

# Spatio-Temporal Hydrologic Modeling of Land Cover Change Effects on Runoff in the Kabacan Watershed, Philippines

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**Abstract-** Rapid urbanization and subsequent changes in land-use/land-cover (LULC) are widely considered to contribute to more frequent and severe floods, but little is known about how vulnerable agricultural watersheds in Mindanao are in this context. This study assesses the effect of changing LULC over time and in the future Comprehensive Land Use Plan (CLUP) LULC scenario (from the respective Local CLUPs of (6) six municipalities covering the watershed) on Peak Runoff Volume and Timing in the Kabacan Watershed, North Cotabato. Hydrological simulations were conducted through 5-, 25-, and 100-year return periods by the Hydrologic Engineering Center's Hydrological Modeling System (HEC-HMS) 4.11 and Soil Conservation Service (SCS) Curve Number method. The analysis separated LULC as a dominant variable for the watershed reaction to downtown growth. The results indicate a clear hydrological fingerprint; while the urban cover is projected to increase by almost 500% (from 0.93% to 5.55%), the rise in peak runoff volume for a 100-year return period was very modest, at just 2.43%. This is indicative of a very high degree of hydrologic resilience, likely because the 11% growth (as natural buffer) in perennial crops would curtail impervious surface runoff. The macro-morphology of the catchment was still the dominant control on its time response, with only a 0.08 h early peak runoff time difference. Based on these findings, preserving perennial agricultural areas should be the highest priority in any flood-management plan for the Kabacan Watershed, as one of the “soft engineering” solutions to flooding. To local policymakers in Region 12, this paper provides an important model for achieving a balance between hydrologic stability and human habitat development.

**Index Terms—** Flood, HEC-HMS, Kabacan Watershed, Land Use/Land Cover, Runoff

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## I. INTRODUCTION

THE Philippines was still considered the world's most disaster-prone nation in 2024 and ranked first in the World Risk Index (WRI), with an overall score of 46.91 points, indicating its high exposure [1][2]. Almost half (46.91%) of the population is affected by climate change-related hazards such as floods, cyclones, and droughts. In a newer estimate, 74% of Filipinos live in hazard-prone areas covering about 60% of the country [3][4]. Warm water is the ideal source of energy for feeding tropical cyclones, spawning an average of 20 per year over the archipelago (8 of which hit land),

earning it a spot in the Pacific “typhoon belt” [5].

Floods continue to pose one of the most disastrous natural hazards, especially in the fertile agricultural lowlands disturbed by extreme rainfall events. It is in such prolonged inundated condition that the need to understand how human land cover activities modify hydrological responses to extreme storms is highlighted [6]. Internationally, decades of both empirical and modeling studies reveal that Land Use/Land Cover (LULC) change—especially the transition from forests or other vegetative covers to urban/built-up or cropland land uses—tends to promote more runoff generation and higher peak flows relative to baseflow. The large samples and meta-analytic investigations generally find an association between urbanization level and peak of floods, with higher peaks in impervious areas paired with reduced forest cover, and observable effects at rather low levels of urbanization. These findings are consistent with global syntheses and multi-catchment studies in major hydrology journals [7][8][9][10][11][12][13].

Sensitivity to LULC change is heightened in the

Philippines by monsoon- and cyclone-driven rainfall regimes and steep headwater–lowland linkage. Recent studies in large Mindanao basins (e.g., on the Pulangi River Basin) suggest that increasing rainfall and warming temperatures cause significant increases in runoff and flood risk, amplifying land use impacts in lower-lying agricultural plains. These trends are consistent with more general expectations of increased wet-season rainfall and upland storm runoff in sensitive tropical watersheds [14].

When combined in a Geographic Information System (GIS) with process-based rainfall–runoff models, such tools offer a powerful methodological setting for diagnosing and attributing hydrologic alterations to LULC dynamics. The Hydrologic Engineering Center’s Hydrological Modeling System (HEC-HMS) is well known for its application in event-based and continuous hydrological modeling, as commonly used to compute flood risk analysis, storm design analysis, scenario testing on the land use and climate change [15][16][17][18][19]. A recent bibliometric analysis (2000–2023) also confirms the strong growth in implementation of HEC-HMS, its integration with GIS and remote sensing tools, and the increasing convergence on calibration and validation protocols which procure reliable simulations [20].

At the watershed scale, GIS was successfully coupled with HEC-HMS. For example, in Palawan’s Irawan Watershed, ArcGIS and QGIS were used to conduct geospatial analyses (e.g., soil, land use, and LULC) to provide HEC-HMS inputs for simulating a major rain event; the model—using SCS loss, Clark unit hydrograph, and Muskingum routing—were calibrated and validated using observed hydrographs with metrics including Nash–Sutcliffe Efficiency and Percent Bias [21]. While modelling flooding of Bukidnon’s Manupali Watershed through a combined use of LiDAR-Derived DEMs and GIS tools in the parameterisation of both HEC-HMS and HEC-RAS, scenarios were run for flood simulations at 5, 25 and 100

return years; developed Flood Hazard Maps were testified using community interviews and focus group discussions with good model performance between observed and simulated flow with  $NSE = 0.65$ ,  $PBIAS = 18.96$ ,  $RMSE = 0.59$  [22]. In Castilla, Sorsogon, the integration of ArcMap and HEC-GeoHMS for basin delineation, storage design, data collection of cross-sections/invert levels, and arc carried flow length measurements, and the integration of these data with computations in ArcHydro, resulted in improved performance of the equipment in simulating micro-watershed response to multiple storm events. These were conducted using HEC-HMS, with calibration and validation performed based on other metrics such as NS-Efficiency (NSE) and peak error/cumulative volume error relative RMSE, showing significant overview accuracy [23]. In the Gingoog River Basin in Mindanao, a combined HEC-HMS/HEC-RAS-based GIS flood hazard mapping approach involved modeling of flood inundation for multiple return periods using LiDAR data to produce extent and depth maps of inundation (5-, 25-, and 100-year storms), thus supporting early warning system development [24].

With the growing prevalence of extreme rainfall events in the Philippines and rapid land-use conversion in Mindanao, study in the Kabacan Watershed is necessary. This research serves as a scientific foundation in estimating the hydrological implications of land cover change by using spatio-temporal modeling of existing data sources for flood risk reduction, sustainable land use planning, and policy informed interventions. In the end, this study does not only contribute to a better understanding of LULC–runoff nexus at watershed scale but also provides valuable information to help inform climate-resilient development and disaster preparedness in a flood-prone agricultural hub of North Cotabato.

In this regard, this study is very much in line with the global Sustainable Development Goals (SDGs) and the

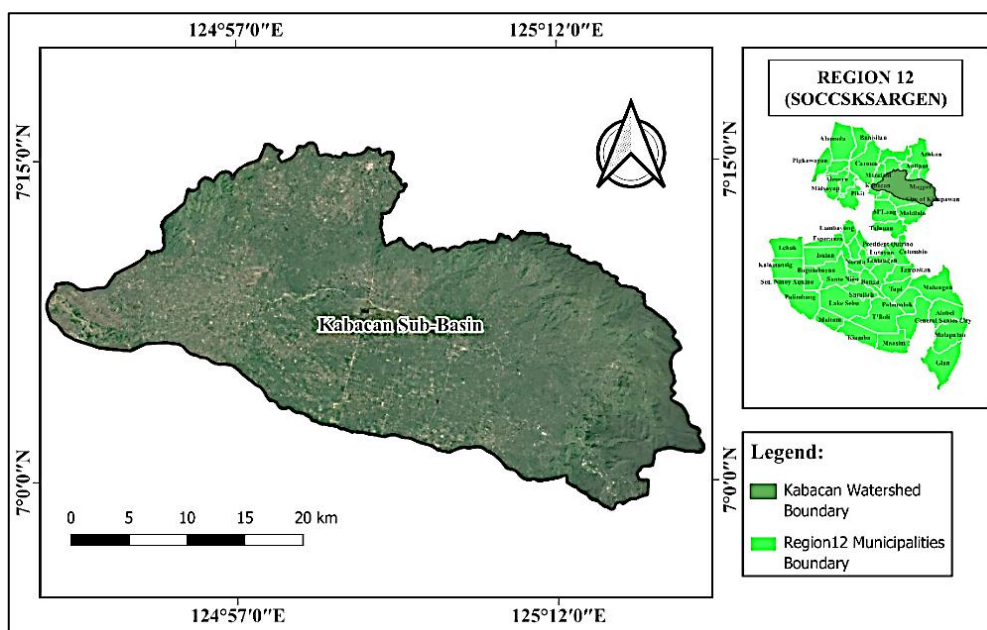


Fig. 1. Study Area

Sendai Framework for Disaster Risk Reduction (2015-2030), which adds to its policy relevance. Through an assessment of the hydrologic impacts of land cover change in a small upland Filipino watershed, this study contributes directly to SDG 15 (Life on Land) by providing input for sustainable land use planning and ecosystem restoration and to SDG 6 (Clean Water and Sanitation) through enhancing understanding of transition-runoff dynamics. It also contributes to SDGs 11 and 13 (Sustainable Cities & Communities, Climate Action) by providing evidence for disaster risk reduction and enhancing the preparedness of cities for precipitation extremes. The work contributes to the achievement of both Target B (substantially reducing the number of people affected by disasters) and Target D (reducing damage to critical infrastructure and disruption of basic services) under Sendai, as it produces spatially and temporally explicit model outputs which are potentially valuable for flood risk mapping, early warning systems, and resilient infrastructure design. In addition, the Philippines has reassured its commitment to the implementation of the Sendai Framework, which aims to strengthen disaster risk governance, involve local governments in disaster risks reduction planning, and enhance data-based decision making for disaster risks [25][26][27].

## II. METHODS AND PROCEDURE

### a. Study Area

For this research, the Kabacan Watershed in North Cotabato and part of Davao Del Sur located in the southern portion of the Philippines is the focus area. The elevation of this watershed is relatively flat at an altitude of around 100 m above sea level (Figure 1). The main hydrological feature in the watershed is the Kabacan River, which runs at approximately 7°8' 20" N and 124°48' 48" E [28].

The Kabacan Watershed, in North Cotabato, Philippines, has a tropical monsoon climate with wet and dry seasons. The rainy season, which occurs between June and October, is responsible for a large portion of the annual precipitation (2,500 mm), thus important for flood evaluation. The area sustains stable environmental condition for hydrological modeling, with an estimated mean temperature of about 27°C. [29].

According to the Modified Coronas Classification, the Kabacan Watershed falls under Climate Type IV characterized by a fairly even distribution of rainfall throughout the year. Nevertheless, the majority of the precipitation falls during rainy season which extends from June to October. Such type of precipitation regime corresponds to the tropical monsoon climate observed in this area with copious rainfall and high temperature all year round [30].

### b. HEC-HMS Model Description

The hydrological model was developed with the HEC-HMS program, a numerical model of surface water systems

provided by US Army Corps of Engineers. Similar to the current study, this numerical model forecasts flow, stages, and timing based on simulating hydrologic responses of watersheds, canals, and water-control structures [31]. In the HEC-HMS model, precipitation is estimated lost to the soil, with excess rainfall converted to overland flow and routing. It consists of three main sections: 1- The basin model, which includes the physical properties of the watershed (i.e., area, connectivity or length of river reaches); 2- The precipitation model, which contains inputs on precipitation data; and 3- The control specifications section, which defines the time at which run simulation occurs and with what duration or at what interval storm should occur.

### c. Data Gathered

Data needed for spatio-temporal hydrologic modeling were collected from national agencies, local governments, and satellite repositories to maintain high spatial resolution as well as policy relevance. Table 1 presents the data employed in this study.

TABLE 1  
DATA FOR SIMULATION

Data	Source
Historical LULC	ESRI Sentinel-2, 10m Resolution (2010, 2015, 2020)
Land Cover	DENR XII – CENRO Matalam, Cotabato.
Future LULC	Proposed land use data of Kabacan, Matalam, Kidapawan, President Roxas, Antipas, and Magpet in North Cotabato
Hydrometeorological and Physical Data	Geo-SAFER CMU

*Historical LULC Data:* Land Use/Land Cover (LULC) maps for 2010, 2015 and 2020 were obtained from ESRI Beta Sentinel-2 at a spatial resolution of 10 meter. These data sets were also validated with geometrically corrected land cover records from the Department of Environment and Natural Resources (DENR) XII – CENRO Matalam, Cotabato.

*Future LULC Projections:* Unlike conventional numerical projections, the “Future LULC” in this paper was built on the available official proposed land use. These were generated from Comprehensive Land Use Plans (CLUPs) of the municipal member LGUs within the watershed which include Kabacan, Matalam, Kidapawan, President Roxas, Antipas and Magpet in North Cotabato. In such a manner, the study ensures that the simulation corresponds to planned regional development.

*Hydrometeorological and Physical Data:* Digital Elevation Model (DEM) and hydrologic data were retrieved from the Geo-SAFER CMU project archive, which contains IFSAR-derived elevation data as well as checked rainfall-streamflow realizations for the January 2018 event to be used

in calibration of the model.

*d. Method*

The overall processing flow (Figure 2) starts with spatial data acquisition and GIS preprocessing. The Digital Elevation Model (DEM) is prepared using utilities such as HEC-GeoHMS or the built-in GIS tools of HEC-HMS – sink filling, computation of flow direction and accumulation, stream definition, automatic delineation of sub-basins and reaches, etc. Following, the LULC and soil maps are superimposed to create a CNs order grid through raster calculations or look-up tables, which accounts for the integrated hydrologic behavior of each land-soil combination; this CNS order grid is read in HEC-HMS as a loss method input where average CN values by sub-watershed are automatically calculated [32].

A main feature uses the Curve Number (CN) to capture various watershed traits in one number. Although it makes estimating runoff easier, there are drawbacks. Rainfall patterns over time do not show up clearly, meaning storms differing in strength or length might lead to nearly identical outcomes. Instead of adjusting, the model sticks to a set starting threshold - often taken as 0.2 of total storage - even when real-world settings differ. Slope across land, shifts in surface cover, and fluctuating soil wetness stay outside its scope, possibly weakening forecasts where landscapes vary widely or shift quickly [33][34].

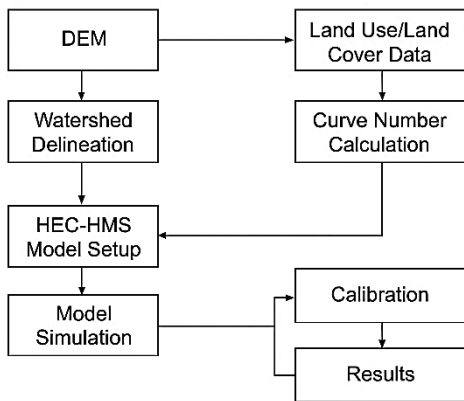


Fig. 2. Workflow of the Study

The construction of the HEC-HMS setup is done by linking three core components: a basin model (sub-areas, reaches and geometric properties), a meteorological model, and specification control settings (defining simulation parameters for each sub-event) with all CN data and spatial layout complete. Subsequently, these surface domains are then utilized in the targeted approach to capture water movement across land; beginning with rainfall conversion represented based on SCS Curve Number loss method described through a model for both generated and joined input containing rainfall runoff (rainfall into streams or rivers), while additional excessive rainfall is transformed into runoff hydrographs using principles from SCS unit

hydrograph considered and some selected background seepage rules are applied e.g., constant-month baseflow recharge or recession methods, routed down channels tap into network of streams rendering to telemetering flows via stream (e.g. Muskingum-Cunge) [33].

Once the model setup is performed simulations are done for each of the LULC scenario, e.g. 2010, 2015, and 2020 with hydrographs produced along with peak runoff and volume of total runoff, as well as timing of peaks. Once model performance is determined—with respect to available discharge data—the calibration cycle begins. Specifically, when modeled results can be compared with real-world observations, calibration adjusts coefficients such that factors like curve number and initial losses (both water quality and runoff) inherit time-based coefficient modifications in order for their outputs to more closely mimic reality.

Finally, the last stage of post-processing involves the extraction of information from simulated results. The potential of the comparison among outputs under different scenario conditions can be used for comprehending through which processes changes in land-cover affect runoff dynamics, therefore assisting flood risk management (and even land-use) decision-making.

*e. Model Calibration and Performance*

The hydrologic model was first run with observed rainfall and flow data for January 26-27, 2018, and then calibrated. Manual overwrites were made for parameters such as Initial Abstraction, Time of Concentration, Storage Coefficient, and Recession Constant. Calibration was accomplished by manually and iteratively tuning these parameters to minimize the differences between simulated and observed runoff, which converged spectacle both painting hydrographs. The performance of the calibration was checked visually by comparing between observed and simulated hydrographs, as commonly practiced when validating model [34]. This process was iterated a few times until the difference between the simulated and observed data was minimized, at which point an unbiased hydrograph was obtained. Figure 3 and Figure 4 show the observed versus simulated outflows before and after calibration, respectively.

To evaluate the accuracy of the calibration, statistical analysis was performed. Table 2 shows the results of evaluation methods that were performed prior to the adjustment for estimating differences between observed and predicted values in view of residual variance.

TABLE 2  
MODEL PERFORMANCE EVALUATION BEFORE CALIBRATION

Statistics	Values	Interpretation
Pearson (r)	-0.02	Unsatisfactory
NSE	-7.76	Unsatisfactory
RSR	2.96	Unsatisfactory
PBIAS	-143.58	Unsatisfactory

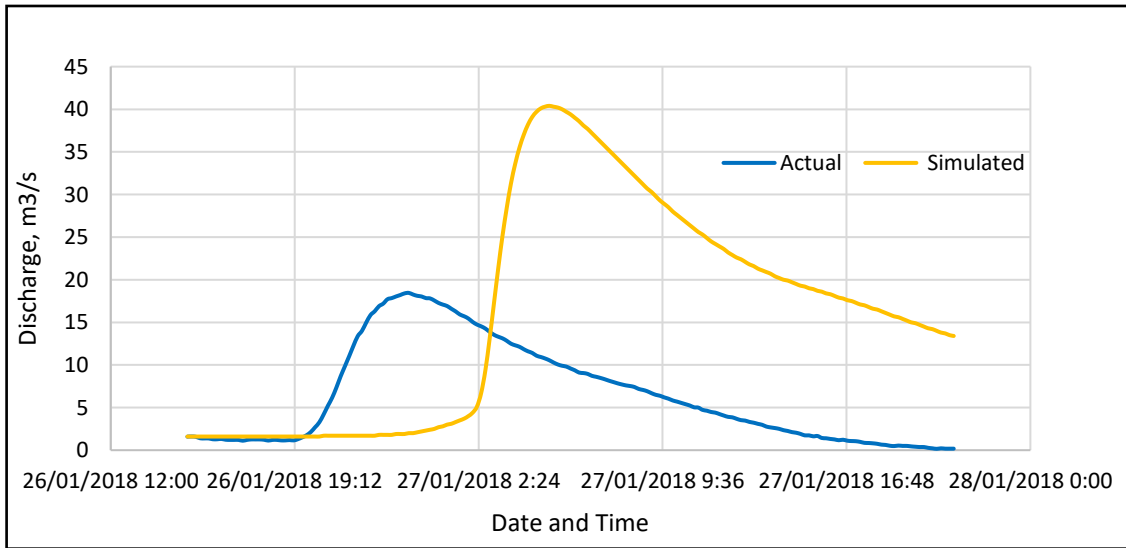


Fig. 3. Actual vs simulated discharge before calibration

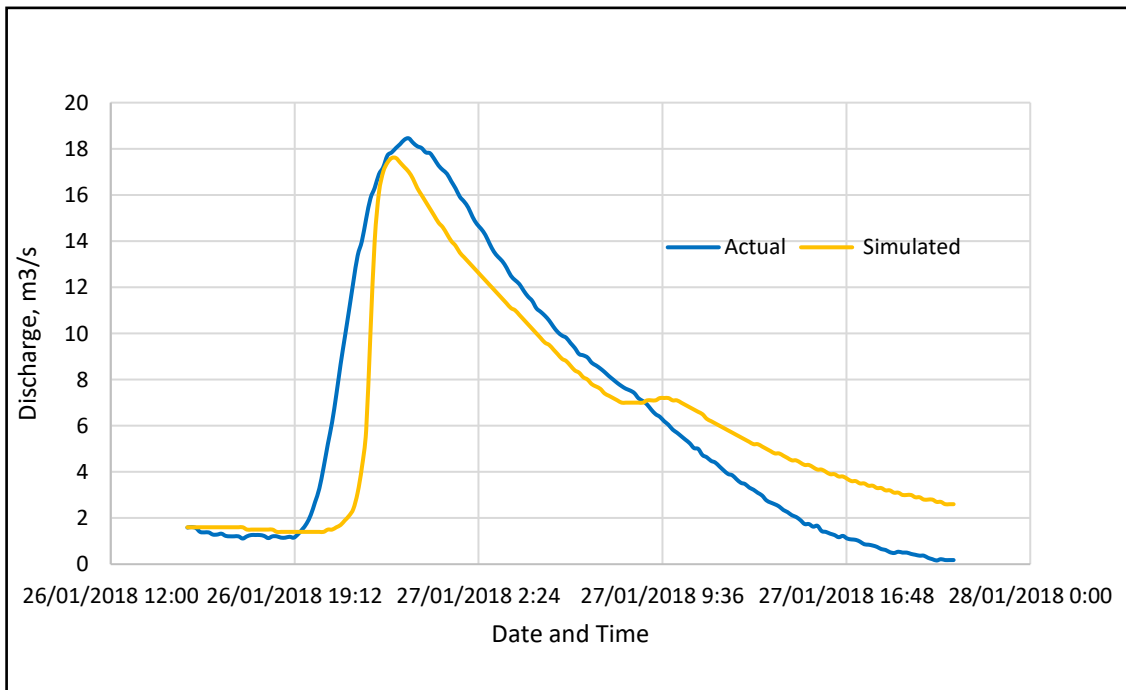


Fig. 4. Actual vs simulated discharge after calibration

In accordance with the statistical assessment in Table 3, it is observed that all evaluation criteria are performed by the hydrologic model very well after calibration. The correlation coefficient ( $r$ ) 0.910 indicates very strong linear relationship between the observed and simulated streams which means that dry and wet seasons are well captured by the model. The Nash–Sutcliffe Efficiency (NSE) of 0.807 is well within the “Very Good” classification ( $> 0.75$ ), and the RSR (0.439) is also below the threshold value of 0.50, indicating also “Very Good” accuracy. In addition, the PBIAS value of 1.135% also implies that there is a little bias and within the  $\pm 10\%$  acceptance criterion for “Very Good” calibration. These are much stricter than the rather permissive “satisfactory” limits usually set with  $NSE > 0.50$ ,  $RSR < 0.70$  and PBIAS falling within  $\pm 25\%$  [35].

TABLE 3  
MODEL PERFORMANCE EVALUATION AFTER CALIBRATION

Statistics	Values	Interpretation
Pearson ( $r$ )	0.910	Very Strong
NSE	0.807	Very Good
RSR	0.439	Very Good
PBIAS	1.135	Very Good

### III. RESULTS AND DISCUSSION

#### a. Land Use/Land Cover Classification

The LULC maps of the Kabacan Watershed reveals how landscape composition have changed through time, as seen on Figure 5. While this layered growth has certainly been a global trend, much more complicated to ascertain here is the specific curve of landcover in Kabacan —the ‘hardening’ and ‘softening’ of hardscapes.

Within agriculture, there was a remarkably bigger internal turnover: Perennial Crop increased from 39.24% (2010) which is contributing to the cover today, to 50.3% (future), while Annual Crop decreased from 30.01% down to 20.66%. That means the watershed isn’t simply transitioning to urbanization but is transitioning into something more like a high-canopy agricultural matrix.”

The gradual increase in the percentage of built-up area from 0.93 to 5.55 is also validated with an observation made by Koneti et al. [36] in other cropland-dominated region. This expansion exacerbates landscape “hardening” since the loss of pervious surfaces is often associated with increased surface runoff and diminished infiltration capacity.

After 2010, woody grasslands disappeared as fishponds began to punctuate the landscape. That shift is emblematic of bigger trends: agriculture growing more concentrated, land use specialized in what it produces. Evidence for this shown in Muriithi [37], where physical terrain itself is remade over time, as water flows under pressure from a declining economic situation. Permanent uses make the land immovable. What evolves isn’t just a fresh appearance above ground but modified flow below it.

In which, the LULC growth projected for Kabacan Watershed would determine future hydrologic responses where urbanization alone cannot be the sole driver but rather the counteracting dynamics between increase in imperviousness and controlling factors present like patches of permanent vegetation cover and aquaculture systems that will moderate this habitability until year 2040. The relative importance of these “hardening” and “softening” processes are likely key both in mitigating runoff generation as well as defining watershed scale hydrologic responses.

#### b. Peak Runoff Volume and Time

Potential peak runoff volumes for the simulated storm events from the LULC-induced changes in CNs (Table 4) were considered. While the volume was higher for all return periods, potentially leading to site-specific indicators of watershed resilience, the percentage change could serve as more general measure.

TABLE 4  
SIMULATED PEAK RUNOFF VOLUMES

Return Periods	Peak Runoff Volume (m <sup>3</sup> )			
	2010 LULC	2015 LULC	2020 LULC	Future LULC
5-year	39.94	40.14	40.27	41.32
25-year	66.52	66.82	66.99	68.39
100-year	89.56	89.92	90.12	91.74

The 100-year peak runoff volume only increased by 2.43% despite a projected 496% increase in built-up area (from 0.93% to 5.55%). This disproportionately low sensitivity indicates that the Kabacan Watershed has a high "Hydrologic Buffer." Although the growth of perennial crops in Kabacan seems to act as a compensatory mechanism, decreasing vegetation within urban catchment areas typically results in greater surface runoff, frequently due to physical infrastructure development intensifying surface runoff and flow velocity [38]. This shows that the agricultural transition is currently lessening the effects of urban growth in this particular watershed, defying the "universal truth" that urbanization causes sharp spikes in runoff. This contradicts Shrestha's [39] findings by demonstrating that the type of vegetation transition is just as important as the increase in built-up area. The simulated peak runoff time (Table 5) showed remarkably slight variations, moving only 0.08 hours (approx. 5 minutes) earlier in the 100-year scenario.

TABLE 5  
SIMULATED TIME OF PEAK

Return Periods	Time of Peak Runoff (hours)			
	2010 LULC	2015 LULC	2020 LULC	Future LULC
5-year	10.75	10.75	10.67	10.67
25-year	10.42	10.42	10.42	10.42
100-year	10.33	10.25	10.25	10.25

In an urbanized context, watersheds are expected to become "flashier" globally, with time-to-peak being significantly diminished. For instance, Zhao et al. [40] noted changes of up to 0.5 h. In Kabacan Watershed, the change is virtually imperceptible. This means that the macro-morphology of the watershed and its large areas planted in agricultural crops are, respectively, the fundamental retardant factors of timing, i.e., "damping" out the flashy response produced by urban surfaces. As noted by Zope et al. [41], land cover changes here increase flood risk largely through volume, not timing. For Kabacan, that means flood warning systems still have a reliable lead time not yet wearing away in the wake of urbanization.

#### IV. CONCLUSION

Agricultural watersheds, such as the Kabacan Watershed in North Cotabato, Philippines, are severely impacted by frequent flooding events due to rapid changes of Land Use/Land Cover (LULC). In this study, HEC-HMS modeling and Future-CLUP LULC scenario (from respective local CLUP per each municipality throughout the watershed) were utilized to quantify peak runoff volume and timing for 5-, 25-, and 100-year return periods as affected by these transitions.

The results reveal a clear hydrologic signature: urbanized areas are projected to increase nearly fivefold (from 0.93% to 5.55%) in size while peak runoff for a 100-year event is only minimally elevated—by just 2.43%.

This relatively low sensitivity of runoff response to land cover change indicates a high level of hydrologic resilience, which in this study is defined as the watershed's ability to maintain stable runoff behavior despite increases in impervious surfaces, as reflected by minimal changes in resulting runoff outputs. This probably due to the perennial crops' simultaneous 11% growth, which acts as a natural buffer against impervious surface runoff. The watershed's macro-morphology still determines its temporal response, as evidenced by the peak runoff timing, which was only 0.08 hours earlier.

According to these results, maintaining perennial agricultural zones should be given top priority in flood mitigation plans for the Kabacan Watershed as a "soft" engineering solution to counteract urban growth. For local policymakers in Region 12, this study offers a crucial framework for striking a balance between hydrologic stability and urban development.

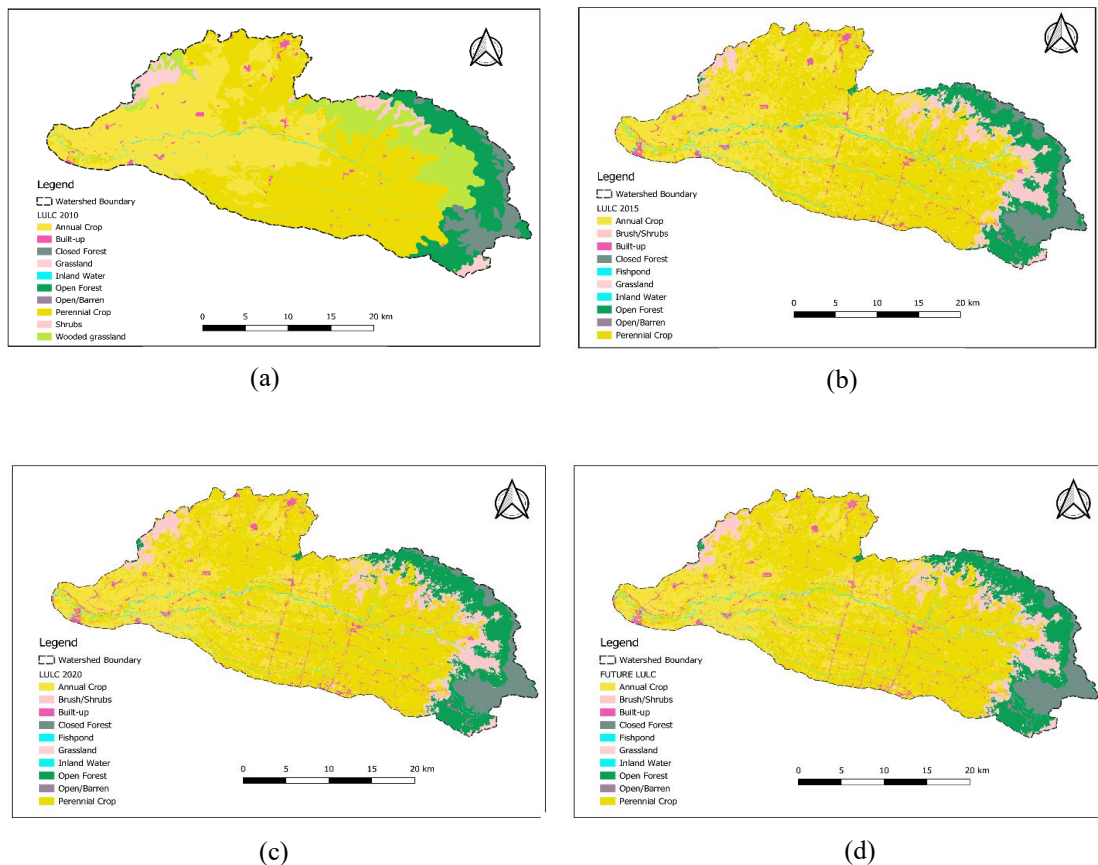


Fig. 5. Land use/land cover map for the year a) 2010; b) 2015; c) 2020; (d) projected future

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