Nakhara: Journal of Environmental Design and Planning
Volume 16, June 2019

Application of HAZUS-MH Flood Model in Developing Countries: The Case of Piura, Peru

Wan Chantavilasvong[*] / Leo Guerrero[**]

[*] Faculty of Architecture, Chulalongkorn University, Thailand
Corresponding author: *wan.c@chula.ac.th*

[**] Water Research Center,
University of Engineering and Technology, Peru
lguerrero@utec.edu.pe

Received March 10, 2019; revised May 22, 2019; accepted May 22, 2019

ABSTRACT

This research looks at the U.S.'s HAZUS-MH Flood Model and adapts some of its methodologies to Piura, Peru, as an example of many regions around the world with limited technical and capital capacity to estimate inundation risks. Thus, this research proposes a methodology for accessible and achievable flood risk estimation which takes into account limited available data. The proposed methodology will produce maps of potential inundation areas and monetized damage values from flood scenarios. These outputs can further help local authorities design, decide, and prepare their risk mitigation and adaptation plans for the future.

Keywords: *spatial analysis, flood risk, impact estimation, flood projection*

INTRODUCTION

The impacts of global warming are being felt across the globe. One impact is an increase in extreme events i.e. droughts, floods, extreme heat, and extreme cold. These extreme events are expected to increase in the coming years despite our ability to limit our impact on global warming to 1.5 degree Celsius higher than the pre-industrial level (IPCC, 2018). On the other hand, the El Niño-Southern Oscillation (ENSO) has historically been a two-to-eight-year cyclical climate phenomenon. The shifts between ENSO's El Niño and La Niña phases create a variety of climate events in countries surrounding the Pacific Ocean. The correlation between ENSO phenomena and climate change are continuously being studied by environmental scientists around the world.

Figure 1:
Peru and Piura Region's locations on the global map.

Peru is located on the eastern coast of South America facing the Pacific Ocean as shown in Figure 1. In the northern parts of Peru, in the region of Piura (Figure 1), the rainy season is generally between December and March and sometimes can extend into April due to the El Niño phase of the ENSO phenomenon. In early 2017, an El Niño year, the amount of rainfall was ten times higher than normal (Di Liberto, 2017). In March of the same year, the LA Times (Leon & Kraul, 2017) reported that the Peruvian national economic loss caused by El Niño-related extreme rainfalls was estimated at $3.1 billion. In the region of Piura, which was hit the hardest, four people were reported dead, hundreds had to flee their flooded homes, and approximately fifteen thousand acres of crops were loss underwater.

To complicate the phenomenon further, the region is situated in a desert area where continuous heavy rainfall is rarely expected. Thus, local dwellers, government officials, and other stakeholders rarely prioritize damage prevention from heavy rainfalls, floods, *huaycos*[1], or mudslides into building design and construction. Furthermore, despite flood-risk maps and drainage plans created by the National Institute of Civil Defense (INDECI) in 2009 (Figure 2), local authorities continued to allow for more development in risky areas. Moreover, without calculations of flood depths at different scenarios, as shown in Figure 2, the risk projections remain difficult to quantify for building damages, which can be further translated in monetary terms. Similarly, local actors often have minimal risk mitigation and prevention plans, such that the detrimental impacts of the last El Niño in Piura were largely due to the local's unpreparedness to face such climate event (French & Mechler, 2017).

With the cyclical nature of El Niño and the increasing trend of extreme climate events due to climate change, Piura has a high probability that heavy rainfalls and floods will occur again in the future. While flood risk estimation for the city of Piura is available, there has not yet been a plan that looks at the impact at a regional level. Lastly, the parachute and technocratic approach to such plans seldom contribute to empowering local authorities to become more adept at realizing their own risks. Thus, there is a need for local authorities to gain sufficient knowledge to understand their climate risks and to start planning for risk mitigation and adaptation.

This research looks at Piura, Peru, as an example of regions that have limited capacity to prepare for extreme rainfalls. The research proposes a method of analysis which is derived from the US's Federal

[1] Huayco is local Quechua term which is sometimes used interchangeably with mudslides. However, locally in Peru, the term often refers to a type of mudslides that include rocks and other debris carried by mud and water. Huaycos often create more damages than mudslides.

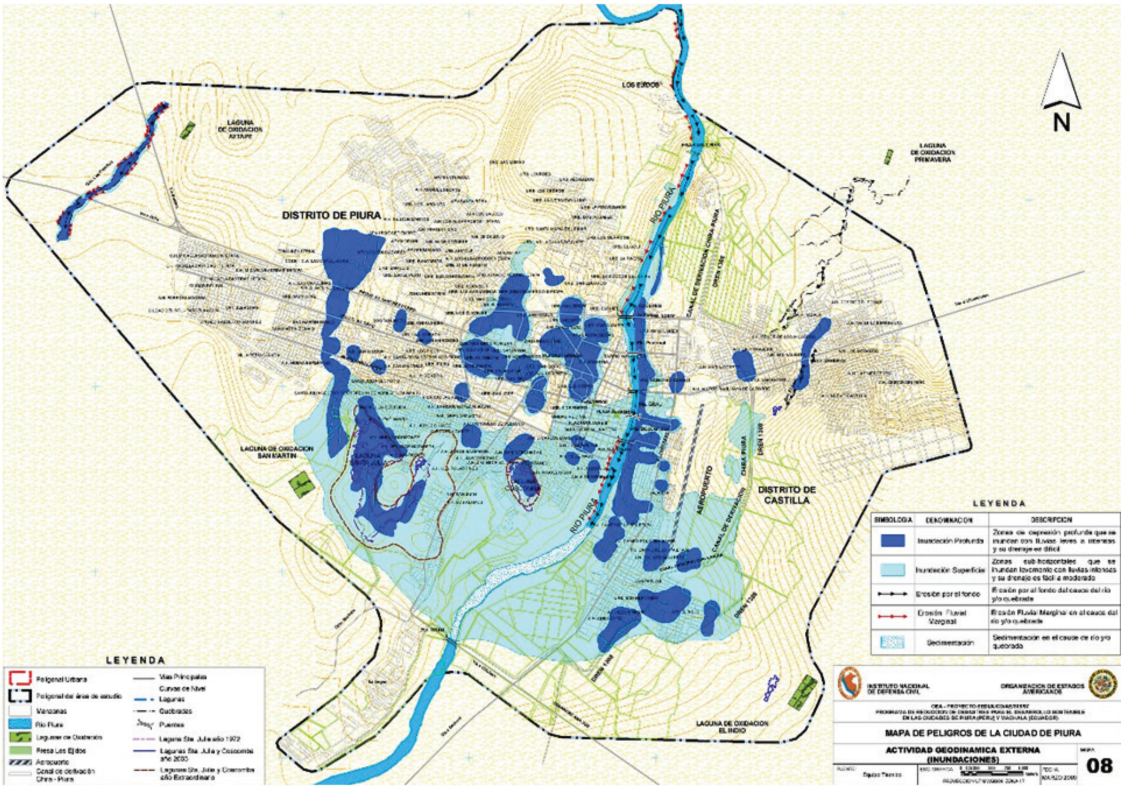

Figure 2:
Risk maps of the city of Piura: External geodynamic activities (inundation) (INDECI, 2009).

Emergency Management Agency's HAZUS-MH Flood Model (FEMA, 2004), which was designed to help guide local authorities in the U.S. to better assess their environmental risks and provide better mitigation plans for future events. While the HAZUS-MH Flood Model provides a robust methodology, a challenge in applying the same process to places like Piura lies in the limitation of available data and the limitation of technical capacity. Such a challenge is also prevalent in many developing countries around the world.

To accomplish such tasks, this research aims to propose a risk estimation methodology that will provide local authorities with a) an accessible and doable analysis methodology which takes into account limited available data and requires minimum QGIS knowledge for spatial analysis, b) spatial distribution maps which help determine areas of potential inundation risks, and c) monetized values of potential construction costs from flood damages which are useful for the design of risk mitigation plans.

This research is organized into seven sections including 1) Introduction, 2) HAZUS-MH Flood Model Framework, 3) Piura building stock, 4) Processing methodology, 5) Results, 6) Research gaps, and 7) Discussion for policymakers.

This research produces two main academic contributions. The first contribution, which is described in Section 4 and 5, is through a free, inclusive, and simple tool for flood projection because floods have direct and indirect impact on building structures, urban dynamics, social relationships, as well as economic well-being. While hydrologists and geographers will most likely be able to create more precise and more detailed flood projections, this research acknowledges the importance of lowering the technical barriers for urban planners, architects, social scientists, and other researchers in related fields to be able to easily create their own flood projections and study flood risks from their various lens of impact. Secondly, this research also identifies gaps which will tremendously make flood projections more accurate, effective, and inclusive, as is described in Section 6 and 7. Often data on building specifications are not collected or are opened to the public because there is no direct use for them. However, as floods and other extreme events are becoming more frequent, the spatial distribution of demography and building structures, heights, and usage are the basis on which cities and communities can better understand their risks and build their mitigation and adaptation plans in the future.

HAZUS-MH FLOOD MODEL FRAMEWORK

HAZUS-MH is a program developed by the United States of America's Federal Emergency Management Agency (FEMA) following the National Disaster Mitigation Act of 2000 (DMA 2000). The DMA 2000 brings forth a new set of requirements for governing entities to coordinate and provide mitigation plans in case of emergencies (FEMA, 2004). Hence, FEMA created HAZUS-MH to provide and support local entities with a nationally standardized assessment tool. HAZUS-MH covers various types of hazards that can occur in the U.S., including earthquakes, floods, hurricanes, landslides, tornadoes, tsunamis, and wildfires. However, this research will focus on the HAZUS-MH Flood Model as it relates most to the context of Piura.

The Flood Model organizes the hazard impacts into six categories including general building stock, essential facilities, hazardous material facilities, high potential loss facilities, transportation system, and utility systems (FEMA, 2004). While a comprehensive risk assessment from floods is a complex task, this research focuses mainly on assessing damages of building stocks due to fluvial flood risks. There are two main advantages in choosing this focus. First, spatial data of buildings are most likely to be available online, which allows local authorities to be specific about buildings in risky areas. Second and more importantly, damage done to buildings are one of the main elements that contribute to other indirect and induced damage including debris, casualty, shelters, and economic loss. Thus, by understanding the damage to buildings, other damage can also be inferred and extrapolated.

As a base model, HAZUS-MH has multiple advantages because the tool has been developed over a long period. This means that many of the calculations were driven by long-recorded data, data that are hard to come by in a short period of time. On the other hand, the tool was tailored to serve within the U.S. contexts and was also driven by data recorded within the U.S. Consequently, there are three main differences that need to be considered in order to apply HAZUS-MH to Piura. Such differences include 1) the granularity of the available data, 2) the historically data-driven projections, and 3) the unit of analysis.

In terms of the granularity of available data, HAZUS-MH model is based on building shapefiles which are linked to other spatial data collected through the American Community Survey. This allows the HAZUS-MH model to know the spatial distribution of usage, tenants, and building types at a building unit or postal code level. On the contrary, the smallest available data in Peru is at a regional level, which is too large of a scale to provide a meaningful social and economic analysis of flood hazards because clusters of towns and cities in Piura tend to be spread out in distant nodes. Thus, without linking statistical data into specific locations, the significance of the spatial distribution of flood analysis is limited only to building structures.

Additionally, HAZUS-MH also uses historical and technical data to project the threshold of flood impacts. For example, the building collapse curves (FEMA, 2014), which only comprises of building types that exist in the U.S. including wood-framed buildings, masonry and concrete buildings, and steel-framed buildings. Buildings in Peru, however, are much more varied due to the informality nature of building systems. While it will be useful to develop impact projections of building types that match with the Peruvian context, the lack of available data requires time and technical capacity to create such projections. Consequently, the discrepancy of using impact projections will require levels of assumption to ease the transferability of the HAZUS-MH model.

The units of measurements in the HAZUS-MH model are based on the English system (inches and feet), which Peruvians widely use the metric system (meters). Because the two units of analysis are not divisible by each other, rounding becomes necessary for the analysis even though it creates a small level of inaccuracy.

Acknowledging the shortcomings of available data and projections, this research will focus on adapting some of the HAZUS-MH analysis by using available data in Piura. Even though the available data is much coarser than ideal, it is enough to build a rough estimation of future flood impacts.

PIURA BUILDING STOCK

Piura is a region situated near the Pacific coasts in the northern part of Peru where the soil is mostly comprised of sand. Most towns and cities in Piura are situated on flat areas inland, which means that they are unlikely to be affected by the coastal flooding. Moreover, this area rarely experiences continuous heavy rainfalls so much so that at certain times of years, many rivers can dry up leaving only traces of where the rivers once were. Consequently, despite the detrimental impact of rainfalls from cyclical El Niño phases, most buildings are rarely designed and constructed in preparation for flood events. In many cases, households were also built in low-lying areas not knowing that the area might become rivers during heavy rains. Furthermore, mitigation plans and other resiliency programs are also lacking, which further make the risk of floods in this area more extreme than what one might expect.

Specific to Piura's building stock, there are three main aspects of building types which relate to the cost of flooding: building heights, building materials, and building usage. While a shapefile dataset with records of each building's height, materials, and usage that are linked to the building block shapefile is ideal, the Department of Piura does not record and/or provide such data. With this limitation, this research needs to estimate and assume those values from other sources.

Building heights in Piura is estimated by looking through Google Street View to provide an idea of the overall building landscape of this region. Example from Figure 3 below shows that most buildings in Piura are within 1-to-2-story high. With such estimation, this research conservatively assumes that buildings in Piura are on average one-story tall or 3-meter high.

While Figure 3 also shows a sense of building materials in Piura, records of building materials in Piura is published at a regional level by the Instituto Nacional de Estadística e Informática (INEI). The INEI surveyed both wall and floor materials, but this research focuses only on using wall materials as the identifier of model building types because for one-story buildings. wall damage is more significant to building structures than floor damages. From the most recent survey in 2017, the INEI report shows that Piura has a total of 469,272 households which are comprised of households with walls made from brick or cement block, adobe or rammed earth, stone with mud, quincha[2], wood, and other materials (Table 1).

Figure 3:
Google Street View of Trujillo Street in Catacaos, Piura, Peru (taken September 11, 2018).

2 Quincha is a traditional construction system of the Quechua which uses bamboo or sugarcane as framings and are covered with mud.

Table 1: Construction materials for housing walls in the Department of Piura (INEI, 2018, p.300).

Wall materials	Households	Percent	Assume same vulnerability as	Households	Percent
Brick or cement block	222,500	47.41%	Concrete/masonry	355,647	75.79%
Stone with lime or cement	1,429	0.30%	Concrete/masonry		
Adobe or rammed earth	130,735	27.86%	Concrete/masonry		
Stone with mud	983	0.21%	Concrete/masonry		
Quincha	61,090	13.02%	Wooden	113,625	24.21%
Wood	8,294	1.77%	Wooden		
Others	44,241	9.43%	Wooden		
Total	**469,272**	**100.00%**	**Total**	**469,272**	**100.00%**

Despite having a more diverse record of wall-materials, the risk analysis still needs to rely on the building collapse curves available in the HAZUS-MH model, which only includes those for wooden, concrete/masonry, and steel structures. Because such modeled curves for Peruvian building types do not exist, this research needs to conservatively match Peruvian wall materials with HAZUS-MH modeled structures by assuming similar strength and vulnerability, which is also shown in Table 1.

As for building usage that will help determine the indirect social and economic impact of floods, INEI does not provide granular data to help determine specific functions of different buildings. Unlike the distribution of building types, which are quite equally distributed throughout the region, building usage relates directly to the function of urban centers. The cross-reference of urban cadastral shapefile with open source data such as the Open Street Map also requires more analysis which is more complicated than the purpose of this research. Consequently, this research will not analyze building usage and will only focus on direct impacts on the general building stock.

PROCESSING METHODOLOGY

This research methodology uses QGIS 3.0.2 as the main program for spatial analysis because it is a free and open sourced program that is available for anyone to use. The method is also based on the available and free data of the Piura Region. The processing methodology is divided into three main sections including 1) delineation of flood hazard areas, 2) calculation of the exposures and damages of general building stocks, and 3) valuation of building damages at different hazard scenarios.

Delineation of flood hazard areas

The first process aims to delineate flood zones at various risk levels by modifying and simplifying processes from HAZUS-MH Flood Model Technical Guide which was used in Williamson Creek (FEMA, 2004. p.4-43 – 4-58). While hydrologists can make more accurate predictions of flood scenarios, this research aims to provide local authorities with a methodology that is free and simple to use. This methodology will provide flood depth scenarios at 1-meter variations because the chosen digital elevation model (DEM) terrain data from the NASA's Shuttle Radar Topography Mission 3 (SRTM3) provides only 1-meter elevation differences. Although there are more detailed and updated DEMs available, the SRTM3 data is available globally. Moreover, because this research looks at a regional scale, data more granular than this will not be more helpful as other available shapefiles and data are also at a larger block level. To process the flood hazards, the following spatial data are used:

- SRTM3 terrain raster file is used to create flood projection with pixel sizes of 9x9 sq.m. and elevations of 1-meter difference. This file can be downloaded from http://www.webgis.com/srtm3.html.

- River shapefile is used as a guide to delineate fluvial flows and its potential spreads, which can be delineated from Google Earth if official data is not available.

The QGIS processing methodology for flood zones has three processes including 1) create grids of contour lines and river offsets to identify rivers' traversed sectional areas, 2) normalize terrain altitudes with rasterized river altitudes, and 3) identify and create shapefiles for potential fluvial inundation spread. Details are as followed:

1. Create grids of contour lines and river offsets to identify rivers' traversed sectional areas, which will be used for normalizing altitudes in step 2.
   a. Select and create contour lines elevations in areas where inundation is likely to occur. In this case, the elevation levels between 0 m. and 200 m. are picked. The 0-meter altitude is used to determined general sea level. The 200-meter altitude is chosen relative to areas where terrains become steeper and rivers narrow down which are proxies for areas with less inundation. As presented in Figure 4, the difference between each contour line is 1 meter and it represents only terrains between 0 to 200 meters above sea level. The contour lines, thus, act as cross sections of rivers at various altitudes.
   b. Create offset lines from the river traces by using the Buffer tool to roughly estimate the spread of flood areas. For Piura, Figure 5 below shows 10 levels of offset lines each with 1 kilometer further away from the rivers. These offset lines, thus, act as parallel lines along rivers which help determine the spread of inundation along river banks.

      In contrast to general flood model simulations where the watershed area is used, this buffering method tries to best estimate the extent of floodplains at various altitude levels—narrower in mountainous areas to the west of Piura and grow wider near the coast of the Pacific Ocean. In this case, floodplains are defined as areas with high potentials of inundation by the lateral overflow of rivers (Junk, Bayley & Sparks, 1989). With this focus, it is more appropriate to use river buffers to delineate areas of flood analysis than to use the whole watershed region.
   c. Create traverse sectional areas of the rivers at various height sections (Figure 6). This process is done manually as QGIS does not have a function for this method. In areas where there are clear contour lines suggesting the river channel, use the upper bound of the contour line for the section block. For areas that are flatter and do not have clear river channels, use an approximation of

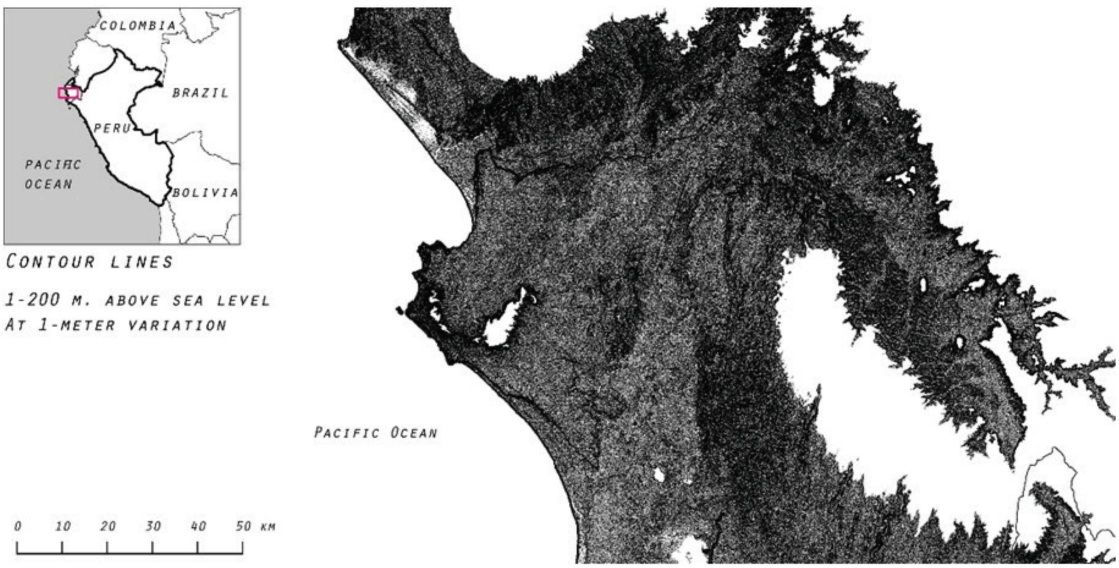

Figure 4:
Piura terrain contours between 0-200 meters created from NASA SRTM raster data.

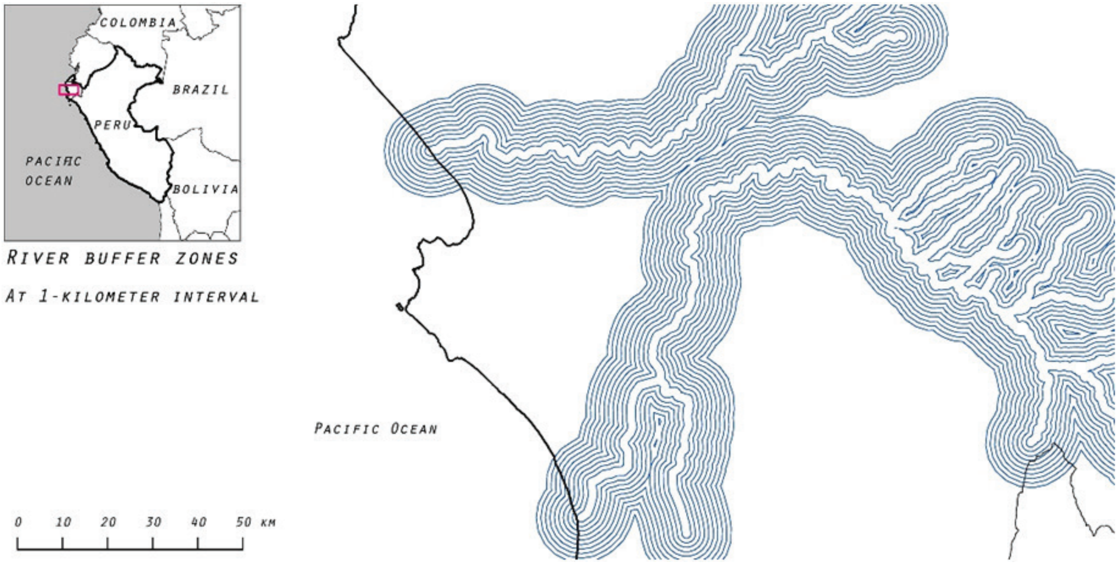

Figure 5:
River buffer zones at 1-kilometer intervals.

the width of the traverse section according to suggestive terrain gradation. In terms of the boundary of inundation spread, boundaries were set using the river buffer zones, which is smaller upstream and spreads wider towards the mouth of the rivers. The created shapefile should have at least two columns including the 'id' column to help differentiate between various rivers and their primary, secondary, and tertiary branches; and the 'elev-upper' column that reflects the upper bound of the altitude value going from 0 to 200 meters high. The 'elev-upper' information will be used to normalize the traversed terrain.

d. Rasterize the traverse river sections using values in the 'elev-upper' column to prepare for raster calculation and save only value data (Figure 7).

2. Normalize terrain altitudes with rasterized river altitudes. Conceptually, the normalized result is when all of the river sections are pulled into the same traversed level. The normalized terrain altitudes will allow for calculations of inundation spread from rivers at different traverse sectional altitudes.

   a. Use the Raster Calculator to normalize the height of the terrain by the traverse sectional areas of the rivers. This process is made by subtracting each pixel from the SRTM3 raster data to the traverse section raster data from step 1d.

3. Identify and create shapefiles for inundation spreads.

   a. Use Raster Calculator to select raster pixels at various levels, which serve as levels of riverine inundation, and save only valued pixels. Because the SRTM3 data has elevation levels of 1 meter, this methodology can only look at inundation levels with a 1-meter difference. Thus, the level of risks associated with the terrain level is identified as high risk for areas of 0-meter, medium risk for areas 1 meter above, low risk for areas 2 meters above (Figure 8). Areas 3 meters and above the 0-meter mark is identified as no risk areas as that level is extremely rare. This step produces the spatial distribution map which helps determine areas of potential inundation risks for local authorities to identify where areas of risks are in relations to the location of cities and buildings.

   b. Vectorize water area at different water levels using Raster Polygonize (raster to vector) tool. This vectorize step prepares the flood risk areas for vector intersection with building shapefiles in the following steps (Figure 9).

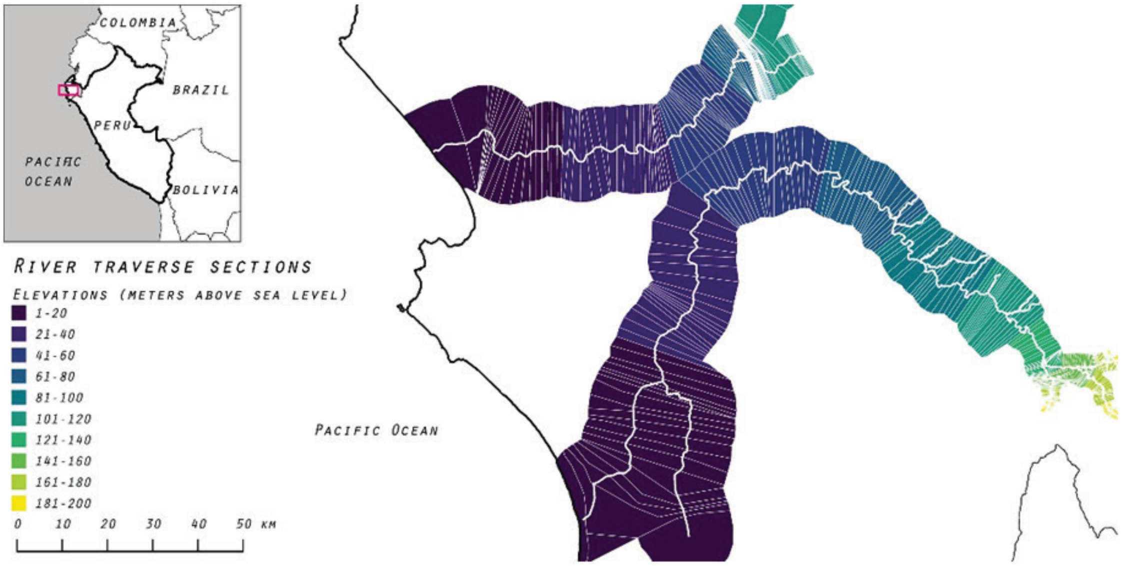

Figure 6:
Manually created shapefile of traverse section to be used to normalize terrain elevations.

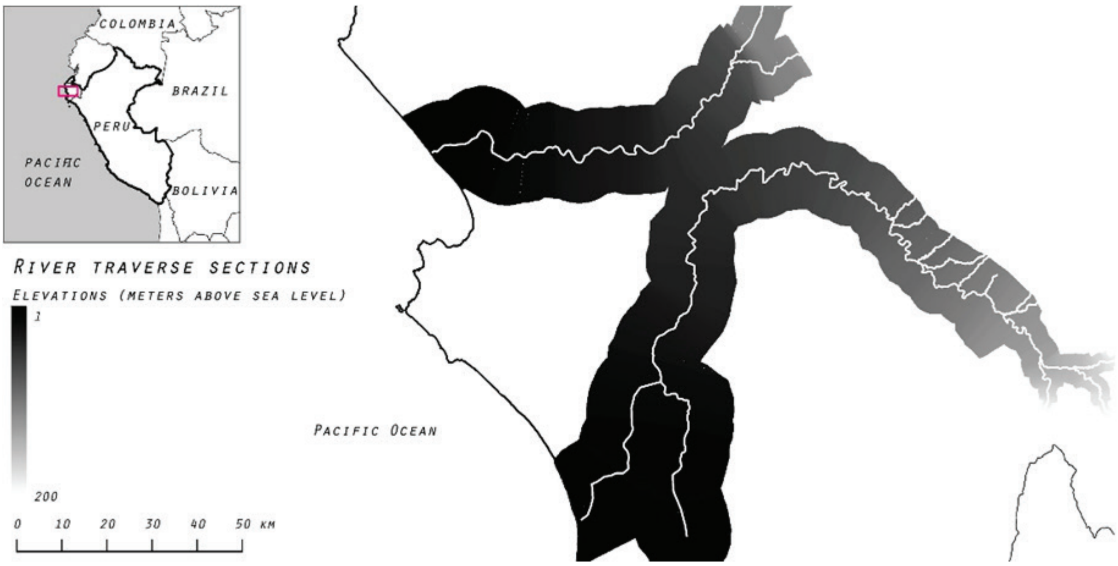

Figure 7:
Rasterized traverse sections from Figure 6.

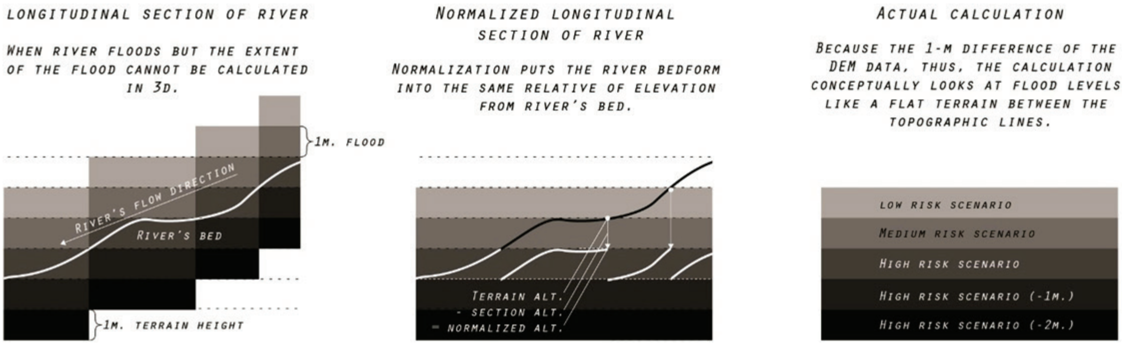

Figure 8:
The conceptual diagram explaining the elevation normalization process.

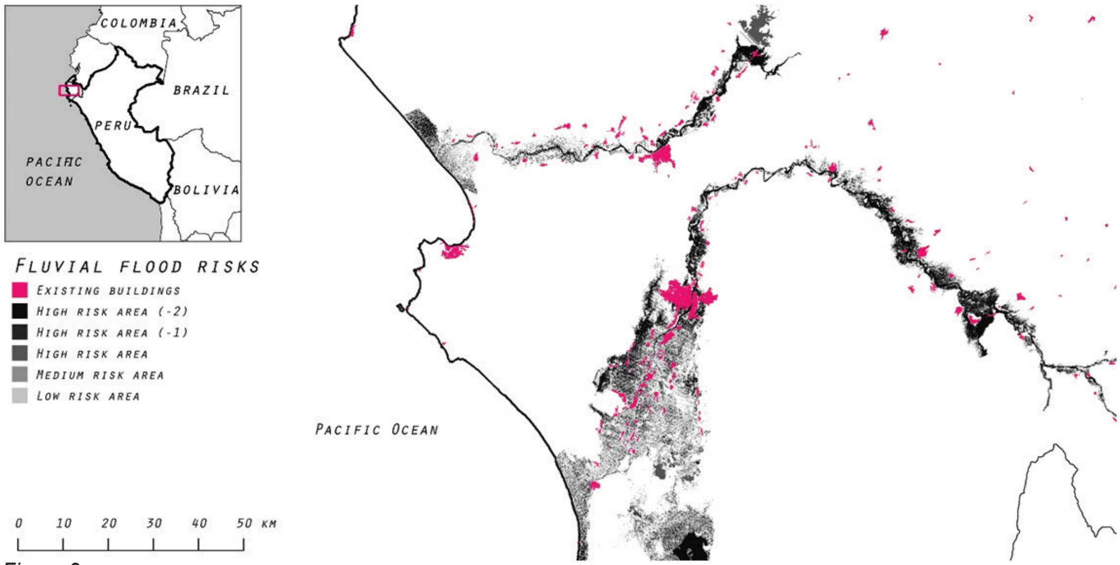

Figure 9:
Fluvial flood risk map for the region of Piura.

Calculation of the exposures and damages of general building stocks

With the map of inundation areas from the process above, the inundation impact on buildings at various scenarios is simply an intersection between the two layers. The conceptual explanation of this section is as shown in Figure 10 below. To process the exposure to floods, the following spatial data are used:

- Areas of high to low inundation risks created from the previous section.
- Urban building blocks shapefile created by D'Ercole, R. & Metzger, P. (n.d.).

The building damage calculation has four processes including 1) find building areas affected by each flood scenario, 2) differentiate between wooden and concrete/masonry buildings, 3) estimate collapsed buildings at different flood scenarios, and 4) estimate the percentage of structural damages for non-collapsed buildings. Details are as followed:

1. Find building areas affected by each flood scenarios.
    a. Intersect the building cadastral shapefile with

the inundation level shapefiles. Then, merge all flooded building areas at different water levels together as separate layers (Figure 11).

b. Calculate building areas that are flooded at different inundation levels using the @ Area calculation and sum the areas for each scenario (Table 2).

2. Differentiate between wooden (24.21%) and concrete/masonry buildings (75.79%) by using the percentage provided in Table 1, Section 3.

a. Because the INEI data does not provide building locations, this research can only assume that the percentage of building types are spread equally across the region. Thus, the amount of concrete/masonry (Table 3) and wooden buildings (Table 4) are affected by different flood scenarios is proportional to the data presented in Table 1, Section 3, of the building type percentage to intersected building areas in Table 2.

3. Estimate collapsed buildings at different flood scenarios. The previous process provides estimations of affected areas which need to be refurbished and reconstructed after a flood scenario occurs. However, the HAZUS-MH Flood Model (FEMA, 2004) also recognizes that various flood depth and velocities can also cause buildings to collapse depending on the buildings' construction materials. The depth collapse curves for wood buildings and concrete/masonry buildings are shown in Figure 12.

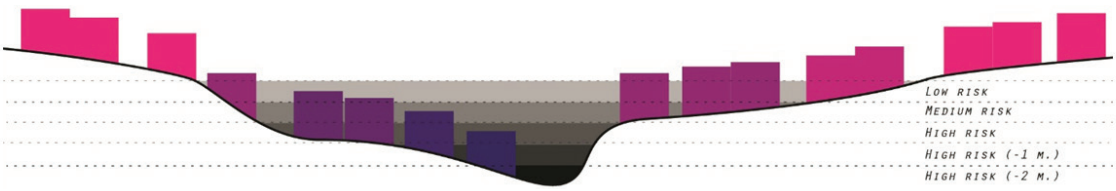

Figure 10:
The conceptual section explaining the differentiation of inundation impact on buildings.

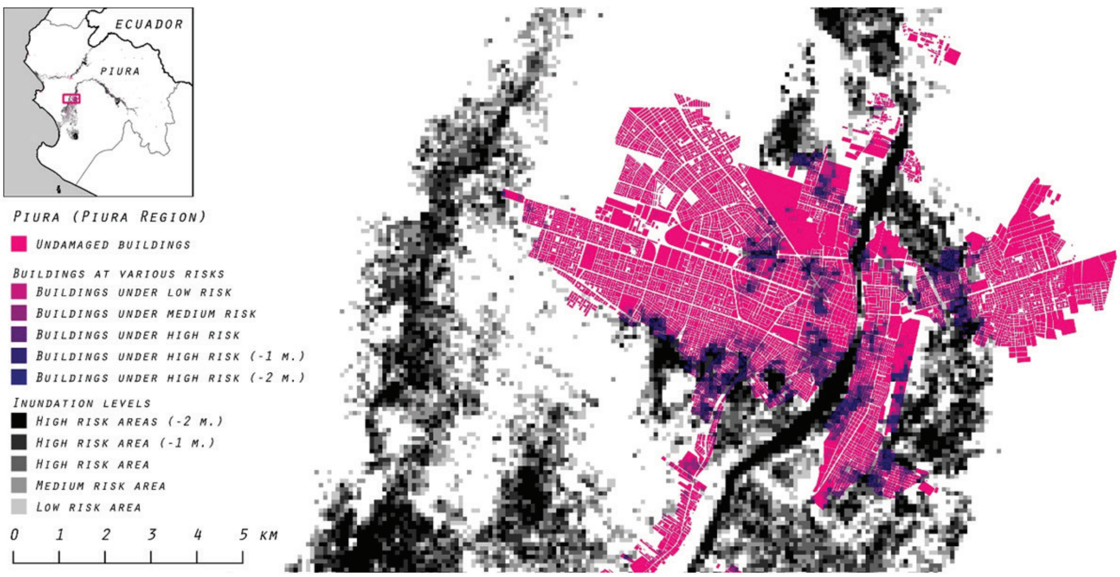

Figure 11:
Fluvial flood risk map for the city of Piura.

Table 2: Building areas affected by different flood scenarios and inundation elevation.

Scenarios at 1-meter difference	Building areas affected by different flood scenarios and inundation elevation (sq.m.)				
	1 m. submerged	2 m. submerged	≥ 3 m. submerged	Total	Percentage of all buildings
High risk scenario	2,856,763	1,545,408	1,872,267	**6,274,439**	**4.89%**
Medium risk scenario	4,488,291	2,856,763	3,417,676	**10,762,730**	**8.39%**
Low risk scenario	6,167,365	4,488,291	6,274,439	**16,930,094**	**13.20%**

Table 3: Concrete/masonry building areas affected by different flood scenarios and inundation elevation

Scenarios at 1-meter difference	Concrete/masonry building areas affected by different flood scenarios and inundation elevation (sq.m.)			
	1 m. submerged	2 m. submerged	≥ 3 m. submerged	Total impact areas
High risk scenario	2,165,141	1,171,265	1,418,991	**4,755,397**
Medium risk scenario	3,401,676	2,165,141	2,590,257	**8,157,073**
Low risk scenario	4,674,246	3,401,676	4,755,397	**12,831,318**

Table 4: Wooden building areas affected by different flood scenarios and inundation elevation.

Scenarios at 1-meter differences	Wooden building areas affected by different flood scenarios and inundation elevation (sq.m.)			
	1 m. submerged	2 m. submerged	≥ 3 m. submerged	Total impact areas
High risk scenario	691,622	374,143	453,276	**1,519,042**
Medium risk scenario	1,086,615	691,622	827,419	**2,605,657**
Low risk scenario	1,493,119	1,086,615	1,519,042	**4,098,776**

a. In Section 3, buildings in Piura are assumed to be one-story tall or approximately 3-meter high. As can be seen Figure 12-left, the curves for wooden structures will collapse under a 10-foot or 3-meter floods. On the other hand, Figure 12-right shows that the collapse curves for concrete/masonry buildings are defined mainly by the water velocity, which cannot be attained from this methodology. However, hydrological research (Guerrero, Farias, & Reyes, 2015) focusing on the upper part of the Piura river found that the river stream can have velocities as high as 1.8 meters/second or 5.9 feet/second, which still does not exceed the concrete building collapse curve. Thus, this process assumes that concrete/masonry buildings will not collapse. Consequently, the number of buildings which will collapse are wooden buildings submerged under a 3-meter-or-more inundation depth. Differentiation between buildings in need of reconstruction or refurbishment will allow for granularity in the monetization process.

4. Estimate the percentage of structural damages for non-collapsed buildings. The percentages of building damages depend largely on depth-damage curves. While the HAZUS-MH technical document provides the curves (FEMA, 2004, p.5-1 – 5-21), there are variations in construction

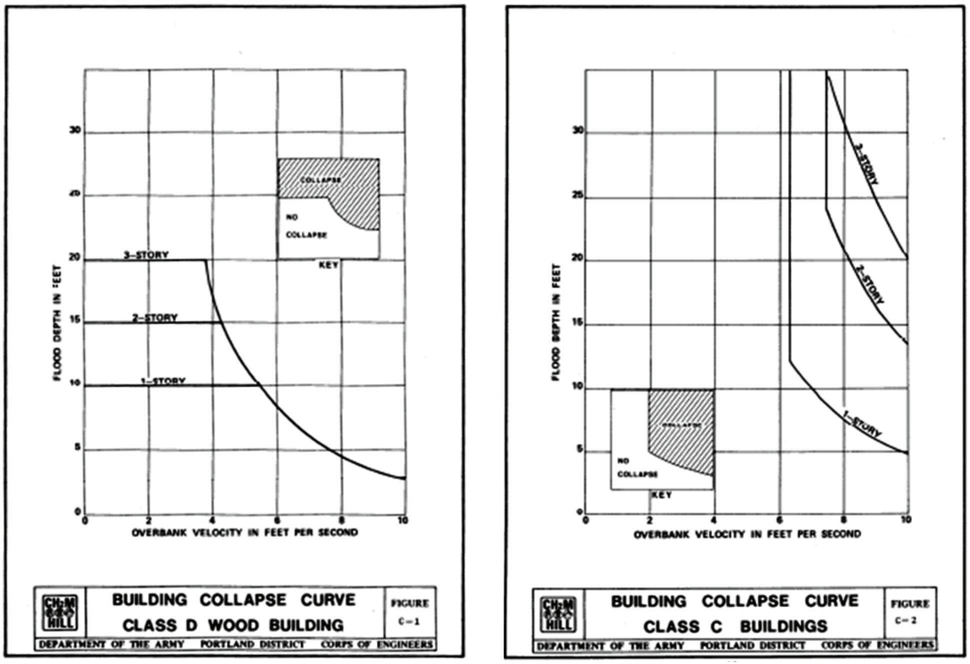

Figure 12:
Building collapse curves: class D wood building and class C concrete/masonry buildings (FEMA, 2004, p.5-23 – 5-24).

Table 5: Building areas that will collapse and not collapse at different flood scenarios.

Scenarios at 1-meter differences	Collapsed buildings (sq.m.)	Non-collapsed buildings (sq.m.)
High risk scenario	1,418,991	5,821,163
Medium risk scenario	2,590,257	9,935,311
Low risk scenario	4,755,397	15,411,052

standards in different continents to be considered. With such regards, the European Union has published a report on global flood depth-damage functions (Huizinga, J., de Moel, H., & Szewczyk W., 2017). The curve for South and Central America Continent was studied from various socioeconomic communities in Brazil and Mexico. While the result from the two countries does not speak directly for Peru, the curve is the closest information available. Moreover, this depth-damage function also does not recognize the variation between wooden and concrete/masonry buildings.

a. Choose an appropriate model for calculation. The global flood depth-damage functions that relate to building stocks are available for residential and commercial buildings (Huizinga, J., de Moel, H., & Szewczyk W., 2017). With the particular nature of the service and commerce sectors that tend to be in smaller buildings and are pervasive throughout urban areas, this research decides to use the damage factor for commercial buildings to be conservative on the damage calculation.

b. Estimate damages in different flood scenarios according to the damage factors for commercial buildings used as a percentage of damage to building structures (Table 7).

Table 6: Average continental damage function for South America – residential and commercial buildings (Huizinga, J., de Moel, H., & Szewczyk W., 2017, p.18, 24, 30).

Water depth (m)	Damage factor for residential buildings	Damage factor for commercial buildings
0	0	0
1	0.71	0.84
2	0.95	0.99
3	0.98	1.00

Table 7: Total damage on built-environment grouped by damages to be refurbished and collapses to be reconstructed.

Scenarios at 1-meter differences	Submerged depth (non-collapsed)			Total damage	
	1 m. (84% damage)	2 m. (99% damage)	≥3 m. (100% damage)	Non-collapsed (refurbishment)	Collapsed (reconstruction)
High risk scenario	2,399,681	1,529,954	1,418,991	**5,821,163**	**453,276**
Medium risk scenario	3,770,164	2,828,195	2,590,257	**9,935,311**	**827,419**
Low risk scenario	5,180,587	4,443,408	4,755,397	**15,411,052**	**1,519,042**

Valuation of building damages at different hazard scenarios

Valuation of building damages depends largely on the cost of construction and refurbishment. This phase has two processes; 1) estimate the cost of refurbishment/reconstruction and 2) estimate the total construction costs at various flood scenarios.

1. Estimate the cost of refurbishment and reconstruction. This step relies heavily on the available data of local construction costs. Ideally, an average or standardized construction cost per square meter for each building type (i.e. concrete and wooden buildings) is preferable for a more accurate calculation. However, the region of Piura lacks any standardized or government-assessed construction values. The only information that the Ministry of Housing Construction and Sanitation (MVCS) provides is a valuation of social housing, which operates under the Fondo Mi Vivienda program (Find My Home). By inferring from the operational regulation of MVCS (Resolución Ministerial Nº 236-2018-Vivienda, 2018), the social housing construction can cost between US$211 to US$597/sq.m.[3]

While the number is local to Peru, it does not reflect the prices of regular housing construction which will be the majority of constructions affected by floods. In contrast, if other areas have a database of updated and standardized construction costs, those numbers will be an ideal choice for a more accurate risk-valuation.

In lieu of the missing data, the European Union has also published research on a

[3] The Resolución Ministerial Nº 236-2018-Vivienda, 2018, Article 5 states that the value of social interest housing (VIS) can cost between 5.9-20 UIT. UIT is the Peruvian national tax imposed unit which takes into account rate of inflation. It was valuated at 4,150 Soles (Ministerio de Economía y Finanzas. 2018) or about US$1,254 at the exchange rate of US$1 = 3.31 Soles. Additionally, in Article 3 of the same regulation, the minimum sizes of a 1-room and 3-room house are 35 sq.m. and 42 sq.m. respectively. Thus, the cost of a Peruvian social housing ranges between US$211 to US$597/sq.m.

correlation function between GDP per capita and construction costs in addition to the global flood depth-damage functions. While the predictive function does not have very high R-square values, an advantage of using this method is in its ability to predict construction costs for various countries as well as its ability to update construction costs depending on the economic well-being of the country at the time. The function is as follows:

$$cY = aX^b$$

when

a and b are coefficients of the functions for different building usage as shown in Table 8;

c[4] is the exchange rate for US$ and Euro which is 0.88 Euro for US$1;

X is the GDP per capita for Piura Region in 2017 is US$3,025[5]; and

Y is the corresponding construction cost in US$/sq.m.

Using the coefficients for commercial buildings to be consistent with the previous analysis, the construction cost becomes $(0.88)Y = (33.6)(3{,}025)^{0.357}$. Consequently, the construction cost for Piura, Peru, in 2017 can be estimated at US$668/sq.m. This number is larger than the ranged derived from the MVCS regulation, which is to be expected as it better reflects real construction cost than that of social housing. Additionally, after asking local contractors and engineers, US$668/sq.m. is also closer to the construction costs than the price range for social housing.

2. Estimate total construction costs for the total impact on Piura using the construction cost of US$668/sq.m. estimated from the previous step.

RESULTS

This research produces the promised outputs including a) an accessible and technically simple methodology (Section 4), b) maps of fluvial flood risk distribution (Figure 9, 10, 12, and 13), and c) monetized values of potential construction costs (Table 9).

The analysis method which underpins this research is based on basic QGIS and mathematic calculations, which can be done through Excel or other similar programs. QGIS is a free and open-sourced program which can be downloaded online with available documentation. There are also free tutorials online which can help guide new learners. The use of QGIS makes the process more technically accessible to local authorities. Additionally, much of the information used for this research can be found and downloaded online, which further supports the method's accessibility. Lastly, by using global data and tools such as the NASA's SRTM3 DEM file and the global flood depth-damage functions (Huizinga, J., de Moel, H., Szewczyk, W., 2017), the methodology of this research can also be adopted in other parts of the world despite the availability of local data.

Table 8: Coefficients of the GDP per capita and construction costs model fit functions for different building usages (Huizinga, J., de Moel, H., & Szewczyk W., 2017, p.18, 24, 30).

Class	a	b	R^2
Residential	24.1	0.385	0.77
Commercial	33.6	0.357	0.80

4 Coefficient c is added specifically in this research to produce results in US$/sq.m. rather than in Euro/sq.m.

5 GDP per capita for Piura was calculated from the regional GDP of 18,593,063 thousand Soles (INEI, 2017a), the regional population of 1,856,809 (INEI, 2018), and the exchange rate of US$1 = 3.31 Soles. Consequently, the regional GDP per capita is estimated at US$3,025.

Table 9: Construction cost estimation at various flood levels.

Scenarios at 1-meter differences	Refurbishment costs estimation (million US$)	Reconstruction cost estimation (million US$)	Total cost estimation (million US$)
High risk scenario	3,888.57	302.79	**4,191.36**
Medium risk scenario	6,636.79	552.72	**7,189.50**
Low risk scenario	10,294.58	1,014.72	**11,309.30**

The regional flood risk maps produced by this methodology is another result of this research (Figure 9, 10, 12, 13). Despite the 1-meter DEM data, the risk maps, generated by this research, are similar to those recorded from the past ENSO events. The risk maps show that many low-lying areas have been developed into residential and/or commercial buildings which put their residents at risk from fluvial floods. The city of Piura, which is in the top right corner of Figure 13, is the largest city in the region of Piura. As the city continues to grow in the future, local authorities can use the produced map to direct the city's growth and to identify risky areas which need proactive mitigation plans against future inundation damages. On the other hand, cities like Catacaos and La Arena, which situate downstream from Piura are known to have the worst damages from fluvial floods in Piura. Figure 13 also shows that the two cities are situated in low lying areas without clear higher grounds that can act as safe heavens during flood disasters. Given their geographic constraints, the two cities and other cities with similar settings will need to take a different approach to prevent and react to their risks.

By knowing the location of low-lying areas and the potential of experiencing fluvial floods, the maps produced by this methodology can help local authorities and residents avoid building on low-lying areas near river flood plains, which are sometimes invisible during dry seasons. The maps can also become a basic resource of spatial knowledge which can help the region and cities within it create resiliency plans, build better enforcement standards, and designate flood-prone areas as urban amenities such as parks or water retention features.

Without any plans put in place, in the most likely high-risk scenario, inundation from continuous heavy rainfalls will affect about 6,274,439 square meters of buildings or 4.89% of all buildings in the region. The amount of damaged buildings can be translated to an estimated number of 5,821,163 sq.m. of damaged buildings and 453,276 sq.m. of buildings collapsed from floods. The latter mainly refers to quincha and other wooden buildings which are likely to be houses of the lower-income population. These distinguishing factors are also suggestive to the number of units needed for emergency shelters and long-term housing supports for those who cannot afford to reconstruct or refurbish their households.

The monetized values of potential costs of flooding at the high-risk scenario are estimated at $4.2 billion for the whole region of Piura. While the value is much higher than what was reported in the LA Times (Leon & Kraul, 2017), only a few days later, the President of Peru announced that the recovery of the 2017 flood in Peru can cost up to $9 billion for over 5 years of reconstruction in impacted locations across Peru (Slattery, 2017). With Piura being the location most affected by the 2017 floods, $4.2 billion of damage in Piura alone is a conceivable number.

While this model should be further refined with more data surveyed and opened for public, the methodology of this research is a good first step in providing a free- and simple-to-use tool for flood estimation. The process can, thus, be used by anyone including local authorities and NGOs. Simple tools, such as this methodology, are keys to empowering local authorities to take action and become more efficient in their plans and responses towards growing climate risks in the future.

RESEARCH GAPS

This research has three main gaps which need to be mentioned: 1) flood modeling, 2) time and data scale sensitivity, and 3) other indirect flood impacts.

This research does not model patterns of water run-offs from heavy rains, which can cause other problems including huaycos and mudslides. One example of such places is in Sullana, Piura (Figure 14). The city is located on high lands and is not at risk according to this flood estimation

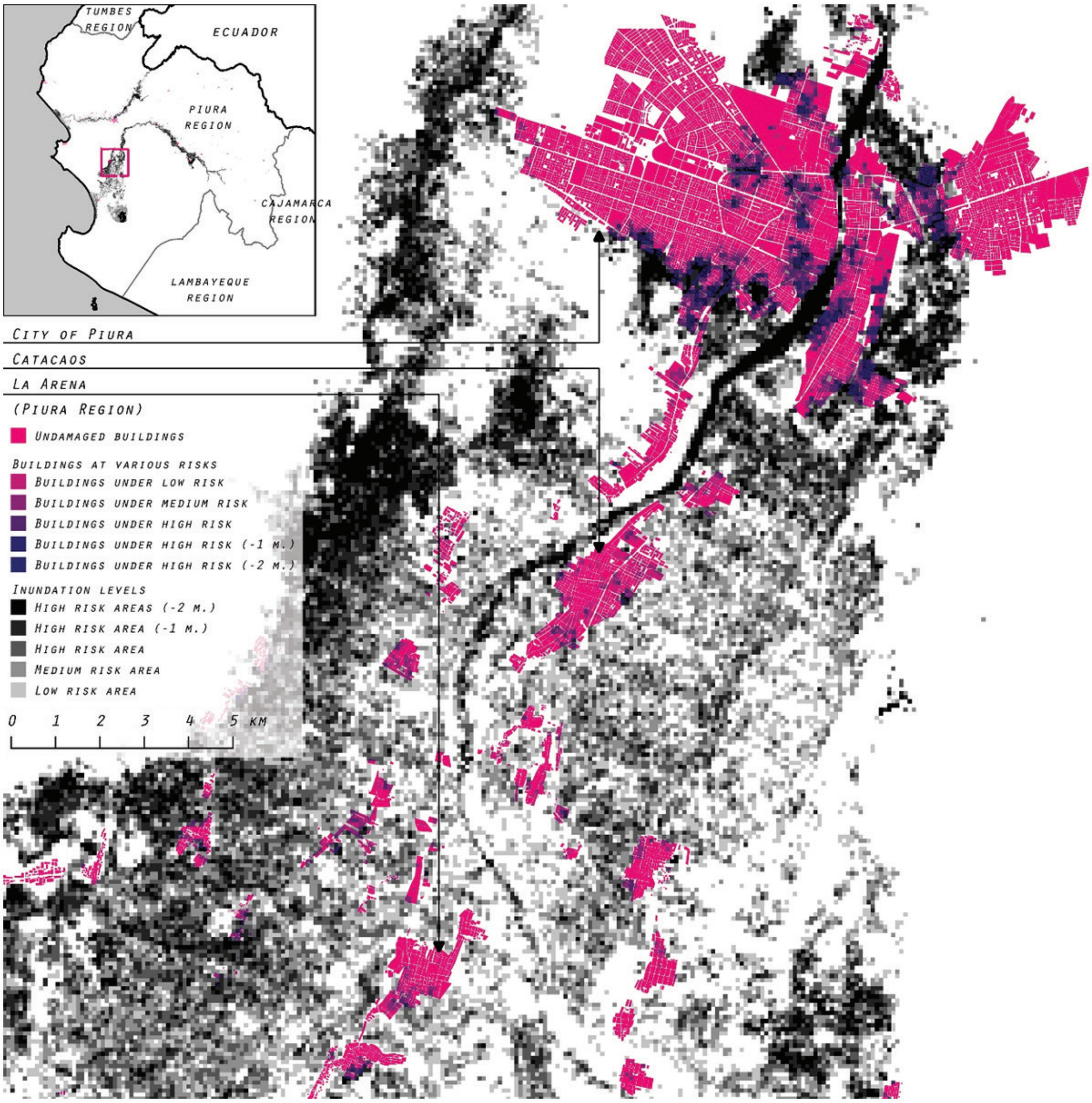

Figure 13:
Fluvial flood risk map for the city of Piura, Catacaos, and La Arena, Piura.

methodology. However, Sullana often experiences pluvial floods which can also be problematic to the city. This methodology cannot assess such risk because it does not include the amount of rainfall, the probability of extreme events, or soil types which will shift the levels of flood and refine the flood estimation. Thus, it is important to note that the flood model of this research looks solely at fluvial floods from the variations in terrain altitudes relative to the estimated river levels. On the other hand, the level of accuracy will more than often be a trade-off with the accessibility and the technicality involved in the modeling process. Consequently, this research weighs the importance of accessibility with rough estimates over higher accuracy with higher technical barriers.

The unavailability of timely data on a detailed scale is the main challenge of risk estimation. Such is not a challenge only in Peru but also in many other countries around the world as well. For example, this research blankets building types, heights, and usage with regional data which does not reflect the actual spatial distribution of various buildings. Furthermore, there are no records of building collapse curves or depth-damage curves, which relates to various building model types surveyed by the INEI (2018). Similarly, there is also a gap in calculating construction costs from GDP. The INEI report shows that Piura's service sector, manufacturing, commerce, and mining respectively are the main sources of income for the region, which in combination, contribute to over 60% of the region's income in 2015 (INEI, 2017b). Many of these sectors consist of large corporations and the earnings of which do not reflect much on the well-being of the local economy and its correlated construction costs. While the methodology provides reasonable results, this method is best used alongside local knowledge to fill the gaps. Such engagement is not only helpful in identifying erroneous issues but is also helpful in empowering locals as important actors in building robust risk mitigation plans.

This research only looks at direct physical damages of building stocks, which are translated to reconstruction costs. However, there are also other direct and indirect costs related to flood damages. As mentioned in Section 2, FEMA's HAZUS Flood Model looks at a variety of impact as shown in Figure 15 including essential facilities, lifelines transport, lifelines utility, vehicles, and agriculture. Consequently, the extent of time flood impacts can actually be much higher than the estimated value, and the time needed for remedial can also be much longer as well. Despite such a gap, more analyses also mean the need for more data which are not available in Piura.

DISCUSSION FOR POLICY MAKERS

In Peru, the institution that concerns itself with natural disaster risks is the National Center for Disaster Risk Estimation, Prevention, and Reduction (CENEPRED). CENEPRED is responsible for the formulation and implementation of national policies and disaster risk management plans at a national level (CENEPRED, n.d.). Nevertheless, local and regional authorities continue to allow for new development and growth regardless of identified risky areas. The reasons behind this gap can be attributed to a lack of training within local government, a lack in local and national enforcement, or simply and more likely a lack of accessibility to disaster risk maps.

As suggested earlier, CENEPRED's parachute and technocratic approach to risk assessment plan seldom contribute to empowering local authorities to become more adept at realizing their own risks. Thus, local authorities can and should start building their own capacity to understand their climate risks, to engage with relative actors, and to plan for their resilient futures. The methodology and the results of this research can play their parts for these developments in three ways: 1) CENEPRED can use this as a tool to engage local authorities and the general public, 2) local authorities can use the result of this tool to design risk mitigation plans, and 3) local authorities can use their findings to better engage with new development projects such as the Ministry of Housing, Construction, and Sanitation to better locate new public housing projects.

Figure 14:
Fluvial flood risk map for Sullana, Piura.

CENEPRED can use this tool as a way to engage local authorities and the general public through capacity building workshops, which aim to empower locals with an ability to create their own risk maps. Through workshops such as these, CENEPRED can use them as platforms to introduce other knowledge regarding risk mitigation and prevention plans. Consequently, local authorities can better learn about the spatial significance of development and growth in relations to disaster risks and learn how to apply to their new knowledge. On the other hand, the general public can also begin to use their acquired knowledge to require the government to act accordingly. This check and balance dynamic requires knowledge capacity on both sides to work well together. Thus, the dynamic is not only suitable for Peru but also anywhere in the world where extreme rainfalls are becoming more frequent and local authorities are not as responsive in providing mitigation strategies.

Once local authorities know the risks, they can better engage in finding plans for prevention, mitigation, and reaction to flood disasters. Commonly, houses in Piura are constructed without supervisions of engineers or architects, and they rarely follow the construction regulations (Reglamento Nacional de Edificaciones, 2006). Recognizing the detrimental costs of inundation can help convince local authorities to be more active in enforcing the regulations. On the other hand, one of the simplest ways to prevent risks is to deter development in risky areas, which can easily be identified from the produced maps. However, for established areas, engineers and architects can join forces to increase resiliency such as building better drainage systems in low-lying areas, designing better river banks as inundation buffers, or creating a building-upgrade methodology which will minimize building damages. Moreover, local authorities can use these maps to plan evacuation routes and safe heavens in preparation for future flood disasters.

The produced risk maps can be used by local authorities to better engage with various development entities. An important example of such entities is the Ministry of Housing, Construction, and Sanitation. The INEI (2017c) looks at the housing deficit through quantitative and qualitative aspects. While the quantitative aspect of housing looks at areas of spatial needs, the qualitative aspects look at the quality of housing materials, the density of living spaces, and the provision of basic services. In many cases, people with lower income in Piura are marginalized and forced to live in risky areas with no access to basic infrastructures including electricity, water and sanitation, streets, or drainage systems. While programs such as Fondo Mivivienda, or as translated to Find My House (www.mivivienda.com.pe), are helping marginal population financing their house construction, local authorities can further help these programs identify safe areas where these low-income houses should locate. This way housing for the low-income population can better support their lives in the long term because they are safe from reconstruction costs associated with inundation risks. Moreover, local

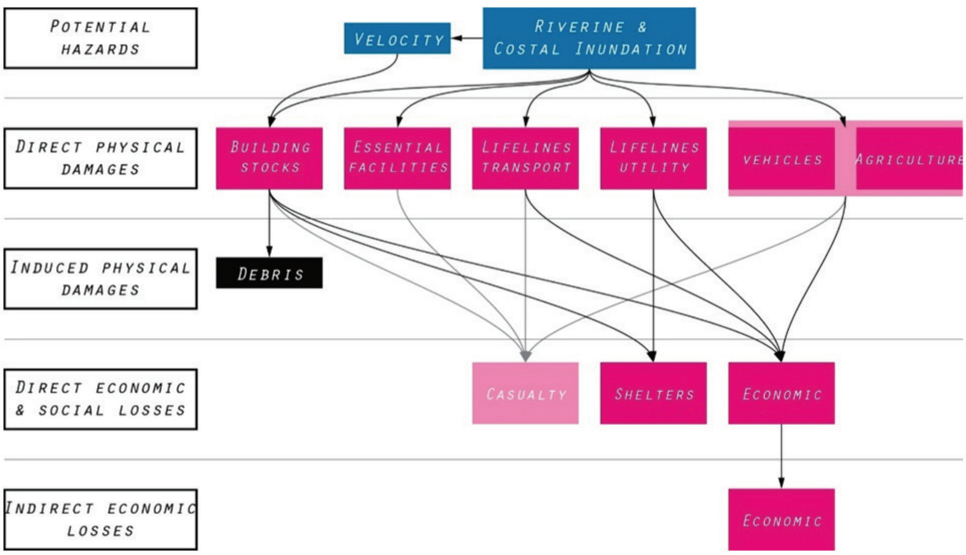

Figure 15:
Relationship of components in the HAZUS-MH Flood Model (summarized from FEMA, 2004).

authorities can begin building basic infrastructure to lead the direction of their cities' growth as well.

There are many other policies and activities that these risk maps and the associated cost projections can serve. The purpose of this research lies in a belief that knowledge is an empowerment tool which is one of the ways that development can be sustained through a long period of time. This research provides a fluvial flood risk estimation tool for locals not only in Piura, Peru, but possibly also in other parts of the world, to self-acquire such knowledge, and from thereon, build civil and political activities around it. While the implementation process will require many actors' involvement, having an accessible tool ready at hand is the first step towards such direction.

REFERENCE

CENEPRED. (n.d.) *Quiénes somos.* El Centro Nacional de Estimación, Prevención y Reducción del Riesgo de Desastres (CENEPRED). Available at: https://cenepred.gob.pe/web/quienes-somos/. Accessed 9 March 2019.

D'Ercole, R. & Metzger,P (n.d.). *Piura region's building cadastral* [map]. Unpublished raw data.

Di Liberto, T. (2017). *Heavy summer rains flood Peru*. Climate.gov. Available at: https://www.climate.gov/news-features/event-tracker/heavy-summer-rains-flood-peru. Accessed 4 March 2019.

FEMA. (2004). *Multi-hazard Loss Estimation Methodology Flood Model Hazus®-MH Technical Manual*. Washington, D.C.: *Department of Homeland Security, Federal Emergency Management Agency, Mitigation Division*. Available at: https://www.fema.gov/hazus-mh-user-technical-manuals. Accessed 16 August 2018.

French, A. and Mechler, R. (2017). *Managing El Niño Risks Under Uncertainty in Peru: Learning from the past for a more disaster-resilient future*. Luxemburg, Austria: *International Institute for Applied Systems Analysis*.

Guerrero, L., Farias, M., and Reyes, J. (2015). *Changing in morphodynamics of the ephemeral Piura River due to ENSO*. The 9th Symposium on River, Coastal and Estuarine Morphodynamics. Iquitos, Peru: RCEM 2015.

Huizinga, J., de Moel, H., and Szewczyk, W. (2017). *Global flood depth-damage functions. Methodology and the database with guidelines*. EUR 28552 EN. doi: 10.2760/16510

INDECI. (2009). *Mapa de peligros de la ciudad de Piura actividad geodinamica externa (inundaciones)* [map]. City of Piura, Peru: INDECI.

INEI. (2017a). *Piura: Valor Agregado Bruto por Años, según Actividades Económicas Valores a Precios Constantes de 2007*. Available at: https://www.inei.gob.pe/estadisticas/indice-tematico/economia/. Accessed 4 March 2019.

INEI. (2017b). *Perú: Principales Indicadores Departamentales 2009-2016*. Lima, Peru: *Instituto Nacional de Estadística e Informática-INEI.* Available at: https://www.inei.gob.pe/media/MenuRecursivo/publicaciones_digitales/Est/Lib1421/libro.pdf. Accessed 16 August, 2018.

INEI (2017c). *Encuesta Nacional de Programas Presupuestales 2011-2016*. Lima, Peru: *Instituto Nacional de Estadística e Informática-INEI.* Available at: https://www.inei.gob.pe/media/MenuRecursivo/publicaciones_digitales/Est/Lib1442/libro.pdf. Accessed 9 March, 2019.

INEI. (2018). *Perú: Perfil Sociodemográfico. Informe Nacional Censos Nacionales 2017: XII de Población, VII de Vivienda y III de Comunidades Indígenas*. Lima, Peru: *Instituto Nacional de Estadística e Informática-INEI.* Available at: https://www.inei.gob.pe/media/MenuRecursivo/publicaciones_digitales/Est/Lib1539/libro.pdf. Accessed 28 February 2019.

IPCC. (2018). Summary for Policymakers. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, Maycock, M. Tignor, and T. Waterfield (eds.)]. Geneva, Switzerland: *World Meteorological Organization*.

Junk, W.J. & Bayley, P.B. & Sparks, R.E. (1989). The Flood Pulse Concept in River-Floodplain Systems. *Canadian Special Publication of Fisheries and Aquatic Sciences*. 106. 110-127.

Leon, A. and Kraul, C. (2017). Peru's brutal season of floods leaves 94 dead, 700,000 homeless. *The Los Angeles Times*, 28 March 2017. Available at: http://www.latimes.com/world/mexico-americas/la-fg-peru-floods20170328-story.html. Accessed 20 February 2019.

Ministerio de Economía y Finanzas. (2018). *Valor de la UIT:1992-2018.* Available at: https://www.mef.gob.pe/es/valor-de-la-uit. Accessed 14 May 2019.

Reglamento Nacional de Edificaciones. Title 1-3. Urbanistas Peru. (2006).

Resolución Ministerial Nº 236-2018-Vivienda. Ministerio de Vivienda, Construcción y Saneamiento. (2018). Lima.

Slattery, G. (2017). Peru's president says flood recovery may cost up to $9 billion. *Reuter*, 8 April 2017. Available at: https://www.reuters.com/article/us-peru-floods-economy-idUSKBN1792T0. Accessed 11 September 2018.