Annual Water Yield Assessment of Andanan-Wawa Watershed Forest Reserve Using GIS Techniques at Bayugan City, Agusan del Sur, Philippines.

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https://doi.org/10.5109/7395716

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 11, pp.1569-1575, 2025-10-30. International Exchange and Innovation Conference on Engineering & Sciences
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Annual Water Yield Assessment of Andanan-Wawa Watershed Forest Reserve Using Gis Techniques At Bayugan City, Agusan Del Sur, Philippines.

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Abstract: *This study assessed the annual water yield of the Andanan-Wawa Watershed Forest Reserve in Bayugan City, Agusan del Sur from 2018 to 2023 using GIS and satellite-based data. The watershed supports irrigation through the Andanan-Wawa River Irrigation System (AWRIS) but faces pressures from land use change, deforestation, and climate variability. Water yield was estimated using the water balance equation Q = P - ET - ΔS and validated with observed discharge data. The highest estimated yield occurred in 2021 at 18,918,640 liters/year, while the lowest observed discharge was in 2022 at 11,222,910 liters/year. Although estimated yields remained stable from 2021 to 2023, observed discharge dropped significantly in 2022 and 2023, with differences of 39% and 33%, respectively, due to flood-related monitoring disruptions. Land use and land cover changes—particularly cropland expansion and forest loss—affected water availability by increasing surface runoff and reducing baseflow. Forested areas yielded less water due to higher evapotranspiration, while built-up and agricultural lands contributed to runoff, raising flood and recharge concerns. The findings highlight the importance of integrated watershed management, forest conservation, and sustainable land use planning to ensure long-term water security in Bayugan City and Sibagat.*

Keywords: Water yield, Water discharge, Land Use Land Cover, GIS.

1. INTRODUCTION

The Wawa River is a significant tributary of the Agusan River and serves as a major source of agricultural irrigation in Agusan del Sur. Its headwaters originate in the municipality of Sibagat and flow through Bayugan, Esperanza, and across the entire province, playing a crucial role in sustaining the region's water supply and ecosystem. The river supports local agriculture, fisheries, and surrounding communities, making it an essential natural resource for the province.

To protect its ecological and hydrological significance, the Andanan River and its surrounding areas were designated as a nature reserve under Presidential Proclamation No. 734, issued on May 29, 1991. The Andanan Watershed Forest Reserve (AWFR) covers 15,097 hectares and includes eight barangays: Sta. Irene, Calaitan, Berseba, Sto. Niño, Mt. Carmel, Mt. Ararat, San Juan, all in Bayugan and Barangay New Tubigon in Sibagat, Agusan del Sur. The area falls under the jurisdiction and supervision of the Department of Environment and Natural Resources (DENR) of the Philippines, specifically through its Forest Management Bureau. In coordination with other government agencies, the DENR aims to preserve the area's function as a vital water source for domestic use, agriculture, power generation, and forestry-related purposes. The Andanan River Watershed supplies potable drinking water and irrigation to Bayugan, Sibagat, and other parts of Agusan del Sur [1]

To further enhance water resource management, the National Irrigation Administration (NIA) developed the Andanan-Wawa River Irrigation System (AWRIS) in 2001 to boost agricultural productivity in Agusan del Sur. This system provides efficient irrigation services to local farmers in Bayugan City and the municipality of Esperanza. Through continuous upgrades and maintenance, NIA AWRIS has expanded its coverage, ensuring water availability for rice and other crops. Located in Bayugan City, NIA AWRIS irrigates 6,150 hectares of farmland, benefiting 3,144 farmers, increasing farm yields, and supporting food security in the Caraga Region.

Water yield refers to the amount of water that becomes available as runoff or base flow from a particular watershed. It is an essential parameter for water resource planning, flood control, and environmental management. Assessing water yield helps in understanding the availability and distribution of water resources within a watershed, which is critical for making informed decisions about water allocation and management strategies [2]. Water yield (WY) is an indicator of the health of a watershed. In a healthy watershed, water fluctuations between the rainy and dry seasons tend to be small. The guaranteed quantity, quality, and continuity of water in a watershed is essential to the concept of water security, which directly or indirectly supports national food and energy security. Understanding WY is very useful for water resource managers to determine the effect of human activities on water [3] By understanding the water yield of a region, informed decisions can be made about water allocation, infrastructure development, and environmental protection [4]

2.MATERIALS AND METHODS

2.1 Methodological Framework

This chapter outlines the step-by-step procedures applied to estimate water yield within a watershed by integrating GIS techniques. The methodology fig. 1. consists of three major components: (1) watershed delineation through terrain analysis using a Digital Elevation Model (DEM); (2) Land Use and Land Cover (LULC) classification using Sentinel-2 satellite imagery via Google Earth Engine (GEE); and (3) water yield estimation based on the water balance equation, utilizing climatic variables and spatial data. The systematic combination of these methods ensures a spatially explicit and data-driven assessment of water availability in the study area.

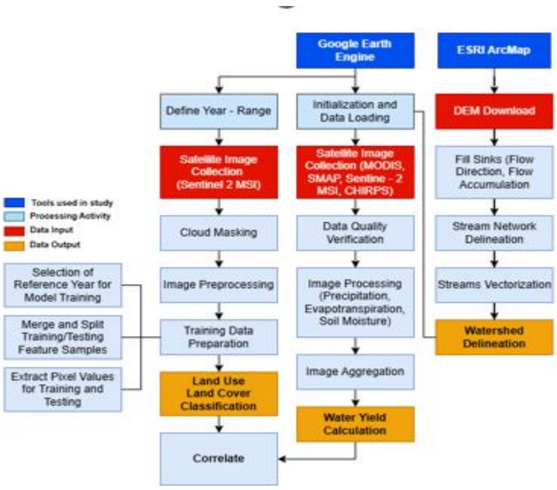

Figure 1. Methodological Framework

2.2 Data Collection

To accurately assess water yield using spatial and remote sensing technologies, five key datasets were collected from different data sources. These datasets in Table 1, form the foundation of the hydrological modeling process and are instrumental in understanding the physical and climatic characteristics of the watershed.

Table 1. Datasets used to estimate the water yield

Data Used	Data Source	Data Function	Data Acquisition
Land Use Land Cover	Sentinel-2 MSI	LULC Classification	2018-2020 2021-2020
Evapotranspiration	Moderate Resolution Imaging Spectroradiometer (MODIS)	Evapotranspiration Estimation	2018-2020 2021-2020
Soil Moisture	Soil Moisture Active Passive.	Soil Moisture Estimation	2018-2020 2021-2020
Precipitation	Climate Hazards Group InfraRed Precipitation with Station data	Precipitation Monitoring	2018-2020 2021-2020
DEM	USGS Earth Explorer	Watershed Delineation, Flow Analysis	2018-2020 2021-2020

2.3 Data Processing

2.3.1 Land Use Land Cover

Land Use Land Cover (LULC) shown in fig. 2, classification was performed using Sentinel-2 multispectral imagery, has 10m spatial resolution from the European Space Agency (ESA) to map cropland, forest land, built-up areas, and water bodies within the Andanan-Wawa River Basin. Supervised classification with a Random Forest algorithm was applied in Google Earth Engine, utilizing training samples collected from feature collection through GEE. Accuracy assessment was conducted using a confusion matrix, achieving an overall accuracy of >93% [5]

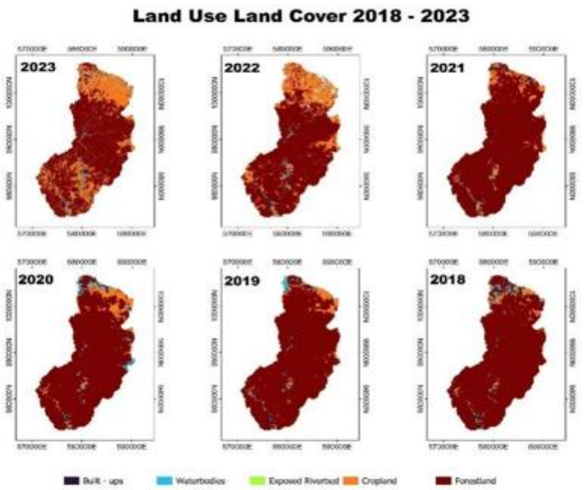

Figure 2. LULC 2018-2023

2.3.2 Watershed Delineation

The Andanan-Wawa River watershed was delineated using NASA Global DEM 10m resolution from ASF. The DEM fig. 3, was preprocessed to fill sinks and remove errors using the ArcMAP. Flow direction and accumulation were calculated using a raster calculator, followed by stream network extraction of the basin area. The watershed outlet was defined at the river's confluence with the Agusan River, and boundaries were validated against topographic maps from the National Mapping and Resource Information Authority (NAMRIA).

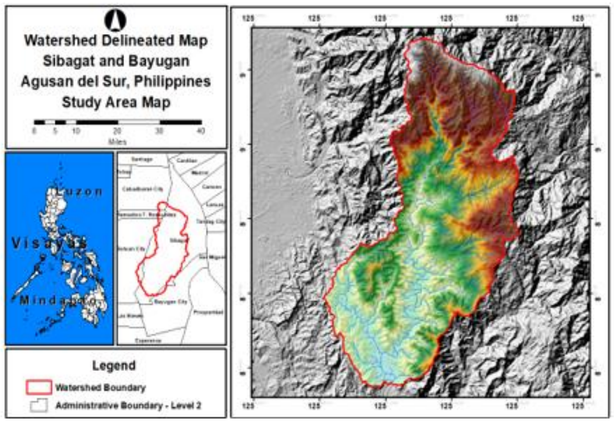

Figure 3. Watershed Delineated Map

Watershed Boundaries and Feature

The watershed boundary is clearly delineated in red, encompassing an area that drains into a common outlet. This boundary was determined through hydrological analysis using DEM processing, which identifies ridgelines that separate drainage basins. The streams within the watershed are represented by blue lines, and they form a dendritic drainage pattern typical of humid tropical regions with varied topography. These streams were extracted from DEM flow direction and accumulation layers, confirming the flow path of surface water from upland to lowland areas. The Region of Interest (ROI) is outlined with a black dashed line, denoting the spatial limit for the hydrological modeling or analysis. This ROI serves as the processing boundary for GIS operations such as flow accumulation, stream network extraction, and watershed delineation.

Evapotranspiration Mapping from 2018-2023

The annual evapotranspiration (ET) maps for the study area from 2018 to 2023 in fig. 3, visually depict the spatial distribution and temporal variability of water loss through evaporation and plant transpiration.

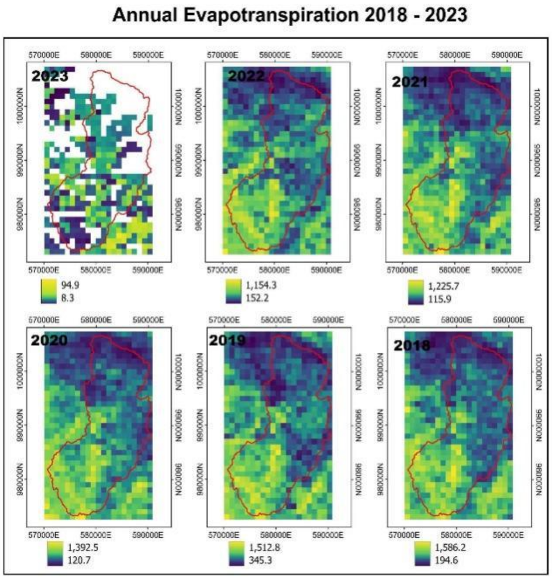

Figure 4. Annual Evapotranspiration Distribution (2018-2023)

2.3.3 Precipitation

Precipitation data were sourced from CHIRPS (Climate Hazards Group InfraRed Precipitation with Stations), a 0.05° resolution dataset blending satellite infrared observations with ground station data [6]. Daily rainfall (mm/day) from 2018–2023 was summed to annual totals and masked to the watershed boundary.

Annual Precipitation Monitoring

The annual precipitation maps from 2018 to 2023 shown in fig. 5, offer a spatial and temporal perspective on rainfall distribution across the study area. Each yearly panel reflects the variation in total precipitation levels, ranging from relatively low values in 2019 and 2020 to significantly higher amounts recorded in 2021 through 2023.

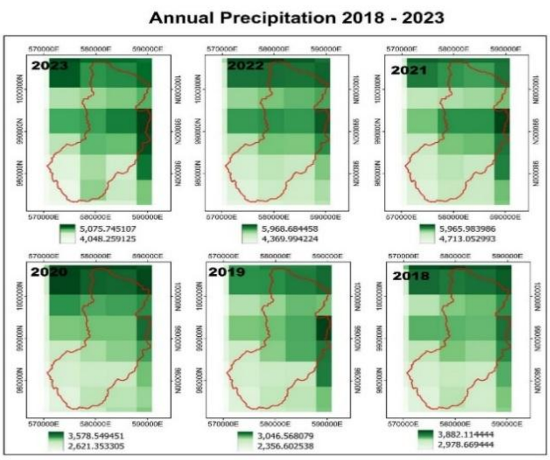

Figure 5. Annual Precipitation Monitoring Map from 2018-2023

The annual precipitation within the Sibagat and Bayugan watershed from 2018 to 2023. Each map corresponds to a specific year and shows the spatial distribution of precipitation within the watershed boundary, outlined in red. The color gradient within each annual map represents the amount of precipitation, with darker shades of green indicating higher annual rainfall and lighter shades indicating lower rainfall.

2.3.4. Soil Moisture (Top Soil)

Surface soil moisture (0–5 cm depth) was obtained from NASA's SMAP Level 4 (9km resolution), which assimilates microwave radar data into a land surface model [7]. Daily volumetric water content (m^3/m^3) was converted to mm using a 0.1m soil layer depth assumption and aggregated to annual means. Gaps from satellite overpass limitations were filled using the *European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis data. Soil moisture dynamics highlighted waterlogging in low-lying agricultural areas during monsoon seasons, influencing groundwater recharge and surface runoff rates.

2.3.5. Water Yield Calculation

Water yield was estimated using a simplified water balance model represented by the equation:

$$Q = P - ET - \Delta S \quad (1)$$

(Where Q = Water Yield, P = Precipitation, ET = Evapotranspiration, ΔS = Soil Moisture) [8]

This model assumes that water yield is the net result of precipitation inputs after accounting for losses due to evapotranspiration and changes in soil moisture. The resulting water yield raster was clipped to the watershed boundary previously delineated using a Digital Elevation Model (DEM) in ESRI ArcMap. The clipped output was then imported into Google Earth Engine (GEE) for further analysis and integration with other spatial datasets.

3.RESULT AND DISCUSSION

3.1 Water Yield Result Under Different Years

This section presents the GIS-based estimated water yield results for the Sibagat and Bayugan study area across different years (2018-2023). The analysis aims to identify temporal variations and patterns in water yield, considering the influence of climatic conditions and data availability within Bayugan City- Sibagat, Agusan del Sur.

3.2 Water Yield from 2018-2023

This subsection focuses on the estimated water yield from 2018 to 2023, serving as a baseline period for comparison. The analysis considers the prevailing climatic conditions and data characteristics during this time to establish foundational insights into water yield behavior within the Bayugan City–Sibagat area of Agusan del Sur.

The water yield in 2019 registered the lowest value of 1,772.23 mm/acre/year, coinciding with the lowest recorded precipitation (2,701.59 mm) and a relatively high evapotranspiration (929.05 mm). In comparison, 2018 and 2020 had similar water yields (2,539.72 mm and 2,342.98 mm, respectively), despite moderate differences in precipitation and evapotranspiration values. Notably, soil moisture improved gradually from 0.27 m^3/m^3 in 2018 to 0.37 m^3/m^3 in 2020, suggesting enhanced soil water retention capacity, which may have aided in the partial recovery of water yield by 2020.

This observation aligns with the findings of [9], who reported that variability in precipitation and evapotranspiration strongly influences annual water yield, particularly in Mindanao's watersheds, where hydrological systems are highly sensitive to climatic fluctuations.

From 2021 to 2023, the watershed recorded elevated precipitation levels, ranging from 4,562.00 mm to 5,339.52 mm, which directly correlated with increased water yield, maintaining outputs above 4,500 mm/acre/year annually. Despite minimal variation in soil moisture (between 0.37 and 0.38 m³/m³), a significant reduction in evapotranspiration from 670.8 mm in 2021 to just 51.6 mm in 2023 further contributed to higher water yield, as more water was retained within the system.

Table 2. Water Yield from 2018-2023

Year	Precipitation (mm)	Evapotranspiration (mm)	Soil Moisture (m³/m³)	Water Yield (mm/acre/yr)
2018	3,430.39	890.4	0.27	2,539.72
2019	2,701.59	929.05	0.31	1,772.23
2020	3,099.95	756.6	0.37	2,342.98
2021	5,339.52	670.8	0.37	4,668.35
2022	5,169.34	653.25	0.38	4,515.71
2023	4,562.00	51.6	0.37	4,510.03

Table 3. Land Use Land Cover Classifications of Bayugan City-Sibagat from 2018-2023(hectare)

Year	Built ups	Water Bodies	Exposed River bed	Crop Land	Forest	Water Yield(mm)
2018	1256.30	1297.75	119.03	30025.80	28389.12	2539.72
2019	1011.31	1125.67	131.06	30386.55	28367.97	1772.23
2020	1134.98	1137.66	180.46	33045.16	26939.90	2342.98
2021	1136.31	1104.15	129.65	33624.41	26418.53	4668.35
2022	957.84	1119.97	91.21	41302.44	22119.81	4515.71
2023	1314.06	1261.39	104.38	49998.09	20856.39	4510.03

In rainfall and corresponding shifts in water availability, offering insights into the region's changing water balance and potential environmental stressors over time. Precipitation fluctuated significantly, starting at 3,400 mm in 2018, dropping to 2,600 mm in 2019, and peaking at 5,500 mm in 2021 before slightly declining in 2022 and 2023. Water yield followed a similar pattern, decreasing from 2,500 mm/acre/year in 2018 to 2,000 mm in 2020 (a 20% drop), then rising sharply to 4,700 mm in 2021. However, it declined steadily to 4,350 mm by 2023 a 7.45% reduction over three years—despite high rainfall, suggesting other factors such as land-use change, soil degradation, or inefficient water retention may be at play.

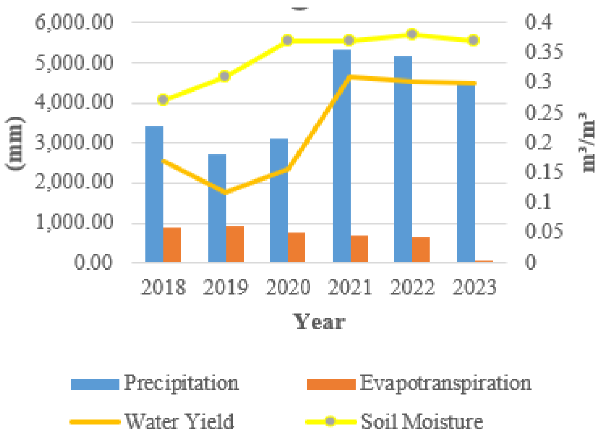

Figure 6. Annual Variation of Water Yield in Relation to Precipitation and Evapotranspiration (2018-2023)

3.3 Annual Water Yield Data Output

In 2018, the water yield ranged from approximately 1,203.79 mm to 3,260.15 mm, while 2019 recorded a significant drop to a range of 637.81 mm to 2,294.83 mm, marking the lowest overall values in the dataset. A partial recovery occurred in 2020, with yields ranging between 973.41 mm and 2,998.91 mm. The following year, 2021, saw the highest yield values of the entire period, with the distribution ranging from 3,233.77 mm to 5,261.74 mm, driven likely by peak precipitation. In 2022, water yield remained high, spanning 2,811.47 mm to 5,361.36 mm, though some areas began showing slight reductions. By 2023, the range had narrowed slightly to 3,614.51 mm to 4,656.09 mm, signaling the beginning of a gradual decline.

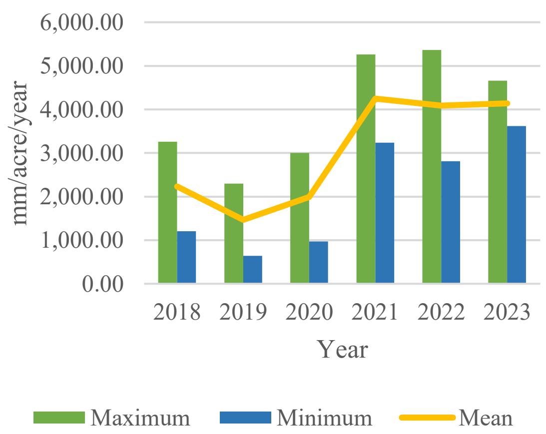

Figure 7. Annual water yield data (2018-2023)

3.4 Water Yield Under Varying Land Use and Land Cover at Year 2018-2023

Quantitative data on the distribution of different land use and land cover types within the specified area over a six-year period. The data within the table allows for an observation of temporal changes in each land use/cover category. For instance, one can track the increase or decrease in forest cover, the expansion of built-up areas, or fluctuations in the extent of crop land and water bodies over the observed years in Bayugan City-Sibagat.

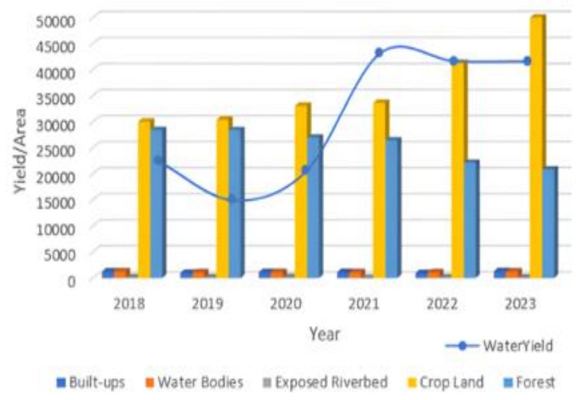

Figure 8. Land Use Land Cover of Bayugan City-Sibagat from 2018-2023

Changes in five land use and land cover categories over a six-year period. The data reveal that cropland consistently occupies the largest area, showing a steady increase, with the most significant growth occurring between 2022 and 2023—indicating a likely expansion of agricultural activities. Forest cover, the second-largest land category, displays a declining trend, particularly a sharp drop in 2022, which may suggest intensified deforestation driven by agricultural expansion, logging, or other land conversion activities. Built-up areas remain relatively small but exhibit a noticeable increase in 2023, possibly reflecting gradual urban development or infrastructure projects. Meanwhile, water bodies remain stable throughout the period, suggesting consistent surface water availability, though slight fluctuations in exposed riverbeds hint at potential seasonal or hydrological changes.

3.4.1 Water Yield Under Varying Land Use and Land Cover at Year 2018-2023

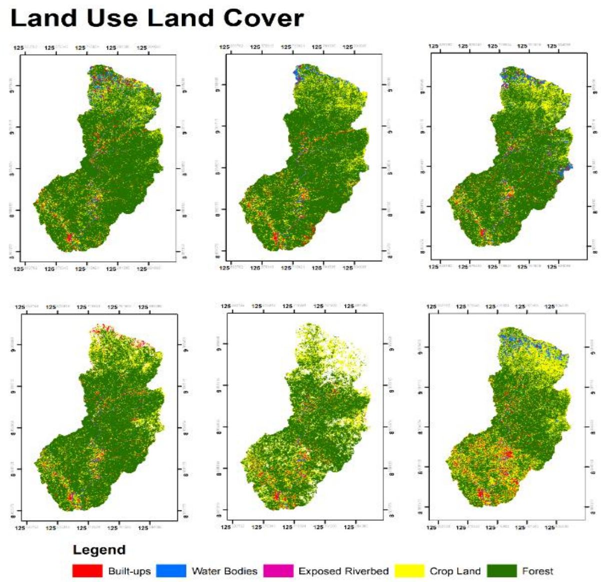

Figure 9. Land Use and Land Cover Distribution (2018-2023)

From 2018 to 2019, the Bayugan City–Sibagat region experienced noticeable land cover changes that began altering its hydrological characteristics. In 2018, cropland covered 30,025.79 units, while forested areas stood at 28,389.12 units. High precipitation levels of 3,430.39 mm and moderate evapotranspiration (ET) at 890.4 mm resulted in a water yield of 2,539.72 mm/acre/year. According to [10] forested areas contribute to lower water yields due to their high ET and infiltration capacities. This year's hydrological output reflected that dynamic higher forest coverage likely contributed to greater water retention and moderated runoff. However, in 2019, cropland expanded to 32,026.65 units, while forest area slightly decreased to 27,401.91 units. More crucially, rainfall dropped significantly to 2,701.59 mm, and ET rose to 929.05 mm, leading to a sharp drop in water yield to 1,772.23 mm/acre/year. These findings align with [11] and [12], who emphasized the high sensitivity of WY to changes in precipitation. The reduction in forest area and increase in cropland intensified surface runoff and reduced the land's ability to retain water, further lowering the WY.

In 2020, cropland continued to grow, reaching 33,045.16 units, while forest cover declined to 26,939.89 units. Interestingly, this year saw a modest recovery in precipitation to 3,430.07 mm, nearly matching 2018 levels. However, ET also slightly increased to 940.4 mm. Despite these counteracting trends, WY improved to 2,489.67 mm/acre/year. This reinforces the principle, supported by [10] and [13] that while LULC changes significantly influence hydrological behavior, precipitation remains the dominant driver of WY. The increase in exposed riverbeds from 138.12 units in 2019 to 180.46 units in 2020 signaled intensified surface runoff and sedimentation likely due to deforestation. [14] confirmed that bare or degraded lands, including cropland and riverbeds, promote runoff, increase erosion, and reduce river capacity.

The year 2021 marked the beginning of more drastic transformations. Cropland grew further to 33,624.41 units, and forest cover reduced slightly to 26,418.53 units. However, precipitation jumped to a high of 5,339.52 mm far above previous years while evapotranspiration dropped to 670.8 mm. These conditions produced a peak WY of 4,668.35 mm/acre/year. This spike aligns with the findings of [15] who emphasized that precipitation exerts a direct positive influence on WY. Despite the gradual forest loss, the overwhelming rainfall more than compensated for the reduction in land retention capacity. Nonetheless, the increasing dominance of cropland over forest suggested the potential for long-term hydrological imbalance.

The situation shifted dramatically in 2022, when forest cover dropped sharply to 2,211.81 units an 11-fold decrease from the previous year suggesting widespread deforestation likely driven by agricultural and urban expansion. Meanwhile, cropland saw only a modest increase to 36,261.14 units, but the ecological consequences were stark. Evapotranspiration plummeted to 58.2 mm, indicating a drastic loss in vegetative water regulation. Precipitation also declined to 4,616.00 mm, yet WY remained relatively high at 4,557.80 mm/acre/year. This decoupling of WY from precipitation levels suggests that surface runoff rather than balanced infiltration and storage was driving the system.

These patterns validate the findings of [16], who found that cultivated and unused lands typically produce more immediate water yield but lack long-term water retention and infiltration benefits. The hydrological stability in WY was thus potentially misleading, masking underlying environmental degradation.

By 2023, cropland experienced a surge to 49,998.09 units an unprecedented 13,736.95-unit increase in a single year while forest cover rebounded partially to 20,856.39 units. Built-up areas also expanded significantly to 1,314.06 units, suggesting further urban development. Interestingly, despite a further drop in precipitation to 4,562.00 mm and a sharp decline in ET to just 51.6 mm, WY remained high at 4,510.03 mm/acre/year. This stability again reflected the dominance of impervious or non-vegetated surfaces, which generate high runoff but contribute little to infiltration. [14] observed similar dynamics in Arequipa, Peru, where rapid urbanization and land degradation led to increased flood risks and deteriorating water regulation.

Table 4. Water Yield Estimation Accuracy Based on Observed Discharge (2021–2023), in liters/year

Year	Estimated Yield	Observed Water Discharge	Percentage Difference
2021	18,918.64	18,440.68	3%
2022	18,261.64	11,222.91	39%
2023	18,238.10	12,253.64	33%

Additionally, the increase in water bodies from 1,104.15 units in 2021 to 1,261.39 units in 2023 may point to accumulation of surface runoff, while the fluctuating trend in exposed riverbeds from 129.65 units in 2021 to 104.38 in 2023 may suggest changes in river morphology due to sedimentation patterns, as supported by [14].

3.6 Comparison of Estimated Water Yield and Observed Water Discharge (2021–2023)

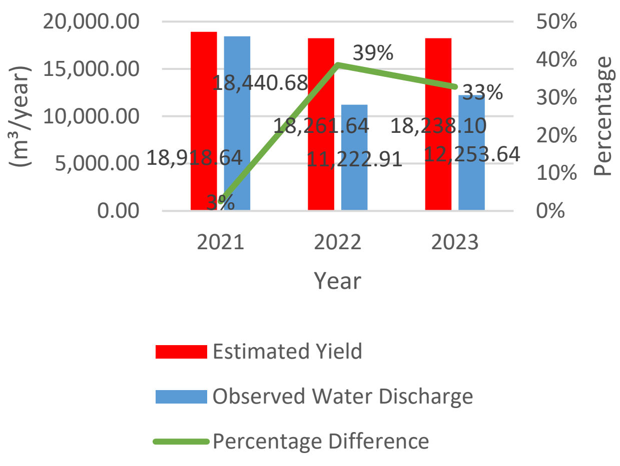

Figure 10. AWRIS Observed Water Discharge Data vs. Estimated Water Yield

Between 2021 and 2023, the estimated water yield remained relatively stable, ranging from 18,918,640 to 18,238,100 liters per year. In 2021, the observed discharge was 18,440,680 liters per year, closely aligning with the estimated yield and resulting in only a 3% difference, which indicates reliable monitoring and favorable hydrological conditions during that year. However, in 2022 and 2023, the observed discharge dropped significantly to 11,222,910 and 12,253,640 liters per year, respectively, resulting in wider gaps of 39% and 33%. These discrepancies are attributed to incomplete data records at the Andanan monitoring station due to extreme flooding events that disrupted measurements. Additionally, no observed discharge data was available from 2018 to 2020, further limiting the scope of temporal analysis. As a result, 2021 served as the most reliable year for validating yield estimates against actual discharge data.

These limitations are consistent with the findings of [17] and [18], both of whom underscore the importance of continuous and reliable hydrological data for accurate modeling and water resource management. [17] reported that data gaps and anomalies at various gauging stations—such as missing years or inconsistent values—compromised their model's calibration and validation processes. Similarly, [18] found that the absence of water quality data along the Srepok River undermined the reliability of simulation outcomes, highlighting the need for a robust and consistent data collection system.

The annual estimated water yield and observed water discharge, along with their percentage differences. The smallest gap was recorded in 2021, indicating a close alignment, while larger discrepancies in 2022 and 2023 reflect data limitations and hydrological variability.

4. Conclusion and Recommendation

This study assessed the annual water yield of the Andanan-Wawa Watershed Forest Reserve from 2018 to 2023 using GIS and remote sensing techniques, revealing key hydrological dynamics influenced by climatic and land use factors. Precipitation and evapotranspiration were identified as the primary drivers of water yield variability. In 2019, the lowest water yield occurred due to reduced rainfall and increased evapotranspiration, while 2021 recorded the highest estimated yield of 18,918.64 liters per year, closely matching the observed discharge of 18,440.68 liters per year—resulting in only a 3% difference, indicating good model reliability for that year.

From 2022 to 2023, the estimated water yield remained relatively stable, with values of 18,261.64 and 18,238.10 liters per year, respectively. However, observed discharge dropped significantly to 11,222.91 liters in 2022 and 12,253.64 liters in 2023. These discrepancies resulted in percentage differences of 39% and 33%, respectively, and are likely attributed to incomplete discharge records caused by extreme flooding events that disrupted monitoring systems. Despite increasing precipitation from 2021 to 2023, the gradual decline in observed yield is likely linked to intensified land use conversion, such as urban development and deforestation. These changes altered surface characteristics by increasing runoff and reducing evapotranspiration, artificially stabilizing yield figures while undermining long-term hydrological sustainability.

Land use and land cover changes significantly influenced water distribution patterns. Forested areas enhanced infiltration and baseflow but contributed to lower water yield due to higher evapotranspiration. In contrast, cropland and built-up areas increased runoff, which temporarily boosted water yield but compromised long-term water stability and watershed health. The conversion of forests to agricultural and urban uses disrupted natural water regulation, elevating risks of sedimentation, flooding, and water insecurity.

To address these challenges, forest conservation and reforestation are recommended to restore watershed function and regulate seasonal flows. Promoting climate-smart and water-efficient agriculture can reduce soil degradation and optimize water use. Continuous LULC monitoring using GIS is essential to guide sustainable land development. Moreover, integrating water yield data into irrigation planning can improve water allocation efficiency. Involving local communities in watershed management will foster stewardship and support long-term sustainability. Implementing these integrated strategies is critical to protecting the watershed's hydrological integrity and securing water resources for agriculture and domestic use in Bayugan City and Sibagat.

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