

Study on using statistical data, remote sensing, and SCS-CN method to assess urbanization impacts on flow characteristics in Cau river basin, Thai Nguyen province, Vietnam

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Abstract: The Cau River basin, particularly the segment flowing through Thai Nguyen province, is undergoing rapid urbanization and industrialization, leading to profound changes in land cover and adverse impacts on the hydrological regime. This paper presents a rapid assessment of these impacts using an integrated methodology that combines the analysis of statistical land use data from 2000-2020, remote sensing spatial data, and the SCS-CN method. The results reveal an intense "concretization" process in new industrial centers like Pho Yen and Song Cong, where impervious surface areas have surged by 221% to over 458%, permanently converting more than 10,000 hectares of natural pervious land. This transformation has significantly increased the area-weighted Curve Number (CN) of the sub-basins (by up to 8%), leading to a drastic rise in the effective runoff coefficient (up to 167% for small rainfall events) and a massive increase in runoff volume during major storms. Spatial analysis has identified "hotspots" with the highest flood risk, concentrated downstream of industrial zones and in the low-lying areas of Thai Nguyen City. The study acknowledges limitations regarding hydraulic modeling of pipe networks but confirms that surface runoff generation has exceeded natural capacities.

Keywords: Urbanization, land use change, runoff coefficient, SCS-CN, flooding, Cau river, Thai Nguyen, remote sensing, GIS.

1. Introduction

1.1. Context and Rationale

The Cau River basin, a critical component of the Thai Binh river system (Figure 1), faces escalating challenges related to water security and natural disaster risk. The segment within Thai Nguyen province, serving as a dynamic economic and industrial corridor for Vietnam's Northern Midland and Mountainous region, has undergone a significant transformation over the past two decades. The rise of nuclear urban centers such as Thai Nguyen City, Song Cong City, and Pho Yen City, along with the establishment of large-scale industrial zones (IZs) like Yen Binh (Samsung complex) and Song Cong I & II, has spurred economic growth but has also triggered an unprecedented process of "urbanization and concretization."

This process has fundamentally altered the land surface cover, replacing natural "sponges" (agricultural land, vegetation) with impervious surfaces like factory roofs, roads, and parking lots. This alteration is a primary driver of numerous negative hydrological consequences: a dramatic increase in surface runoff, a dangerously shortened time of concentration, more frequent urban flooding, and a diminished natural drainage capacity of the river and stream network. In

the context of climate change, with its trend of increasing extreme rainfall events, these challenges are further exacerbated, posing a direct threat to livelihoods and the region's sustainable development (Shuster et al., 2005).



Figure 1. Schematic map of the Cau River basin within the Thai Binh river system basin

Although these impacts are recognized, a comprehensive, quantitative, and systematic study is still lacking to answer key questions: What is the extent of land cover change? To what degree has the runoff coefficient increased? And which areas are at the highest risk of reduced drainage capacity? The absence of such scientific answers creates a significant

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gap in planning, leading to reactive and inefficient solutions. Therefore, a rapid and scientific assessment of these impacts is urgently needed to provide a basis for sustainable management strategies.

1.2. Literature Review

Globally, the combined use of statistical data, Remote Sensing (RS), and Geographic Information Systems (GIS) has become an effective methodology for assessing the impacts of urbanization. Statistical land use data offers a general overview of the scale of change, while RS and GIS "spatialize" these numbers (Lu et al., 2004).

To quantify hydrological impacts, the Soil Conservation Service Curve Number (SCS-CN) method (SCS, 1986) is widely applied. However, recent studies in Southeast Asia emphasize the need for "Sponge City" concepts to mitigate these impacts (Nguyen et al., 2019). This study applies this methodology to the rapidly industrializing context of Thai Nguyen, filling a critical research gap.

2. Study area

This study focuses on the upper and middle Cau River basin, covering Bac Kan and Thai Nguyen provinces. This region represents a distinct transition from mountainous terrain in the north to industrial midlands and lowlands in the south.

- Upstream (Bac Kan): Characterized by steep, forested mountains and narrow river valleys. Development is modest, centered around Bac Kan City. This area serves as the primary water source for the basin.

- Midstream (Thai Nguyen): This section features wider valleys, rolling hills, and expansive, low-lying plains. It is a dynamic economic hub and the epicenter of rapid land use change. Analysis is concentrated on three key urban-industrial centers:

- Thai Nguyen City: The administrative core, experiencing significant urban sprawl that has increased impervious surfaces and encroached upon natural drainage channels like the Xuong Rong stream.

- Song Cong City: A major industrial center where traditional agricultural land has been replaced by large industrial zones (Song Cong I & II).

- Pho Yen City: The area of most intense transformation due to massive high-tech industrial parks like the Yen Binh (Samsung) complex, resulting in a dramatic increase in "concretized" surfaces.

The sharp contrast between the stable upstream and the rapidly developing downstream provides a clear case for assessing the hydrological impacts of urbanization and industrialization.

3. Data and methodology

The study employs an integrated methodology, combining statistical data analysis with remote sensing spatial analysis.

3.1. Data Used

- Statistical Data: "Land Use Status" figures for the years 2000, 2010, and 2020 from the Statistical Yearbooks of Thai Nguyen and Bac Kan provinces.

- Remote Sensing Data:

- Global Forest Watch (GFW): Tree Cover Loss (Year) and Tree Cover in 2000 datasets (Hansen et al., 30m resolution).

- Basemap Imagery: High-resolution satellite imagery from Google Satellite, available in GIS software, for verifying the causes of change.

- Base GIS Data: Digital Elevation Model (DEM) from SRTM (30m), administrative boundaries, and soil maps.

3.2. Research Methods

The research process involves two parallel methods:

- a) **Land Cover Change Analysis based on Statistical Data:** This involves a three-step process of Data Collection, Data Reclassification into hydrological classes (Impervious, Pervious, etc.), and Change Analysis to calculate trends.

- b) **Spatial Analysis and Rapid Hydrological Impact Assessment:** This is a five-step process:

1. Land Cover Change Analysis from GFW: Use the "Tree Cover Loss" layer to create a binary "Change Mask Map."

2. "Before-After" Land Cover Mapping: Create a "Before" map from GFW's 2000 data and an "After" map by combining the Change Mask with visual verification on Google Satellite.

3. Rapid Estimation of Runoff Coefficient Change (SCS-CN).

4. Estimation of Flood Runoff Coefficient (α_{eff}).

5. Risk Zone Delineation: Use GIS overlay analysis to identify hotspots.

3.3. Theoretical Basis: The SCS-CN Method and Assumptions

To quantify the hydrological impact, this study employs the Soil Conservation Service Curve Number (SCS-CN) method (SCS, 1986). The CN value integrates the effects of soil type, land use, and antecedent moisture conditions into a single parameter. The relationship between rainfall and runoff is governed by the following equations:

- a) Potential maximum soil moisture retention (S): $S = (25400 / CN) - 254$ (in mm).

b) Initial Abstraction (Ia): $Ia = 0.2 * S$.

c) Runoff Depth (Q): $Q = (P - 0.2*S)^2 / (P + 0.8*S)$ (for $P > Ia$; otherwise $Q = 0$).

From this, the effective runoff coefficient (α_{eff}) for a specific storm event (P) can be derived: $\alpha_{eff} = Q / P$. Unlike the constant coefficient in the Rational Method, α_{eff} is dynamic, increasing with both rainfall depth and the basin's CN value.

Key Assumptions and Parameter Selection:

- Hydrologic Soil Group (HSG): Based on the pedological characteristics of Thai Nguyen (predominantly Ferralsols and Acrisols in hilly areas, and alluvial soils in valleys), the study area is generally classified as Group C (soils with moderately high runoff potential when wet, containing significant clay and loam) to provide a conservative safety margin for runoff estimation.

- Antecedent Moisture Condition (AMC): The study assumes AMC II (average moisture condition) for all scenarios to standardize the comparison between pre- and post-urbanization states.

- Area-Weighted CN: Since land use is heterogeneous, the composite CN for each administrative unit is calculated using: $CN_w = (\sum (CN_i * A_i)) / A_{total}$. CN values are referenced from Technical Release 55 (TR-55): Forest/Agriculture (CN ~ 70-74 for Group C), Industrial/Urban Impervious areas (CN ~ 90-98)

4. Results and discussion

4.1. Land Cover Change (2000-2020)

After collecting and reclassifying data from the Statistical Yearbooks of the two provinces (Thai Nguyen and the former Bac Kan), the land cover change results are summarized in the table below:

Table 1. Statistics of land cover change for major classes during the 2000-2020 period

Unit: hectare (ha)

Administrative Unit	Land Cover Class	Year 2000	Year 2010	Year 2020	Change 2000-2020	Change Rate (%)
Pho Yen City	Impervious Surface	850	1,600	4,750	+3,900	+458.8%
	Pervious Surface (Agriculture + Forest)	15,400	14,500	11,200	-4,200	-27.3%
Song Cong City	Impervious Surface	1,150	2,050	3,700	+2,550	+221.7%
	Pervious Surface (Agriculture + Forest)	13,050	11,900	10,150	-2,900	-22.2%
Thai Nguyen City	Impervious Surface	3,450	4,750	6,400	+2,950	+85.5%
	Pervious Surface (Agriculture + Forest)	13,550	12,200	10,500	-3,050	-22.5%
Bac Kan City	Impervious Surface	450	650	900	+450	+100.0%
	Pervious Surface (Agriculture + Forest)	9,800	9,550	9,250	-550	-5.6%

The analysis reveals a large-scale land use structure transformation in Thai Nguyen's industrial centers. In Pho Yen City, the impervious surface area skyrocketed from 850 ha (2000) to 4,750 ha (2020), a 458.8% increase. In Song Cong City, this figure grew from 1,150 ha to 3,700 ha (a 221.7% increase). This growth came at the direct expense of pervious surfaces, with a total converted area of over 7,100 ha in Pho Yen and Song Cong combined. In contrast, Bac Kan City showed a much slower rate of change, highlighting a clear difference in development drivers. Spatial analysis from GFW data corroborates this trend, showing dense

"hotspots" of tree cover loss concentrated around the Yen Binh, Diem Thuy, and Song Cong I & II IZs. Time-series analysis indicates this process was most intense during the 2011-2020 period, coinciding with the boom in FDI.

4.2. Impact on Runoff Coefficient

Based on the land cover changes, the area-weighted average CN values were calculated. The results show a significant increase in the industrialized areas, most notably an 8.0% increase in Pho Yen City, from 71.3 to 77.0. Using these CN values, the effective runoff coefficient (α_{eff}) was calculated for different rainfall scenarios (Table 2).

Table 2. Estimated Change in Effective Runoff Coefficient (α_{eff}) under Major Storm Scenarios (2000-2020)

Administrative Unit	Rainfall (P)	CN (2000)	α_{eff} (2000)	CN (2020)	α_{eff} (2020)	Increase in α_{eff} (%)
Pho Yen City	100 mm	71.3	0.35 (35%)	77	0.45 (45%)	28.40%
	200 mm	71.3	0.57 (57%)	77	0.65 (65%)	14.00%
	300 mm	71.3	0.67 (67%)	77	0.74 (74%)	10.10%
	400 mm	71.3	0.73 (73%)	77	0.79 (79%)	8.10%
	500 mm	71.3	0.77 (77%)	77	0.82 (82%)	6.90%
Song Cong City	100 mm	71.8	0.36 (36%)	75.9	0.43 (43%)	19.20%
	200 mm	71.8	0.58 (58%)	75.9	0.64 (64%)	9.80%
	500 mm	71.8	0.78 (78%)	75.9	0.81 (81%)	4.30%
Thai Nguyen City	100 mm	74.2	0.40 (40%)	77.1	0.45 (45%)	12.60%
	200 mm	74.2	0.61 (61%)	77.1	0.65 (65%)	6.40%
	500 mm	74.2	0.80 (80%)	77.1	0.82 (82%)	2.70%

Note: α_{eff} represents the effective runoff coefficient - proportion of rainfall that becomes surface runoff.

The quantitative results in Table 2 reveal critical insights into how the urbanized landscape now responds to rainfall:

a) *Increased Runoff Generation and Flood Volume:* The most direct consequence is the substantial increase in runoff volume. For a 100 mm storm in Pho Yen, the effective runoff coefficient increased by 28.4%. This translates to a massive increase in the absolute volume of water that the drainage system must handle. For every 1,000 hectares of developed land, a 400 mm storm now generates an additional 240,000 cubic meters of surface runoff compared to its pre-development state. When scaled across the thousands of hectares of new IZs and urban areas, this additional volume is sufficient to cause widespread and deep flooding.

b) *Increased Basin "Inertness":* The basin has lost much of its natural "sponge-like" regulatory capacity. For an extreme 500 mm event in Pho Yen, the α_{eff} in 2020 reached 0.82. This means 82% of the immense rainfall becomes direct runoff, a response characteristic that approaches that of a fully impervious surface (typically 0.85 to 0.95). The basin now functions more like a "glazed funnel" than a natural landscape, channeling almost all rainfall directly into the drainage network. The infiltration and storage capacity of the soil is nearly negligible during such extreme events.

c) *Increased Vulnerability to Smaller Storms:* Although not detailed in the table, the non-linear nature of the SCS-CN method means that the *relative* increase in the runoff coefficient is most pronounced for smaller, more frequent rainfall events. Analysis shows that for a 30mm storm, the α_{eff} in Pho Yen has increased by over 167%. This scientifically explains the common phenomenon of

localized "nuisance flooding" occurring even after moderate rainfall, as the drainage systems are now subjected to runoff more frequently than they were designed for.

In summary, the land cover transformation has fundamentally altered the basin's response to rainfall. The increased runoff coefficient has not only heightened the risk and severity of major flood events but has also increased the frequency of localized flooding from smaller storms, placing immense and continuous pressure on the existing, outdated drainage infrastructure.

4.3. Reduced Natural Drainage Capacity and Risk Zones

Beyond increasing runoff generation, the rapid land cover change has severely degraded the natural drainage capacity of the landscape. By integrating spatial analysis of land use change with topographical data from a Digital Elevation Model (DEM), this study has successfully delineated the specific "hotspots" where flood risk is most concentrated.

a) The risk zones were identified using an overlay analysis in a GIS environment. This method combines multiple data layers to pinpoint areas of conflict. The primary layers used were:

- *Pressure Source Layer:* The "Change Mask Map" derived from GFW and satellite imagery, identifying areas with the highest concentration of new impervious surfaces (i.e., the sources of increased runoff).

- *Vulnerability Layer:* Topographical data derived from the DEM, including:

- Low-lying areas: Regions with low elevation relative to the surrounding landscape.

- Low-slope areas: Flat terrain (slope < 2%) where water drainage is naturally slow.

○Flow accumulation paths: The natural channels and depressions where surface water converges.

The intersection of these layers reveals the hotspots-areas that not only receive a dramatically increased volume of runoff but also lack the topographical capacity to drain it effectively.

b) *Delineation and Analysis of Key Hotspots*: The analysis has identified three primary types of high-risk zones within the study area:

• *Downstream areas of large Industrial Zones (e.g., Yen Binh, Song Cong I & II)*:

○*Spatial Characteristics*: These zones are located on formerly flat agricultural plains immediately adjacent to the new IZs. The DEM analysis shows these areas have extremely low slopes (<1%) and a sparse, low-capacity network of agricultural drainage ditches.

○*Mechanism of Flooding*: These areas are the first recipients of the massive, rapid runoff generated by the vast impervious surfaces of the IZs. This phenomenon can be described as a "man-made flash flood." The runoff, concentrated by the IZs' internal drainage systems, is discharged at high velocity into natural channels designed only for slow agricultural drainage. The hydraulic capacity of these channels is overwhelmed almost instantly, causing water to back up and spill onto the surrounding low-lying land. This creates rapid, localized, but severe flooding that affects adjacent residential areas and remaining agricultural lands.

• *New Urban Areas and Peri-Urban Fringes (surrounding Thai Nguyen City and Pho Yen)*:

○*Spatial Characteristics*: These are typically residential or mixed-use developments built on former paddy fields or low-lying land. DEM analysis shows these areas often sit in natural depressions or "saucer-like" basins. The development process is often fragmented, with drainage infrastructure lagging behind the pace of construction.

○*Mechanism of Flooding*: These areas become localized "flood pockets" due to two compounding factors. First, the conversion of pervious soil to impervious roofs and pavement increases local runoff. Second, they receive concentrated runoff from higher-elevation areas that have also been urbanized. Without an adequate and well-connected drainage outlet system, this water becomes trapped in the topographical depressions, leading to prolonged, stagnant flooding even after the main storm has passed.

• *Low-lying Areas along Major Drainage Axes (e.g., the Cong River and Xuong Rong Stream)*:

○ *Spatial Characteristics*: These are natural floodplains and low-lying urban corridors located

along the main tributaries of the Cau River. DEM analysis confirms their low elevation relative to the main river.

○ *Mechanism of Flooding (The "Dual Impact")*: These hotspots suffer from a dual hydraulic pressure:

- *Increased Upstream Inflow*: They must convey a higher and faster flood peak coming from the newly urbanized and industrialized upstream catchments.

- *Backwater Effect*: During major rainfall events, the water level in the main Cau River rises significantly. This high water level acts as a hydraulic barrier, preventing or severely slowing the outflow from its tributaries. The water in the Cong River and Xuong Rong stream cannot drain, causing it to back up and spill over its banks, inundating the surrounding areas. The encroachment on the natural floodplain by construction further constricts the channel, exacerbating this effect.

In conclusion, the spatial analysis provides undeniable evidence that the risk of flooding is not uniformly distributed. It is highly concentrated in specific hotspots where the man-made pressure of increased runoff converges with the natural vulnerability of low-lying, flat terrain. This detailed delineation provides a critical scientific basis for prioritizing targeted interventions, such as the construction of retention ponds downstream of IZs, the upgrading of drainage systems in new urban areas, and the protection of natural floodplains along major rivers.

4.4. Limitations of the Study

While this study provides a critical *rapid assessment*, it acknowledges specific limitations:

- *No Hydraulic Modeling*: The study uses the SCS-CN method for surface runoff estimation (hydrology) and does not model flow routing through the river network or the capacity of the drainage pipe system (hydraulics).

- *Infrastructure Ignored*: The analysis does not account for the mitigation effects of existing man-made drainage infrastructure (pumps, existing canals) or local storage capacities (small ponds, paddy fields) that might temporarily detain water.

- *External Factors*: The study focuses on land-use change within the province and does not fully account for upstream flow variations from Bac Kan province or complex backwater effects from the Red River system.

5. Conclusion and recommendations

5.1. Conclusion

The study confirms that urbanization in Thai Nguyen has fundamentally altered the basin's hydrology. The effective runoff coefficient has increased by up to 28.4% for major storms and over 167% for smaller frequent rains. The "concretization"

of over 10,000 ha of natural land has created high-risk flood zones, particularly in Pho Yen and Song Cong.

5.2. Recommendations

- *Update Standards*: Drainage designs must be recalculated using the new composite CN values (approx. 77-80) rather than historical agricultural baselines.

- *Sponge City Application*: Implement Low Impact Development (LID) techniques such as permeable pavements and rain gardens in new industrial zones to offset the lost infiltration capacity.

- *Detailed Modelling*: Future studies should integrate these findings with 1D/2D hydraulic models (e.g., MIKE Urban or SWMM) to assess the pipe network's capacity

References

Shuster, W.D., Bonta, J., Thurston, H., Warnemuende, E., & Smith, D.R. (2005). *Impacts of impervious surface on watershed hydrology: A review*. Urban

Water Journal, 2(4), 263-275.

Lu, D., Mausel, P., Brondizio, E., & Moran, E. (2004). *Change detection techniques*. International Journal of Remote Sensing, 25(12), 2365-2401.

Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S.A., Tyukavina, A., et al. (2013). *High-resolution global maps of 21st-century forest cover change*. Science, 342(6160), 850-853.

Soil Conservation Service (SCS) (1986). *Urban hydrology for small watersheds*. Technical Release 55 (TR-55). Washington, DC: U.S. Department of Agriculture.

Nguyen, T.T., Meon, G., & Kumar, P. (2019). *Implementation of Sponge City Concepts in Vietnam: Challenges and Opportunities*. Sustainability, 11(12), 3420.

Voyde, E., Fassman, E., & Simcock, R. (2010). *Quantifying evaporation from green roofs: A comparison of lysimeter and field station measurements*. Journal of Hydrology, 390(3-4), 157-170.