Estimation of Runoff Retention Capacity of Agricultural Areas in San Francisco, Agusan del Sur, Caraga, Philippines

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Abstract: *Despite being the country's backbone, agricultural areas have faced significant threats from stormwater casualties. This study focused on assessing the runoff retention capacity of agricultural lands in San Francisco, Agusan del Sur. Using InVEST software, a comprehensive analysis was performed to create a concentration map of agricultural runoff and retention volumes. The study found that agricultural lands' retention capacity has decreased over the years. There were fluctuations in both total runoff distributions during the study period, which were attributed to changes in land covers and climate. The area experienced drought in 2015 resulting in a runoff decline while runoff increased to an average runoff volume of 69, 998. 64 m³/year in 2020 attributed to agricultural activity, changes in weather, and management practices. With the total runoff of the entire municipality, 96.38%, 93.52%, and 91.49% were retained in the agricultural areas during 2010, 2015, and 2020, respectively.*

Keywords: runoff, InVEST, agriculture, stormwater, and retention capacity

1. INTRODUCTION

Stormwater runoff affects ecosystems, infrastructure, and water quality extensively, making it a prevalent and complicated environmental problem that needs to be addressed. Rain or snowmelt that runs off the land is known as stormwater runoff [1], [2]. It has the potential to infiltrate into the ground, drain inlets, flow straight into streams or other bodies of water, or evaporate into the sky. The mechanisms of dispersion and infiltration can be used to absorb stormwater runoff on agricultural land.

There is a correlation between the dangers of flooding and excessive surface water runoff and the assessment of soil and landscape retention capacity. The ability of the soil to hold onto water after it has fallen as rain is known as the landscape water retention capacity, and it helps to complete the water cycle [3], [4]. Extreme surface water runoff and flooding can be significantly reduced by utilizing the soil's and the landscape's retention capacity. This ability is essential for collecting precipitation, lowering runoff volume and velocity, and lowering the risk of erosion and flooding.

The municipality of San Francisco, Agusan del Sur, Caraga, Philippines is vulnerable to flooding and its risk associated. Flooding is a significant concern due to the region's geographical and climatic conditions. The province experiences intense and prolonged rainfall, particularly during the monsoon season and typhoons, which leads to excessive water accumulation. The area is traversed by several rivers, including the Agusan River, which can overflow during heavy rains, inundating nearby areas. Riverbanks and floodplains are often prone to flooding due to the high volume of water flow [5], [6], [7], [8], [9].

Additionally, converting land to agriculture or urban development can interfere with natural water drainage and retention systems. Deforestation in upstream areas also diminishes the soil's capacity to absorb rainwater, increasing runoff and the risk of flooding downstream [10], [11]. The topography of the region, which consists of flat plains and low-lying areas, also contributes to its susceptibility to water retention and delayed drainage.

Numerous stormwater runoff models exist, that are used to designed to simulate and predict the movement of rainwater over surfaces [12]. The models or software vary in complexity, incorporating factors such as land use, topography, and precipitation patterns to enhance their accuracy in assessing potential impacts on water systems. Since the goal of environmental modeling is to scientifically predict natural processes, it is complicated, especially when it comes to stormwater and water quality modeling.

The Nature Capital Project created the well-known Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) tool for evaluating ecosystem services (ESs) [12], [13], [14]. This tool is a collection of models that are in line with classification frameworks like the Common International Classification of Ecosystem Services (CICES) and the Millennium Ecosystem Assessment (MA). Urbanization and climate change are making stormwater runoff more problematic. For this reason, tools like InVEST are essential to building resilient and ecologically sound communities.

This paper aimed to assess the retention capacity of the agricultural area of San Francisco, Agusan del Sur, Philippines, and to generate an agricultural runoff concentration map. The goal was to employ inVEST software for an in-depth analysis, allowing the determination of the area's stormwater retention capacity as an essential component in sustainable water resource management.

2. METHODOLOGY

2.1 Study Area

Fig. *1* shows the boundary of the study area located in the province of Agusan del Sur, Caraga, Philippines. The municipality of San Francisco has a land size of 392.53

square kilometers and makes up 3.93% of Agusan del Sur's overall area. In the 2020 PSA Census, the municipality has 80,760 total population making up 10.92% of the province of Agusan del Sur's total population or 2.88% of the Caraga region's total population. It is located at 8.5090° N, 125.9697° E. Its average annual precipitation is 104.27 mm recorded to be highest in January while lowest in April when the summer season begins.

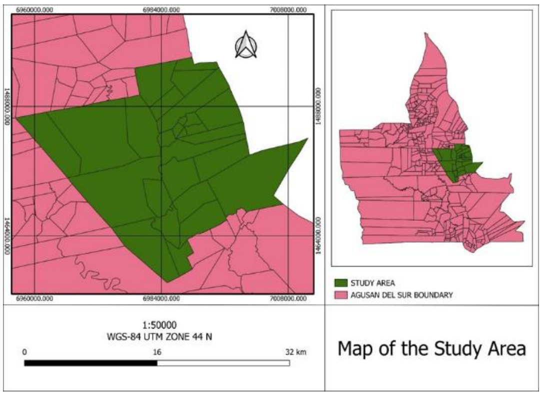


Fig. 1. The Study Area

The area's minimum and maximum elevations ranged from 33.7 meters and 110.5 meters above mean sea level. It possessed a level to nearly level elevation to undulating and rolling type which belonged to hydrologic soil groups A, B, and D dominated by sandy loam and loamy soil type which makes it a favorable area for agriculture. The municipality is home to rice production and oil palm plantation which have been their major produce and have been cultivated by almost every barangay becoming their source of income and livelihood. This municipality was stated as the primary municipality in the province of Agusan del Sur which is majorly comprised of agricultural areas.

2.2 Datasets and Methodology

Various methodologies as shown in Fig. *2* were employed in configuring the primary software required for this study, encompassing tasks such as data collection, processing, analysis, inputting data into the model, model execution, calibration, and validation. Initially, preprocessed data, including land use/land cover details, soil maps, and meteorological data such as precipitation, temperature, and agricultural runoff records, will be gathered to initiate the process. This information is essential for the effective and precise functioning of the software.

After data collection, processing, involving reclassification was employed and simulated to identify and rectify any inconsistencies that might potentially compromise the accuracy of the utilized model. The raster from the land use/land cover, hydrologic data, precipitation data, and biophysical table, was utilized to simulate the agricultural runoff volume, percolation volume, and retention volume. The intensity and volume of the rainfall using the historical data were used in making hydrologic frequency analysis- a graph that predicts how often a certain value of a variable phenomenon may occur to assess the reliability of the prediction.

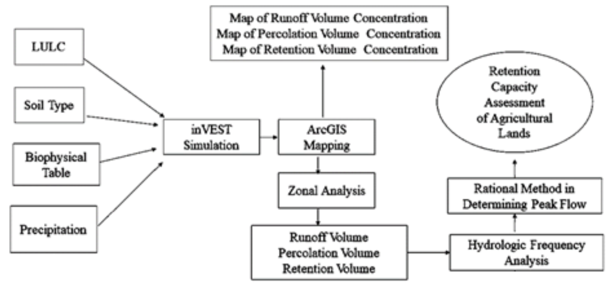


Fig. 2. Methodological Framework of the Study

The output was integrated into the inVEST software to determine the retention capacity of the area which will subsequently be assessed if it could accommodate the runoff from agricultural lands and activities. This step aimed to verify the accuracy and reliability of the model by assessing its agreement with the actual observations.

The land use land cover map was used to identify and classify the different types of land cover in the study area. The classification of land cover was based on the different spectral signatures obtained from the satellite images. Using the GIS tools, it was input and reclassified by adding values for generating the final output of the LULC map. On the other hand, the soil data was sourced from the Bureau of Soils and Water Management in San Francisco, Agusan del Sur. The soil map was used to classify the different soil types that contain information on the soil attribute of the study area while 30 years of meteorological data such as precipitation, and minimum and maximum temperature were obtained from DOST-PAGASA.

2.3 Data Processing

The collected datasets were processed using InVEST and ArcGIS 10.4 software. The rainfall volume and intensity were used as a basis for the determination of the runoff and pattern of precipitation, which were processed in ArcGIS to map and determine the runoff pattern of the area. Using InVEST software, the potential runoff in the area was determined. This model exhibits the capability to simulate diverse hydrologic processes which includes water infiltration to the soil, surface runoff, and retention volume of the study area.

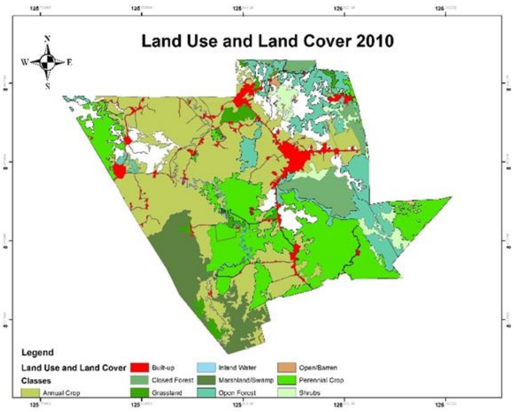
2.4 Validation of Results

To validate the results, the researchers compared the flood maps of the municipality acquired from the Municipal Disaster Risk Reduction and Management Office (MDRRMO), Provincial Environment and Natural Resources Office (PENRO), and Mines and Geosciences Bureau (MGB) including the weather and disaster reports.

3. RESULTS AND DISCUSSION

3.1 Land Use and Land Cover Classifications

The study used the generated Land Use Land Cover map of San Francisco from 2010, 2015, and 2020 which was retrieved from the Geoportal website. The map was used as one of the inputs in the InVEST- Stormwater Retention Model. As shown in Fig. 3 and Table *1*, there were significant changes in land use and land cover patterns over time.



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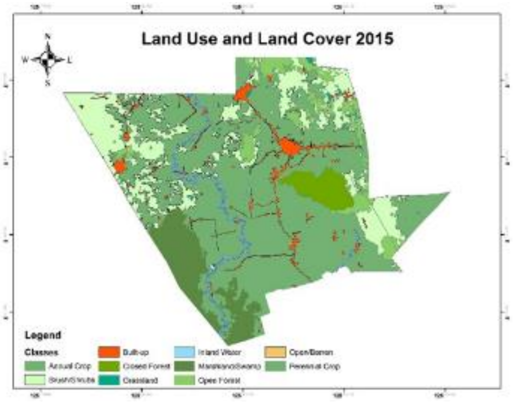

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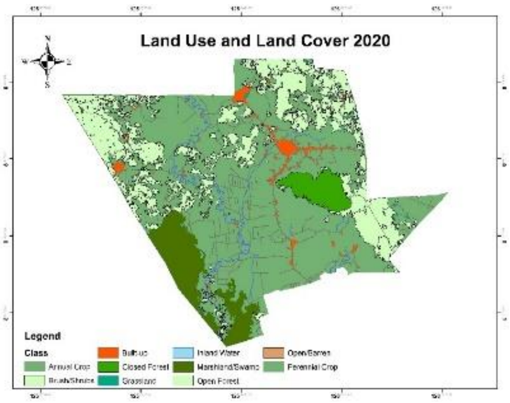

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Fig. 3. Land Use Land Cover of San Francisco, Agusan del Sur (a) 2010 LULC, (b) 2015 LULC, and (c) 2020 LULC

Table 1. Areal Distribution of Land Use Land Cover of San Francisco from different years

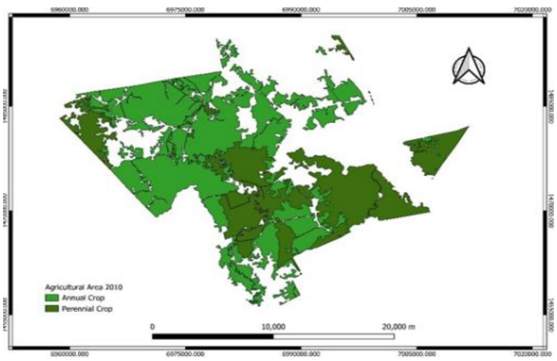
Land Use Land Cover in 2010-2020 (ha)			
Classes	**2010**	**2015**	**2020**
Annual Crop	410.62	396.88	389.39
Built-Up	29.08	38.63	50.43
Shrubs	207.77	210.65	231.56
Grassland	1.25	4.86	5.27
Closed Forest	468.53	468.53	468.53
Open Forest	4.74	2.93	0.79
Perennial Crops	27,207.87	26,491.69	24,209.50
Inland Water	9090.86	9090.86	9090.86
Marshland	1824.71	2542.65	4803.75
Barren	7.57	5.32	2.92

In the year 2010, the map revealed ten classes found in San Francisco, Agusan del Sur such as annual crop, built-up, brush/shrubs, closed forest, grassland, inland water, marshland/swamp, open forest, open/barren, and perennial crop. It shows that annual and perennial crops were the dominant land covers in the area showing the region's primary economic activity. Open and closed forests were relatively extensive, followed by the shrubs area, indicating a significant portion of the area under natural vegetation cover. Built-up areas were limited, with scattered settlements. Wooden grassland is present but in relatively small proportions. Also, the inland water and marshland had comparable land coverage, and it is visible in perennial and annual crop areas.

In 2015, the same 10 classes were identified, the predominant land uses were annual crop, built-up, brush/shrubs, closed forest, grassland, inland water, marshland/swamp, open forest, open/barren, and perennial crop. In agricultural areas, the annual and perennial crops declined. There were significant changes in the brush and shrub areas this year. These areas expanded and became scattered within the annual croplands, others were transformed into residential areas, which resulted in a decrease in the total area covered by annual crops and an increase in built-up areas. In open forests, the area coverage decreased while closed forests and inland water remained unchanged. Notable change was also observed for marshland.

In 2020, the effects of interventions implemented over the previous decade became more evident. Significant changes were observed in the agricultural areas, annual and perennial crops continued to decrease as the built-up area increased along with the coverage of shrubs while there was an observed significant decrease in the barren and open forest areas. These changes could be attributed to the expansion of the built-up areas of the area and the harvest of perennial crops such as falcata as one of the timber products of the area.

3.2 Runoff Volume and Retention Capacity of the Agricultural Areas



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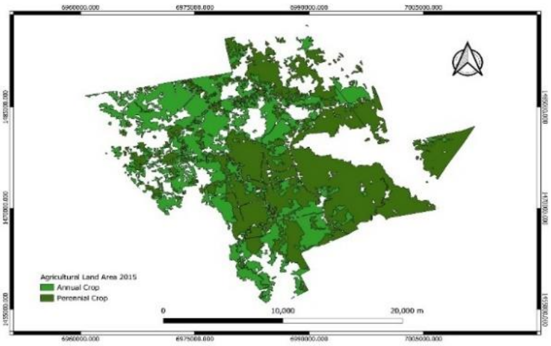

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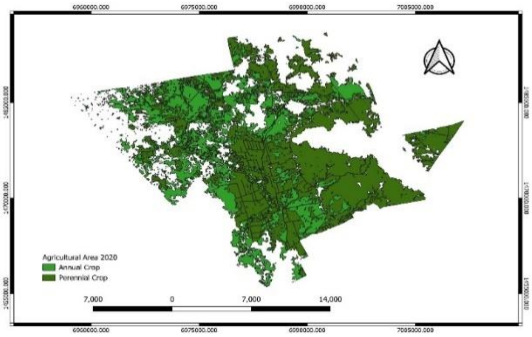

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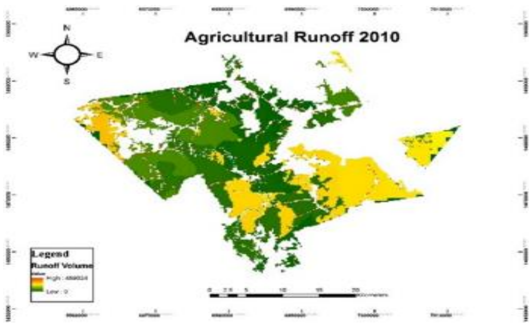
Fig. 4. Agricultural Land Area of San Francisco, Agusan Del Sur (a) 2010 LULC, (b) 2015 LULC, and (c) 2020 LULC

Through the utilization of the software InVEST, a runoff map was produced which focused mainly on the agricultural areas of the municipality as shown in Fig. 4 and Fig. 5. It shows that there was a decrease of the total agricultural land area with 27,618.49 ha, 27,606.51, and 27,577.93 in 2010, 2015, and 2020, respectively. With the 5-year intervals, an average of 0.07% change was observed.



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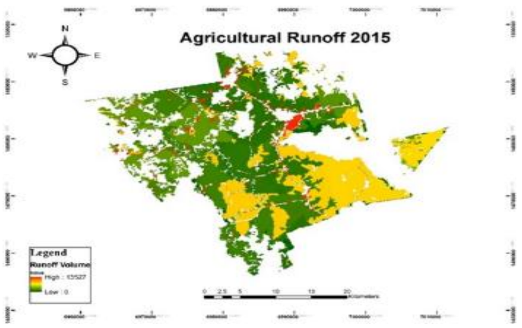

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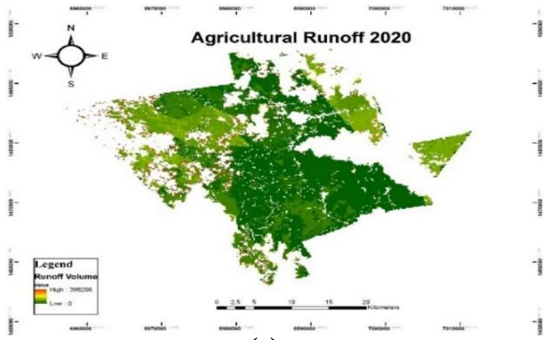

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Fig. 5. Estimated Agricultural Runoff (a) Year 2010, (b) Year 2015, and (c) Year 2020

Table 2. Estimated Runoff Volume in Agricultural Areas in different years

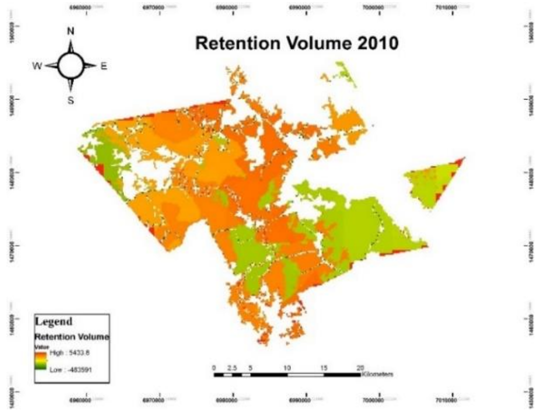
Year	Land Area (ha)	Average Runoff Volumes (m^3/ year)
2010	27,618.49	189,424
2015	27,606.51	4,993.37
2020	27,577.93	69,998.64

Based on the results, there was an average runoff distribution of 189,424 mm^3/year in 2010. This indicates that agricultural land in the study area contributed approximately 25% of the total runoff. This high percentage indicates intensive agricultural practices during this period, which likely contributed to the observed runoff.

In 2015, there was a decrease in both total runoff and agricultural runoff, with total runoff dropping to 13,527 m^3/year and agricultural runoff decreasing with a minimum value of 4,993.47 m^3/year covering an agricultural area of 27,606.51 ha. The agricultural runoff thus constituted around 36.91% of the total runoff. The runoff decline could be attributed to climatic conditions and better water management strategies. During this period, the Philippines experienced a dry spell that affected several provinces in Luzon, Visayas, and Mindanao including Agusan del Sur. Thus, the runoff distribution in San Francisco for 2015 decreased due to a dry spell.

The year 2020 shows an increase in both total and agricultural runoff levels. The total runoff increased to 398,205.59 m^3/year, while agricultural runoff has an average runoff volume of 69,998.64 m^3/year constituting 17.58% of the total runoff. This increase in agricultural runoff is attributed to an increase in agricultural activity, changes in weather patterns resulting in higher precipitation, or less effective runoff management practices. According to PAG-ASA, four typhoons occurred in the CARAGA Region during October 2020 namely, Typhoon Opel, Pepito, Qunita, and Ba Roly. This explains that October 2020 shows the onset of the wet season in the area.

Another product of the software InVEST- Stormwater Retention model, was the retention concentration maps for runoff volumes generated and the results are shown in Figure 6 and the estimated agricultural runoff retention volumes in percent are presented in Table 3. The precipitation pattern, climate change fluctuations, hydrologic soil group, and land use degradation were considered to have direct effects on the retention capacity of the area.



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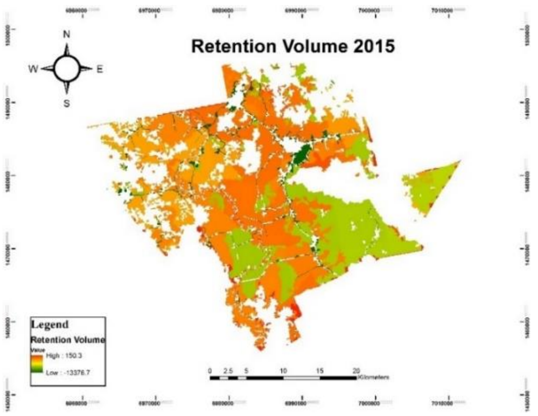

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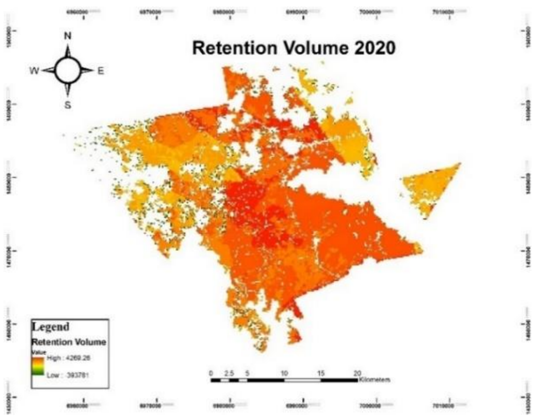

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Figure 6. Generated Maps for Agricultural Runoff Retention Volume (a) Year 2010, (b) Year 2015, and (c) Year 2020

Table 3. Estimated Agricultural Runoff Retention Volumes and Percentage retained in different years

Year	Land Area (ha)	Average Retention Volumes (m^3/ year)	Percent Retained
2010	27,618.49	184, 636	96.38 %
2015	27,606.51	4,870.62	93.52 %
2020	27,577.93	69, 998.64	91. 49 %

Based on the result, the retention distribution volumes in 2010 were substantially higher compared to 2015 and 2020, suggesting a significant reduction in runoff retention over time. The data shows notable changes in agricultural retention in San Francisco over the analyzed decade. Several factors could contribute to the observed changes, such as agricultural practices, urbanization, and land use changes. Shifts in farming methodologies and the adoption of more sustainable practices could significantly impact runoff retention. Techniques such as no-till farming, cover cropping, and contour plowing are known to reduce runoff in agricultural areas [15].

Urban development and other land use changes can directly affect retention volumes. The conversion of agricultural land to urban areas or other uses can reduce the natural capacity of the land to retain water [16], [17]. Despite the increase in total agricultural area from 27,606.51 ha in 2015 to 27,577.93 in 2020, urban developments might have altered the natural runoff patterns, impacting retention volumes. Also, changes in rainfall patterns and climatic conditions are significant factors in retention volume. The type of soil and its corresponding water-holding capacity also affects the retention capacity of the area.

Based on the soil type map from the Bureau of Soil and Water Management, clay, and clay loam types dominate in the agricultural lands, hence it is suitable for agriculture. This type of soil has a retention capacity of 1.20- 2.00 inches per depth which means that it could store enough water if it was saturated for 48 hours. However, some other factors such as Years of drought or heavy rainfall can alter runoff dynamics. For instance, increased rainfall frequency can lead to higher runoff volumes that are challenging for the land to retain.

The changes in runoff and its retention capacity can be influenced by a variety of natural and human-induced factors that include climate, topography, soil type and condition, vegetation cover, geology, change in land use and land cover, and agricultural and water management practices. In this study, the agricultural land of San Francisco had a good retention capacity because of the presence of the marshland/wetlands. Primarily, this marshland/wetlands control and regulate the runoff by absorbing excess water from rainfall and runoff during storms. This reduces peak flows downstream, helping to control flooding by temporarily storing water. Additionally, the presence of vegetation slows down the movement of water, allowing for gradual release into surrounding water bodies or groundwater aquifers. This helps regulate streamflow and maintain baseflow during dry periods.

3.3 Validation of the Results

The results of this study were validated using the flood maps acquired from the Municipal Disaster Risk Reduction and Management Office (MDRRMO), Provincial Environment and Natural Resources Office (PENRO), and Mines and Geosciences Bureau (MGB) office. The results were only validated based on the trend of the recorded precipitations and occurrence of typhoons. In 2010, MDRRMO reported that four barangays were flooded up to 2 meters depth while in 2015, only barangays near rivers and creeks were flooded due to overflowing with the hit of Tropical Depression Onyok in December. Lastly, two strong typhoons hit the region where the municipality of San Francisco was one of the areas greatly damaged in 2020 [18]. To quantify and further validate the results, the researchers recommend field observations and monitoring.

With these results, the researchers concluded that the use of InVEST- SWM has proven its capacity to quantify the volumes of runoff and retention. The retention capacity of the area and its associated environmental cost does not limit its effects to agriculture alone but also to the environment, social, economic, and safety of the people surrounding the area. Aside from being a source of food, it is also a source of income for the people which would be greatly affected by the decreasing capacity of the area to retain water.

Stormwater runoff management systems would be beneficial to cater to runoff and mitigate its impacts on agricultural areas. One of these systems is the retention basin/ponds, though not yet extensively implemented in the Philippines and not thoroughly studied it would be beneficial to the farmers since it would retain water for long periods, diminishing the runoff and avoiding flash floods, pollution, and its effects on the environment. It would also be a good help for the farmers as it would be a possible resource for irrigation.

Overall, the findings of this study will have important implications for the management and conservation of agricultural areas which is a vital source of income for the residents in the area. By implementing recommended actions, policymakers, stakeholders, and concerned citizens will ensure the long-term sustainability of agricultural areas and their ecosystems.

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