CSID Journal of Infrastructure Development

Volume 6 | Issue 2 Article 3

12-31-2023

Impact Analysis of Land Use Changes on Inundation Map In The Ciliwung River Watershed

Muhammad Raihan Arkan Abiyan Zein
Universitas Indonesia, abiarkan10@gmail.com

Evi Anggraheni
Universitas Indonesia, evi.anggraheni@yahoo.com

Dadang Muhamad Yahya
Directorate General of Water Resource, dadang@gmail.com

Recommended Citation
Zein, M. R., Anggraheni, E., & Yahya, D. M. (2023). Impact Analysis of Land Use Changes on Inundation Map In The Ciliwung River Watershed. *CSID Journal of Infrastructure Development, 6*(2). https://doi.org/10.7454/jid.v6.i2.1117

CSID Journal of Infrastructure Development (6) 2: 169-184
ISSN 2407-4438

IMPACT ANALYSIS OF LAND USE CHANGES ON INUNDATION MAP IN THE CILIWUNG RIVER WATERSHED

Muhammad Raihan Arkan Abiyan Zein[1, *], Evi Anggraheni[1], Dadang Muhamad Yahya[2]

[1]Civil Engineering Department, Faculty of Engineering, Universitas Indonesia, Depok, 16424, West Java, Indonesia
[2]Pemali-Juana River Basin Area, Directorate General of Water Resources, Ministry of Public Works, Semarang, 50246, Central Java, Indonesia

(Received: August 2023/ Revised: October 2023/ Accepted: December 2023)

ABSTRACT

The rapid population growth in Indonesia's DKI Jakarta Province has escalated the demand for housing, increasing built-up land at the expense of green open spaces, known as *Ruang Terbuka Hijau* (RTH). This shift has significantly reduced the land available for water infiltration, resulting in increased runoff and flow discharge, particularly in the Ciliwung River Watershed. This research aims to map inundation in the Ciliwung River Watershed, which is attributable to land cover changes from 1990 to 2022. The study examines flood flow discharge and inundation patterns by utilizing HEC-HMS 4.10 for hydrological modeling and HEC-RAS 6.1 for 1D and 2D hydraulic models. Boundary conditions were based on recorded flood flow discharge at the Manggarai Water Gate and Katulampa Dam, combined with historical rainfall data, to represent watershed conditions accurately. Applying 1D and 2D models provides a detailed visualization of inundation changes over time. Findings reveal that identical rainfall events result in varying flood flow discharges and inundation extents due to different land covers. The Kinematic Wave routing method demonstrated high accuracy, with Nash-Sutcliffe Efficiency (NSE) and regression coefficient values of 0.93 and 0.99, respectively. The study concludes that flow discharge and inundation areas increase with the Curve Number (CN) value. Furthermore, the magnitude of rainfall return periods significantly influences discharge volumes and inundation depths, with areas experiencing 0 – 0.3 meters of flooding predominant in the Ciliwung watershed.

Keywords: Flow discharge; Inundation area; Kinematic wave; Land cover; Nash-Sutcliffe Efficiency (NSE)

1. INTRODUCTION

DKI Jakarta province, where Indonesia's capital is now currently located, is one of the world's most densely populated metropolitan areas. The 2022 statistics from the Central Bureau of Statistics and Rachim et al. (2022) report a population of 10.64 million within an area of just 662.33 km². With a population growth rate of 0.38%—higher than the previous year—the demand for housing continues to intensify. This expansion has significantly decreased green spaces and water catchment areas, exacerbating environmental challenges.

*Corresponding author's email: abiarkan10@gmail.com, Tel. +62-881-18010234
DOI: 10.7454/jid.v6.i2.1117

Over the decades, a drastic decline in the city's green space has been observed. The Directorate General of Spatial Planning of the Ministry of Agrarian Affairs and Spatial Planning / National Land Agency notes a decrease from 35% in the 1970s to merely 9.9% - 14.9% in 2021, as highlighted by the former Head of the DKI Jakarta Forestry Service, Suzi Marsitawati, and the World Resources Institute (WRI) (Harahap, 2021).

This starkly contrasts the vision outlined in Article 6 Paragraph 5b of DKI Jakarta Regional Regulation Number 1 of 2012, which projects a 30% green open space area comprising 20% public and 10% private spaces (Eni, 2015). The diminishing green spaces impede rainwater infiltration, increasing surface runoff and straining the Ciliwung River Watershed.

Flooding, exacerbated by excessive surface runoff, is a frequent issue in DKI Jakarta, particularly along the riparian zones, which have been transformed into densely populated areas, diminishing their capacity to function as floodplains. The Ciliwung River, a significant watercourse spanning 119 km from Puncak, Bogor, through the Depok Region into Jakarta, with a catchment area of 328 km² (Purwanti & Pontiawaty, 2013), is often implicated in these flood events. According to the Head of Katulampa Dam, this river is a primary contributor to seasonal flooding, as evidenced by the January 1, 2020 event that recorded the highest rainfall in 24 years at Halim Perdanakusuma Air Force Base, with 377 mm/day, leading to a peak flood discharge of 3,389 m^3/sec, surpassing the river's capacity of 2,357 m^3/sec (Abay & Haryanto, 2021). This resulted in widespread flooding, affecting 158 urban villages in Jakarta and its environs.

This study aims to analyze the exacerbating flood situation in the Ciliwung River Watershed about land cover changes. Utilizing the Kinematic Wave routing method, hydrological and hydraulic analyses were conducted using land cover data in 1990, 1995, 2000, 2009, 2016, and 2022. This analysis aims to assess the impact of land cover alterations on flood hydrographs and the resulting inundation within the watershed.

2. LITERATURE STUDY

2.1. Floods

Floods are the inundation of water beyond its normal confines, such as from rivers, rainwater, or tidal seawater (Amalia & Wesli, 2015). In Indonesia, flooding is attributed to several interrelated factors: high-intensity rainfall, sedimentation in river channels, planning and construction errors in river channel development, improper spatial planning around watersheds, and malfunctioning watershed retention systems (Maryono, 2020; Taryana et al., 2022; Widyaiswara, 2020).

The Ciliwung Watershed, emptying into DKI Jakarta, is particularly prone to flooding, notably in its downstream urban areas. The watershed's morphology plays a significant role in this vulnerability. In the upper reaches, up to the Katulampa Dam, the watershed exhibits a dendritic (fan-like) pattern. However, towards the middle and downstream sections, the watershed narrows into a parallel formation (BPDAS Ciliwung-Citarum, 2007). According to Trisakti et al. (2008), this narrowing at the Katulampa Dam section results in significant runoff from upstream areas, accounting for about 44% of the watershed’s discharge. The transition from a dendritic to a parallel pattern also contributes to flash floods, exacerbated by the constriction of the watershed's shape.

2.2. Design Rainfall and Area Rainfall

The analysis of design rainfall begins with a crucial initial step, an outlier testing. The primary goal is to detect any anomalies within the collected rainfall data. This process includes examining data distributions and conducting consistency tests, which utilize probability distributions to establish the relationship between the frequency and magnitude of extreme rainfall events (Kementerian PUPR, 2018). For this purpose, the study employs Normal Distribution, Log Pearson Type III, and Gumbel Distribution. The consistency of the data is verified using the Chi-Square and Smirnov-Kolmogorov tests, ensuring the reliability of the rainfall data for subsequent analyses.

Once the design rainfall analysis is completed, the study proceeds to calculate regional rainfall. This step is vital for understanding how rainfall varies across the study area. To accomplish this, there are three methods involved, including the arithmetic average method, the Thiessen polygon method, and the isohyet method. Given the favorable abundance of rain gauge stations within the Ciliwung watershed, the Thiessen polygon method emerges as the most suitable choice. The formula for the Thiessen polygon method is:

$$\underline{R} = \frac{A_1R_1 + A_2R_2 + A_3R_3 + \cdots + A_nR_n}{A_1 + A_2 + A_3 + \cdots + A_n} \tag{1}$$

Where $\underline{RR}$ is the regional rainfall (mm), A_1, A_2, ..., A_n is the area of influence of each precipitation station on the reviewed area (m^2), and R_1, R_2, ..., R_n Which is the rainfall at the reviewed precipitation station (mm).

2.3. Soil Conservation Service-Curve Number (SCS-CN) Method Design Flood

The Soil Conservation Service-Curve Number (SCS-CN) method is an empirical technique extensively utilized for estimating direct runoff from rainfall events, as outlined in Nasjono's research (2018). This method is versatile and applicable across various catchment types, such as small farms, forests, and urban areas. It is particularly effective in integrating diverse catchment characteristics into runoff calculations. The SCS-CN method is based on specific relationships between several hydrological parameters, which are computed as follows:

$$\begin{gathered} P_e = \frac{(P - I_a)^2}{P - I_a + S} \\ S = 25.4\left(\frac{1000}{CN} + 10000\right) \end{gathered} \tag{2}$$

Where P is precipitation (mm), P_e is direct runoff (mm), I_a is initial abstraction (mm), S is maximum retention potential (mm), and CN is curve number.

The SCS-CN method's efficacy lies in its simplicity and adaptability, enabling the integration of various catchment attributes into a unified runoff model. Its application in this study facilitates a nuanced understanding of runoff dynamics in the context of diverse land covers and urbanization patterns within the catchment area.

2.4. Hydrological Model

In this study, hydrological modeling is conducted using the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS). This robust tool transforms rainfall data into various hydrological components like runoff volume, direct runoff, baseflow, and channel flow. A critical component of this modeling process is the routing method, for which the Kinematic Wave method is employed.

The Kinematic Wave method is chosen based on its applicability in time series analysis and integration into semi-distributed hydrological models. This method incorporates mathematical modeling through transfer and production functions (Chow et al., 1988). Transfer functions theoretically model the response to the output from various potential inputs, while production functions transform an input into different outputs based on available data.

Key parameters within the Kinematic Wave method are numerous and complex, including channel slope, overland flow rate, channel cross-sectional area, channel roughness, and conveyance factor. Due to this complexity, certain assumptions are made in the modeling process. The Kinematic Wave method is particularly well-suited for urban areas, where such complexities are commonplace and must be accurately represented in hydrological models.

2.5. Nash-Sutcliffe Efficiency (NSE) Model Validation

The Nash-Sutcliffe Efficiency (NSE) test is a widely recognized method for assessing the accuracy of hydrological models. It evaluates the model's validity by comparing the observed and simulated data sets. The NSE is calculated using the following equation (Suhartanto et al., 2019; Zhao et al., 2017):

$$NSE = 1 - \frac{\Sigma_{i=1}^{n}(O_i - S_i)^2}{\Sigma_{i=1}^{n}\left(O_i - \underline{O_i}\right)^2}, -\infty < NSE \leq 1 \quad (3)$$

Where NSE is the Nash-Sutcliffe coefficient, n is the amount of data, S is the modeled flow discharge value (m^3/s), O is the observed flow discharge value (m^3/s), and $\underline{O}$ is the average observed flow discharge value (m^3/s). Table 1 shows the value criteria of the NSE.

Table 1. Nash-Sutcliffe Efficiency (NSE) Value Criteria

NSE Value	Interpretation
NSE > 0,75	Good
0,36 < NSE < 0,75	Fair
NSE < 0,36	Not Satisfied

(Motovilov et al., 1999)

This model validation step is crucial in ensuring the reliability and accuracy of the hydrological model used in the study. The NSE test provides a quantitative measure of the model's predictive power, allowing for an objective evaluation of its performance against observed data.

2.6. Hydraulics Model

Hydraulic modeling is a critical aspect of understanding river flow dynamics. As Potter et al. (2011) describe, channel flow is the movement of water particles, which can be classified based on their average velocities. In river hydraulics, water flow is typically categorized into four distinct types: steady flow, unsteady flow, uniform flow, and non-uniform flow. Each type offers unique insights into the behavior of water in natural and engineered channels. Hydrologic Engineering Center's River Analysis System (HEC-RAS) software is employed for hydraulic modeling in this study. HEC-RAS provides the tools to conduct both one-dimensional (1D) and two-dimensional (2D) hydraulic analyses.

In the 1D Hydraulic Modeling, the cross-section and channel geometry of the river were involved. 1D modeling is essential for understanding the flow patterns and velocities along the river channel, providing a detailed look at how water moves through and interacts with the channel.

On the other hand, in the 2D Hydraulic Modeling, the 2D component of HEC-RAS, particularly the RAS Mapper, is used to generate inundation maps. These maps are crucial for visualizing and analyzing the extent of inundation resulting from varying flow discharges, especially the impacts of land cover changes within the Ciliwung watershed.

Through the combination of 1D and 2D modeling, this study aims to understand the hydraulics within the Ciliwung watershed comprehensively. This approach enables the exploration of how land cover changes influence river flow dynamics and the consequent inundation patterns, which are critical for effective flood management and planning in the region.

3. METHODS

3.1. Research Flow Chart

The methodology of this study is systematically outlined in a research flow chart, depicted in Figure 1. This flow chart visually represents the sequential steps in the research process, from the initial data collection phase to the final analysis and interpretation of results.

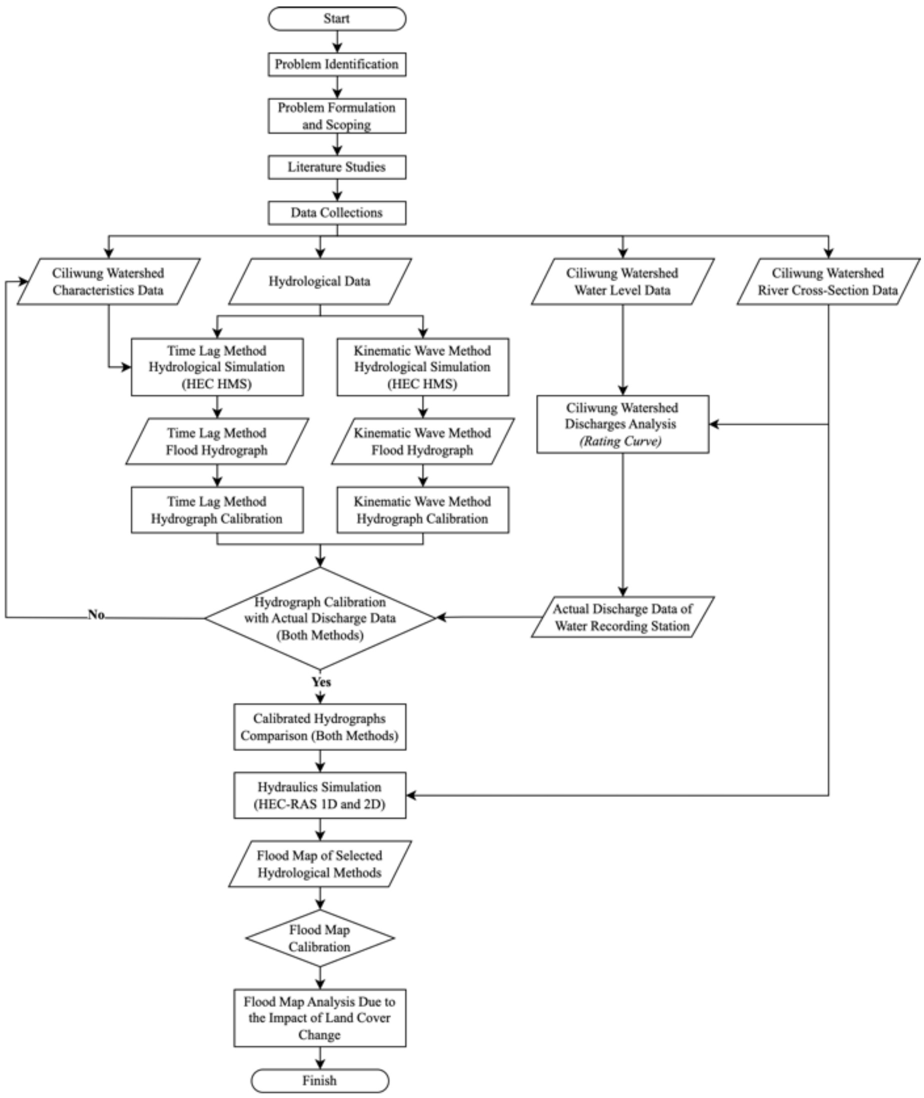


Figure 1 Research Flow Diagram

The flow chart begins with collecting relevant hydrological and hydraulic data, including rainfall records, river flow data, and land cover changes. Following data collection, the study analyzes this data using the methodologies outlined in the previous sections, such as the SCS-CN method for runoff calculation and HEC-RAS for hydraulic modeling.

Subsequent steps in the flow chart illustrate the model calibration and validation process, using techniques like the Nash-Sutcliffe Efficiency test to ensure the accuracy and reliability of the models. The final stages of the research involve applying these models to simulate various flood scenarios within the Ciliwung River Watershed, analyzing the impacts of land cover changes, and formulating recommendations based on the findings.

3.2. Research Location

This study focuses on the Ciliwung Watershed, an essential hydrological feature spanning several key regions in Indonesia. The research comprehensively covers the entire watershed stretch, starting from its upstream areas, extending through its middle course, and concluding at its downstream termination.

The upstream portion of the Ciliwung watershed originates at Telaga Warna Pangrango, situated at the base of Mount Pangrango in the Puncak region of Bogor. This area is critical as it sets the initial river flow conditions and characteristics.

Progressing downstream, the watershed traverses through the Depok area. This section represents the middle part of the watershed, where significant changes in land use and urbanization patterns are observed, influencing the river's hydrological behavior.

The study extends to the downstream end of the watershed, concluding at the Manggarai Sluice Gate in East Jakarta. This point marks the final convergence of the watershed's flow before integrating into Jakarta's larger hydrological system.

The selection of the Ciliwung watershed as the research location is strategic, encompassing diverse ecological, urban, and geographical features. This comprehensive coverage allows an in-depth analysis of the watershed's hydrological dynamics, from its natural mountainous origins to its heavily urbanized lower reaches.

3.3. Data Sources

The research employs a comprehensive data collection approach, utilizing spatial, hydrological, and hydraulic data to facilitate an in-depth analysis of the Ciliwung watershed.

a) Spatial Data.
   Digital Elevation Model (DEM) and Landsat-8 Images: These datasets, spanning the years 1990, 1995, 2000, 2009, 2016, and 2022, are crucial for creating detailed land cover data. This data aids in the calculation of rainfall-runoff relationships and in determining flood plans using the SCS-CN method. The DEM data is also instrumental in delineating the Ciliwung watershed for HEC-HMS modeling and forming the terrain model for HEC-RAS 2D.
b) Hydrological Data.
   Daily Rainfall Data: Covering a 23-year period from 1998 to 2021, this dataset is essential for understanding precipitation patterns and trends within the watershed.
   Flow Rating Curve Data and Hourly Water Level Data: Sourced from Manggarai and Katulampa, these data sets are used to calculate flow discharge values. They play a vital role in validating the modeled discharge using the Nash-Sutcliffe Efficiency (NSE) and Linear Regression methods.

c) Hydraulic Data:
Cross-Section Data: Obtained at various points along the Ciliwung River, this data is provided by BBWS Ciliwung-Cisadane and BMKG. Constructing accurate hydraulic models and understanding the river's flow dynamics is essential.

This structured approach to data collection ensures a comprehensive understanding of the Ciliwung watershed's hydrological and hydraulic behaviors. Integrating spatial, hydrological, and hydraulic data enables a multidimensional analysis crucial for accurate flood modeling and watershed management.

4. RESULTS AND DISCUSSION

4.1. Land Cover

The study's analysis of land cover within the Ciliwung watershed is crucial for understanding the impact of land use changes on hydrological behaviors. The Watershed Delineation was performed utilizing ArcGIS software, identifing its boundary and classify its 14 sub-watersheds. This delineation is essential for targeted analysis within each subwatershed. The resulting map of the Ciliwung watershed and its sub-watersheds is illustrated in Figure 2.

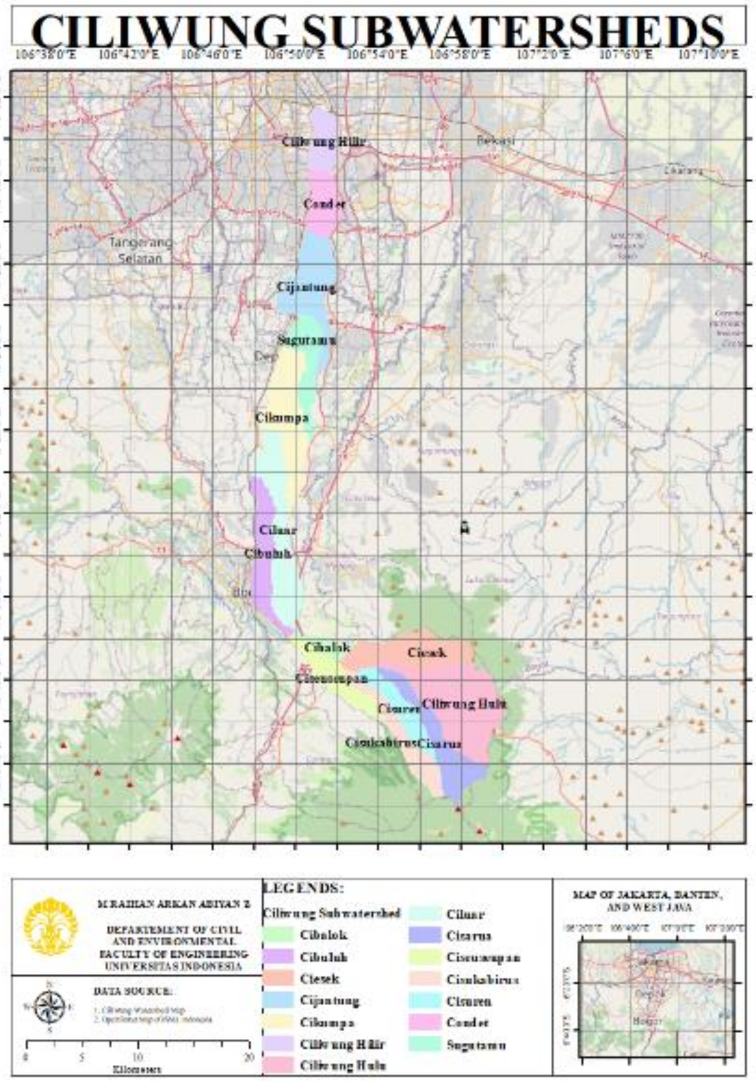
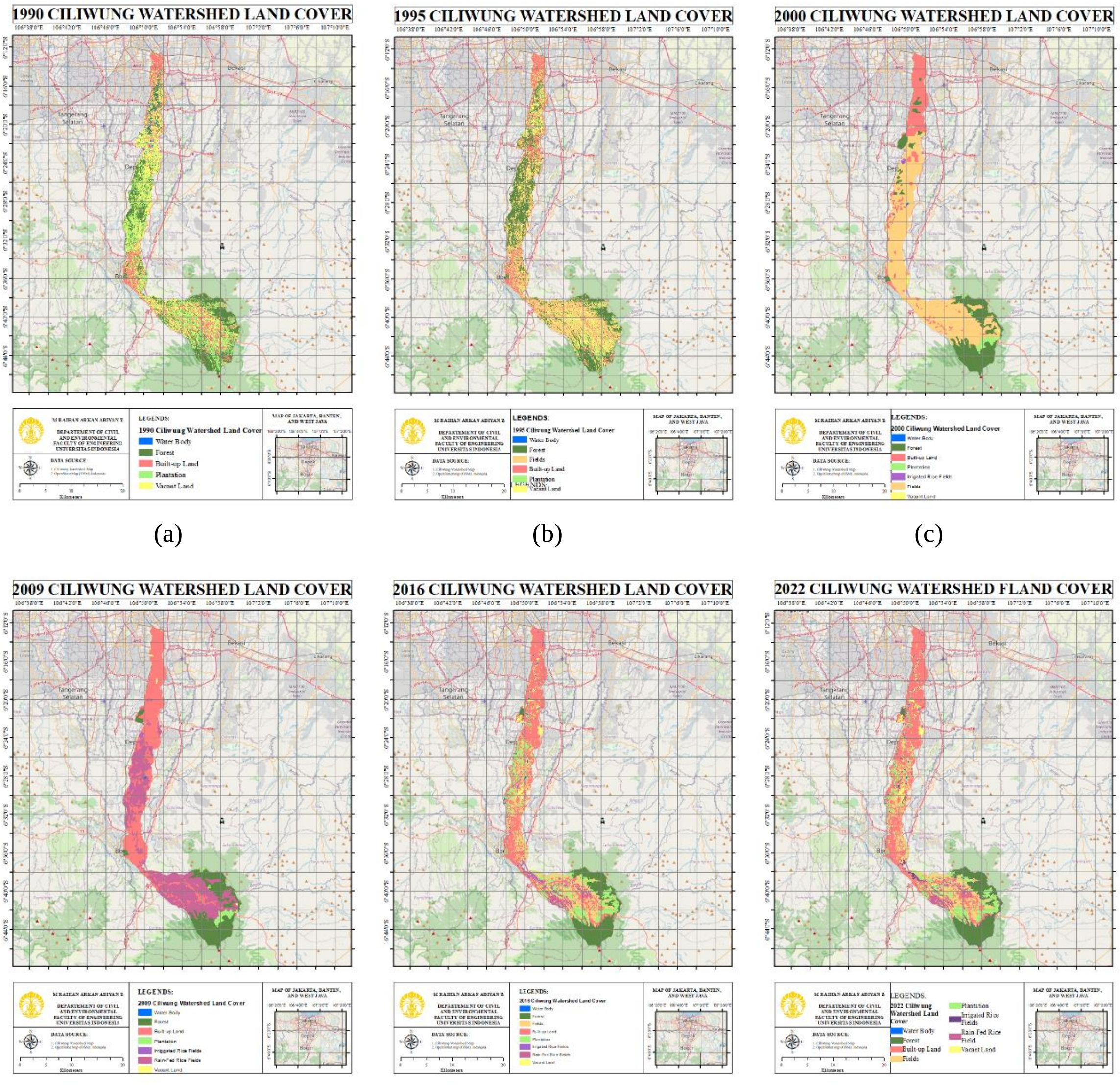


Figure 2. Ciliwung Sub Watershed

Land cover classification for each review year was determined using the image classification method, which enables the categorization of various land cover types within the watershed. Figure 3 depicts the changes in land cover over the years, visually representing these shifts.



(a) (b) (c)

(d) (e) (f)

Figure 3. Ciliwung Watershed Land Cover Changes (a) Year 1990, (b) Year 1995, (c) Year 2000, (d) Year 2009, (e) Year 2016, and (f) Year 2022

The analysis of changes in land cover reveals a noteworthy trend, particularly in the substantial increase of "built-up land." As illustrated in Figure 4, there has been a remarkable surge both in the area and the percentage of built-up land, surging from 20.72% (equivalent to 67.97 km²) in 1990 to a substantial 43.76% (equivalent to 136.88 km²) in 2022. This significant transformation reflects as a clear indicator of the rapid urbanization occurring within the watershed and raises important questions about its potential implications on water management and flood risk mitigation.

The results highlight a critical shift in the Ciliwung watershed's land cover over the past three decades, underlining the need for updated water management strategies to adapt to these changes. The increase in built-up areas suggests a decrease in permeable surfaces, likely contributing to altered hydrological dynamics and increased flood risks in the region.

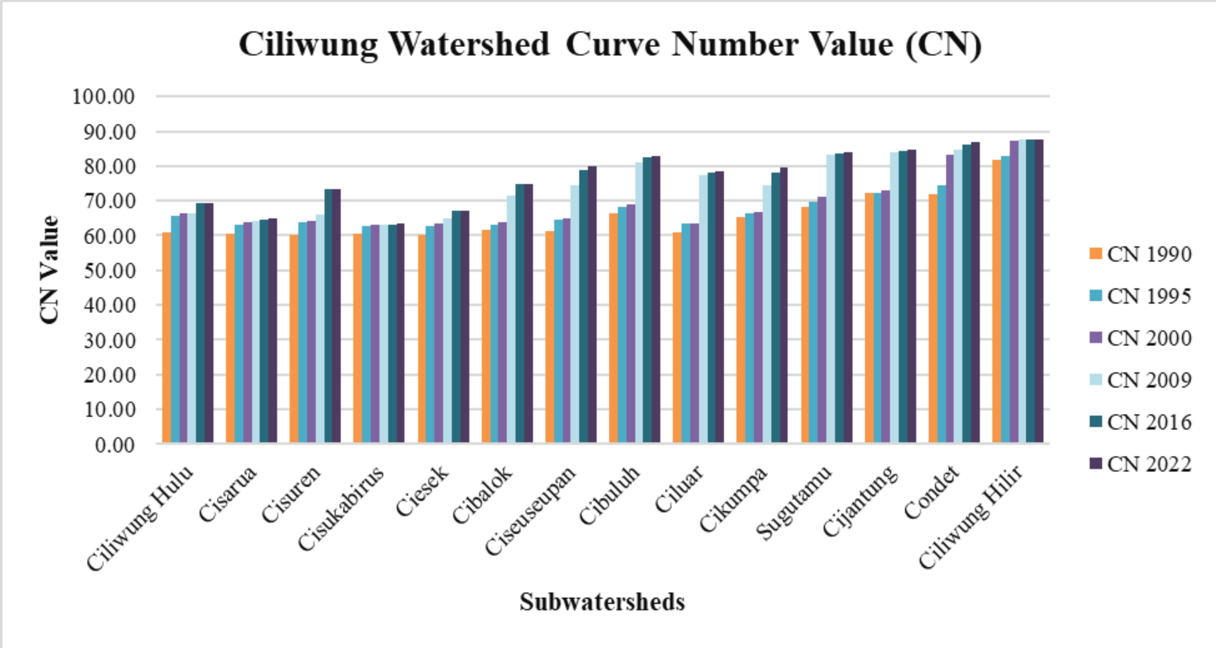


Figure 4. Ciliwung Watershed Curve Number (CN) Changes

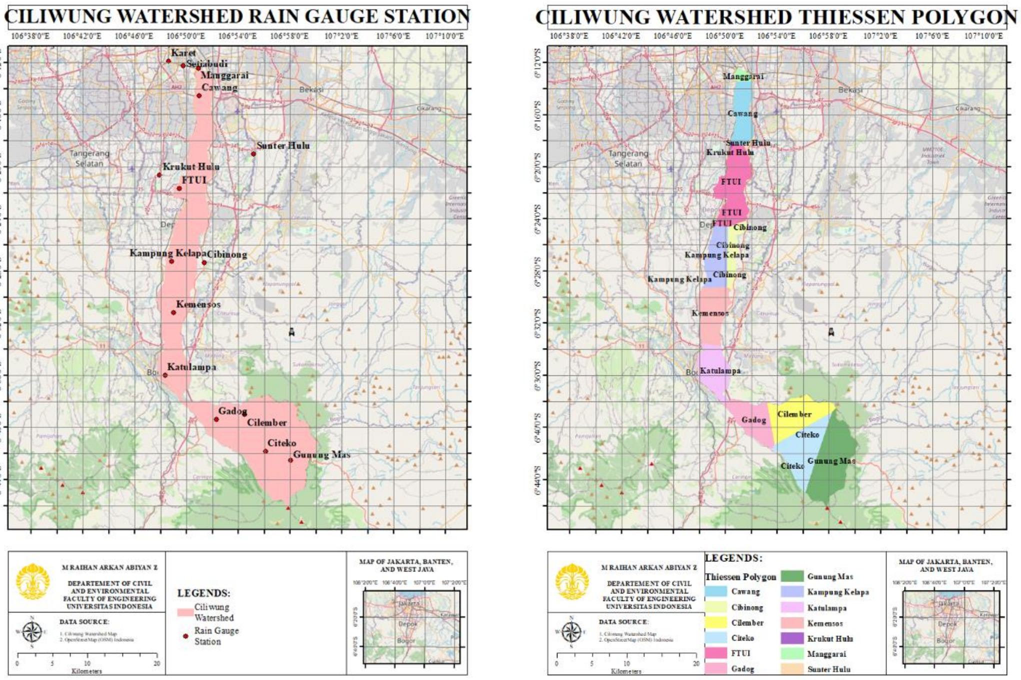
4.2. Design Rainfall

Determining design rainfall involved rigorous testing of rainfall data, particularly for the initial planning of 50-year and 25-year rain return periods. This analysis made the Log Pearson Type III distribution method the most suitable for our design rainfall calculations, as outlined in Table 2. This choice was based on successfully fulfilling all test criteria, making it the preferred method in our study.

Table 2 Design Rainfall Value of Every Rain Gauge Station in Ciliwung Watershed

Precipitation Stations	XTr 25-year (mm)	XTr 50-year (mm)
Manggarai	208.401	224.166
Karet	180.873	204.178
Setiabudi Timur	247.822	287.182
Cawang	194.765	203.103
Krukut Hulu	164.228	170.968
Sunter Hulu	285.330	342.699
Kemensos	72.025	73.650
Kampung Kelapa	157.035	157.804
FTUI	166.143	176.389
Cibinong	153.923	164.653
Cilember	151.413	159.632
Gadog	162.938	171.203
Citeko	199.527	223.882
Katulampa	155.236	161.711
Gunun Mas	164.724	172.068

Following the design rainfall analysis, regional rainfall was assessed using the Thiessen polygon method. This method facilitated the division of affected areas within the Ciliwung watershed based on the proximity and influence of each rain gauge station. Figure 5 illustrates the locations of these stations and the corresponding Thiessen polygons, providing a spatial understanding of their influence on the watershed's rainfall distribution.



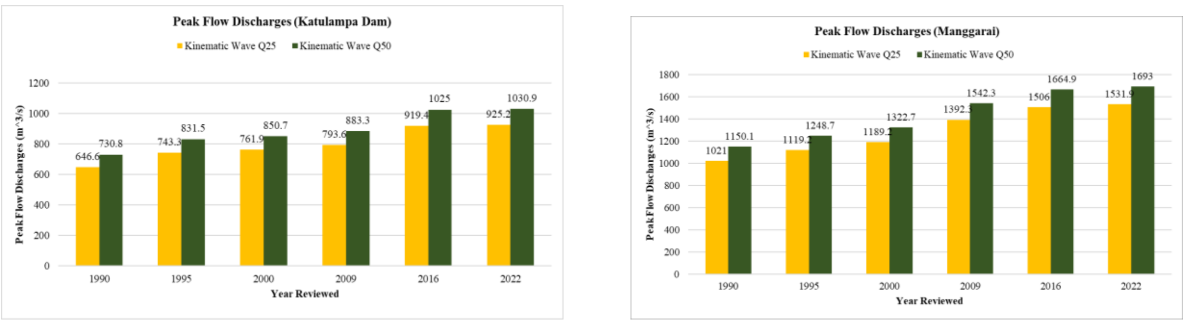
(a) (b)

Figure 5. Ciliwung Watershed (a) Rain Gauge Station Location and (b) Thiessen Polygon

The analysis of design rainfall and regional rainfall distribution plays a crucial role in understanding the hydrological dynamics of the Ciliwung watershed. By identifying the rain return periods and assessing the spatial influence of rainfall, this section lays the groundwork for subsequent flood modeling and water management strategies.

4.3. Hydrological Model of HEC-HMS

The hydrological modeling conducted using HEC-HMS reveals distinct characteristics in the flood hydrographs, influenced by various scenarios. A notable observation from this analysis is the increase in peak discharge at both the Katulampa Dam (junction-5) and the Manggarai Dam (outlet) for the 25-year and 50-year return periods, spanning from 1990 to 2022. This trend, depicted in Figure 6 and detailed in Table 3, highlights the region's evolving nature of flood risks.



(a) (b)

Figure 6. Graph of Peak Flow Discharges in Ciliwung Watershed (a) In Katulampa Dam and (b) In Manggarai

Despite consistent rainfall values, the differences in discharge for each review year can be attributed to land cover changes and variations in Curve Number (CN) values. These changes affect surface runoff from the land, which subsequently influences flow discharge.

Table 3 Peak Flow Discharges of the Year Reviewed in Katulampa and Manggarai Viewpoint

Year	Peak Flow Discharges			
	25-Year Return Period		50-Year Return Period	
	Junction-5 Katulampa (m^3/s)	*Outlet* Manggarai (m^3/s)	*Junction*-5 Katulampa (m^3/s)	*Outlet* Manggarai (m^3/s)
1990	646.6	1021.0	730.8	1150.1
1995	743.3	1119.2	831.5	1248.7
2000	761.9	1189.2	850.7	1322.7
2009	793.6	1392.3	883.3	1542.3
2016	919.4	1506.0	1025.0	1664.9
2022	925.2	1531.9	1030.9	1693.0

In the HEC-HMS hydrological modeling, the Kinematic Wave routing method was employed. This method was chosen due to its ability to consider complex hydrological parameters comprehensively, including the celerity index, channel geometry, slope, and Manning's coefficient. Utilizing the Kinematic Wave method ensures a detailed and accurate representation of flow dynamics within the Ciliwung watershed, capturing the nuances of hydrological changes over time.

4.4. Nash-Sutcliffe Efficiency (NSE) and Regression

Data calibration in this study was crucial for enhancing the alignment between observed and modeled hydrological responses. We employed the Nash-Sutcliffe Efficiency (NSE) and linear regression methods to validate the modeled flow discharge impacted by land cover changes. The observed discharge data selected for comparison was based on significant rainfall events on four specific dates in 2020, as recorded by the Manggarai AWLR (see Table 4).

Table 4 Comparison of Observed Modelled Peak Flow Discharge at Manggarai Viewpoint

Dates	Peak Time	Q Observed (m^3/s)	Q Modelled (m^3/s)
January 1, 2020	12:00	917.57	767.90
February 8, 2020	23:00	432.84	443.10
February 23, 2020	23:00	453.64	470.20
February 25, 2020	23:00	667.16	414.20

The initial modeling results showed significant deviations between the observed and modeled discharges. The NSE coefficient and linear regression values were notably distant from the ideal 1 (E = 1; R = 1), indicating the need for model recalibration.

Consequently, we calibrated the CN value of built-up land from 85 to 88 and included additional review dates in 2020. This recalibration aimed to achieve a more accurate match between the modeled and observed data, as shown in Table 5.

Table 5 Comparison of Calibrated Observed and Modelled Peak Flow Discharge at Manggarai Viewpoint

Dates	Peak Time	Q Observed (m^3/s)	Q Modelled (m^3/s)
January 1, 2020	12:00	917.57	830.50
February 8, 2020	23:00	432.84	401.20
February 23, 2020	23:00	453.64	437.10
February 25, 2020	23:00	667.16	619.50
March 1, 2020	06:00	399.05	342.70
March 27, 2020	06:00	520.32	519.70

Post-calibration, the modeled discharges were noticeably closer to the observed values, achieving a more accurate NSE value of 0.93 using the Kinematic Wave method (see Table 6).

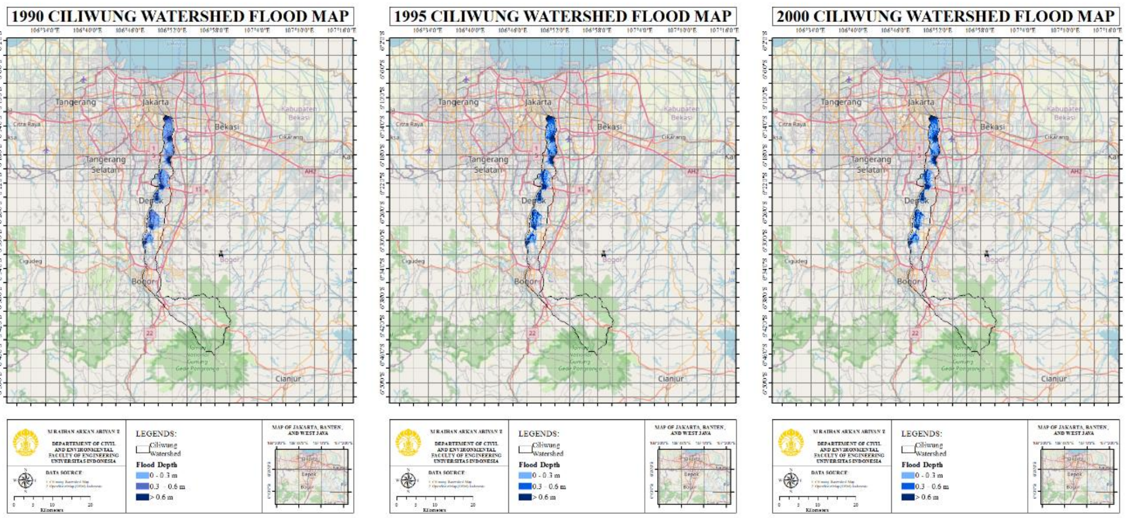
Table 6 Comparison of NSE and Regression Coefficient

Method	Before Calibration		Calibrated	
	NSE	Regression	NSE	Regression
Kinematic Wave	0.43	0.82	0.93	0.99

The improved NSE value of 0.93 and regression coefficient of 0.99 post-calibration indicate the effectiveness of the Kinematic Wave method in hydrological modeling. With its complex parameterization, this method results in outputs that closely represent real-world conditions, demonstrating its suitability in hydraulic modeling.

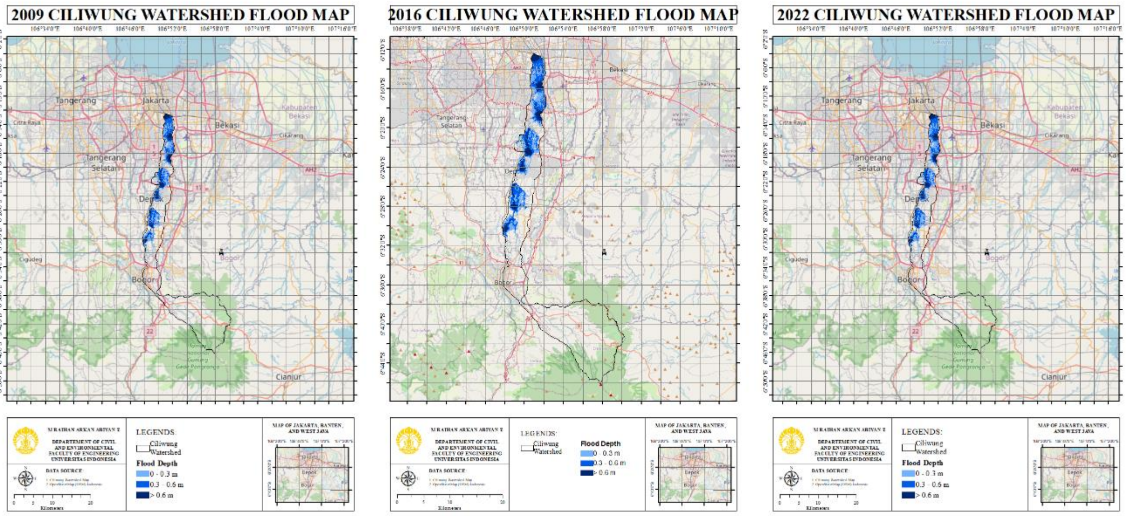
4.5. Hydraulics Model of HEC-RAS

This section discusses the hydraulic modeling results using HEC-RAS, complemented by RAS Mapper, for visualizing inundation in the Ciliwung watershed. The model relies on discharge data from the HEC-HMS Kinematic Wave routing method, focusing on a 50-year rainfall return period (Q50) scenario. The focal point of the analysis lies in the creation of detailed inundation maps by HEC-RAS, utilizing Digital Elevation Model (DEM) data. These inundation maps, showcased in Figure 7, offer a visual representation of flooding patterns across the watershed at various time points.



(a) (b) (c)

Figure 7. Ciliwung Watershed Flood Area Changes (a) 1990, (b) 1995, (c) 2000



(d) (e) (f)

Figure 7. Ciliwung Watershed Flood Area Changes (d) 2009, (e) 2016, and (f) 2022

Flood Depth and Area Changes: Table 7 detailing the inundation areas categorized by different flood depths from 1990 to 2022 presents the changes in flood depth and the inundation area over the years. These changes highlight the evolving nature of flood risks within the watershed.

Table 7 Changes of Flood Depth and Flood Area of Ciliwung Watersheds

Scenarios	Inundation Area (km^2)			Total Area (km^2)
	Depth of 0 – 0.3 (m)	Depth of 0.3 – 0.6 (m)	Depth of > 0.6 (m)	
1990 Q50	22.229	18.163	11.156	51.548
1995 Q50	23.221	18.769	11.773	53.763
2000 Q50	24.466	19.238	12.295	56.0
2009 Q50	27.092	25.768	12.672	65.532
2016 Q50	28.689	27.380	13.634	69.703
2022 Q50	28.935	27.399	14.114	70.449

The results of the flood area trend analysis in Figure 8, showing a graph of the total flood area from 1990 to 2022, emphasizes the increasing trend in inundation. Notably, the inundation area expanded from 51.548 km² in 1990 to 70.449 km² in 2022.

The observed increase in flood discharge and corresponding inundation areas from 1990 to 2022 is significant. It indicates that changes in flood flow discharge are pivotal in exacerbating inundation within the watershed. The influence of land cover changes, particularly the Curve Number (CN) parameter, is evident. The progressive increase in built-up land and reduction in green spaces, especially in the urban areas of Central to Lower Ciliwung, exacerbates flooding. Flat topography also contributes to the extent of inundation in these areas.

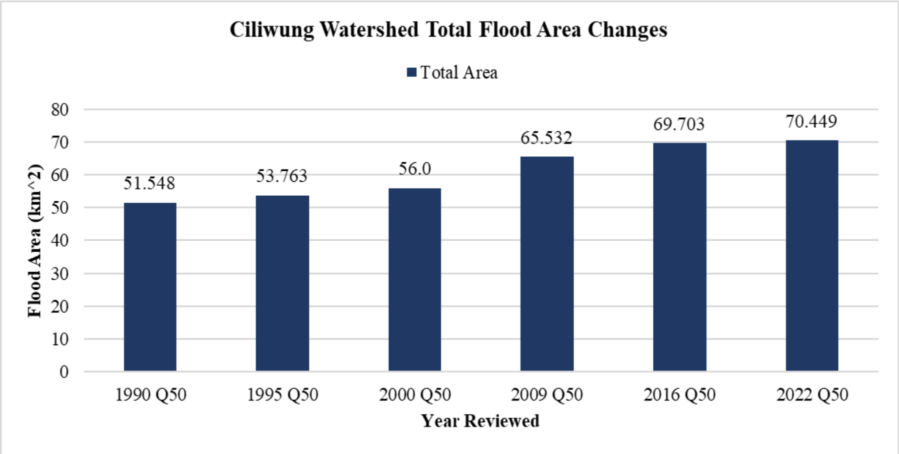


Figure 8. Graph of Total Flood Area in Ciliwung Watersheds from 1990 to 2022

For the historical inundation mapping, a close correlation was observed by comparing the inundation points from this study (Figure 7) with historical flood data for the Jakarta area (Figure 9). This comparison underscores the study's relevance and accuracy in capturing flood patterns in the Ciliwung watershed.

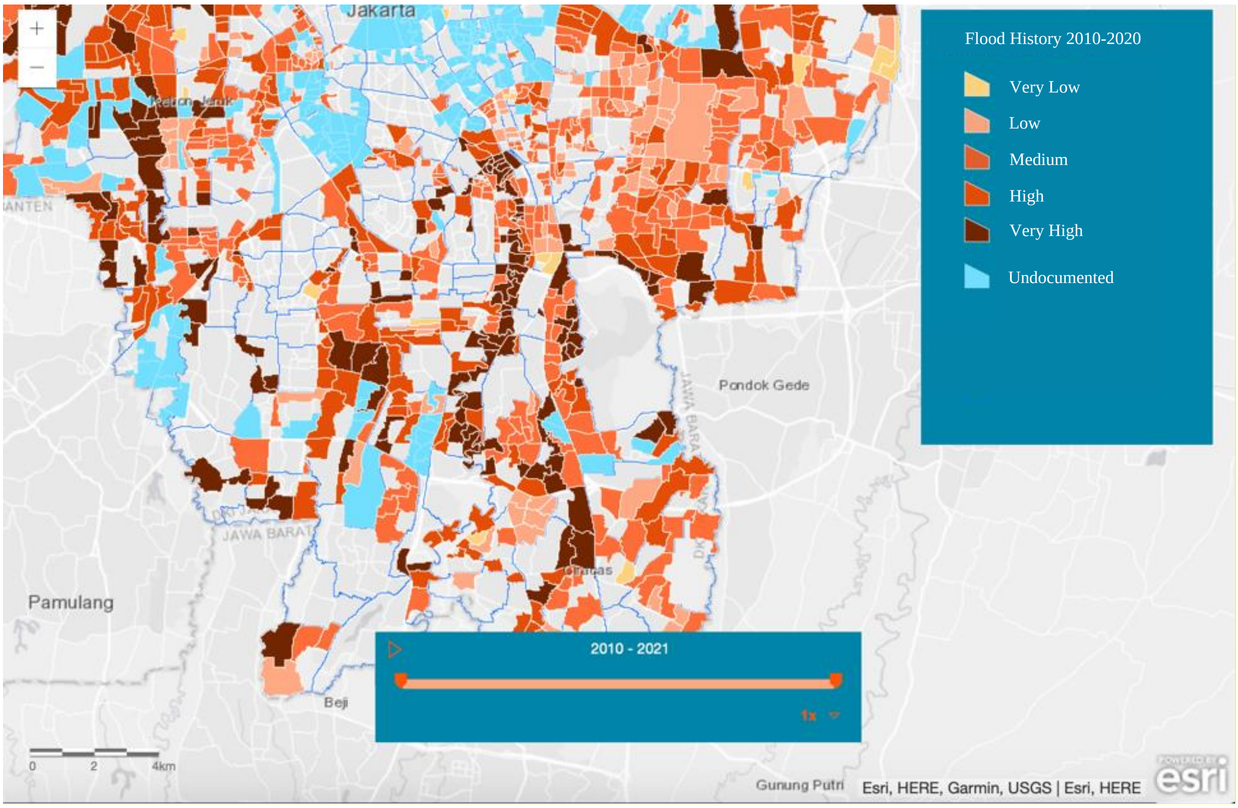


Figure 9. Historical Inundation Map of Jakarta Area

5. CONCLUSION

This study comprehensively analyzed the impact of land cover changes in the Ciliwung watershed from 1990 to 2022. Notable findings include a significant transformation in the land cover, particularly in the built-up land, which exhibited an increase of 23.04%. Concurrently, there was a marked decrease in green open spaces by 35.85%. These changes directly influenced the hydrological dynamics of the watershed. The flow discharge model, validated using the Nash-Sutcliffe Efficiency (NSE) and Linear Regression methods, demonstrated high accuracy with NSE and regression values of 0.93 and 0.99, respectively. These results were achieved using the Kinematic Wave method, validating the model's effectiveness in simulating flood scenarios.

There are two key observations found in this the study. Firstly, a progressive increase in the depth and area of inundation from 1990 to 2022 is linked to the rising flood flow discharge each year. This trend is attributed to the ongoing land cover changes within the watershed. Secondly, the inundation predominantly affects the middle to downstream areas of the Ciliwung watershed. The extent of inundation escalated from 51.548 km² in 1990 to 70.449 km² in 2022. Most inundation occurred at depths ranging from 0 to 0.3 meters.

Overall, the study underscores the significant impact of urbanization and land cover changes on the hydrological behavior of the Ciliwung watershed. The increasing trend in built-up areas, coupled with the reduction in green spaces, has led to heightened flood risks, particularly in the more urbanized downstream segments of the watershed. These findings highlight the need for sustainable urban planning and effective water management strategies to mitigate future flood risks in the region.

6. ACKNOWLEDGEMENT

The Author would like to acknowledge the University of Indonesia for their assistance in this research, BBWS Ciliwung-Cisadane, BMKG, and all those who have provided data for this research, as well as my advisor, Evi Anggraheni, who has assisted in writing this research paper and Dadang Muhamad Yahya who facilitate the data sources for this research.

REFERENCES

Abay, F. M. J., & Haryanto, Y. D. (2021). Analisis Dinamika Atmosfer Dan Distribusi Awan Konvektif Menggunakan Teknik Red Green Blue (RGB) Pada Citra Satelit Himawari-8: Studi Kasus Banjir Jakarta 30 Desember 2019 - 1 Januari 2020. *Megasains*, *12*(1), 34–39.

Amalia, & Wesli. (2015). Penelusuran Banjir Menggunakan Metode Level Pool Routing pada Waduk Kota Lhokseumawe. *Teras Jurnal*, *5*(1).

BPDAS Ciliwung-Citarum. (2007). *Kelembagaan Kegiatan Bidang RLPS di Wilayah Kerja BP DAS Citarum-Ciliwung*.

Chow, V. Te, Maidment, D. R., & Mays, L. W. (1988). *Applied Hydrology*. McGraw-Hill.

Eni, S. P. (2015). *Kebutuhan Ruang Terbuka Hijau Kota Jakarta*. *3*(1).

Harahap, I. H. (2021). Analisis Ketersediaan Ruang Terbuka Hijau dan Dampaknya Bagi Warga Kota DKI Jakarta. *Journal of Entrepreneurship, Management, and Industry (JEMI)*, *4*(1), 18–24.

Kementerian PUPR. (2018). Analisis Hidrologi dan Sedimen. In *Modul Pelatihan Perencanaan Bangunan Sabo Tahun 2018* (Modul 3).

Maryono, A. (2020). *Menangani Banjir, Kekeringan, dan Lingkungan*. UGM Press.

Motovilov, Y. G., Gottschalk, L., Engeland, K., & Rodhe, A. (1999). Validation of a Distributed Hydrological Model Against Spatial Observations. *Agricultural and Forest Meteorology*, 255–277.

Nasjono, J. K. (2018). Keandalan Metode Soil Curve Conservation Services-Curve Number untuk Perhitungan Debit Puncak pada DAS Manikin. In *Jurnal Teknik Sipil: Vol. VII* (Issue 2).

Potter, M. C., Wiggert, D. C., Lemeda, S. (2011). *Mekanika Fluida*. Jakarta. Erlangga. ISBN 978-979-075-888-9.

Purwanti, H., & Pontiawaty, I. (2013). Manajemen Risiko pada Pengendalian Banjir di Sungai Ciliwung. *Jurnal Teknologi*, *1*, 21–32.

Rachim, D. K. N., Firdaus, A., & Saputro, A. G. W. (2022). Analysis of the Impact of Population Growth in DKI Jakarta Using Logistic Model. *Jurnal Pendidikan Matematika (Kudus)*, *5*(1), 69. https://doi.org/10.21043/jpmk.v5i1.14276

Suhartanto, E., Cahya, E. N., & Maknum, L. (2019). Analisa Limpasan Berdasarkan Curah Hujan Menggunakan Model Artificial Neural Network (ANN) Di Sub DAS Brantas Hulu. *Jurnal Teknik Pengairan*, *10*(2), 134–144.

Taryana, A., Rifa, M., Mahmudi, E., & Bekti, H. (2022). Analisis Kesiapsiagaan Bencana Banjir di Jakarta. In *Jurnal Administrasi Negara), Februari* (Vol. 13).

Trisakti, B., Teguh, K., & Susanto. (2008). Kajian Distribusi Debit Aliran Permukaan di Daerah Aliran Sungai (DAS) Berbasis Data Satelit Pengideraan Jauh. *Jurnal Penginderaan Jauh*, *5*, 45–55.

Widyaiswara, E. (2020). Analisis Penyebab Banjir Di DKI Jakarta. *Jurnal Inovasi Penelitian*, *1*(6).

Zhao, K., Fang, K., & Yang, M. (2017). *Analysing for Measuring Characteristics of Nash-Sutcliffe*. 355–359.