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Original Article

Quantifying Ecosystem Disservice in the Philippines through Water Release Potential Estimation Using ES-Based Model: The Case of Balanac Watershed

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Abstract

Background: *Rapid land use change and intensified climate change impacts have altered a landscape's natural hydrological processes and ecosystem services. These changes may cause flooding, water quality degradation, and water scarcity.*

Methods: *This study used the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) Water Yield model to estimate the potential amount of water released by varying land cover in the Balanac Watershed, Philippines. The model calculated the change in the amount of water that is being released as surface runoff from different land cover types across spatial units of the landscape.*

Results: *Findings showed that vegetated areas had the lowest water yield estimate, while built areas had the highest due to increased surface runoff.*

Conclusion: *The study offers valuable information, particularly regarding the relative differences in water releases across various land cover types. It contributes to the limited knowledge of ecosystem service-based modeling in the Philippines.*

Keywords

ecosystem service, InVEST, land cover change, water yield, watershed, Philippines

INTRODUCTION

Ecosystem services play a crucial role in protecting human well-being and promoting sustainable development (Hu et al., 2020). Freshwater provision is one of the vital ecosystem services in a watershed, contributing significantly to regional water security (Pei et al., 2021). However, rapid land use conversion exerts pressure on the water balance and the availability of water resources in the watersheds (Daneshi et al., 2021; Wu et al., 2015; Yifru et al., 2021). Tong et al. (2012) highlighted that converting vegetated landscapes into impervious areas can detrimentally affect the quality and quantity of water resources. This change in land use specifically impacts runoff generation, water demand and supply, soil infiltration, evapotranspiration, and groundwater recharge (Daneshi et al., 2021). As noted by Daneshi et al. (2021) and Guo et al. (2021), climate change is another factor that can influence the availability of water resources. Hence, understanding the effects of climate change on various meteorological variables (e.g., temperature and precipitation) is crucial.

The concept of ecosystem disservices (EDS) highlights the potential threats nature can pose to human well-being, which is often overlooked in discussions that focus solely on ecosystem services (Sinasson et al., 2024). While a substantial body of research has underscored the benefits that humans derive from nature, such as goods and services essential for health, economy, and the environment (Döhren & Haase, 2022), there is a tendency to downplay or ignore the negative impacts that ecosystems can also generate. These disservices include harmful effects like disease transmission, disasters, and other ecosystem outputs that can damage infrastructure or disrupt livelihoods. Failure to recognize these negative aspects can lead to unintended consequences, such as policies that promote conservation at all costs without considering the potential harm to human well-being (Sit et al., 2024). Thus, acknowledging EDS is also crucial to achieving a more balanced ecosystem management approach that safeguards nature and people.

Given the importance of understanding both ecosystem services and disservices, information on these has become critical for water resource managers, land use planners, and policy- and decision-making bodies (Benra et al., 2021). Quantitative assessment and visualization of water yield and its spatiotemporal variations are essential for effective water resource management and protection (Wu et al., 2015; Yang et al., 2019). Hydrological models are valuable tools for predicting spatiotemporal changes in water availability, making them vital in water resource management (Benra et al., 2021; Yang et al., 2019). The Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) is among these models and has been widely used for quantifying ecosystem services, including water yield.

One of the advantages of using InVEST is that it is spatially explicit, allowing for the visualization and analysis of ecosystem services across landscapes (Bougerra et al., 2024). The model also uses readily available global datasets, making it applicable in data-scarce regions (Benra et al., 2021). Vigerstol and Aukema (2011) explained that InVEST requires less detailed data inputs, computing capacity, and user expertise compared to traditional hydrological tools such as the Soil and Water Assessment Tool (SWAT) and the Variable Infiltration Capacity (VIC) model. Although InVEST relies on simplifying hydrological processes, its results for hotspot distribution and trade-off relations are comparable with SWAT (Cong et al., 2020). Compared to other ecosystem-based models, such as Artificial Intelligence for Ecosystem Services (ARIES), which also requires less data inputs, InVEST has more user-friendly coding, making it more transparent and intuitive (Vigerstol & Aukema, 2011). Despite these benefits, its application in the Philippine context remains limited (Ureta et al., 2022).

The InVEST models were included as one of the tools in the Sukat ng Kalikasan: High Conservation Value Areas Framework and the Natural Capital Accounting (HCVA-NCA) Framework of the Philippines. This framework serves as a standardized guide for planning, monitoring, and addressing threats in protected and conservation areas in the Philippines (Mallari et al., 2024). With the enactment of the Philippine Ecosystem and Natural Capital Accounting System (PENCAS) Act (Republic Act No. 11995), the tools recommended in the Sukat ng Kalikasan toolkit would be instrumental in generating natural capital accounts both at the local and national levels. While the application of the InVEST models was documented for the global and regional analysis, little is known about its capability to quantify ecosystem services at a sub-watershed level.

While ecosystem service modeling is increasingly employed globally, its research application on ecosystem service quantification is still limited in the Philippines. Hence, this study provides a crucial local-scale application of the InVEST Water Yield model in the Philippines by providing a much-needed local perspective and actionable insights into the Balanac watershed, thus adding a novel dimension to the existing body of knowledge. Thus, this paper aims to assess how different land cover types influence changes in water yield in small watersheds, like the Balanac Watershed, using the InVEST Water Yield model by quantifying the potential water yield.

METHODS

Site description

Located in the provinces of Laguna and Quezon, the Balanac Watershed (14°08'51" N 121°28'19" E) is considered one of the priority critical watersheds in Region IV-A (CALABARZON), Philippines. It covers an estimated area of 65.75 km2 (Figure 1). The watershed is a part of the National Irrigation System (NIS) that caters to the agricultural water supply needs of Magdalena, Majayjay, Luisiana, and Lucban municipalities. The total NIS service area within the Balanac Watershed is 1,056 ha. Moreover, the watershed is suitable for the agricultural production of rice, coconut, corn, vegetables, root crops, and fruit trees (CALABARZON Regional Development Council 2017, as cited in Ureta et al., 2022). Figure 1 further shows that the Balanac Watershed drains into the municipalities of Magdalena and Sta. Cruz.

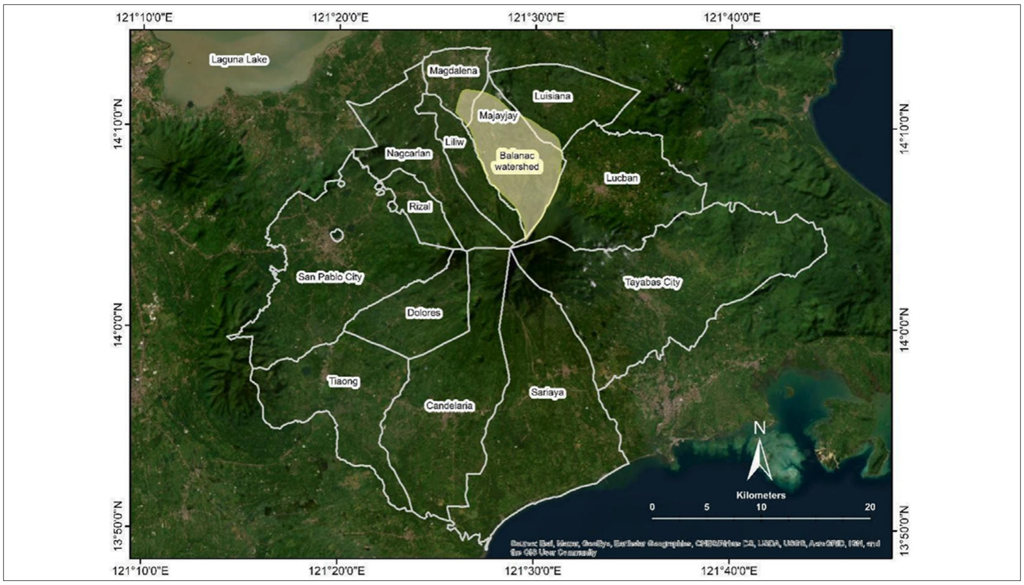

Figure 1. *Location of the Study*

The local economies of the four municipalities within the watershed depend on agriculture and other livelihood sectors. These sectors include the commercial and tourism sectors. These livelihood sectors contribute to the income of these municipalities. Based on the current income classification, three municipalities within the watershed remain to be low-income municipalities (see Table 1). Table 1 also presents the profile of these municipalities. The municipality of Lucban had the highest population growth in 2020. This growth can be attributed to its proximity to other cities in the province, which are the center of local economic activities. Moreover, the municipality of Magdalena has the highest annual population growth rate of 2.04%, which is also higher than the national annual population growth rate of 1.63%.

Table 1. *Profile of Municipalities within Balanac Watershed*

Municipality	Income Classification	Population (2020 Census) 1	Growth Rate (2015-2020) 1
Lucban	2nd class	53,091	3.14%
Magdalena	4th class	27,816	10.09%
Majaujay	4th class	27,893	0.36%
Luisiana	3rd class	20,859	5.78%

Source: Philippine Statistics Authority, 2021

InVEST Water Yield Model

The InVEST Water Yield model, otherwise known as the InVEST Reservoir Hydropower Production model, estimates the annual average amount of water released by the land cover into streams and rivers. Developed by the Natural Capital Project at Stanford University (Belete et al., 2020) as part of the InVEST suite of tools, the model quantifies the changes in ecosystem services and visualizes them through maps (Hu et al., 2020). It is derived from the Budyko curve and annual mean precipitation (Hu et al., 2020; Pei et al., 2021) (Equation 1):

$$Y\ (x) = \left(1 - \frac{AET\ (x)}{P(x)}\right) \cdot P(x) \quad (1)$$

where $Y(x)$ is the annual water yield of every x *pixel*; $AET(x)$ is the annual actual evapotranspiration of every x pixel; and $P(x)$ refers to the annual precipitation of pixel x.

It is important to note that the model does not distinctly compute surface, subsurface, and baseflow separately; instead, it assumes that the water yield reaches the point of interest through any of these pathways (Guo et al., 2023). The model relates actual evapotranspiration to potential evapotranspiration (PET) for easier estimation (Equation 2).

$$\frac{AET(x)}{P(x)} = 1 + \frac{PET(x)}{P(x)} - \left[1 + \left(\frac{PET(x)}{P(x)}\right)^{\omega}\right]^{\frac{1}{\omega}} \quad (2)$$

PET is the product of the reference evapotranspiration and the crop coefficient for each pixel. ω is the plant's available water content (AWC), precipitation, and constant Z (Redhead et al., 2016) (Equation 3).

$$\omega = Z\frac{AWC\ (x)}{P(x)} + 1.25 \quad (3)$$

The study applied the InVEST Water Yield model version 3.9.0, particularly its ability to analyze the amount of water released by various land covers. It compared the potential water release from different land cover types using 2018 and 2021 land cover data while keeping other variables constant. While the model was designed to estimate the annual contribution of the landscape to hydropower production, the study focused on estimating the amount of water released by different land covers instead since no hydropower plant is present in the study site. In this framework, the study interprets the computed water yield per pixel as an ecosystem disservice rather than an ecosystem service since the amount of water that will be released per pixel is more likely to contribute to surface runoff in the landscape. As shown in Figure 1, Balanac Watershed drains to the municipalities of Magdalena and Sta. Cruz, which are both flood-prone areas (Paringit & Abucay, 2017). If not properly managed, water release from Balanac Watershed could contribute to flooding incidents in these two low-lying municipalities.

Datasets

This study utilized publicly accessible global geospatial data (Table 2). A vector boundary representing the watershed was used as a spatial mask within a GIS environment to focus the analysis on the study area. This process extracted the relevant subset of each global dataset, delineating the study area. To ensure spatial consistency and facilitate subsequent analyses, all raster datasets were resampled to a 10-meter spatial resolution.

Table 2. *Datasets utilized in the study*

Input	Source
Precipitation	(Fick & Hijmans, 2017)
Reference evaporation	(CGIAR-CSI, 2019);1970-2020
Depth-to-root restricting layer	Harmonized World Soil Database (Fischer et al., 2008)
Plant availability water fraction	Harmonized World Soil Database (Fischer et al., 2008)
Land cover map	(Karra et al., 2021)

Ethical considerations

This study relies on publicly available datasets which were understood to have ethical clearances when collected. The researchers are cognizant on the ethical implications of the study adhering to ethical codes and conduct.

RESULTS

Land cover change in the Balanac Watershed

In 2018 and 2021, trees covered most of the watershed, accounting for at least 80% of the land. Crops occupied approximately 9% of the total area. By 2021, however, the tree-covered area decreased by around 87 ha, while the cropland area expanded by 45 ha. Additionally, the number of built areas increased by 55 ha due to the conversion of other land cover types. Despite these changes, the majority of the area of the watershed was still covered by trees (Figure 2, Table 3).

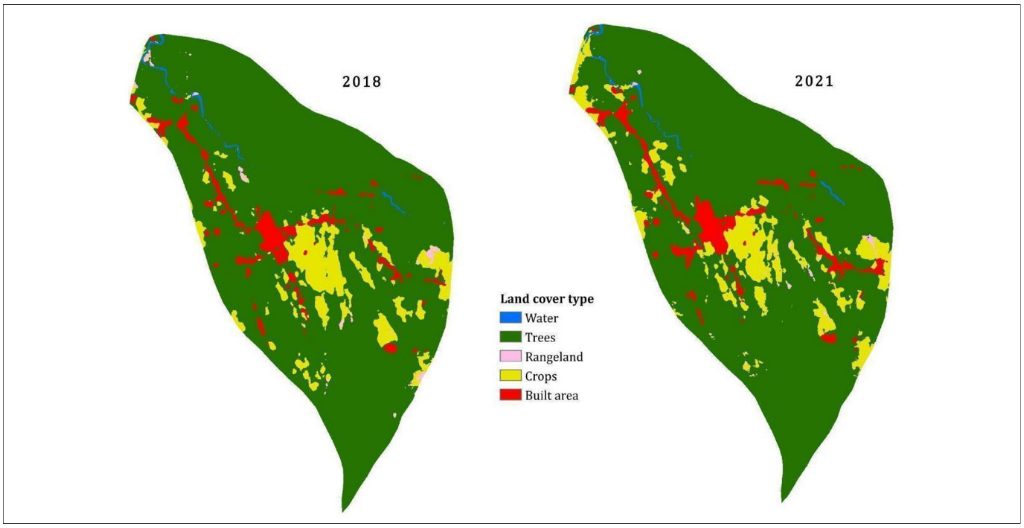

Figure 2. *Land Cover Map of Balanac Watershed in 2018 and 2021 (ESRI)*

Table 3. *Land cover area, proportion, and change, Balanac Watershed, 2018-2021*

Land Cover	2018		2021		Change
	Area (ha)	Proportion (%)	Area (ha)	Proportion (%)	
Water	30.61	0.47	30.72	0.47	0.11
Trees	5,588.40	85.02	5,500.85	83.68	-87.55
Crops	622.67	9.47	667.26	10.15	44.59
Built area	294.72	4.48	350.25	5.33	55.53
Rangeland	36.86	0.56	24.44	0.37	-12.42

Water yield in the Balanac Watershed

The results revealed that the areas that released the most water were located in built areas and the southern part of the watershed (Figure 3), the peak of Mt. Banahaw. Notably, as shown in Figure 4, the southern area recorded the highest amount of precipitation, with an estimated total of 3,100 mm in 2018, based on average annual rainfall data.

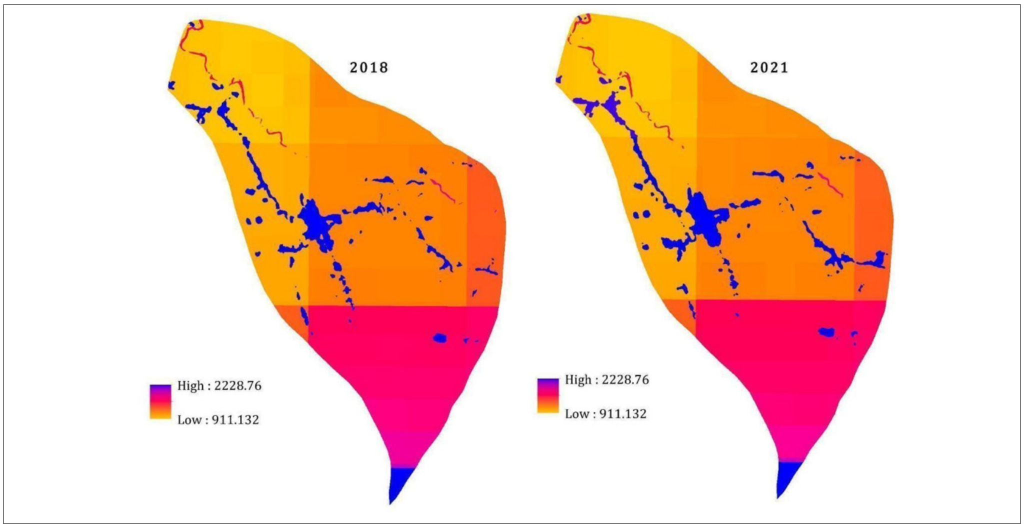

Figure 3. *Water yield in the Balanac Watershed in 2018 and 2021*

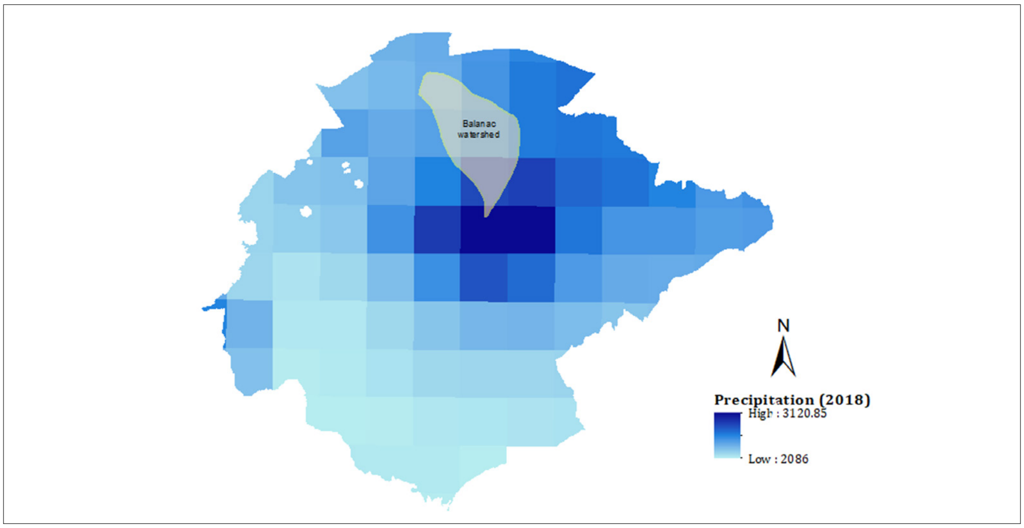

Figure 4. *Average annual rainfall (Fick & Hijmans, 2017)*

Table 4. *Summary statistics of the water yield (WY) model results, Balanac Watershed, 2018 and 2021*

Land Cover	2018				2021			
	Area (in ha)	Total WY (in '000 mm)	% Contribution	Ave. WY (in '000 mm/ha)	Area (in ha)	Total WY (in '000 mm)	% Contribution	Ave. WY (in '000 mm/ha)
Water	31	4,353	0.6	142.2	31	4,371	0.6	142.3
Trees	5588	627,827	82.4	112.3	5501	620,653	81.0	112,8
Crops	623	69,734	9.2	112.0	667	72,645	9.5	108.9
Built Areas	295	55,360	7.3	187.8	350	65,761	8.6	187.8
Rangeland	37	4,233	0.6	114.8	24	2,755	0.4	112.7
Overall	6573	761,508		115.8	6574	766,185		116.6

Considering precipitation and land cover in the InVEST water yield (WY) model, the combined tree-covered/forested areas had the highest total water yield in 2018 and 2021 (Table 4). Total water yield indicates the overall contribution of the land cover type to the amount of water that potentially goes to the stream. The result was anticipated, given that trees cover a large portion of the watershed.

Meanwhile, using the average water yield per hectare shows that built areas contribute the highest in terms of releasing water across the landscape in both years (Table 3), 62% higher than the overall average rate of release of the entire watershed. In contrast, the vegetated areas (trees, crops, and rangeland) contribute the least in releasing water due to the vegetation's water-holding capacity, which retains the water in its place.

Changes in water yield

The study analyzed the differences in water yield estimates for every hectare change of the land cover type (Table 5), highlighting the potential of certain land uses in maintaining water balance within the Balanac Watershed. The findings indicated that the loss of a hectare of trees or forestland resulted in an additional water release of approximately 81,947 mm annually. Similarly, each additional hectare of built area conversion led to an additional 187,305 mm of water being released annually, consistent with the findings of Nie et al. (2011), as cited by Lang et al. (2017), where they measured the impact of land use change on water resources and found that urbanization has a positive relationship with water yield.

Table 5. *Changes in water yield per land cover type in the Balanac Watershed*

Land Cover Type	Δ Land Cover Area (ha)	Δ Total Water Yield (mm)	Marginal Effects (mm/ha)
Water	0.11	17,706	160,964.80
Trees	-87.55	-717,4495	81,947.41
Crops	44.59	2,911,110	65,286.16
Built area	55.53	10,401,041	187,304.90
Rangeland	-12.42	-1,477,771	118,983.21

DISCUSSION

The findings of this study present insights into the complex dynamics between land cover and water yield within the Balanac Watershed. A higher water release rate increases the likelihood of surface runoff, which may lead to flooding. Depending on the soil quality, it can also increase sediment export (Ureta et al., 2022). Tundu et al. (2018) further explained that this can affect both the quality and quantity of water available for the local communities. Thus, a higher average water release rate can be considered an ecosystem disservice. It could have detrimental effects on the livelihood and general welfare of local stakeholders, especially in the absence of runoff management practices. These findings have significant policy implications for urban planning and development. The increased runoff from built areas has been documented in various studies, including in Sharma (2017), wherein the link between urbanization and increased streamflow has been discussed. Similar findings were reported by Birkinshaw et. al. (2021), who observed increased runoff coefficients in urbanized catchments. It emphasizes the need for stricter regulations on impervious surface coverage and the implementation of stormwater management infrastructure (Im, 2019). Examples of this stormwater management infrastructure include green infrastructure (e.g., green roofs, permeable pavements, bioswales) and traditional engineering solutions (e.g., detention basins). These measures can mitigate the increase in surface runoff from built areas, and consequently reduce the risk of flooding and water quality degradation. Local ordinances should incentivize or mandate incorporating these practices in future local development.

While urban development presents significant environmental challenges, it is also important to consider the contribution of other land cover types. The findings highlight that rangeland exhibited a high average water yield even with its limited area coverage. The high average water yield of rangeland can be attributed to its geographical location within the watershed. Rangelands are located in the southern part of the Balanac Watershed, which is characterized by a high precipitation rate. Considering that precipitation is among the main factors influencing the InVEST Water Yield Model, the findings illustrate a high water release rate for rangeland areas. To add further, although the overall contribution of rangeland in the water yield of Balanac Watershed can be considered limited, its average per hectare water yield remains significant when compared to other land cover types.

Understanding the changes in land cover is crucial, as they affect hydrological processes in watersheds (Iizuka et al., 2017). While built areas release more water on average, it should be emphasized that the InVEST Water Yield model does not account for the quality of the water being released. Without stormwater management practices and flooding control measures, runoff from built areas can contribute to water quality degradation and flooding (Sparkman et al., 2017). In contrast, water released from vegetated areas, although smaller in volume on average, could benefit local agriculture along with other livelihood sectors. In the context of agricultural development, Schilling et al. (2008) noted that converting grasslands into agricultural lands could increase water yield, highlighting the need for careful consideration of land use change impacts on hydrology, even within agricultural landscapes.

Land cover changes, specifically unmanaged and unplanned urban development, can potentially result in detrimental effects on environmental conditions and the provision of ecosystem services (Wohlfart et al., 2017). Therefore, development policies must balance the economic need to change land use and their potential adverse effects on ecosystem services. The institutionalization of a Philippine land use policy would enhance the protection of critical land use cover types in the Balanac Watershed and across all watersheds in the country. An ordinance protecting vegetative areas such as forest lands should be formulated at the local level. These findings, combined with the quantitative estimates of water release, can inform targeted watershed management strategies, including reforestation, erosion control, and appropriate stormwater management. Integrating ecosystem service considerations into land use planning and policy is crucial for balancing economic growth with environmental protection and ensuring long-term water resource availability.

Apart from estimating the total amount of water that can be accumulated in a watershed, the InVEST Water Yield model also helps understand how land use affects the delivery of water by estimating the amount of water released by land cover type. In this study, InVEST was applied to estimate the water release potential of the various land covers in the Balanac Watershed. The findings showed that vegetated areas within the watershed had the lowest water release potential due to the water-holding capacity of vegetation. Conversely, built areas in the Balanac Watershed had the highest water release potential. Precipitation was also found to influence water release potential significantly, meaning that areas with higher precipitation rates will also release water. This study also noted that the InVEST Water Yield model does not discriminate against the water pathways. Thus, an increase in water yield does not automatically translate to an increase in groundwater or surface runoff alone. This pattern of water release is exacerbated by rapid land use changes, particularly the conversion of vegetated areas to impervious surfaces like those found in built areas. These changes and existing climate conditions characterized by high precipitation rates are the main driving factors influencing water yield in the watershed.

Understanding the water yield potential of different land cover types allows local development planners identify areas that likely contribute to water release during heavy rains and guide the development accordingly. The study findings recommend using a more localized set of data to validate and improve the accuracy of the InVEST Water Yield model estimates. Comparing the results with other more robust hydrological models is also recommended.

The study has certain limitations, primarily due to using global data for a study site smaller than 100 km^2. Additionally, ground validation was not conducted, which may have affected the accuracy of the results, particularly at the watershed and municipal levels. It should be noted that the InVEST Water Yield model also has several limitations, such as not accounting for surface–groundwater interactions or the temporal dimension of water supply, complexity of land use patterns or underlying geology, and flow regulations, among others (The Natural Capital Project, n.d.).

Given these constraints, the study was designed to explore the potential of InVEST as a tool for resource-constrained local government units (LGUs) and state universities and colleges (SUCs). Despite the limited available data, LGUs and SUCs can still utilize InVEST to assess tradeoffs between ES under different land use scenarios. For instance, InVEST could be used to examine the impact of ES's provision of reclassifying certain areas into other land use. InVEST also offers a broader range of applications beyond soil and water-related ecosystem services compared to the Soil and Water Assessment Tool (SWAT), which is commonly used in the Philippines. It requires less data and is considered a more user-friendly model than SWAT for initial rapid assessments (Cong et al., 2020).

CONCLUSION

This study is among the early efforts to demonstrate the use of the InVEST models in sub-watershed level analysis in the Philippines. While the inVEST Water Yield model simplifies hydrological processes by relying on empirical relationships and not explicitly simulating complex subsurface flow, potentially introducing uncertainties, the insights generated by this study remain valuable for initial assessments of water yield potential and water release estimates by land cover in Balanac Watershed. The methods employed in this study contribute to the growing practice of ecosystem accounting, as noted in the Sukat ng Kalikasan toolkit following the passing of the PENCAS. Future research could incorporate more process-based hydrological models that account for the actual complexities, integrate field-based hydrological data for model calibration and validation, or explore the model's sensitivity to input parameter uncertainty to enhance the accuracy and reliability of water yield assessments.

Author Contributions

G. Trespalacio: Conceptualization, data curation, formal analysis, investigation, methodology, project administration, software, supervision, visualization, writing—original draft, writing—review & editing; **A. Sapugay:** Conceptualization, data curation, formal analysis, investigation, methodology, validation, visualization, writing—original draft, writing—review & editing; **N. Anastacio:** Conceptualization, data curation, formal analysis, project administration, software, supervision, writing—original draft, writing—review & editing; **J.C. Ureta:** Conceptualization, data curation, formal analysis, investigation, methodology, software, supervision, visualization, writing—original draft, writing—review & editing; **J. Ureta:** Conceptualization, data curation, formal analysis, investigation, methodology, software, supervision, visualization, writing—original draft, writing—review & editing

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Ethical Approval

Not applicable.

Competing interest

The authors declare no conflicts of interest.

Data Availability

Data will be made available by the corresponding author on request.

Declaration of Artificial Intelligence Use

The authors declare that no artificial intelligence (AI) tools were used in the development of this paper. All content is the result of the authors' work and original thought.

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