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Original research article

Prediction of changes in land use/land cover and hydrological response in the upper Ciliwung Watershed

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A R T I C L E I N F O

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A B S T R A C T

As a result of rapid urbanization, in 2021, it was recorded that the forest area in the Upper Ciliwung Watershed was only a quarter of the total area. Therefore, the watershed cannot optimally perform its hydrological functions. This research aimed to consider the adequacy of the forest area in the watershed and estimate the discharge and volume of water related to changes in land use in the future. Thus, it is hoped that data will be available to support the formulation of appropriate policies to improve the hydrological conditions in this watershed. The spatial-temporal dynamics of LULC and its hydrological response were estimated using an integrated approach that combines remote sensing, Cellular Automata-Markov Chain based on Multi-Layer Perceptron, and an HEC-HMS modeling system. Multitemporal satellite imagery is used to understand LULC changes and projections for 2031 and 2051. The analysis shows that in 2001-2051, the forest area experienced the worst decline, 22,423,493 m2. Meanwhile, the developed area experienced a significant increase of 49,771,952 m2. This changing pattern has a negative impact on hydrological characteristics. Hydrological modeling shows that the volume and discharge are projected to increase drastically to reach 258.61 x 106 m3 and 26.3 m3/s, respectively, in 2051.

1. Introduction

The Ciliwung watershed is included in the 15 priority watersheds set by the government of the Republic of Indonesia [1]. This watershed consists of three essential parts: the upstream, middle stream and downstream [2]. In 2021, at least 4,000 hectares of forest area remained in the upstream part of the watershed. 50% of which are conservation areas, and the other half are production forests. Nonetheless, the total forest area is only a quarter of the area of the Upper Ciliwung watershed, and only a tiny part of the entire Ciliwung watershed continues to be affected by urbanization [3], [4].

Referring to laws and regulations, the area is not in accordance with the provisions of Article 18 (2) of Law Number 41 of 1999 on Forestry, which states that the area of forest that must be maintained is at least 30% of the total area of the watershed.

There are several reasons underlying the determination of the minimum forest area limit of 30%; one of the most important is to support the protection function [5]. However, the minimum area limit is still being debated, and many even think this figure is no longer relevant to current conditions [6]. Despite the differences of opinion and controversy, this article was later abolished, replaced with a policy stating that the forest area of each watershed would be determined further by the Minister of Environment and Forestry based on several criteria for the physical and geographical conditions of the watershed and islands [7], [8].

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Interestingly, the article was abolished amid the many studies that have revealed that in recent decades the hydrological condition of the Upper Ciliwung watershed has continued to decline [9]–[14]. One of the leading causes is the conversion of the land cover into non-forest areas, settlements, plantations, and tourist areas, which continue to grow from time to time [11]–[13]. The condition is a significant threat to the entire Ciliwung watershed, especially to the Jakarta area located downstream .

For instance, from 2000-2009, the conversion of vegetated land into a developed area of 50 km^2 in the Ciliwung watershed, or the equivalent of 7,100 football fields, is indicated to be one of the causes of flooding in Jakarta because these conditions can produce runoff volumes that are 17 times the volume of the Gelora Bung Karno's stadium with rain intensity for 7 hours [15]. The studies mentioned above clearly show how vital the existence of forests in the upstream region is for the entire Ciliwung watershed. Therefore, it is necessary to protect the existence of forests in this watershed [11]. One of the protective steps that can be taken is to review policies to be optimised for maintaining the existing forest area [5]. To support this, it is possible to simulate the existing forests in maintaining hydrological conditions amidst the massive rate of urbanisation. This step will involve analysing land change over the years in the Upper Ciliwung watershed. Many researchers have analysed land use change to observe the hydrological response in the Ciliwung or Upper Ciliwung watershed [2], [14], [16]–[19]. However, only a few have observed the hydrology response of future land changes [11], [20] and observed this relationship using integrated modelling such as CLUE-S [13]. Moreover, research has yet to be conducted in this watershed using hybrid modelling, such as the Land Change Modeler (LCM). Therefore, this study was conducted to fill this gap by estimating future land changes using this method.

One indicator of a decrease in hydrological conditions due to changes in land use is an increase in water discharge and volume from time to time which can be estimated through empirical equations [18]. Nonetheless, this study is not only limited to estimating discharge and water volume but also tries to answer several aspects, such as the trend of land use changes in the Upper Ciliwung watershed in the last few decades and the future; and how significant the impact is in maintaining the existing forest area in minimising the risk of future disasters occurring due to the high pace of development.

By taking advantage of the rapid development of technology, these steps can be taken in an integrated manner using several modelling applications on computer systems. As previously mentioned, the prediction of land use change is analyzed through spatial-based modelling, the Land Change Modeler (LCM) [21], which is integrated into the TerrSet Geospatial Modeling and Monitoring System version 2020. Meanwhile, hydrological models that can integrate various methods in dendritic watershed systems [22], HEC-HMS [23], were used to simulate rainfall-runoff using projected climate and land use data [11]. With this method, information will be available regarding the factual relationship between changes in land use and the volume of water discharge as well as projected rates of change in land use in the future and their hydrological response. In addition, this research is expected to provide a different perspective on the management of development in the Upper Ciliwung Watershed in the future, provide consideration for calculating the adequacy of forest area and cover in the Upper Ciliwung Watershed, contribute to disaster mitigation, assist in realizing ecosystem sustainability and harmony, and can be useful in sustainably managing natural resources.

2. Material and Methods

2.1 Study Area

The study was conducted in the Ciliwung Hulu watershed in Bogor District, West Java Province, Indonesia. Geographically, the watershed is located at 6° 37' 30.58" - 6° 46' 7.24" S and 106° 50' 12.93" - 107° 0' 15.61" E with an area of 14,992.2951 hectares. The Ciliwung Hulu watershed is an essential and inseparable part located upstream from one of the priority watersheds in Indonesia, namely the Ciliwung watershed, with a 117-kilometre-long main river [24] that flows through Jakarta to Jakarta Bay on the north side of Java Island. The Upper Ciliwung Watershed's location can be seen in Figure 1.

Fig 1. The location of the Upper Ciliwung watershed and rain stations used in the study.

2.2 Data and Materials

The following are the data and materials used in the study:

2.2.1. Satellite Imagery and Maps.

The satellite images and maps used in this study are described as follows:

- Landsat 7 ETM+ Path 122, Row 65 for 2001, 2011 and 2021
- High-resolution satellite imageries (Google and Bing)
- DEM ASTER and SRTM with 30-meter spatial resolution
- National DEM with a spatial resolution of 0.27-arcsecond
- Topographic Map of Indonesia, scale 1: 25,000
- Upper Ciliwung Watershed boundary map
- Land unit, soil, road, river stream and slope maps
- Map of the 2011-2030 National Level Forestry Plan
- Administrative region map
- Rain station map

2.2.2 Hydrological Data.

All data used in this study was collected systematically to correlate land change with peak discharge through calibrated and validated data. This study uses daily rainfall data from the Gunung Mas, Cilember and Gadog rain stations and data on the water level at the Katulampa Dam in 2011 and 2020 obtained from the Ciliwung Cisadane River Basin Center. In addition, rain data from the Citeko rain station managed by the Meteorology, Climatology and Geophysics Agency are also used over the same year. The distribution of rain stations in the study location can be seen in Figure 1.

2.2.3. Software.

The software used in analyzing the data above includes QGIS version 3.22.9, ArcGIS Desktop version 10.8, TerrSet Geospatial Monitoring and Modeling System version 2020, and HEC-HMS version 4.9.

2.3 Study Stages

This study was carried out through the following stages:

2.3.1. Spatial Data Preparation.

This stage begins with procuring satellite imagery and the Digital Elevation Model (DEM), followed by basic image processing such as geometric and radiometric corrections. The watershed boundary of the Upper Ciliwung and its sub-watershed was determined using the DEM data. The determination of these limits was done by utilizing the HEC-HMS software. This watershed boundary map was then used as a basis for further spatial data processing.

2.3.2. Generating Land Use/ Land Cover Maps.

Land use/ land cover (LULC) maps in this study were made using the IDRSI Image Processing software integrated into the TerrSet Geospatial Monitoring and Modelling System version 2020. This study used one of the supervised classification methods, maximum likelihood. The supervised maximum likelihood classification is a classification that is guided by the pixel values that have been categorized as objects or made in training samples for each land cover object. The method is one of the most widely applied due to a simple and mature algorithm and a slight possibility of misclassification so that it can be used for land use and land cover analysis [25], [26].

2.3.3. Land Cover Change Prediction.

Changes in LULC were simulated using the Cellular Automata Markov (CA Markov) method, a combination of Cellular Automata and Markov Chain [27]. This methodwas combined with the machine learning method by utilising the reliability of the Terrset 2020 software [27], [28]. Several software was used to model land change, which was integrated into Terrset 2020: IDRISI GIS Analysis, IDRISI Image Processing and Land Change Modeler.

The maps used in this study are land use maps in the Upper Ciliwung watershed in 2001, 2011 and 2021. The maps were processed from Satellite Imagery through the IDRISI Image Processing software and validated using the QGIS open-source software. The 2001 and 2011 land use maps were the basis for future land use changes. The projected land use map for 2021 was generated by analysing the two maps. Then the 2021 land use projection map was validated with the actual 2021 land use map. Validation is done by calculating the Relative (or Receiver) Operating Characteristic (ROC) in the IDRISI GIS Analysis software, integrated with TerrSet 2020. ROC provides a measure of the correspondence between quantitative model images, which indicate the possibility that a particular class exists, and Boolean images of that class [29]. The range of ROC values is 0-1; the closer the value is to 1, the better.

Once the validation values between the two maps were acceptable, future land use projections (2031 and 2051) were made by modifying various parameters. The important aspect that needs to be emphasised here is that this study solely predicted land use in 2031 and 2051, focusing on changes in developed and forest areas. Modelling of changes in land cover was carried out by involving some variables or driver factors such as 1) Development pattern and direction of developed area, 2) Road network, 3) River network, 4) Forest, 5) Elevation, 6) Slopes, and 7) Development plan.

2.3.4. Regional Rainfall Analysis.

The rainfall used in this study was obtained from four rain stations spread across the Upper Ciliwung watershed, namely the Gadog, Cilember, Citeko and Gunung Mas rain stations. The four rain stations represent the elevation of thestudy area. The data used as input for modelling using the HEC-HMS are for 2011 and 2020. Rainfall data from the four rain stations were processed using the Thiessen polygon to determine regional rainfall [30].

2.3.5. Determination of Soil Hydrologic Groups and SCS Curve Number.

Determination of soil hydrological groups (SHG) can be done using several approaches, such as soil texture analysis, minimum infiltration rate and detailed soil maps [31]. However, making the SHG map in this study also involved previous research data at the exact location [14]. The map was adopted from the 1:50,000 scale land unit map issued by the Centre for Soil and Agro-climate Studies in 1992.

The hydrological analysis used in estimating runoff is the SCS Curve Number. This method aims to relate the characteristics of a watershed, such as soil, vegetation, and land use, with runoff curve numbers (CN) which indicate the potential for runoff for particular rainfall [32].

The CN method is based on the infiltration relationship of each soil type to rainfall. Curve numbers are obtained from SHG maps and land use maps based on the Antecedent Moisture Condition (AMC). SHG maps, land use maps and sub-watershed boundary maps are overlayed to determine CN in AMC II conditions. The value of the Curve Number for AMC II for each type of land use is determined by referring to the CN table issued by the United States Army Corps of Engineers.

The CN value in AMC I and AMC III can be determined by converting the CN value in AMC II using the following equation [33]:

$$CN_I = \frac{4.2\ CN_{II}}{10 - 0.058\ CN_{II}} \tag{1}$$

And

$$CN_{III} = \frac{23\ CN_{II}}{10 - 0.13\ CN_{II}} \tag{2}$$

The determined CN value is the basis for determining the maximum retention potential (S) and initial abstraction (Ia) through the following equation [31]:

$$S = \frac{25{,}400}{CN} - 254 \tag{3}$$

And

$$I_a = 0.2\ S \tag{4}$$

These values are then used to estimate runoff volume (Q) involving rainfall (P) through the following equation:

$$Q = \frac{(P - 0.2\ S)^2}{(P + 0.8\ S)} \tag{5}$$

2.3.6. Discharge and Water Volume Estimation.

HEC-HMS (Hydrologic Engineering Centre-Hydrologic Modelling System) software version 4.9 is the primary tool used for estimating discharge and water volume in the study area. This estimation process involves several stages: basin modelling, inputting hydrological data, meteorological modelling, developing a control model, and calibration and validation.

The development of the hydrological model was carried out by involving rainfall data and other data in 011. The discharge data from the modelling results were then calibrated with the observed discharge data for 2011. Calibration was carried out manually by modifying parameter values sensitive to flow rate. These parameters were CN values, baseflow, and K and X constants in the Muskingum method. This process was carried out repeatedly to obtain ideal and acceptable results. The calibration metrics used in this study are The Nash-Sutcliffe efficiency (NSE), Root Mean Square Error (RMSE), and the coefficient of determination (denoted as R2). These calibration metrics are the most commonly used statistical performance measures [34], [35]. The assessment of the performance of each metric used in this study refers to the study of Moriasi et al., (2015) [34].

Once the resulting calibration value was acceptable, the validation process was carried out. Validation was carried out using daily discharge data for one year in 2020. Validation was carried out using calibrated parameter values to compare the data with observational data. Once the validation. value was acceptable, the built model was used to predict water discharge and volume for 2031 and 2051.

3. Result and Discussion

3.1 The Upper Ciliwung Hulu Watershed

The Upper Ciliwung watershed stretches from an altitude of 343 to 2,988 MASL. The highest point of this region is in the Mount Gede Pangrango National Park. Forest areas and conservation forests dominate areas above 2,000 MASL. While areas below an altitude of 2,000 are cultivation areas. This area reaches 93.95 % of the total area of the Upper Ciliwung Watershed. The slope class > 40 % dominates this area with a percentage of 23.66 % of the total study area. In contrast, the slope class of 0-8 % is the least, with 14.05 %.

The development in the study area continues to strengthen along with the increasing number of residents and tourists to this region. These pressures lead to the negative exponential growth of natural resources. Population density increases the need for land for residence, life support facilities, industry, and so forth. This impacts land conversion from land that can absorb water to impermeable land. The population in the study area increased from 245 thousand people in 2010 to 278 people in 2020. With this growth rate, it is predicted that there will be 421 thousand people living in the Upper Ciliwung watershed area in 2051.

3.2 Land Use Prediction

3.2.1. Land Use in the Upper Ciliwung Watershed.

This study divided LULC into four types: forest, cultivated area, bare surface, and developed area. Visually, the area and transformation of each type of LULC can be seen in Figure 2 and numerically referred to in Table 1.

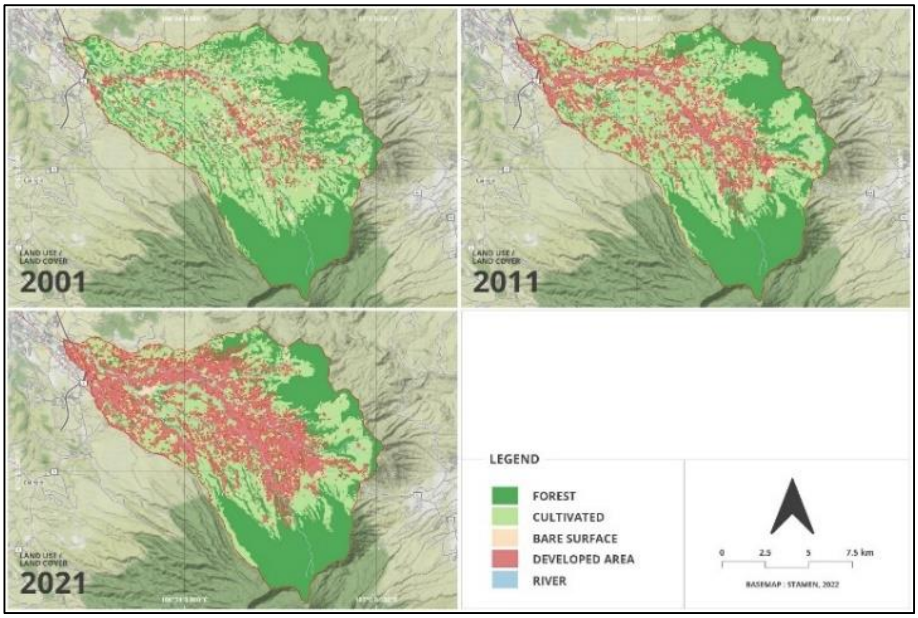


Fig 2. The map of LULC changes in the Upper Ciliwung watershed for 2001, 2011 and 2021.

Table 1
Comparison of the area of each land use type for 2001, 2011 and 2021.

Class ID	LULC	2001		2011		2021	
		Area (m2)	%	Area (m2)	%	Area (m2)	%
1	Forest	64,473,785	43.00	53,567,519	35.73	49,852,395	33.25
2	Cultivated	68,294,124	45.55	69,256,270	46.19	59,724,470	39.84
3	Bare Surface	10,909,090	7.28	7,040,404	4.70	4,245,167	2.83
4	Developed	6,245,952	4.17	20,058,758	13.38	36,100,919	24.08
	Total	149,922,951	100	149,922,951	100	149,922,951	100

The table shows that from 2001 - 2021 there was a reduction in the area of almost all types of land use except for developed areas. The forest area is the most degraded, having decreased by 14,621,390 m^2 in the last two decades. However, in terms of percentage, the bare surface has the highest percentage reduction in area, with 61.09 %, followed by forest and cultivated area, with 22.68 % and 12.55 %, respectively. In contrast, the developed area has increased by 477.99 % from 6,245,952 m^2 in 2001 to 36,100,919 m^2 in 2021.

3.2.2. The Changes in LULC.

The analysis shows that the changes in Ciliwung Hulu in a decade were genuinely dynamic. However, there was persistence for each type of LULC. The area of forest that could be maintained in this period was 45,491,020 m^2, while the cultivated area was 49,074,425 m^2. Of the forest area, 20,637,716.88 m^2 was used as a conservation forest, including national parks, nature reserves and nature tourism parks. Meanwhile, another 20,190,754.84 m^2 was used as production forests.

The most striking change was the massive change from forest to cultivated areas. Analysis shows that the extent of this type of transition reaches 14,703,890 m^2. Apart from these types of transitions, the transition from cultivated area to developed area was also indicated to be relatively massive, with a total area of 8,114,404 m^2.

Developed areas experienced the most significant increase percentage in terms of land transition. In 2001-2011, the percentage of transition from all LULC types to developed areas was 221.15 %. Whereas in 2011-2021, the transition of all LULC types to developed areas increased to 256.84 %. Thus, the total increase in the developed area in the last two decades was 477.99 %, as shown in Table 1. The LULC transition for 2001-2011 can refer to in Table 2.

Table 2
The transition of each LULC type to another.

ID	Transition		Area (m2)
1		Forest to Forest	45,491,020
2		Cultivated to Forest	7,349,728
3		Bare Surface to Forest	663,186
4		Developed to Forest	26,082
5		Forest to Cultivated	14,703,890
6		Cultivated to Cultivated	49,074,425
7		Bare Surface to Cultivated	4,794,811
8		Developed to Cultivated	708,183
9		Forest to Bare Surface	1,278,010

ID	Transition		Area (m2)
10		Cultivated to Bare Surface	3,777,708
11		Bare Surface to Bare Surface	1,740,159
12		Developed to Bare Surface	246,826
13		Forest to Developed	3,042,011
14		Cultivated to Developed	8,114,404
15		Bare Surface to Developed	3,715,644
16		Developed to Developed	5,196,864
Total			149,922,951

3.2.3. Determinant of Land Use Change.

The dynamics of changes in land use can occur due to several dominant factors influencing it. Factors driving these land changes may include population pressure and economic, technological, institutional, cultural, and biophysical factors. However, in reality, often, these factors cannot be mapped, modelled or predicted.

Even though the factors that influence change are very complex to describe in a mathematical algorithm, several approaches can be taken. One approach that can be taken is to utilize the Multi-Layer Perceptron (MLP) method and remote sensing technology, which have continued to progress in the last few decades [26]–[28], [36]. In the process, the relationship between driving factors was calculated to produce opportunities for the emergence of specific land use types. In this study, the driving factors used were the pattern of land change trends from one type of land to another, the direction of urban expansion, distance from roads, distance from rivers, elevation, slope, and the existence of conservation areas.

3.2.4. Land Use Change Modelling.

Several essential stages were used in the modelling: First, a simulation was run to model the 2021 LULC map. Second, the 2021 LULC modelling was based on changes in land use in 2001-2011 combined with the factors influencing land use changes. Third, the modelling was run based on the transition probability matrix, as shown in Table 3. Lastly, the simulated 2021 LULC map was compared with the actual 2021 LULC map to test the model's validity.

Table 3
Transition probability matrix.

LULC	Forest	Cultivated	Bare Surface	Developed Area
Forest	0.5236	0.3385	0.0316	0.1063
Cultivated	0.1584	0.5782	0.0554	0.208
Bare Surface	0.1052	0.438	0.0643	0.3925
Developed Area	0.0388	0.1962	0.0457	0.7193

Each combination of transition sub-models and several driving factors is run repeatedly to get ideal results. An example of the running of the transition sub-model process can be seen in Figure 3. Many experiments using the trial-and-error method were conducted to obtain high accuracy. One way is to change the number of hidden layer nodes and the learning rate. Thus, in the case of this study, the number of hidden layer nodes used differed in each transition sub-model used. This, of course, refers to the argumentation of Clark Labs (n.d.) [37], which states that the number of hidden layers (layer 1) nodes and the learning rate are the two most crucial parameters and influence the accuracy and skill measure.

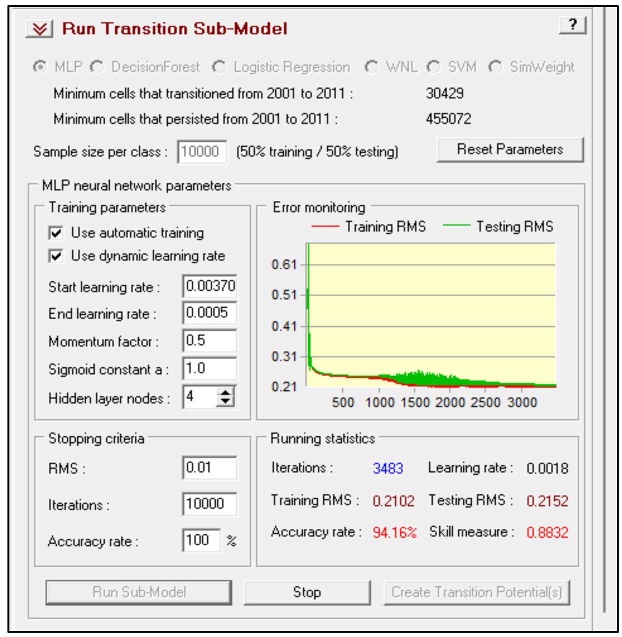


Fig 3. An example of the running of the transition sub-model process.

The next stage was to determine the number of changes that may occur at a time using the Markov Chain prediction process. The output of this stage was the LULC projection map for 2021, as shown in Figure 4.

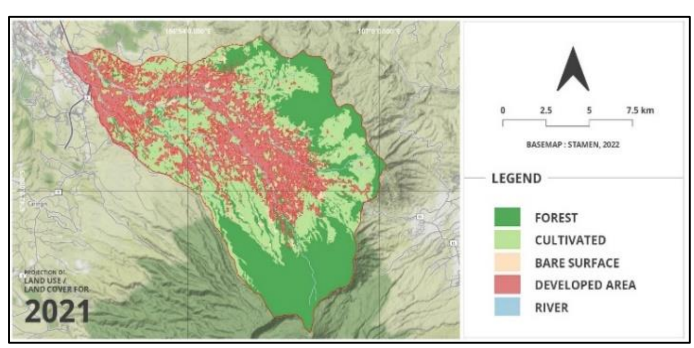


Fig 4. LULC projection map of the Upper Ciliwung watershed for 2021.

The projected 2021 LULC map was validated using the actual 2021 LULC map. The validation results using the Relative (or Receiver) Operating Characteristic (ROC) method show a value of 0.92. By referring to the value, the modelling meets the requirements to be continued the prediction process for the planned years. Besides using the ROC method, this study also calculates the difference in area between the simulated LULC and the reference (actual) LULC. This was done to provide a numerical result. The results of these calculations can be seen in Table 4.

Table 4
Comparison between the actual 2021 area and the predicted 2021 area.

Class ID	LULC	Area (m^2)		Diff.	%	Accuracy
		Actual	Projected			
1	Forest	49,852,395	51,043,910	1,191,515	2.39	97.61
2	Cultivated	59,724,470	61,027,983	1,303,513	2.18	97.82
3	Bare Surface	4,245,167	4,643,191	398,024	9.38	90.62
4	Developed Area	36,100,919	33,207,867	-2,893,052	-8.01	91.99

3.2.5. Future Land Use Projections.

The LULC maps for 2031 and 2051 can be seen in Figure 5. While the area coverage and percentage of area in the study area are provided in Figure 6.

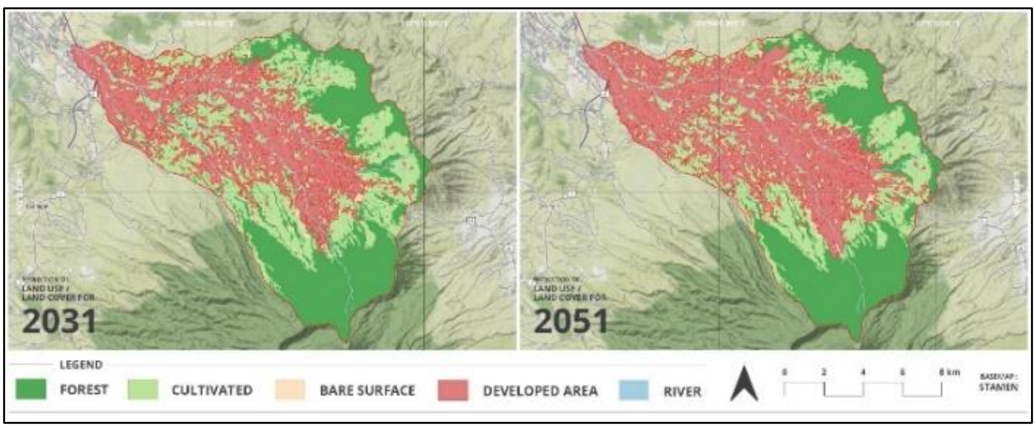
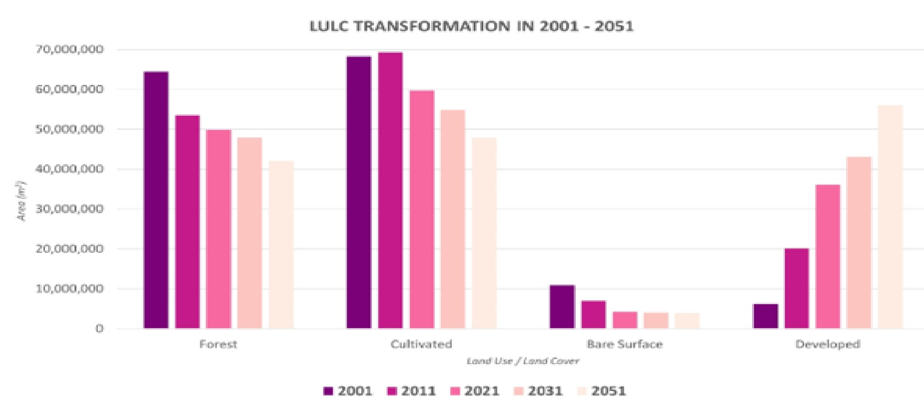


Fig 5. The map of the LULC projection in the Upper Ciliwung watershed in 2031 and 2051.



LULC	AREA									
	2001	%	2011	%	2021	%	2031	%	2051	%
Forest	64,473,785	43.00	53,567,519	35.73	49,852,395	33.25	47,872,033	31.93	42,050,292	28.05
Cultivated Area	68,294,124	45.55	69,256,270	46.19	59,724,470	39.84	54,848,862	36.58	47,888,020	31.94
Bare Surface	10,909,090	7.28	7,040,404	4.70	4,245,167	2.83	4,086,897	2.73	3,966,735	2.65
Developed Area	6,245,952	4.17	20,058,758	13.38	36,100,919	24.08	43,115,159	28.76	56,017,904	37.36
TOTAL	149,922,951	100	149,922,951	100	149,922,951	100	149,922,951	100	149,922,951	100

Fig 6. LULC transformation in 2001-2051.

Based on the table in Figure 6, it can be seen that the forest area, cultivated and bare surface, has decreased significantly in the area over the past 50 years. During this period, forest areas were identified as experiencing the most significant decline, with a total decrease of 22,423,493 m2, followed by cultivated and bare surface areas with 20,406,104 m2 and 6,942,355 m2, respectively. The only type of LULC that continues to climb is the developed area, from 6,245,952 m2 to 56,017,904 m2 in the middle of this century. In 2031-2051, it is predicted that there will be an increase in the developed area by 37.36 With this significant increase, the developed area will be predicted to become the LULC type that dominates the Upper Ciliwung watershed area in 2051. Replacing the cultivated area, which has always been the dominant use type in this area, at least until 2031.

The decline in the forest area to its lowest point in 2051 is due to the use of forestry policy assumptions (the Law Number 41 of 1999 on Forestry). The assumption is the permissibility of using forest areas for development purposes other than forestry activities. However, according to the law, the development permitted in modelling can only be carried out in production and protected forest areas. Figure 5 shows that in 2051, the forest cover in the north of the area will be converted into a developed area. Forests in these areas are currently being used as production forests. Therefore, in this study, the development is only assumed to occur in those areas. In comparison, the forest area in the East to South region will remain the same because, in this area, the forest area functions as a conservation forest.

3.3 Discharge and Water Volume Estimation

3.3.1. Regional Rainfall.

The determination of regional rainfall is estimated using the Thiessen polygon method. Rain data used in this study were obtained from four rain stations spread across the Upper Ciliwung watershed, namely Gunung Mas station (1,138 MASL), Cilember station (660) and Gadog station (463) operated by the Ministry of Public Works, and Citeko station. (982) managed by the Meteorology, Climatology and Geophysics Agency. Based on the method, it is estimated that the Gunung Mas Rain Station has a coverage area of 50,416,652.37 m^2 (or 33.63% of the total watershed area), Citeko with an area of 35,235,536.16 m^2. (23.50%), Cilember with an area of 39,151,350, 37 m^2 (26.11%), and Gadog with an area of 25,119,412.10 m^2 (16.76%). Visualization of the coverage area of each station can be seen in Figure 7.

3.3.2. Hydrological Characteristics.

The analysis of the hydrological characteristics used in estimating discharge was the SCS Curve Number. The curve number was determined based on soil properties, hydrological conditions, land treatment, land use and soil water content related to the antecedent rainfall for five days. The SHG map in the Upper Ciliwung watershed can be seen in Figure 8.

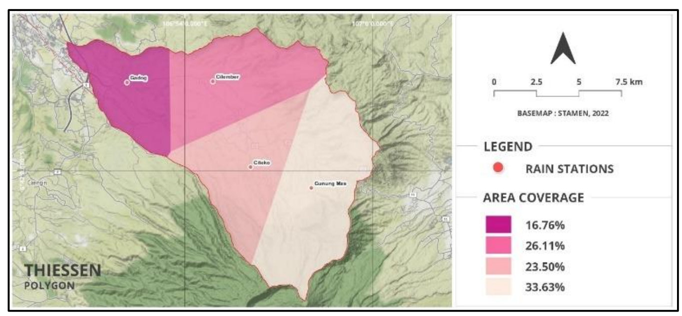


Fig 7. The coverage area for each rain station.

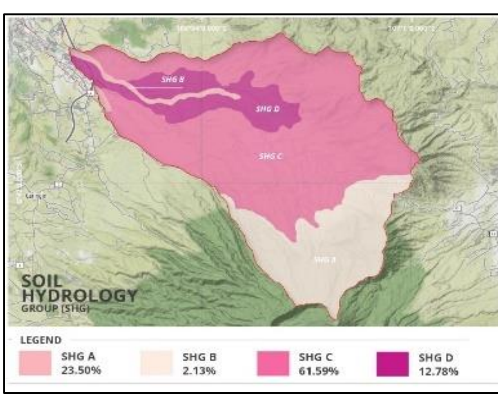


Fig 8. Distribution of soil hydrologic groups in the Upper Ciliwung watershed.

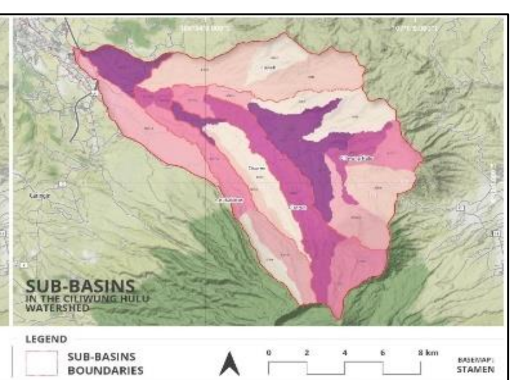


Fig 9. Map of the distribution of sub-basins and sub-sub basins based on the HEC-HMS modeling system.

The SHG map, as shown in Figure 8, the LULC map (Figures 2 and 5) and the sub-sub basin boundary map (Figure 9) delineated using HEC-HMS were overlayed to determine CN in AMC II conditions. The value of the curve number for AMC II for each type of land use was determined by referring to the CN table issued by the United States Army Corps of Engineers.

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Once the CN value was known, this value was then used to calculate the maximum retention potential (S) and Initial Abstraction (Ia). The process was continued by determining the Time of Concentration (Tc) and Lag Time. Tc and Lag Time were determined using the longest flow path length and basin slope information on the HEC-HMS and the previously known S value. The results of the calculation of the composite CN, S, Ia, Tc and Lag Time for 2011, 2021, 2031 and 2051 are provided in Appendix 1-4. The values describe the hydrological characteristics of the study area for the years studied.

3.3.3. Hydrological Modelling.

Regional rainfall data for 2011 was used as input in developing a hydrological model using the HEC-HMS. In this stage, the characteristic hydrological data used as input is shown in Appendix 1. This initial data was optimised later to get ideal results. Daily discharge data in the same year was used as the basis for calibration. If the calibration is acceptable, the built model will be validated with the characteristics and daily discharge of 2020. The input used in this stage is the 2020 regional rainfall data. The peak discharge data obtained from the observations of the Ministry of PUPR in 2011 shows the number 22.2 m^3/s with a volume of 225,2 x 10^6 m^3. In comparison, the simulation results show that the discharge volume in 2011 was 227.88 x 10^6 m^3 with a peak discharge of 19.1 m^3/s.

3.3.4. Calibration and Validation.

Calibration was carried out manually by modifying parameter values sensitive to flow rate. This process was carried out repeatedly to obtain ideal and acceptable results. A performance assessment of the calibration process is provided in Table 5.

Table 51
Assessment of the performance of the calibration process.

Measure	Scale	Output Response	Temporal scale	Result	Performance evaluation criteria
RMSE	Watershed	Flow	Daily	1.209	*
NSE	Watershed	Flow	Daily	0.815	Good
R^2	Watershed	Flow	Daily	0.829	Good

** The smaller the RMSE value, the more accurate the model is built.*

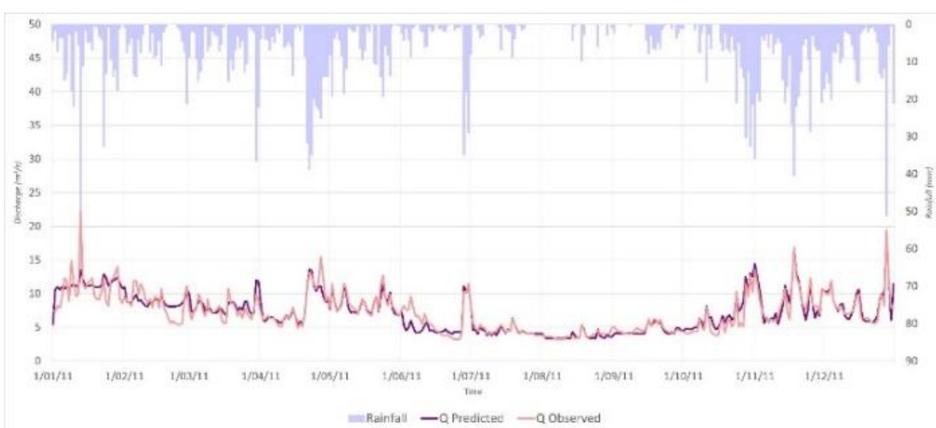

Fig 10. Hydrograph comparison of discharge data from model simulation results and observation discharge for one year in daily terms in 2011.

Validation was carried out using daily discharge data for one year in 2020. A performance assessment of the validation process is provided in Table 6.

Table 6
Assessment of the performance of the validation process.

Measure	Scale	Output Response	Temporal scale	Result	Performance evaluation criteria
RMSE	Watershed	Flow	Daily	2.706	*
NSE	Watershed	Flow	Daily	0.694	Satisfactory
R^2	Watershed	Flow	Daily	0.705	Satisfactory

** The smaller the RMSE value, the more accurate the model is built.*

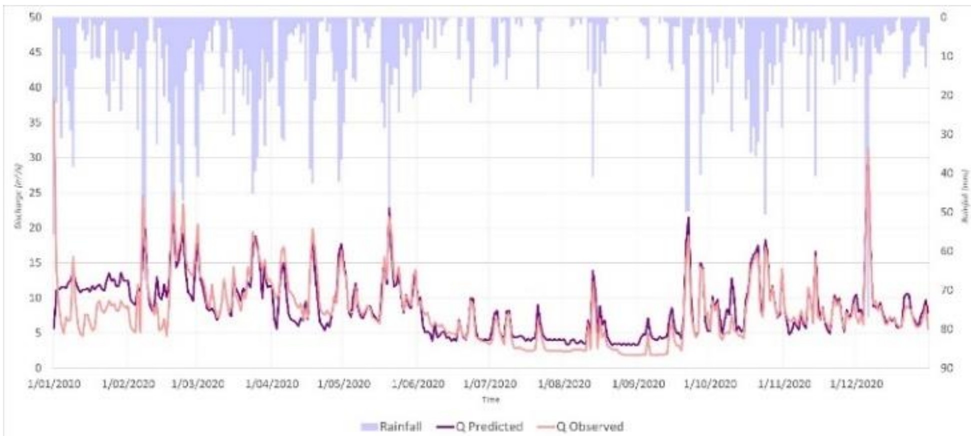

Fig 11. Hydrograph comparison of discharge data from model simulation results and observation discharge for one year in daily terms in 2020.

3.3.5. Discharge and Water Volume Projection in 2031 and 2051.

The simulation results show a significant volume and peak discharge increase, especially in 2051. The increase in water volume in 2031 is not too significant, with the projected volume of water at 228,47 x 10^6 m^3 with a peak discharge of 19.2 m^3/s. Nonetheless, a higher volume increase is projected to occur in 2051. That year, the water volume will reach 258,61 x 10^6 m^3 with a peak discharge of 26.3 m^3/s. The percentage increase in water volume in 2031-2051 is 13%.

3.4 Discussion

Land changes in the Upper Ciliwung watershed have detrimental effects on hydrological patterns. The changes that took place in the Upper Ciliwung watershed from the periods of 20 years (2001-2021) have been mapped. During this period, the forest area decreased drastically from 64,473,785 m^2 to 49,852,395 m^2. Over the years, the area had been converted into a relatively impermeable area because it was dominated by a densely developed area. Looking more detail at the table, in 2001, the developed area in this watershed had an area of less than 5 % of the total area. That year, this watershed was dominated by cultivated and forest areas scattered in almost all directions. However, 20 years later (2021), the area of the developed area has snowballed, making nearly a six-fold jump from its initial area size, so that it controls almost a quarter (24.08 %) of this watershed area.

The fast development of developed areas in the above period is a logical consequence of the increasing population in this region. In addition, this area is also a popular natural tourist destination.

An analysis involving several factors driving change shows that the developed area will continue to grow and become dominant in 2051. Meanwhile, forest and cultivated areas are projected to continue to decline. Nonetheless, it is projected that the decline in forest area in the 2031-2051 period will not be as dramatic as in the 2001-2021 period. This is because, in this study, it is assumed that the conservation forest area, which controls the highest elevations of this area, will mostly stay the same.

By knowing the above, it can be logically predicted that this watershed hydrological characteristic will move exponentially in a negative direction. To provide a numerical estimate, hydrological modelling was carried out using historical rainfall data against the projected LULC. This is done to predict the value of the increase that will occur.

The analysis shows that a significant water volume increase will be felt in 2051. The water volume will be 258.61 x 10^6 m^3 with a peak discharge of 26.3 m^3/s. The apparent reason is that many absorption areas have been converted into impermeable areas. Nicely exemplifying this point is the transformation of sub-sub basins with codes SCH12 and SCH23 (Figure 9). These areas are located in the Cipayung Village area, which has the highest population in the Megamendung District. These two areas are the largest runoff contributor areas in 2051 because they are dominated by developed areas (71.5 % for SCH23 and 77 %

for SCH12). On the other hand, this region's forest area is projected to completely disappear sometime between 2031-2051. Thus, in 2051, both will have a composite CN value above 89.

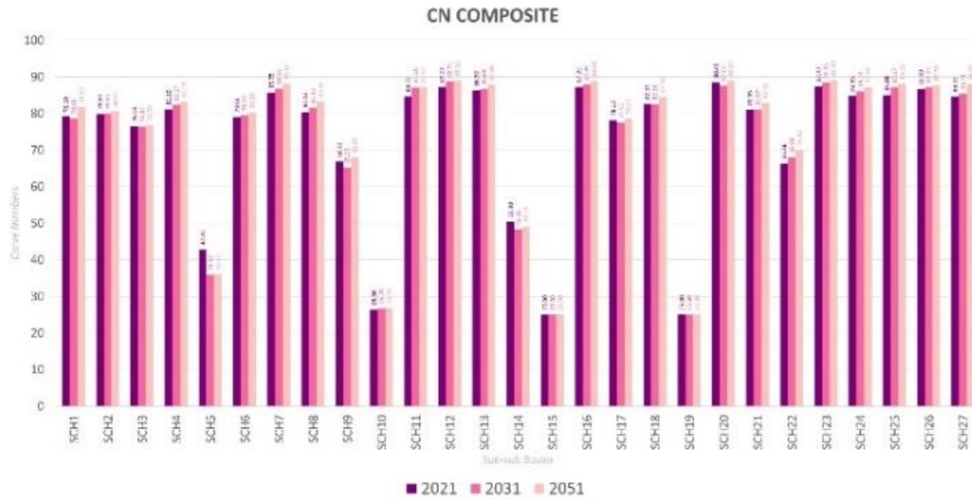

Fig 12. Comparison of the CN composite in 2021, 2031 and 2051.

Overall, this study yields composite CN values of 72.7, 73.0 and 74.2 on the watershed scale for 2021, 2031 and 2051, respectively. What is also interesting to highlight here is the increase in the value of the CN composite in 2031, which is insignificant compared to the CN value in 2021. This has a real effect on the predicted water volume and discharge. As a result, the increase in water volume in 2031 will also be insignificant.

The above is inseparable from the dynamics of LULC changes, which are projected to occur in 2031. Composite CN values in 2031 in most sub-sub basins have increased, except for the sub-sub basins with codes SCH1, SCH3, SCH5, SCH9, SCH14, SCH17, SCH 18 and SCH20, which decreased, as shown in Figure 12. It should be noted that most of these areas are located on or adjacent to conservation areas. The most significant decrease in CN values occurred in SCH5 areas adjacent to Mount Gede Pangrango National Park. From the perspective of conservation area management, this area is classified as a conservation area buffer zone. Having this argument, this area is given an ideal assumption, which is to be managed by integrating conservation interests and the community's economy to support the sustainability of conservation areas and to become a buffer in reducing development pressure. In this area, it is projected that there will be an additional forest area of 513.178 m2. The nascent forest area can dampen the projected addition of a developed area of 50 m2 in 2031 and 12,170 m2 in 2051, which is accompanied by the addition of a bare surface area of 436 m2. The same condition happened to the area with the SCH14 code. This area also acts as a buffer zone for the national park area. It is just that SCH14 is in the administrative area of Tugu Selatan Village, which has a high population and is projected to increase remarkably to 25,950 people in 2051. With these assumptions, the analysis results show that there will be fluctuations in forest area in the next three decades. In 2031, it is projected that the forest in this area will increase, but the number will continue to decrease until it reaches 3,758,320 m2 in 2051. On the other hand, the area of developed areas will continue to experience a significant increase over the next three decades.

Besides fluctuations in CN values, this study found that several sub-sub basins experience constant CN values. These areas are SCH10, SCH15 and SCH19, where 100 % of the area is in the Gunung Gede Pangrango National Park Area, which is assumed to be entirely forest.

The steepest increase in CN values in 2031 will occur in areas dominated by settlements and bare surfaces such as SCH7, SCH11 and more. In SCH11, it is projected that the forest area will completely disappear in 2031. On the other hand, the developed area in this region will continue to grow, like with SCH7, where the developed area is projected to dominate in 2051, replacing the dominance of the cultivated area. The absenteeism of forests will reduce the ability of these areas to regulate, store, support natural processes and provide clean water.

In the 2005-2025 Bogor Regency Regional Spatial Plan, it is implied that the management of this area is directed at ecological balance as a catchment and flood control area. However, according to Afifah (2010) [38], much spatial planning needs to be more consistent in this area. For the Cisarua sub-district, it was estimated that there was 1,742 ha of inconsistent land, with the most significant being in Tugu Utara Village [38]. The most extensive inconsistency occurs in a protected forest with an existing function as a tea plantation covering an area of 524 ha [38]. This inconsistency will gradually lead to an expansion of the impermeable area, which leads to an increase in water volume. This is in line with the results of this study, as evidenced by the transition map adopted from changes that occurred in the past. The highest transition trend in the

Upper Ciliwung watershed is transforming forest areas into cultivated areas, followed by transforming cultivated areas into developed areas. This shows that changing the function of a forest to a cultivated area will further stimulate the expansion of impervious areas, which in this study are represented by developed areas.

4. Conclusions and Recommendations

This study shows that there has been a very significant increase in the size of developed areas over the years. In contrast, the remaining LULC types experienced a decrease. In the period 2001-2051, forests experienced the most severe decline in area, namely 22,423,493 m^2. Meanwhile, the developed area during the same period experienced a significant increase of 49,771,952 m^2.

Rapid and massive LULC changes in the Upper Ciliwung watershed have detrimental effects on hydrological characteristics. Hydrological modelling shows that volume and discharge are projected to increase drastically to reach 258.61 x 10^6 m^3 and 26.3 m^3/s in 2051, respectively. The discharge as a watershed output stores information and characteristics of the watershed. Therefore, the predicted increase in discharge illustrates that the hydrological processes in this watershed are moving in a negative direction. This also shows that the area of forest areas and conservation areas is no longer able to reduce the hydrological impacts that occur due to population growth and rapid development.

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