Flooding Resiliency of Surigao del Sur, Caraga Region, Philippines Residents Through Rainwater Catchment and Storage System

Anastacio G. Pantaleon, Jr.1*, Franco G. Pantaleon1, Jun Rey S. Lincuna1, Leo Ian D. Jovero1

1North Eastern Mindanao State University – Bislig Campus, Philippines

ARTICLE INFO

ABSTRACT

Urbanised areas in Northeastern Mindanao have a problem of addressing flooding occurrences. This study primarily aimed to provide insights into how the rainwater catchment system of uptown communities and their cooperation could increase flood resiliency of downtown communities in the Surigao del Sur, Caraga Region, Philippines. This research employed quantitative analysis of the eleven (11) year (2010-2020) data from the Philippine Atmospheric, Geophysical, and Astronomical Services Administration - Hinatuan, Surigao del Sur station. The recommendable optimum rainwater storage capacities for a given number of household occupants, roof areas at run-off efficiency of 90%, and three (3) day rainfall characteristics at 36.9% averaged probability of exceedance were initially determined. Through scenario analysis, uptown communities emptying their rainwater storages before heavy downpour occurs could provide sufficient flood volume reduction and buffer time for downtown communities to prepare. The output of this research is vital in the environmental planning, management, and policies of cities and regions.

INTRODUCTION

Human life was never out of challenges. Disasters disturb natural, constructed, and social environments, affecting communities and people. They can be caused by climatic, geophysical, technical, or human-caused events, or a mix of these (Liu et al., 2018; McCoy et al., 2014; Bourque, et al., 2007). A database was created from 1970 until 1999 to estimate the hazard of life from Atlantic tropical storms in the

* Corresponding author. E-mail address: agpantaleon@nemsu.edu.ph
https://doi.org/10.24191/bej.v21i1.479
©Authors, 2024
contiguous United States and surrounding coastal seas (Rappaport, 2000). During those thirty (30) years, freshwater floods were responsible for more than half of the six hundred (600) deaths in the United States caused directly by tropical storms or their remnants, with most deaths occurring in inland counties (Rappaport, 2000). The flood deaths that are most easily identifiable are those that occur as a result of drowning or trauma, such as being struck by items in fast-flowing waters (Adikari et al., 2010; Ahern et al., 2005; Jonkman & Kelman, 2005). Bernard et al. (2001) explained that because of the increased overall water volume, rapid water flow rates, and a limited warning period in which to seek refuge, flash floods caused by massive rainfalls in short intervals are the deadliest. Studying and anticipating how global climate change may impact severe rainfall, flooding frequency, and size (Schumacher, 2017). With good disaster conditions and a lack of preparation and mitigation, disaster is just around the corner, ready to strike (Khaerani, 2022).

Because of its location, typhoons, tropical depressions, and persistent heavy rainfall (B. Racoma et al., 2021) are the most common causes of flooding in the Philippines (Corporal-Lodangco & Leslie, 2016). Since the mid-twentieth (20th) century, the country's extreme rainfall intensity and frequency have risen, and tropical storms and cyclones—often accompanied by storm surges, strong winds, flooding, and landslides—have produced fatal and expensive disasters (Yonson, 2019; Cinco et al., 2016; Franta et al., 2016). Furthermore, climate models suggest that precipitation would (continue to) drop in the dry season while increasing in the rainy season until mid-century, increasing the risk of flooding and landslides (Tubog et al., 2023; Cabrera & Lee, 2018; Froude & Petley, 2018).

Human activities are related to these problems. It has been known that urbanisation has caused detrimental effects on the environment (Johnson et al., 2020; Wang et al., 2019; Newman, 2006) especially on vegetation (Brandalise et al., 2019; De Carvalho & Szlafsztein, 2019; Guan et al., 2019; National Disaster Risk Reduction and Management Council (NDRRMC), 2015; Pandey & Seto, 2015) eventually leading to increased flood risks (Mahmoud & Gan, 2018; Chen et al., 2015; Li et al., 2013; Zhang et al., 2008). Along with it, the informal settlers' expansion and a lack of tenure have also pushed many to squat in marginal and hazard-prone places such as flood-prone zones, riverbanks, along the seashore, and on steep hillsides, making them exposed to natural hazards such as flooding (Swiss NGO DRR, 2014). In addition, bronchitis, respiratory tract infection, influenza, chickenpox, measles, typhoid fever, diarrhoea, leptospirosis, dengue fever, hypertension, and heart disease are all linked to one or more of the flood variables: exposure, height, or duration (Okaka & Odhiambo, 2018; Yonson, 2018). This also causes flood-related diseases, costing the government a lot of money and putting a lot of strain on afflicted families, pushing non-poor households into poverty (Jha et al., 2018) and the marginalised further into poverty (Yonson, 2018; Torti, 2012).

Government investment in infrastructures alongside sustainable policy direction plays a critical part in protecting the welfare of urban and rural residents. An example is the building flood mitigation structures which contributed to society's flood mitigation efforts have been thoroughly researched and improved throughout the years (Madden et al., 2023; Basack et al., 2022; Nurjanah & Apriliani, 2021; Starominski-Uehara, 2020; Sayers et al., 2013; de Bruijn, 2004). However, community resilience is not solely a government responsibility but also involves the active engagement and participation of the community members themselves (Shi et al., 2022; Pramudita & Nugroho, 2021; Sulaiman et al., 2019; Vårheim et al., 2018; Zamboni, 2017). While researchers (Fewkes & Warm, 2000; Alfonso et al., 2019; Chang et al., 2018; Gerolin et al., 2010; Jameson & Baud, 2016; Vaes & Berlamont, 2001) have already justified the use of household rainwater harvesting systems to help buffer flood occurrence, only few contextualised it in the Philippines as part of countermeasures to flooding were made (A Oraya, 2023; Ching Tan, 2023; Bañados & Quijano, 2022). Finding the optimum storage tank sizes in the context of local climatic conditions is still challenging (A Oraya, 2023).
This study aimed to optimise the sizing of rainwater tank storage for housing development concerning its climate type. For this case, Surigao del Sur, Philippines, has a Type II climate defined as a no-dry season with a very pronounced maximum rain period from November to January (DOST- PAG-ASA, n.d.). Furthermore, this intended to do one of its functionalities – simulating the reduction of flood and providing an efficient buffer period based on the capacity of rainwater tanks to harvest rainwater. The outcome of this study shall enable us to formulate policies that can add to the body of knowledge and alter social behaviours in responding to the call for risk reduction.

LITERATURE REVIEW

A community manifesting resiliency meets the Sustainable Development Goal (SDG) of sustainable cities and communities (SDG 11), contributing to the disaster mitigation efforts of the locality and the country. A resilient community also gathers and reserves the financial resources needed from a variety of sources, including national capital markets, for climate change mitigation and adaptation initiatives, as well as response and reconstruction in the event of natural disasters, particularly earthquakes, floods, and storm surges that are endemic to the East Asia Region (Costa et al., 2016). Resiliency becomes evident during disastrous and hazardous events, especially during floods. Floods are the natural hazard with the highest frequency and the widest geographical distribution worldwide (United Nations, 2021; World Meteorological Organization, 2021; CRED, 2019; Chandrappa et al., 2011). Flood hazards continuously disrupt human living conditions globally, so flood resiliency became a framework for risk reduction in water-related disasters (Liao, 2012). To better understand the concept of resiliency in this study, the author anchored on Brujin’s (2004) definition of resilience as the ability of a system to maintain its most important processes and characteristics when subjected to disturbances. Systems may be about engineering, ecological, or socio ecological. Specifically, Zevenbergen et al. (2020) classified engineering resilience as an outcome that relies on the design, adaptation, construction, and deployment of flood-resilient technologies and structures in reducing the recovery time after failure, consequences during failure by floodwater and the probability of failure focusing on flood hazard mitigation.

Interagency Efforts

The Philippines is one of the most vulnerable countries in Southeast Asia, continuously being at risk of floods (Noor & Maulud, 2022; Thomalla et al., 2017). Heavy rainfall and precipitation caused by weather systems contribute to minor and major flooding incidents in the country. Recently, the Philippines reported that floods damaged two hundred and ninety-three (293) houses due to Southwest Monsoon rains (European Civil Protection and Humanitarian Aid Operations, 2021). Continued interagency efforts have mitigated flood casualties and damages in the country through flood advisories, warnings, and bulletins. The National Disaster Risk Reduction and Management Council (NDRRMC), with the Office of Civil Defense (OCD) as its implementing arm, serves as the main frontline in informing and responding to the local government units (LGU). NDRRMC communicates and collaborates with the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA) and the Department of Public Works and Highways (DPWH) in exercising flood management (Unite, 2021). It operates under the National Disaster Risk Reduction and Management Framework (NDRRMF), which anchors the National Disaster Response Plan (NDRP). At present, the NDRP expects all LGUs to have emergency plans for Hydro-Meteorological Hazards (typhoons, monsoons, low-pressure areas, flooding, storm surge, and rain-induced landslides) along with their Local Disaster Risk Reduction and Management Plans (LDRRMPs) in place (Alcantara & Christopher, 2019).

Before NDRRMC was implemented through the Philippine Disaster Risk Reduction and Management Act of 2010, the Republic Act 6716 (RA), known as the Rainwater Collection and Springs Development Law of 1989, was promulgated. RA 6716 seeks to provide for the Department of Public Works and
Highways’ (DPWH) construction of water wells and rainwater collectors, the development of springs, and the rehabilitation of existing water wells in all barangays in the Philippines.

Rainwater Harvesting Systems for Flood Reduction

Rainwater harvesting (RWH) is an engineering method known for collecting water from storms and rainfalls (Jamali et al., 2020; Semaan et al., 2020; Farrey et al., 2011; Imteaz et al., 2011; Helmreich & Horn, 2009). However, the practice of RWH is not limited to the collection of water alone but also poses several advantages, which include mitigating flood and enabling environment-friendly engineering design (Vojinovic et al., 2021; Jamali et al., 2020; World Bank, 2019; Teston et al., 2018; Melville-Shreeve et al., 2016; Burns et al., 2010). These advantages motivated countries to the scientific design of cost-effective and highly efficient rainwater harvesting systems, which ensures sustainability and efficiency in supplying water and maintaining urban structures during heavy rainfall events (Pelak & Porporato, 2016; Chiu et al., 2015; Matos et al., 2013; Esguerra et al., 2011; Roebuck et al., 2011). Over the years, installing rainwater harvesting technologies to mitigate floods has continued to be a subject of scientific inquiry.

There were contrasting views. It was stressed that RWH mainstream techniques can only mitigate slight rain (Qin, 2020; Mentens et al., 2006). Another case study by Kim & Yoo (2009) simulated that the flood reduction effect is estimated to be only 1% when using 10% of the entire city area as the rainwater collecting surface. On the flip side, some posited (Alfonso et al., 2019; Chang et al., 2018; Jameson & Baud, 2016; Gerolin et al., 2010; Vaes & Berlamont, 2001; Fewkes & Warm, 2000) that indeed rainwater promoting rainwater harvesting systems to significantly reduced flood incidence. Freni & Liuzzo (2019) concluded that RWH systems are essential in lowering flood volumes and averting potential drainage system breakdowns during storm events, and in flooded regions, they can be decreased by up to 100% during minor rainfall events. A rainfall event with a depth of up to 50 mm might result in a 35% reduction in a flooded area. For heavy rainfall events, the reduction in inundated areas is minimal. In the Philippines, Borgonia & Fornis (2020) simulated a rooftop rainwater harvesting system in Mandaue City and reported that flood volume reduced from 6.03% to 15.27%. Most literature emphasised the efficiency of rainwater harvesting systems on flood reduction in urban areas while decreasing efficiencies during heavy or severe rainfalls (Borgonia & Fornis, 2020; Qin, 2020; Mentens et al., 2006) have been observed. In any case, both sides scientifically explored avenues to explain its effectiveness and efficiency.

However, urban residences have different topographies from the countryside. There is significant uncertainty regarding contextualised quantitative comparisons of how much rainfall volume is observed from one region to the other. Furthermore, most methodologies used in determining storage sizes were weekly (Xu et al., 2020) or monthly rainfall data (Nguyen & Han, 2017; Imteaz et al., 2012), which may not be relevant in Type II Climate areas. Through these gaps, the researchers are optimistic about obtaining significant results.

METHODOLOGY

Precipitation Data

The initial objective of this research is to recommend storage capacities that apply to different factors. Researchers (Matos et al., 2013; Imteaz et al., 2010; Khastagir & Jayasuriya, 2010) evaluated the dependability of rainwater tanks or storage under several scenarios, including climatic conditions, roof areas, tank sizes, household water needs, and the percentage of total demand met by rainwater. Recorded precipitation is vital in the analysis (Nguyen et al., 2018; Furumai, 2016; Matos et al., 2013; Moruzzi et al., 2012; Imteaz et al., 2011; Islam et al., 2011; Khastagir & Jayasuriya, 2010; Pachpute et al., 2009).

The climatic conditions of this study were based on eleven (11) years (2010 to 2020) of rainfall data gathered from the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAG-
ASA) Surigao del Sur, Caraga Region. Because it does not rain every day, this research recommended considering the three (3) day accumulation. Thus, calculating the average accumulated three (3) day rainfall for the eleven (11) years recorded yields the equation.

\[
\text{RainfallAve}_t = \frac{1}{N} \sum_{j=2010}^{2020} x_j
\]

(1)

where, \(x_j\) is the three (3) days of accumulated rain for the year \(j\), and \(N\) is the number of years (11 years).

**Probability of Exceedance**

Thomas and Martinson (2007) expressed that sizing rainwater storage is accompanied by roughly 30% uncertainties due to the generalisation of precipitation data from different locations. Rainwater catchment and storage system design should be based on estimations of rainfall depths that can be predicted with varying probabilities or return periods rather than the long-term rainfall data average because rainfall varies over time (Dirk, 2013). The statistical probability, also known as the probability of exceedance, refers to the likelihood that actual rainfall will be equal to or greater than the expected rainfall depth over time (Dirk, 2013). The likelihood of exceedance, \(P_x\), of the eleven (11) year three (3) day rainfall data as explained below using statistical tool regression coefficients.

\[
P_x = Ae^{-Bx} + P_0
\]

(2)

where \(x\) is the three (3) day rain inputs. Every averaged three (3) day data distributed over the year has a certain chance of exceeding. The rainfall depths may then be estimated using the mean probability of exceedance.

The three (3) day rainfall run-off is computed using the following equation to determine the harvestable rain, RR (Khastagir et al., 2010; Khastagir & Jayasuriya, 2009)

\[
RR = R_{\text{eff}} \times C_R \times A
\]

(3)

where \(R_{\text{eff}}\) is the three (3) day rain volume per unit area (m³/m²) at the calculated probability of exceedance, \(C_R\) is the constant of run-off, and \(A\) is the roof area coupled to the tank (m²). The constant of run-off used was 0.90 for smooth and impervious surfaces (Kinkade-Levario, 2007).

**Water Demand/Requirement**

Since rainfall data is on hand and the demand for the analysis daily, it would be justifiable to be consistent with the daily use of time (Xu et al., 2020; Freni & Liuzzo, 2019; Zhang & Hu, 2014; Burns et al., 2010; Kim & Yoo, 2009). Daily water consumption per capita was used to determine rainwater tanks. This paper was simulated based on the number of consumers according to water demand and the average water utilisation. When a lengthy rainfall time series is used to simulate the demand as a continuous drawdown, knowing the daily variance of the household's water use is of minimal relevance (Vaes & Berlamont, 2001; Fewkes & Warm, 2000). Researchers (Freni & Liuzzo, 2019; Nguyen et al., 2018; Lopes et al., 2017; Campisano & Modica, 2012; Ghisi, 2010) used two (2) to five (5) numbers of residents per household. With the average household size in the Philippines in 2020 being 4.4 people per household (ESRI, 2013), this research used the range from two (2) to five (5) people per household.
**Rainwater Tank Optimisation**

Determining optimal rainwater tanks entails many benefits in rural residences involving efficient collection and installation. This research followed the methods of Nguyen & Han (2017) in optimising the sizes of rainwater tanks with modifications in the variables. A simple rainwater harvesting, and storage system comprises a rooftop, downpipe, first flush, storage tank, water supply, and overflow (see Figure 1 below).

![Diagram of Simple Rainwater Harvesting and Storage System](Diagram.png)

**Sources:** Authors, 2023

Initially, simulation of the water flow (equation 4) in a rainwater tank as a precursor in determining the water balance (equation 5) with the following:

\[
Q_{in,t} = R_{eff} \times A \times C_R \times 0.001 = RR \times 0.001 \tag{4}
\]

\[
V_t = V_{t-1} + Q_{in,t} \Delta t - Q_{out,t} \Delta t - Q_{sup,t} \Delta t \tag{5}
\]

where:

- \(Q_{in,t}\) is the inflow rate into the rainwater tank (m\(^3\)/three (3) day) at time \(t\) and is the same as the run-off flow rate from the roof in three (3) days;
- \(V_t\) is the cumulative water stored in the tank (m\(^3\)) at time \(t\);
- \(V_{t-1}\) is the cumulative water stored in the tank (m\(^3\)) at time \(t-1\);
- \(\Delta t\) is the time increment (three (3) day);
- \(Q_{sup,t}\) is the water supply rate from the rainwater tank (m\(^3\)/three (3) day) at time \(t\); and
- \(Q_{out,t}\Delta t\) is the overflow rate from the tank (m\(^3\)/three (3) day) at time \(t\).
\( Q_{\text{sup},t} \) and \( Q_{\text{out},t} \) can be mathematically described as follows:

if \( V_t \leq 0 \rightarrow Q_{\text{sup},t} = 0 \); and

if \( V_t > 0 \), the water supply is limited by the cumulative water stored and inflow quantity in the tank.

\[
\begin{align*}
\text{if } V_{t-1} + Q_{\text{in},t} \Delta t < D_t \Delta t & \rightarrow Q_{\text{sup},t} \Delta t = V_{t-1} + Q_{\text{in},t} \Delta t \\
\text{if } V_{t-1} + Q_{\text{in},t} \Delta t \geq D_t \Delta t & \rightarrow Q_{\text{sup},t} = D_t
\end{align*}
\]

(6)

(7)

where:

\( D_t \) is the water demand (m\(^3\)/day) based on the product of average water consumption with an average estimate of hundred and fifthly (150) litres per capita per day for personal hygiene, sanitation, laundry, and kitchen activities (Andres & Loretero, 2021; Berwanger & Ghisi, 2018), and the number of household members.

If \( V_t \leq V \rightarrow Q_{\text{out},t} = 0 \)

where \( V \) is the full capacity volume of the storage tank.

If \( V_t > V \) the tank is full

\[
Q_{\text{out},t} \Delta t = V_{t-1} - V + Q_{\text{in},t} \Delta t - Q_{\text{sup},t} \Delta t
\]

(8)

The analyses provided the basis for the optimisation of rainwater tanks; a high water-saving value indicates that higher tap water can be saved by using rainwater and is mathematically described as:

\[
\text{Water Saving} = \sum Q_{\text{sup},t} \Delta t
\]

(9)

The above discussion is presented in Figure 2 below in the yearly \( (T_{\text{sim}}) \) simulation algorithm.
Fig. 2. Water Balance Algorithm

Sources: Authors, 2023

https://doi.org/10.24191/bej.v21i1.479

©Authors, 2024
This study collected daily rainfall data for Surigao del Sur, Caraga (Region 13), Philippines. The rainfall data were analysed with a 36.9% average probability of exceedance. A typical roof area range was quantified conservatively (Figure 1), and a range of tank sizes ranging from 0.5 to 3 m$^3$ was considered. In equation 1, 0.9 is a constant value based on the estimated run-off efficiencies considering smooth, impervious surface joints in residential houses in the Surigao del Sur, Caraga region (Region 13). Combined variables were identified in estimating optimal rainwater tank storage, roof area, and household water demand. Optimal value was accomplished when a curve's values begin to saturate, demonstrating less returns in progress (Bayoumy, et. al., 2020; Mahmoudi & Feylizadeh, 2018; Kubanek, 2017).

Table 1. Simulation parameters in determining optimal rainwater tank storage

<table>
<thead>
<tr>
<th>Variables</th>
<th>Range of Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1 - 200 m$^2$</td>
</tr>
<tr>
<td>S (water storage capacity)</td>
<td>0.5 - 3 m$^3$</td>
</tr>
<tr>
<td>$D_t$</td>
<td>150 liters per capita</td>
</tr>
</tbody>
</table>

Sources: Authors, 2023

**Flood Reduction and Time Buffer Simulation**

The rainwater harvesting systems are essential in reducing flood volumes and averting potential drainage system breakdowns during storm events. Nonetheless, the magnitude of rainfall impacts these systems’ efficacy (Freni & Liuzzo, 2019). Various studies used different rain classifications (Golz et al., 2016; Lu et al., 2021; Langousis & Veneziano, 2007). The PAG-ASA (n.d.) have quantitative values starting from very light rains (exposed surfaces do not get wet irrespective of duration), light rains (rate of fall: from trace to 2.5 mm per hour), moderate rains (rate of fall: from 2.5 to 7.5 mm per hour), and heavy rains (rate of fall: greater than 7.5 mm per hour). This study's simulation was based on 15, 30, 45, and 60 millimetres per hour of rainfall intensity.

Flood buffers were analysed utilising the transposed no-water day. In the same analogy of pre-releasing waters as a significant dam management strategy in reducing flood impact (Ishak & Hashim, 2018; Ahmed & Mays, 2013; Chen et al., 2012; Huang & Hsieh, 2010; Valeriano et al., 2010; Viseu & Almeida, 2009), rainwater storages, especially from uptown urban areas, maybe emptied before heavy rains and storms. It can be mathematically expressed as:

$$T_{buff} = V + Q_{in,t}$$  \(10\)

where:

$T_{buff}$ is the buffer or the time duration to fill the water tanks;

$V$ is the tank volume;

$Q_{in,t}$ is the inflow rate.

**DISCUSSIONS**

Findings revealed that the calculated probability of exceedance ranges between 15.54% and 50% in each three (3) day of a year, as presented in Fig. 3 below. Its average is 36.9% ($R^2=0.977$), and integrating it to the yearly three (3) day accumulated rain depth and run-off coefficient of 90% is illustrated in Figure 4, showing the harvestable rain, RR, when multiplied by the roof area.

https://doi.org/10.24191/bej.v21i1.479

©Authors, 2024
Figure 3 below illustrates the yearly three (3) day water-saving characteristics of tank sizes S0.5 (black=0.5 m$^3$), S1 (red=1m$^3$), S2 (blue=2m$^3$), and S3 (green=3m$^3$) plotted on various roof areas (0.9 run-off factor) concerning the number of household users H2 (2 persons), H3 (3 persons), H4 (4 persons), and H5 (5 persons). Optimum sizes also vary depending on the number of consumers per household. For H2, the savings are steeped on roof areas within the range of 0 m$^2$ to 15 m$^2$ until the curve bends and gets less efficient until its benefit ceases on areas between 70 m$^2$ to 80 m$^2$. H3 has optimum benefits with 0 m$^2$ to 20 m$^2$ and less beneficial onwards until all tank sizes would only have minute savings from 90 m$^2$ and beyond. The greater the number of consumers, the higher our tank sizes are optimised and plotted on larger roof areas.
Fig. 5. Yearly water savings as a function of storage sizes, water demand, roof area, and rainfall characteristics at 36.9% probability of exceedance in Surigao del Sur, Caraga Region

Sources: Authors, 2023

Households may now decide how large their rainwater system is based on how they weigh the benefits and costs. Prices vary on the sizes of tanks or storage, depending on the availability of funds. One should remember that in most cases, one large tank will cost around 23.3% less than three (3) smaller tanks of equal size (Thomas & Martinson, 2007, p. 71).

Figure 6 to Figure 9 below illustrates the time duration for a tank to fill (in hours) of tank sizes S0.5, S1, S2, with respect to roof areas (run-off factor is 0.9) on the severity of rainfall. Consequently, storage of different sizes will have faster (less time needed) to get filled as roof areas increase (Allen & Haarhoff, 2015; Imteaz et al., 2011; Lopes et al., 2017; Ward et al., 2010). RWH tanks' efficiency for flood protection has been determined to depend on rainfall factors since RWH tanks have less influence on the surcharge from the drainage network as rainfall depth, intensity, and duration increase (Jamali et al., 2020). Nevertheless, time which is vital against flood risks (Rapant & Kolejka, 2021; Hapuarachchi et al., 2011; Konstantine P. Georgakakos, 2006; Creutin & Borga, 2003; K. P. Georgakakos, 1986) will be given to downtown settlers to react should the local government request, or uptown communities empty their storages before predicted heavy rain.
Fig. 6. Time duration to fill 0.5 cubic meter tank ($S_{0.5}$) on different rainfall intensities (mm/hr)

Sources: Authors, 2023

Fig. 7. Time duration to fill 1 cubic meter tank ($S_{1}$) on different rainfall intensities (mm/hr)

Sources: Authors, 2023
**Housing Project Types, and Rainwater Catchment and Optimum Storage Size**

Table 2 illustrates the yearly water savings based on the output that generated Figure 5, given the housing types (HLURB, 2009; HLURB, 2008) in the Philippines, indicating the orange-highlighted values as the optimum rainwater tanks or storage sizes (curve starts to saturate) for each type (see Appendix A). Results suggest that socialised housing projects have an optimised one (1) cubic meter rainwater storage. In contrast, the economic housing, medium-cost housing, and open market housing units may be provided with two (2) cubic meter storage. As the requirement of affordable housing would limit the profit for housing developers, the least values were recommended to buffer their expenses (Saleh et al., 2022; Moghayedi et al., 2021; Uwayezu & Vries, 2020; Olanrewaju & Idrus, 2019).
Table 2. Yearly water savings based on housing project types optimised rainwater storage capacity

<table>
<thead>
<tr>
<th>Housing Project Type</th>
<th>Minimu m Floor Area (sq. m.)</th>
<th>Probable Roof Area (sq. m.) with one (1) meter roof/overhang</th>
<th>Yearly Water Savings (in cubic meters) Given the Rainwater Storage Capacity for a Typical of Four (4) Family Members</th>
<th>Yearly Water Savings (in cubic meters) Given the Rainwater Storage Capacity for a Typical of Five (5) Family Members</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socialized</td>
<td>18</td>
<td>39</td>
<td>150</td>
<td>153</td>
</tr>
<tr>
<td>Economic</td>
<td>22</td>
<td>45</td>
<td>163</td>
<td>166</td>
</tr>
<tr>
<td>Medium Cost</td>
<td>30</td>
<td>56</td>
<td>180</td>
<td>182</td>
</tr>
<tr>
<td>Open Market</td>
<td>42</td>
<td>72</td>
<td>196</td>
<td>198</td>
</tr>
</tbody>
</table>

Sources: Authors, 2023

**Flooding Resiliency Simulation**

The types of knowledge utilised and the amount of ownership by the various entities participating in governance processes impact its successful application in urban management (Hordijk & Baud, 2006). Adaptive forms of governance in cooperation with the community are best suited to dealing with the uncertainty and complexity involved with social-ecological systems reacting to natural problems (Fournier et al., 2016; Lo et al., 2015; Eriksen & Selboe, 2012; Frank et al., 2011; Marfai et al., 2008). Flood-resilient communities are best served by governments that adopt proactive and aggressive actions, whether via laws, legislation, or incentives (Cao, 2023; Ibrahim, et. al., 2023; Warsilah & Choerunnisa, 2023; Chang et al., 2018; Driessen, et. al., 2016; Vale, 2014). Brankenridge et al. (2017) recommended that regions of near-yearly flooding be subjected to the strictest development or land-use rules to protect water conveyance and storage during significant floods.

Consider a hypothetical scenario wherein a group of residential housing projects will be constructed in an uptown part of a city in Surigao del Sur, Caraga Region, Philippines. Based on the information, the immediate local government unit (LGU) has already implemented an ordinance requiring rainwater catchment and storage for new establishments, particularly housing projects, for water-saving and flood risk reduction (Ilyasa et al., 2020; Lusiana & Widiyarta, 2021). Optimum sizes of storage were recommended from the result of this study. Suppose there are thousand (1000) of economic housing units with designed household dwellings for four (4) to be built. Based on Figure 1, the developer provided a two (2) cubic meter capacity rainwater reservoir, saving hundred and sixty-six (166) cubic meters yearly. When a service provider imposes a Php 20.00 per cubic meter of water for the entire year, there will be Php 2,320 savings for each dwelling. Furthermore, the project's expected yearly water stress reduction in the area will be 166,000 cubic meters.

Now, suppose an incoming heavy rain with forecasted rain intensity of 45 mm/hr is coming, and all these uptown residents heeded the request of the LGU to empty their storage a day prior. Therefore, the run-off reduction in downtown areas will be 2,000 cubic meters, giving a valuable reaction time of at least 1.097 hours or 65.82 minutes (refer to Appendix B and Figure 2) for the community to react to possible floods brought by that volume of water. Research suggests that the Expected Annual Damage (EAD) of flooding would decrease by up to 30% (Jamali et al., 2020) with a 28-35% floodwater decrease (Akter et al., 2020; Freni & Liuzzo, 2019) once Rain Water Harvesting (RWH) tanks were installed with accompanied water-saving advantages.

**CONCLUSION**

This research provided information about optimised rainwater catchment and storage systems appropriate for Surigao del Sur, Caraga Region, Philippines residents. Yearly water savings vary regarding the reservoir capacity, the number of consumers, and roof areas. There are suggested limitations of catchment areas.
concerning storage and vice versa because there is part of the curve whereby combined sizes of roof areas and storage as savings variables would cease to provide benefits. Integrated residential rainwater harvesting facilities in uptown areas could significantly reduce heavy rainfall and derivatively reduce floods among low-lying communities. Furthermore, it also provides sufficient time for preparation in downtown areas.

RECOMMENDATIONS

(i) The researchers only utilised eleven (11) years of data from PAG-ASA Hinatuan, Surigao del Sur, Caraga Region, Philippines. For higher accuracy, it is recommended to use thirty (30) years or more precipitation data;
(ii) It is recommended for the Local Government Unit within Surigao del Sur, Caraga Region, to craft and implement local ordinances about rainwater harvesting facilities of incoming residential housing projects for austerity measures, relieve water stress in the area, increase the community's resilience against flood risks, and provide sufficient time for downtown communities to react to flooding;
(iii) It is also recommended to residents in Surigao del Sur, Caraga Region to install rainwater harvesting and storage systems in their homes to: (a) ensure water supply in the aftermath of natural hazards (earthquakes, typhoons, tsunamis, landslides, liquefaction) or man-made disasters (like terrorism and insurgencies) that may disrupt water pipes or power supply resulting in the water supply cut-offs; (b) minimise the chance of water disruption for both scheduled and unscheduled repair and maintenance of water systems; (c) sustain women and children’s’ hygiene and sanitation; (d) be part of the solutions to turbidity issues of water supplies during heavy rain occasions; and as a positive response to DILG Memorandum Circular No. 2012-02 entitled “Promoting the Construction of Rainwater Collectors in All Barangays in the Philippines to Mitigate the Adverse Impact of Climate Change”; and
(iv) Monitoring and evaluating the policy through research for enhancement is recommended regularly.

ACKNOWLEDGEMENT

We want to acknowledge the North Eastern Mindanao State University for the funding and support in conducting this research. Our words of gratitude are highly incomprehensible.

CONFLICT OF INTEREST STATEMENT

The authors conducted this research without any self-benefits or commercial or financial conflicts and hereby declare the absence of conflicting interests with the North Eastern Mindanao State University as the funder.

AUTHORS’ CONTRIBUTIONS

Anastacio G. Pantaleon, Jr. and Franco G. Pantaleon conceptualised the central research idea, provided the research framework, conducted the research, and wrote and revised the article. They also anchored the review and revisions and approved the article submission. Jun Rey S. Lincuna provided vital insights, carried out data analysis and graphical presentations, and was assisted by Leo Ian D. Jovero.

REFERENCES


Adikari, Y., Osti, R., & Noro, T. (2010). Flood-related disaster vulnerability: An impending crisis of


https://doi.org/10.24191/bej.v21i1.479

©Authors, 2024


ESRI. (2013). Philippines average household size. https://www.arcgis.com/home/item.html?id=5e9a37f7a6734cac9e5c3ec0431e56f3


https://doi.org/10.24191/bej.v21i1.479


https://doi.org/10.24198/bej.v21i1.479 ©Authors, 2024


https://doi.org/10.24191/bej.v21i1.479

©Authors, 2024


McCoy, D., Montgomery, H., Arulkumaran, S., & Godlee, F. (2014). Climate change and human survival. *BMJ (Online)*, 348(March), 1–2. https://doi.org/10.1136/bmj.g2351


<table>
<thead>
<tr>
<th>Appendix A</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Table 1</strong></td>
</tr>
<tr>
<td><strong>Location</strong></td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>8</td>
</tr>
</tbody>
</table>

https://doi.org/10.24191/bej.v21i1.479

©Authors, 2024
<table>
<thead>
<tr>
<th>Week</th>
<th>Time in hours</th>
<th>Days</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>50</th>
<th>75</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
<td>1</td>
<td>50</td>
<td>70</td>
<td>77</td>
<td>80</td>
<td>85</td>
<td>90</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>2</td>
<td>50</td>
<td>70</td>
<td>77</td>
<td>80</td>
<td>85</td>
<td>90</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>3</td>
<td>50</td>
<td>70</td>
<td>77</td>
<td>80</td>
<td>85</td>
<td>90</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>14</td>
<td>4</td>
<td>50</td>
<td>70</td>
<td>77</td>
<td>80</td>
<td>85</td>
<td>90</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>16</td>
<td>5</td>
<td>50</td>
<td>70</td>
<td>77</td>
<td>80</td>
<td>85</td>
<td>90</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>6</td>
<td>18</td>
<td>6</td>
<td>50</td>
<td>70</td>
<td>77</td>
<td>80</td>
<td>85</td>
<td>90</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>7</td>
<td>20</td>
<td>7</td>
<td>50</td>
<td>70</td>
<td>77</td>
<td>80</td>
<td>85</td>
<td>90</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>8</td>
<td>22</td>
<td>8</td>
<td>50</td>
<td>70</td>
<td>77</td>
<td>80</td>
<td>85</td>
<td>90</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>9</td>
<td>24</td>
<td>9</td>
<td>50</td>
<td>70</td>
<td>77</td>
<td>80</td>
<td>85</td>
<td>90</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>10</td>
<td>26</td>
<td>10</td>
<td>50</td>
<td>70</td>
<td>77</td>
<td>80</td>
<td>85</td>
<td>90</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>11</td>
<td>28</td>
<td>11</td>
<td>50</td>
<td>70</td>
<td>77</td>
<td>80</td>
<td>85</td>
<td>90</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>12</td>
<td>30</td>
<td>12</td>
<td>50</td>
<td>70</td>
<td>77</td>
<td>80</td>
<td>85</td>
<td>90</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>13</td>
<td>32</td>
<td>13</td>
<td>50</td>
<td>70</td>
<td>77</td>
<td>80</td>
<td>85</td>
<td>90</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>14</td>
<td>34</td>
<td>14</td>
<td>50</td>
<td>70</td>
<td>77</td>
<td>80</td>
<td>85</td>
<td>90</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>15</td>
<td>36</td>
<td>15</td>
<td>50</td>
<td>70</td>
<td>77</td>
<td>80</td>
<td>85</td>
<td>90</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>16</td>
<td>38</td>
<td>16</td>
<td>50</td>
<td>70</td>
<td>77</td>
<td>80</td>
<td>85</td>
<td>90</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>17</td>
<td>40</td>
<td>17</td>
<td>50</td>
<td>70</td>
<td>77</td>
<td>80</td>
<td>85</td>
<td>90</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>18</td>
<td>42</td>
<td>18</td>
<td>50</td>
<td>70</td>
<td>77</td>
<td>80</td>
<td>85</td>
<td>90</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>19</td>
<td>44</td>
<td>19</td>
<td>50</td>
<td>70</td>
<td>77</td>
<td>80</td>
<td>85</td>
<td>90</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>20</td>
<td>46</td>
<td>20</td>
<td>50</td>
<td>70</td>
<td>77</td>
<td>80</td>
<td>85</td>
<td>90</td>
<td>95</td>
<td>100</td>
</tr>
</tbody>
</table>

Appendix B


©Authors, 2024