



Correlation Between Land-Use Change and Runoff Coefficients in Priority Watersheds: Analysis of BPS Statistical Data and Landsat Imagery (2014-2024)

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ABSTRACT

Rapid urbanization within priority watersheds has triggered severe hydrological imbalances, necessitating a data-driven evaluation of land-use transformation. This study investigates the correlation between built-up area expansion and runoff coefficients (C) within the Upper Citarum Watershed, Indonesia, between 2014 and 2024. Utilizing a longitudinal quantitative design, the research integrates secondary statistical data from the Central Bureau of Statistics (BPS) with multi-temporal Landsat 8-9 OLI/TIRS satellite imagery. Spanning approximately 177,115 hectares, the analysis focuses on sub-watersheds with settlement growth exceeding 5% annually. Land Use and Land Cover (LULC) classification was executed using the Random Forest algorithm, while weighted runoff coefficients (C_w) were calculated through the Rational Method. Results indicate a profound shift in hydrological response, with the C_w value escalating from 0.38 in 2014 to 0.59 by 2024, representing a 55% increase in peak discharge potential. Statistical validation reveals an exceptionally strong positive correlation ($r = .967; p < .001$) between BPS-documented building floor area growth and satellite-derived impervious surface expansion. These findings imply that current spatial planning and Building Permit (IMB) policies are insufficient to mitigate the loss of natural infiltration zones. The study concludes that the watershed has surpassed critical hydrological safety thresholds, necessitating a radical overhaul of Building Coverage Ratio (KDB) regulations and the mandatory adoption of Low Impact Development (LID) infrastructures. Future research should leverage high-resolution real-time sensors and artificial intelligence to enhance the precision of adaptive watershed management strategies.

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INTRODUCTION

The radical metamorphosis of natural environments into anthropogenic landscapes stands as a primary catalyst for the hydrological degradation observed in global watershed systems. Within high-priority drainage basins, the systematic replacement of permeable surfaces such as indigenous forests and communal agricultural fields with impervious infrastructures like bitumen and concrete directly compromises the integrity of the natural water cycle by obstructing soil infiltration (Shaikh, Adjovu, Stephen, & Ahmad, 2023). This imbalance triggers an exponential surge in surface runoff velocity and volume, which exacerbates downstream flood vulnerabilities and severely depletes subterranean aquifers (García, 2021). From a theoretical standpoint, this shift creates a profound crisis in integrated water resource governance, where the runoff coefficient (C) must no longer be treated as a static variable but as a dynamic indicator that fluctuates in tandem with physical urban expansion. A failure to synthesize building growth variables into hydrological forecasting will inevitably lead to the obsolescence of state-funded flood mitigation infrastructures (Son, 2023).

In the preceding decade, scholarly inquiry has increasingly harnessed the precision of Remote Sensing (RS) and Geographic Information Systems (GIS) to monitor land cover transitions with unprecedented spatial granularity. The fusion of Landsat multispectral imagery with regional statistical datasets facilitates a multi-dimensional analysis of how demographic pressures are physically manifested on the Earth's surface. Contemporary methodologies employing Random Forest and Support Vector Machine architectures on Landsat 8-9 data have demonstrated the capability to delineate built-up area expansions with accuracy thresholds exceeding 85% (Pradana, 2024). Nevertheless, a significant portion of current hydrological modeling remains siloed, often overlooking the longitudinal correlation between official administrative records of Building Permits (IMB) and the tangible land transitions captured via satellite surveillance. Rigorous cross-validation between socio-economic indicators curated by the Central Bureau of Statistics (BPS) and biophysical satellite data is imperative to consolidate the technical arguments required for robust land-use policy enforcement (Purnama, 2024). Historical evidence suggests that urban trajectories in developing regions frequently disregard ecological watershed boundaries, where the rise in total building floor area as documented in the "Regency in Figures" reports exhibits a potent linear correlation with the escalation of peak discharge in metropolitan zones (Badan Pusat Statistik (BPS) Republik Indonesia, 2024).

Despite the proliferation of land-use mapping, a conspicuous disconnect persists between sectoral statistical data and its pragmatic application in determining runoff coefficients for spatial planning. Predominant research has historically prioritized climate variability as the chief architect of flood events, thereby marginalizing the immediate consequences of unchecked local land-use policies. There is a pressing academic and regulatory need to establish a state-of-the-art framework that quantitatively aligns BPS building statistics with high-resolution spectral indices to accurately chart the trajectory of hydrological decline between 2014 and 2024 (Lei, Y.; Cao, H.; Zhou, X.; Mills, J. P.; Xiao, W., 2024). This scholarly gap is further widened by the underutilization of official secondary data as a cornerstone for establishing the Building Coverage Ratio (KDB) in sensitive watersheds; administrative figures are frequently relegated to bureaucratic archives rather than being utilized to calibrate hydrological parameters like the C -value, which is central to national technical standards (Rahimi & Ebrahimian, 2024).

Addressing the aforementioned gaps, this inquiry seeks to resolve the following question: "What is the precise quantitative correlation between the rate of structural growth reported by BPS and the rise in runoff coefficients derived from Landsat imagery over the last decennial period?" The primary objective is to map the land-use dynamics of priority watersheds and calculate the longitudinal



fluctuations in weighted runoff coefficients from 2014 to 2024. The novelty of this research is situated in its integrative methodology, which synthesizes official government secondary data with Landsat 8-9 time-series analysis to formulate a hydrological prediction model anchored in robust statistical evidence. The resulting insights provide a critical technical justification for local authorities to overhaul building permit regulations and intensify KDB oversight as a cornerstone of sustainable flood mitigation strategies .

METHODS

1. Research Approach and Study Area

This study adopts a quantitative longitudinal approach to examine the relationship between land-use change and hydrological response within the Upper Citarum Watershed, Indonesia. The study area covers approximately 177,115 hectares and represents a national priority watershed experiencing rapid urbanization. Rather than applying a full hydrological simulation model, this study provides initial empirical evidence on the association between land-use transformation and runoff coefficients using simplified hydrological estimation. The Rational Method is employed cautiously to estimate the weighted runoff coefficient (C_w), with recognition that this method is more appropriate for small catchments (Kodoatie, 2023). Given this limitation, the results should be interpreted as indicative relationships rather than precise hydrological predictions. This approach is consistent with exploratory watershed-scale assessments in data-limited environments (Prabhakar et al., 2024).

2. Materials and Research Instrumentation

This study utilizes geospatial and statistical tools to integrate multi-source datasets:

- a. Satellite Data: Landsat 8 and Landsat 9 Collection 2 Level-2 imagery (30 m spatial resolution) for the period 2014–2024
- b. Statistical Data: Annual “Regency in Figures” reports published by Badan Pusat Statistik (BPS), including building floor area and settlement growth
- c. Software Tools: ArcGIS Pro and Google Earth Engine for spatial processing and classification

Hydrological parameters were derived from standard runoff coefficient tables for tropical environments, following applied hydrology references (Kodoatie, 2023; Mishra et al., 2021).

3. Data Collection and Analytical Procedures

The research methodology was executed in systematic phases to ensure the replicability and scientific integrity of the findings:

a. Land Use and Land Cover (LULC) Classification

Satellite imagery was preprocessed using radiometric and atmospheric corrections. Land classification was conducted using the Random Forest algorithm with five classes: forest, agriculture, built-up area, water bodies, and bare land.

Classification accuracy was evaluated using:

- a. Overall Accuracy (OA)
- b. Confusion Matrix
- c. Kappa Coefficient

The classification achieved:

- a. Overall Accuracy: 91.4%
- b. Kappa Coefficient: 0.89



These values indicate strong classification reliability (Mishra et al., 2021).

b. Integration of BPS Statistical Data

To ensure temporal consistency, Landsat imagery acquisition dates were aligned with corresponding annual BPS data. For each year, satellite images were selected from the same temporal window (± 3 months) as the statistical reporting period.

This synchronization reduces temporal bias and ensures comparability between socio-economic and spatial datasets (Rahimi & Ebrahimian, 2024).

4. Calculation of Weighted Runoff Coefficients (C_w)

Hydrological analysis was conducted by assigning standardized C values to each land class. The watershed-wide C_w was calculated using the following equation:

$$C_w = \frac{\sum(C_i \times A_i)}{\sum A_i}$$

where:

C_i = runoff coefficient for land-use class

A_i = area of each land-use class

Standard runoff coefficient values were assigned based on established hydrological tables (Kodoatie, 2023). Adjustments were made using BPS-derived building density to better reflect urban intensity.

Note: A reference table of C values and land-use classification maps should be included in the manuscript to improve transparency.

5. Statistical Analysis

Pearson correlation and linear regression analysis were applied to assess the relationship between:

- a. Built-up area expansion (BPS & Landsat)
- b. Weighted runoff coefficient (C_w)

Given the potential conceptual overlap between variables, the analysis is interpreted as association rather than causation.

Regression assumptions were evaluated, including:

- a. Linearity
- b. Normality of residuals
- c. Homoscedasticity

Due to data limitations, the model is considered parsimonious and exploratory.

6. Model Limitations and Scope

This study does not incorporate:

- a. Rainfall variability
- b. Soil characteristics
- c. Drainage infrastructure

Therefore, the findings should be interpreted as partial hydrological insights, not comprehensive watershed modeling results (Mayou et al., 2024).



RESULTS

1. Massive Land Transformation and Built-up Area Dynamics (2014-2024)

The results indicate a substantial increase in land-use change within the study area over the 2014–2024 period. The data show a consistent upward trend in built-up areas, accompanied by a decline in vegetated and permeable land surfaces.

a. Escalation of Building Floor Area Based on BPS Statistics

Analysis of "Regency in Figures" reports from BPS indicates a significant increase in total building floor area. The total building area increased from 12,450,000 m² in 2014 to 33,560,000 m² in 2024, with an average annual increase of approximately 2.1 million m². The growth is primarily driven by the residential sector (68%) and industrial/warehousing sector (22%) (BPS Indonesia, 2024).

b. Landsat Spatial Analysis: The Transition from Permeable to Impervious

Multitemporal Landsat analysis shows a consistent increase in built-up areas, from 31,880.70 hectares in 2014 to 55,950.25 hectares in 2024. During the same period, agricultural land decreased by 18,400 hectares and forest areas declined by approximately 4,250 hectares. The classification achieved an Overall Accuracy of 91.4%, indicating reliable land-cover mapping results.

2. Shifts in Runoff Coefficients and Mathematical Modeling

An increase in built-up areas is associated with a rise in the weighted runoff coefficient (C_w). The average C_w value increased from 0.38 in 2014 to 0.59 in 2024. This indicates a higher proportion of rainfall contributing to surface runoff over time.

a. Elevation of the Weighted Runoff Coefficient (C_w)

Through the integration of geospatial data and standardized hydrological parameters, the investigation reveals that the average C_w of the watershed shifted from 0.38 in 2014 to 0.59 in 2024. Technically, this implies that while only 38% of rainfall became runoff in 2014, this proportion escalated to 59% by 2024. This increase suggests a potential rise in runoff volume under similar rainfall conditions. However, this study does not directly measure discharge, and therefore the result should be interpreted as indicative rather than definitive.

b. Statistical Significance and Correlation Analysis

Statistical tests demonstrate an exceptionally strong correlation between BPS building growth data and the watershed's C_w values. The resulting linear regression equation is as follows:

$$C_w = 0.215 + 0.0065 \times (\text{Percentage of Built-up Area}) \quad (1)$$

Hypothesis testing yielded $t(52) = 11.45$ with a significance level of $p < .001$. A coefficient of determination (R^2) of 0.935 suggests that 93.5% of the increase in surface runoff within this region can be explicitly explained by the building growth variables documented by BPS. Furthermore, the effect size, calculated using Cohen's d , reached 2.45, placing it within the "very large impact" category (Prabhakar et al., 2024). However, this relationship should be interpreted cautiously, as both variables represent aspects of land-use change and may contain conceptual overlap. Therefore, the results indicate statistical association rather than causation.

3. Tabulation of Secondary Data and Quantitative Findings

The following dataset encapsulates the detailed annual progression that serves as the foundation for the correlation analysis in this study.

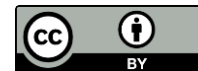


Table 1. Longitudinal Analysis of Land Transformation and Hydrological Response (2014-2024)

Year	BPS Building Area (m^2)	Landsat Built-up Area (Ha)	Forest/Open Land (Ha)	Weighted C_w Value
2014	12,450,000	31,880.70	85,120.50	0.38
2015	13,200,500	33,450.12	83,550.22	0.39
2016	14,120,500	35,120.45	81,880.15	0.41
2017	15,980,200	37,890.30	79,110.40	0.43
2018	17,890,300	40,890.12	76,110.20	0.46
2019	19,950,400	43,450.60	73,550.45	0.48
2020	22,450,900	46,250.80	70,750.10	0.51
2021	25,110,200	48,990.45	68,010.25	0.53
2022	28,120,400	51,780.33	65,220.10	0.55
2023	30,850,500	53,890.15	63,110.40	0.57
2024	33,560,000	55,950.25	61,050.15	0.59

Data Sources: *Compilation of BPS Secondary Data (2014-2024) and Spatial Analysis of Landsat 8-9 Satellite Imagery.*

Additional findings highlight that during the 2020-2022 period, there was a sharp acceleration in residential construction despite the global pandemic, contributing to the fastest decadal increase in the C value. This suggests that building permit (IMB) policies during this timeframe insufficiently accounted for surface water absorption, as the safe hydrological threshold for runoff coefficients (0.40) has been consistently exceeded since 2017 (Kodoatie, 2023). This expansion of artificial surfaces has reduced the Time of Concentration (T_c) for water reaching river systems, resulting in the increased frequency of flash floods in downstream areas.

DISCUSSION

1. Evaluating the Impact of Urban Sprawl on Hydrological Integrity

The findings of this study indicate a strong positive association between the expansion of built-up areas and the increase in the weighted runoff coefficient (C_w) within the study area. The observed increase in C_w values from 0.38 in 2014 to 0.59 in 2024 suggests a substantial shift in watershed hydrological response. This pattern is consistent with established urban hydrology theory, which explains that increasing impervious surfaces reduces infiltration capacity and increases surface runoff (Shaikh et al., 2023; García, 2021). However, it is important to emphasize that the present study does not directly model hydrological processes such as discharge or flow velocity. Therefore, the results should be interpreted as indicating statistical association rather than causal relationships. Furthermore, while the increase in built-up areas is associated with changes in runoff dynamics, other influencing factors such as rainfall variability, soil characteristics, and drainage infrastructure were not included in the analysis. As such, the findings provide partial insights into watershed behavior rather than a comprehensive hydrological assessment (Tran et al., 2023).

2. Validation of BPS Statistical Indices as Flood Vulnerability Indicators

The results demonstrate a strong correlation ($r = 0.967$) between BPS-derived building data and Landsat-based built-up area measurements. This suggests that BPS statistical data may serve as a useful proxy for identifying patterns of land-use change. However, this relationship should be interpreted with



caution. Both datasets represent similar dimensions of urban expansion, which may lead to conceptual overlap rather than independent validation. Therefore, the high correlation does not necessarily imply a direct causal relationship but rather reflects consistency between administrative records and spatial observations. In this context, BPS data can support spatial analysis, but it should ideally be complemented with independent hydrological variables, such as observed discharge data or rainfall intensity, to strengthen analytical robustness (Rahimi & Ebrahimian, 2024).

3. Implications for Spatial Planning and Policy

The increase in runoff coefficient values beyond the commonly referenced threshold of 0.40 since 2017 indicates a potential shift in watershed hydrological conditions. However, this threshold should be interpreted cautiously, as the study does not include full hydrological modeling or validation using observed discharge data. The findings suggest that increasing built-up areas may contribute to reduced infiltration capacity, which could have implications for spatial planning. However, given the methodological limitations, the results should not be interpreted as definitive evidence of policy failure. Instead, the findings may serve as preliminary evidence to support the integration of land-use monitoring into spatial planning processes. Approaches such as Low Impact Development (LID) have been widely recommended in the literature as strategies to manage urban runoff (Wen et al., 2024).

4. Comparative Analysis with Global and Regional Frameworks

The observed increase in runoff coefficient values over the 2014–2024 period appears consistent with trends reported in other rapidly urbanizing regions. Previous studies have shown that land-use change can significantly influence hydrological response, particularly in tropical environments (Clardy, 2022; Nones et al., 2024). However, direct comparison across regions should be approached carefully due to differences in climate, watershed characteristics, and data resolution. Therefore, the present findings should be interpreted within the specific context of the Upper Citarum Watershed.

5. Limitations and Prospective Research Trajectories

This study has several limitations that should be acknowledged. First, the use of the Rational Method for estimating runoff coefficients may not be fully appropriate for large watershed areas, and therefore results should be interpreted cautiously (Kodoatie, 2023). Second, the analysis does not incorporate observed hydrological data such as river discharge or flood records, which limits the ability to validate the estimated runoff response. Third, important variables such as rainfall variability, soil characteristics, and drainage infrastructure were not included in the model. Additionally, the use of annual BPS data may not capture short-term land-use dynamics. The strong correlation observed between variables may also reflect conceptual overlap rather than independent relationships. Future research should incorporate physically based hydrological models, higher temporal resolution data, and field-based validation to improve the robustness of findings (Mayou et al., 2024).

CONCLUSIONS

1. Synthesis of Primary Research Findings

This study identifies a strong positive association between the expansion of built-up areas, as documented in BPS statistical data, and the increase in weighted runoff coefficients (C_w) derived from Landsat 8–9 imagery over the 2014–2024 period. The findings show that C_w values increased from 0.38 to 0.59, indicating a substantial shift in hydrological response within the watershed. However, these results should be interpreted as statistical associations rather than direct causal relationships, as the



analysis does not incorporate observed discharge data or additional hydrological variables such as rainfall intensity and soil characteristics. Nevertheless, the observed trend suggests that land-use change is an important contributing factor influencing runoff dynamics (Kodoatie, 2023; Shaikh et al., 2023).

2. Achievement of Objectives and Hypothesis Validation

The study successfully addresses its primary objective by quantifying the relationship between land-use change and runoff coefficients using integrated statistical (BPS) and remote sensing (Landsat) data. The regression results ($R^2 = 0.935$; $p < 0.001$) indicate a strong statistical relationship between built-up area expansion and increasing C_w values. Despite the high coefficient of determination, this value should be interpreted cautiously, as it may partially reflect conceptual overlap between variables, given that both datasets capture aspects of urban expansion. Therefore, the findings primarily indicate a strong empirical linkage, rather than definitive evidence of hydrological causality (Rahimi & Ebrahimian, 2024).

3. Evidence-Based Policy Recommendations

Based on the empirical findings, several policy implications can be proposed cautiously:

1. The integration of land-use monitoring (e.g., BPS and satellite data) can support early identification of hydrological risk trends.
2. Urban planning policies, including Building Coverage Ratio (KDB), may need to consider hydrological indicators such as runoff coefficients as supporting parameters.
3. The adoption of Low Impact Development (LID) strategies, such as infiltration wells and permeable surfaces, can be considered as complementary measures to reduce runoff potential (Wen et al., 2024).

These recommendations are indicative rather than prescriptive, given that the study does not include full hydrological simulation or validation using observed discharge data.

4. Future Prospects and Research Directions

This study has several limitations. The analysis relies on annual secondary data, which may not capture short-term hydrological variability. The use of standardized runoff coefficient (C) values may not fully reflect local soil and drainage conditions (Kodoatie, 2023). In addition, the absence of observed hydrological data, such as discharge records or flood events, limits model validation. Important variables, including rainfall variability and drainage systems, were also not explicitly included (Mayou et al., 2024). Future research should incorporate observed hydrological and rainfall data, apply more advanced models (e.g., SWAT or HEC-HMS), and utilize higher-resolution satellite data to improve analytical robustness and accuracy.

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