Mapping Super Typhoon Odette (STY Rai)-Induced Storm Surge Hazard in the Municipality of San Juan, Southern Leyte, Philippines

Semblante, O.D. [1*], Loreto, L.M.A.[2], Laurente, M.L.[3], and Marte, J.Z.C.[4]

[1]Department of Physics, Visayas State University, Philippines

[2]Philippine Atmospheric, Geophysical and Astronomical Services Administration, Department of Science and Technology, Philippines

[3]Regional Climate Change Research and Development Center, Visayas State University, Philippines

[4]Department of Meteorology, Visayas State University, Philippines

*oliver.semblante@vsu.edu.ph

Abstract: *Storm surges are a threat to coastal communities. The most recent devastation in the Philippines was brought by Super Typhoon Odette (STY Rai) in 2021 with confirmed reports of storm surge occurrences. One of the severely damaged areas is the Municipality of San Juan, Southern Leyte in the eastern part of the Philippines facing the Pacific Ocean. While local government units in the country are required to integrate Climate and Disaster Risk Assessments (CDRA) in their Comprehensive Land Use Plans (CLUP), there was no consideration of storm surge hazard in the municipality's CDRA. Part of this dilemma is unavailability of detailed hazard map. In this study, we report a storm surge hazard mapping in the Municipality of San Juan, Southern Leyte based on actual occurrence during landfall of STY Rai. Ground data on storm surge inundation depths and extents were collected from eyewitnesses through a survey in 14 affected barangays. Using these anecdotal water level data, we plotted their geographical locations in QGIS and interpolated them using Inverse Distance Weighted interpolation to come up with a generalized pattern of STY Rai-induced storm surge for the entire municipality. Based on the storm surge classification scale indicated by the state weather bureau, 6 barangays showed high exposure levels (having inundation depths >4 meters); 5 barangays were predominated by moderate exposure (1.01 – 4 meters); and the remaining 3 barangays at low exposure (less than a meter inundation depth). Due to STY Rai's category, the exposure levels obtained therefrom are expected to provide an extreme case scenario. The storm surge hazard map generated herein would lay the foundation for the Municipality of San Juan to craft a more accurate CDRA, and hence a better CLUP.*

Keywords: *Storm Surge, STY Odette (Rai), Exposure Mapping, Disaster Management*

Introduction

In the World Risk Report 2022, the Philippines topped the list having significant exposure to natural hazards with typhoons being the most recurrent. There are about 20 tropical cyclones (TC) entering the Philippine Area of Responsibility (PAR) each year, with about 8 or 9 of them traversing through the archipelago from 1948-2023. The most devastating typhoon by far is Super Typhoon (STY) Haiyan - locally known as Yolanda in 2013, incurring an estimated damage of 95.5 billion pesos (Gonzales, 2020). In 2021, STY Rai - locally known as Odette, wreaked havoc in the country resulting in agricultural and infrastructural damages amounting to about 47 billion pesos (Andrade, 2022). In most cases of TCs, the majority of the damages sustained are caused by the TC-induced secondary hazards such as flooding, lightning, storm surges, landslides, among others (Jonkman et al., 2009; Lin, et al, 2015; Yan et al., 2016). Kinghorn (2018) reported that the storm surge induced by STY- Haiyan in 2013 was even more destructive than the typhoon itself, which eventually led to more than 6000 deaths (Locsin, 2014). When STY-Rai ravaged the province of Southern Leyte province in the Philippines, leaving 21 people dead and 11 missing (Lim, 2021). The National Disaster Risk Reduction and Management Council (NDRRMC) considered the Municipality of San Juan (or San Juan for brevity) in Southern Leyte, as one of the most severely affected areas by storm surge and having the most casualties as four people died and nine reported missing (Philippine Information Agency, 2022). San Juan is a low-lying area situated near the southernmost tip of the province, facing the Leyte Gulf. Furthermore, its population density is 160/km^2 based on 2020 census with about one-fifth of its total residences situated within 200 meters from the coastline (Philippine Statistics Authority, 2020). This highlights the importance of disaster preparedness, mitigation, and adaptation measures, which can reduce the impacts of future disasters in the municipality and its communities.

Mapping of exposures to climate-related hazards – including storm surges – is an essential component in Climate and Disaster Risk Assessments (CDRA), a requirement for Local Government Units (LGUs) in the Philippines for crafting Comprehensive Land Use Plans (CLUP) in compliance with housing and land use regulations (HLURB, 2015). Ironically, the most recent CDRA (2021) of San Juan does not incorporate storm surge. This gap in their CLUP poses a significant vulnerability to disaster in the coastal areas where about a fifth of its population resides. The underpinning aim of this study therefore, is to provide a storm surge exposure map for coastal areas in San Juan for potential use in the municipality's preparation of disaster risk assessment.

Literature Review

After the disastrous storm surge events during STY-Haiyan in 2013, attempts have been made to supplement hazard maps that could guide decision-making during projected TC scenarios. Most of these studies, like those by Lapidez et al. (2015) and Rodrigo et al. (2018), make use of synthetic TCs to model storm surge situations in different parts of the country. Lapidez et al. (2015) conducted simulations that calculate the maximum probable storm surge height for Haiyan-type phenomenon and produced a nationwide storm surge inundation map. Meanwhile, Rodrigo et al. (2018) performed a city-level risk assessment on Leyte Gulf using synthetic TCs generated using a combination of Poisson point process and Monte Carlo simulations implemented in Delft3D software. Both studies however were assimilated into the Nationwide Operational Assessments of Hazards (NOAH), a government project implemented by the University of the Philippines before being turned over to PAGASA, the state weather bureau. NOAH classified storm tide levels according to their peak height to create the following four Storm Surge Advisories (SSA): SSA 1 (2.01m to 3m), SSA 2 (3.01m to 4m), SSA 3 (4.01m to 5m), and SSA 4 (5m and above) (NOAH, 2021). From NOAH's metadata for storm surge and inundation maps, these geospatial products were generated "using Japan Meteorological Agency's storm surge model to simulate 721 tropical cyclones entering the Philippine Area of Responsibility from 1951 to 2013, together with maximum tide levels from WXTide software." Inundation simulation was also performed using "FLO-2D, a two-dimensional flood modeling software that uses continuity and dynamic wave momentum equation" (NOAH, 2021). Figure 1 shows an aggregated map of the Storm Surge Advisories produced by NOAH.

In a courtesy visit to San Juan Disaster Risk Reduction Office last May 11, 2023 however, it was found that the storm surge advisory levels indicated in Figure 1 do not coincide with field reports when STY-Rai struck in 2021. This is understandable because the storm surge model from NOAH were not specifically field validated for San Juan. Meaning, there is a need to compare the simulated storm surge advisories with actual occurrences. In a communication letter dated March 29, 2023 sent by PAGASA through its administrator, Dr. Vicente B. Malano, the bureau conducted coastal inundations measurements on field over two provinces, namely: Leyte and Southern Leyte – a province is a level higher than a municipality in Philippine political hierarchy. The letter noted that nine (9) survey points distributed over five (5) mostly geographically disjoint municipalities were obtained between April 19 to May 3, 2022. Out of these nine points, only one was taken within the borders of San Juan.

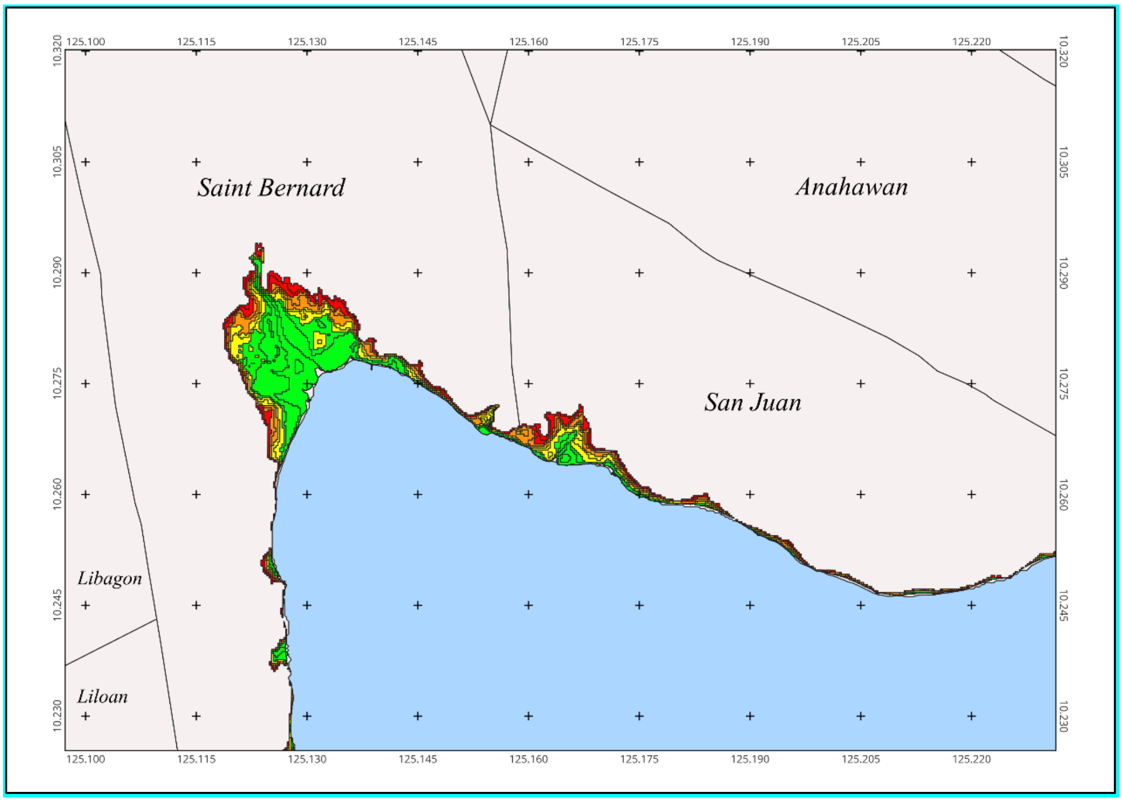

Figure 1. Aggregated Storm Surge Advisory (SSA) maps produced by UP NOAH over a portion of Southern Leyte (green=SSA 1, yellow=SSA 2, orange=SSA 3, and red=SSA 4).

While the validation results of PAGASA may have served their objectives, a single validation point in San Juan is clearly insufficient to establish the suitability of storm surge hazard maps obtained from NOAH for use in determining exposure levels of coastal communities in the municipality. Consequently, there is a need to bridge this gap by providing a better representation of exposure levels in the coastal barangays (i.e. a town that is a level below a municipality in Philippine political hierarchy) of San Juan. As such, it was deemed necessary to extend the coastal inundation measurements started by PAGASA using the same ground truth data for STY Rai-induced storm surge.

Methodology

The general framework of this study is anchored on the survey method of PAGASA in approximating coastal inundation depths and extent inland after a storm surge event. This was indicated in their March 29, 2023 communication letter. Essentially, personnel from PAGASA interviews residents who were able to experience the actual rise in seawater level rise then measured the height. In addition, high water marks may also be used as proxy for inundation depths if clearly available. While the bureau only took one reading for San Juan, the measurements can be expanded in all affected areas. A similar method is also found in the work of Yi et al (2015) wherein the following survey questions were noted: (1) the coordinates of the storm surge extent(s); (2) the inundation depth; (3) whether the water was salty or not; (4) the direction of the water movement; and (5) the time during which the water rose. The last three questions will confirm whether the rise in water level coincides with the landfall of STY Rai or a mere flooding event. A map of these collection sites is indicated in Figure 2.

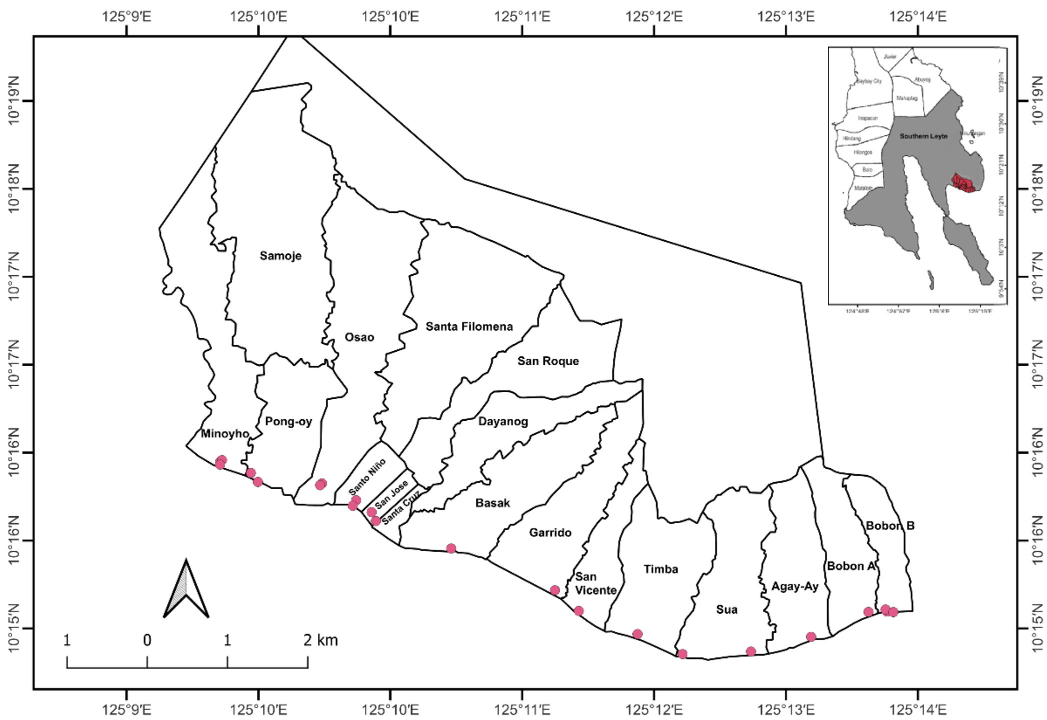

Figure 2: Map of data colletion sites in San Juan. Inset shows the location of San Juan relative to the whole Southern Leyte Province in mid-Eastern Philippines.

It is important to note however that during the courtesy visit at San Juan, the local disaster risk reduction officer emphasized that they were able to conduct pre-emptive evacuation. Hence, the sampling sites were expected to be sparse, and a snowball sampling technique was applied considering the time constraint and unfamiliarity with the study area (Hofmann, 2008; Levine et al., 2022). Enumerators would visit a town via the local chief, and then the enumerators are directed to the residence of the possible respondent. This method offers improved chances of getting respondents who witnessed the storm surge as they are more likely to have shared their stories with some of the community already. This respondent may then be referred to the enumerator through an acquaintance with the first respondent (Naderifar et al., 2017). The distribution of these sampling sites can be seen in Figure 2 whereby they appear to have a natural clustering when it is only a consequence of the snowball sampling method. All in all, 26 affected individuals were found and interviewed throughout San Juan using the questions used by Yi et al (2015). Each respondent was asked to provide the inundation depth or water level relative to the ground, and the GPS coordinates of the location where they were at that time was also tagged. The responses aggregate into a set of points corresponding to inundation depth at a certain location, they will have to be converted into a surface via interpolation to represent an average water height per barangay.

Since the water levels were measured with respect to the ground, their heights denoted by **i** in Figure 3, had to be converted to ellipsoidal heights in WGS84 datum before being interpolated for purposes of interoperability with other geospatial data. This was carried out by overlaying the GPS coordinates of the locations provided by respondents onto an SRTM DEM and then extracting the DEM height **H**, thereof. Other types of DEM may also be used. The final height **h**, of the actual water level given by the respondents relative to would be the sum of the height of water **i**, given by respondents and the DEM height **H**; that is **h** = **H** + **i**. This step is illustrated in Figure 3. After conversion to ellipsoidal heights, a surface interpolation was then performed.

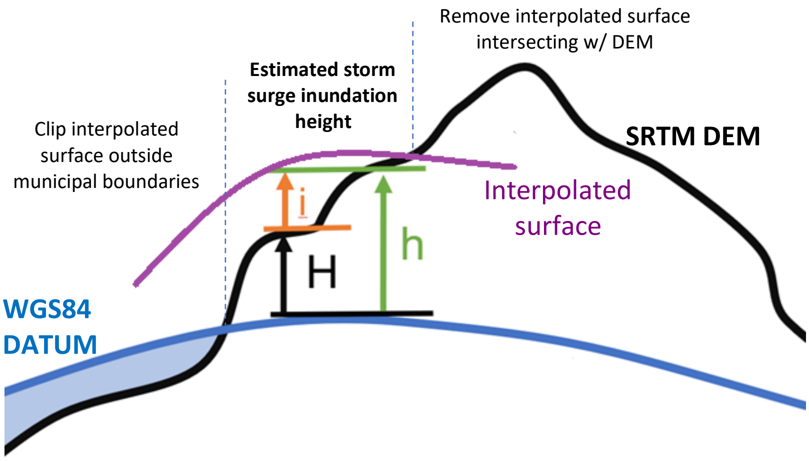

Figure 3: Determining the ellipsoidal height of STY-Rai induced inundations.

Various interpolation methods like the mean statistic, median statistic, Kriging, and Inverse Distance Weighting (IDW) methods are available to create a uniformly spaced terrain surface. From this list, Detweiler and Ferris (2010) identified that Kriging and IDW interpolators are advantageous. IDW is considered as the simplest interpolation method (National Center for Geographic Information and Analysis, 2023). Nonetheless, a study by Zimmerman et al. (1999) showed that Kriging is more accurate than IDW. However, accurate estimates of variograms are needed for reliable prediction by Kriging and subsequent mapping (Oliver & Webster, 2015). But variogram accuracy depends on the sample size. Since the number of points to be interpolated were sparse (only 26 points), IDW method was preferred over Kriging. On top of that, the method has to be kept simple for easy transfer of knowledge since the expected end users of the results herein will be coming from the local government unit with varying degrees of acumen for geospatial analysis. Furthermore, IDW is a built-in functionality in QGIS and can be readily used by LGU without needing further plugin installations for Kriging.

The interpolated surface is expected to extend outward to the sea and underneath the land surface. Extraneous parts extending seaward were clipped off using the municipal boundaries while those extending under the landmass intersected with the DEM. The retained interpolated surface, which is a raster data containing different inundation depths, is then classified according to inundation thresholds provided by PAGASA, namely: Low ($\mathbf{i} \leq 1.0$m), Moderate (1.0 m $< \mathbf{i} \leq 4.0$ m), and High ($\mathbf{i} > 4.0$ m).

Results and Discussion

Interpolation results for surveyed inundation depths and extents are shown in Figure 4. The extended parts of the interpolated surface are unnecessary and must therefore be removed to have a more sensible result. Results after removal of these extraneous data and classification according to SSA levels by NOAH are shown in Figure 5A, which is basically the storm surge exposure map of San Juan based on STY-Rai. It can be seen in Figure 5A that among the three inundation classes, Low inundation seems to be the more prevalent exposure level. Meanwhile, the Moderate and High inundation levels are concentrated along the central and western seaboards of San Juan. The maximum extent storm surge is found in Barangay Basak, which encroached to about 260 meters inland from the coastline. The highest inundation levels are found in seven barangays of San Juan. Some of them are concentrated on the central seaboard of San Juan, specifically in Santa Cruz, Basak, Garrido, and San Vicente.

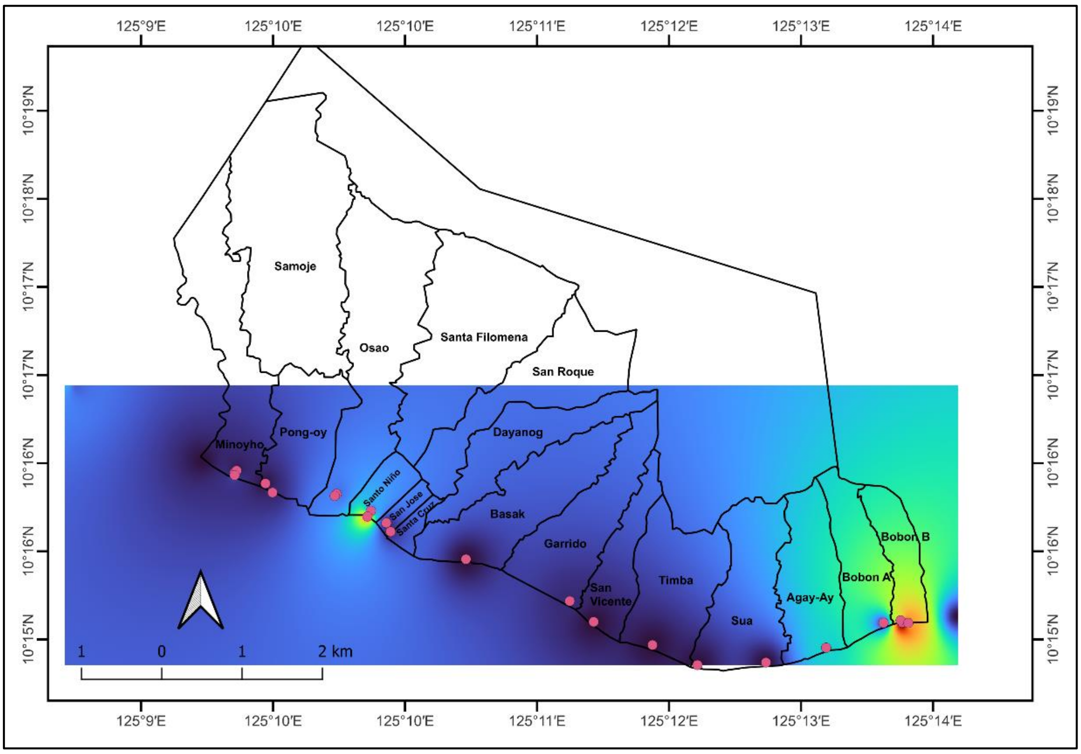

Figure 4. IDW interpolated ellipsoidal heights of STY-Rai induced inundations.

In these areas, inundation depths reach as high as about 11 meters, which is comparable to the height of a streetlamp. The remainder being located on the southeastern side of San Juan, particularly Agay-ay, Bobon A, and Bobon B. Towns with moderate exposure include all the aforementioned seven barangays, plus some portions of Osao, Santo Niño, San Jose, and Pong-oy. All 13 coastal towns in San Juan were affected by Low storm surge inundations except for Sua. This could imply that when considering establishment of important infrastructures such as government service offices or even evacuation centers, Sua might offer something valuable. At the moment, most of the government offices are located in Santo Niño which is exposed to Moderate and Low inundations. Figure 5B on the other hand is another storm surge exposure map provided by PAGASA to San Juan LGU. This map indicates that barangays that are prone to High inundations would be near the southwestern seaboard of San Juan, namely: Osao, Santo Niño, Pong-oy and Minoyho. Comparing this with Figure 5A – the derived storm surge map in this study however, it can be observed that there are glaring disparities. In the data coming from the state weather bureau, Osao and Santo Niño were expected to be heavily hit by storm surge when they were not as badly damaged during the actual occurrence of STY-Rai.

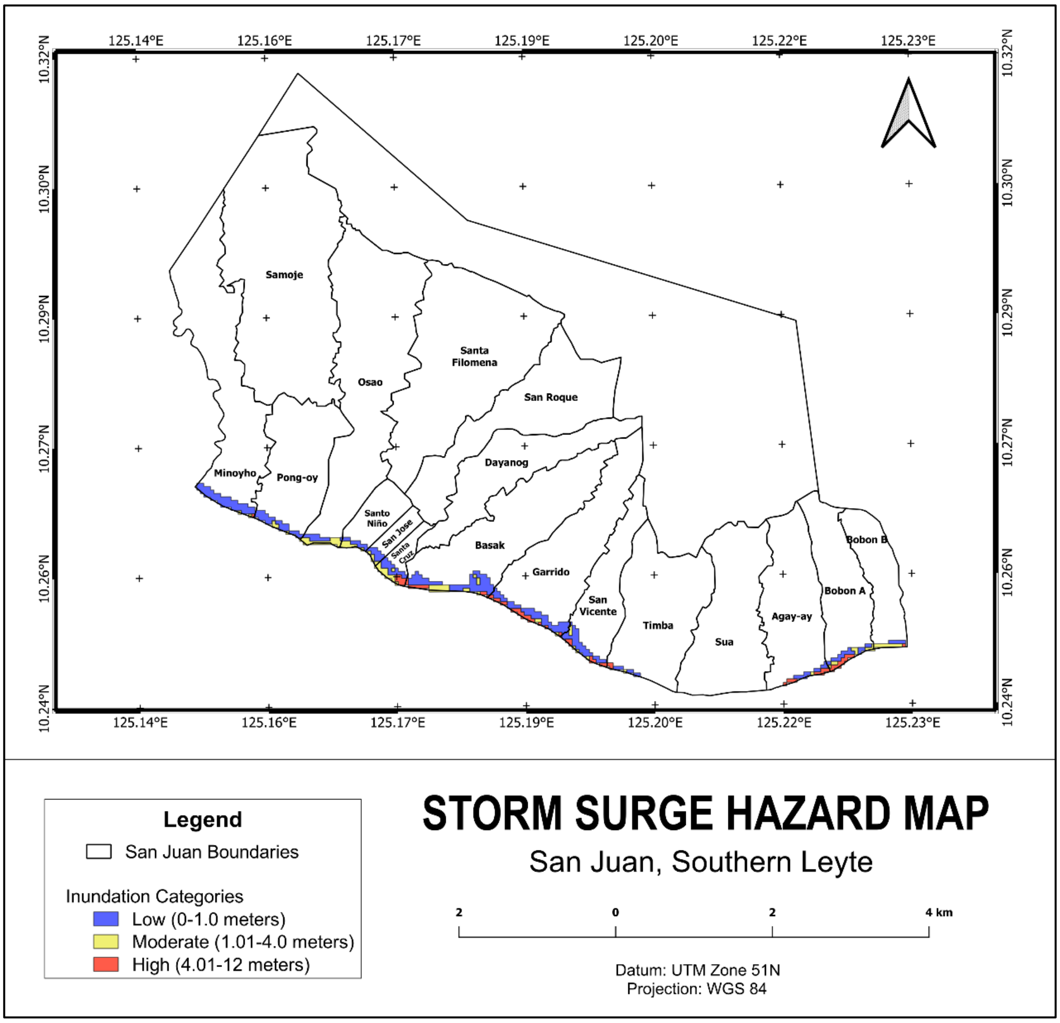

Figure 5A. San Juan storm surge hazard map categorized as Low (**i** ≤ 1.0m), Moderate (1.0 m < **i** ≤ 4.0 m), and High (**i** >4.0 m).

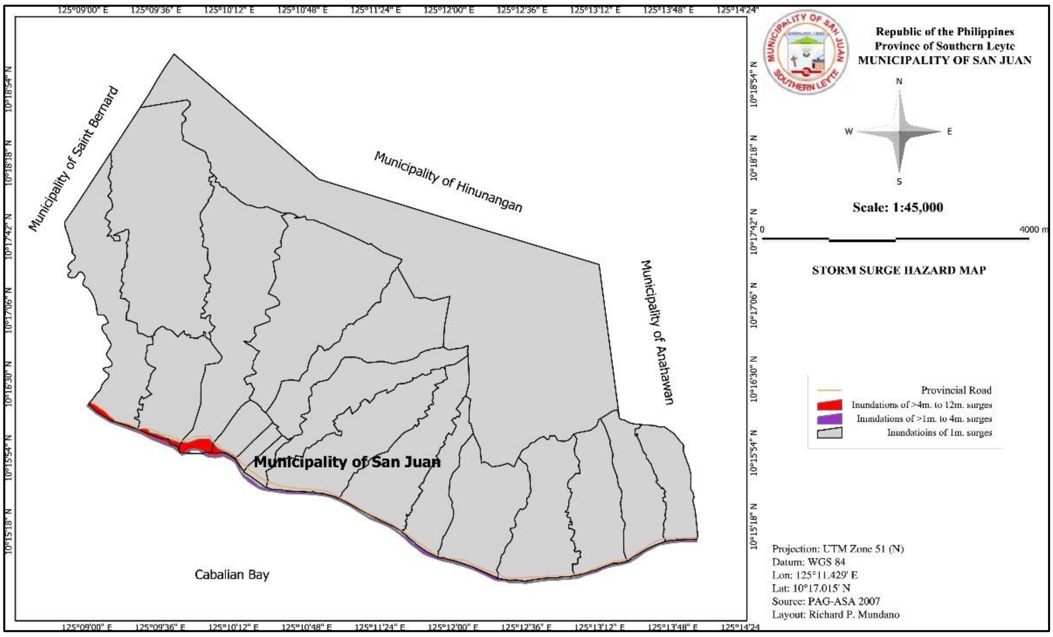

Figure 5B. Storm surge exposure map provided by PAGASA to San Juan.

In Figure 5B, the towns of Osao, Santo Niño, Pong-oy and Minoyho would be the focus of concerns as far as storm surge inundations are concerned while the remaining 10 coastal barangays are considerably less likely to incur damage. On the contrary, the figures reported in this map are not supported very well by actual data.

Conclusion and Recommendation

While there is an already available storm surge exposure map for San Juan, this was based on simulations without validation specific for the said locality. The importance of confirming this kind of hazard exposure map could not be overemphasized even if it is the best available data at the time. Policies such as land use guidelines put in place based on the same map might not be able to bring out the most benefit for the municipality and could even have dire consequences. The exposure map being provided in this study is just but one occurrence and the number of respondents who shared their experiences with the storm surge brought by STY-Rai were only a handful. Moreover, the responses were practically anecdotal in nature and the gap between the actual typhoon occurrence and the interview is about one and a half year. This could raise some questions on the accuracy of the data. But there is no better alternative because the event happened some time ago and STY-Rai may have a return period of 1/100 or even smaller. The chances of such an extreme case recurring is slim but mapping the extents of storm surge it induced can give a more realistic picture compared to the prevailing storm surge models for San Juan. In most cases wherein the model does not support the actual results, it may need to be revised if not scrapped at all.

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