and an estimate of cost of outage. An increase in number of consumers affected appear to be gradual with an increase in flood magnitude.

3.3 Vulnerability of Households

The result of the flood simulations generated information that included the product of the water depth and velocity for different return periods. With this, the damage that can be incurred due to flood for all MRIs can be estimated using the categories from the adjusted Clausen criterion.

Table 5 gives a distribution of affected households under the different *d-v* ranges. More than 90% of the households in the local districts of. Canlanipa, Washington, and Taft fall under $d\text{-}v < 2$ m^2/s and generally makes it “unsafe for people and vehicles” for all MRIs. While structures may be of lesser concern, life safety becomes the primary concern.

Table 5 *d-v* distribution of households

d-v ranges	Bgy. Canlanipa 5-yr MRI	10-yr MRI	25-yr MRI	50-yr MRI	Bgy. San Juan 5-yr MRI	10-yr MRI	25-yr MRI	50-yr MRI
d-v <= 2	2,561	2,580	2,603	2,632	174	181	192	195
2 < *d-v* <= 4	47	77	55	73	0	0	1	0
d-v > 4	68	67	95	81	0	0	0	1
Total	2,676	2,724	2,753	2,786	174	181	193	196
d-v ranges	Bgy. Washington 5-yr MRI	10-yr MRI	25-yr MRI	50-yr MRI	Bgy. Taft 5-yr MRI	10-yr MRI	25-yr MRI	50-yr MRI
d-v <= 2	3464	3522	3544	3603	4732	4753	4836	4832
2 < *d-v* <= 4	70	62	97	91	177	236	247	319
d-v > 4	116	145	173	190	123	160	255	263
Total	3650	3729	3814	3884	5032	5149	5338	5414

Table 6 Results of the survey on inconvenience of power outage

Causes of inconvenience	Average inconvenience Rating, *R* (range:1 - 4) San Juan	Washington	Taft	Total	Rank
cannot charge gadgets	1.65	2.93	3.56	3.08	1
cannot use electric fan	1.48	2.83	3.08	2.81	2
cannot use television (TV)	1.72	2.99	2.80	2.80	3
impaired visibility due no lighting	1.19	2.05	3.47	3.47	4
spoilage of food due to no refrigeration	0.90	2.50	2.02	2.02	5
cannot use washing machine	0.66	2.31	1.04	1.04	6
cannot use the radio	0.87	1.81	0.68	0.68	7
cannot use internet (WiFi)	0.55	1.94	0.42	0.42	8
cannot use computers	0.51	1.63	0.17	0.170	9
cannot use air conditioner (AC)	0.47	1.55	0.22	0.87	10

Generally, the houses that are located farther from the Surigao riverbanks exhibit *d-v* < 2. For d-v > 4, the houses counted were found to be nearer the Surigao river where flood depths are deeper, and velocities are higher.

Cross-referencing the counts in Tables 3 and 5, the greater numbers of houses are found in grids where depths $d \leq 0.5$m and *d-v* < 2. In barangay Taft, the number of houses under *d-v* ≥ 2 exceed the numbers of houses under $d \geq 0.5$m under the 25 year and 50-year return period. This may indicate that the velocity parameter begins to influence the nature of hazard. San Juan has the least number of affected households considering its small population.

3.4 Inconvenience Loss Due to Power Outage

The result of the survey of 1,021 households is reflected in Table 6. It appears that inconvenience from power loss mean possible loss of communication as well. Also based on survey, the average inconvenience loss per hour is about Php 580 (US$ 11/ hour).

4. CONCLUSIONS

It is desirable that communities are able to recover and resume their normal activities as quickly as possible after a disaster. The study shows that SURNECO incurs a loss of around US$7,781 to US$8,676 for a two-day power outage for different return periods of extreme flood events. As such, the use of depth *d* and *v-d* parameters can influence SURNECO's priorities and policies to reduce revenue loss and especially avoid loss of lives. These two parameters also show that a 50-year 24-hour rainfall-flood event will affect about 22% of households in the study area.

Inconvenience loss is also introduced in this study to substantiate what households are likely to lose during a power outage. The survey of 1,021 households show that the inconvenience loss due to power outage is approximately US$ 11/hour.

For future work, this paper can be scaled up to consider implications to emergencies and property protection.

5. RECOMMENDATIONS

The assessment of the damage potential for each household was done on a macro level. To further improve the output, the authors suggest conducting a micro-level assessment of each household considering other parameters such as typology, wall type, household flood defense, among others.

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