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Analysis of the relationship between land use change and potential inundation rob in The Cipunagara River Basin using machine learning algorithms on google earth engine

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A B S T R A C T

Changes in land use in watersheds play a major role in the study of changes in tidal inundation. Land use is a form of human effort to change the environment into a stable environment such as agricultural land, roads, plantations, and settlements. The purpose of this study is the slope of the catchment area, changes in land use in 1996-2020, and the potential for tidal flooding due to changes in land use in the Cipunagara watershed. The method used is the analysis of satellite images available on the Google Earth Engine platform data cloud using machine learning algorithms. The results of the slope analysis in the Cipunagara watershed are divided into five classes, namely the flat category with an area of 52.67 km^2, the sloping category covering an area of 823.98 km^2, slightly steep covering an area of 226.79 km^2, steep covering an area of 126.02 km^2, and very steep covering an area of 74.96 km^2. Spatial changes in land use from 1996 to 2020, namely for open land/settlements decreased by -15% (-196.92 km^2), forest vegetation increased by +11% (+145.78 km^2), waters/water decreased by -13% (-164.96 km^2), and paddy fields/ponds increased by +17% (+216.11 km^2). Analysis of the potential for tidal inundation (river runoff) downstream of the Cipunagara watershed correlates with changes in the use of open land, forest vegetation, and rice fields with an area of 1,982 ha (47%). Meanwhile, the potential for tidal inundation (tidal events) is correlated with changes in the use of paddy fields and waters/water with an area of 2,213.93 ha (53%). The results of the research can be utilized in the management of flood risk in the downstream area of the watershed.

A B S T R A K

Perubahan penggunaan lahan pada daerah aliran sungai memainkan peran utama dalam studi perubahan luasan genangan banjir rob. Tata guna lahan merupakan bentuk usaha manusia mengubah lingkungan menjadi lingkungan yang mapan seperti lahan pertanian, jalan, perkebunan dan pemukiman. Tujuan dari penelitian ini adalah identifikasi kelerengan *catchment area*, identifikasi perubahan spasial tataguna lahan tahun 1996-2020 dan memetakan potensi banjir rob akibat perubahan tataguna lahan di DAS Cipunagara. Metode yang digunakan adalah analisis citra satelit yang tersedia di *cloud data* platform Google Earth Engine dengan menggunakan algoritma *machine learning*. Hasil analisis kemiringan lereng pada DAS Cipunagara terbagi atas lima kelas yaitu kategori datar dengan luas 52.67 km^2, kategori landai seluas 823.98 km^2, agak curam seluas 226.79 km^2, curam seluas 126.02 km^2, dan sangat curam seluas 74.96 km^2. Perubahan spasial tataguna lahan tahun 1996 sampai dengan 2020 yaitu untuk lahan terbuka/pemukiman mengalami pengurangan sebesar -15% (-196.92 km^2), vegetasi hutan mengalami penambahan sebesar +11% (+145.78 km^2), perairan/air terjadi pengurangan sebesar -13% (-164.96 km^2), dan lahan sawah/tambak terjadi penambahan sebesar +17% (+216.11 km^2). Analisis potensi genangan rob (kejadian limpasan sungai) di hilir DAS Cipunagara berkorelasi dengan perubahan tataguna lahan terbuka, vegetasi hutan, dan sawah dengan luas 1,982 ha (47%). Sementara potensi genangan rob (kejadian pasang surut) berkorelasi dengan perubahan tataguna lahan sawah dan perairan/air dengan luas 2,213.93 ha (53%). Hasil riset dapat dimanfaatkan dalam manajemen risiko banjir rob pada area hilir daerah aliran sungai.

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1. Introduction

Population growth and the development of science cause human needs to increase. This has an impact on the use of land use, especially in watersheds. Changes in land use in watersheds play a major role in the study of changes around tidal inundation. Land use is a form of human effort to change the environment into a stable environment such as agricultural land, roads, plantations, and settlements. Land use can also be defined as a few human arrangements, activities, and inputs on a particular land [1][2]. Cipunagara is one of the watersheds in West Java which has issues related to land use in the upstream watershed area and has an impact on increasing the potential for tidal flooding in the downstream area of the watershed. Intensification of agriculture, deforestation, clearing of ponds, and population increase are factors that accelerate changes in use in the upstream Cipunagara watershed and the expansion of the tidal flood inundation area downstream of the Cipunagara watershed. The problem of tidal flooding is often associated with the effects of sea-level rise and land subsidence, but the analysis of the potential for tidal flooding due to changes in land use in the watershed area is still often neglected. Therefore, the available data on land use change can provide important input for changes in tidal flood inundation area, tidal flood disaster management, decision making, and future planning [3][4]. So that the study of analyzing the potential for inundation (tidal flooding) due to land use changes using machine learning algorithms in the Cipunagara watershed area as a case study, is important because it can improve and take different approaches which have an impact on differences in the accuracy of tidal flood mapping. Therefore, the purpose of this study was to map the potential for tidal flooding due to land use changes in the Cipunagara watershed using satellite imagery recording data (remote sensing) which was analyzed using machine learning algorithms available on Google Earth Engine to find out how much influence land use changes have. Especially in the downstream Cipunagara watershed to the area of tidal flood inundation.

2. Research Methodology

2.1. Material

The remote sensing data that will be used in this research activity are Landsat 5, Landsat 7, Landsat 8, Digital Elevation Model (DEM), Global Surface Water (GWS) data, and the Cipunagara Watershed Administration Shapefile.

2.2. Machine Learning Algorithm

Supervised machine learning algorithms are useful for exploring abundant image data, and finding hidden relationships between several candidate input variables (parameters) and target or output variables (classification results), so it is very important and one of the solutions to the abundance of satellite image data and helps in mapping usage. The multi-temporal land area of coastal wetlands (downstream area of the Cipunagara watershed). Google Earth Engine (GEE) provides a cloud-based platform for processing many multi-temporal satellite imageries that is available free of charge. Google Earth Engine also provides a set of advanced machine learning classifiers for pixel-based classification that can be used for multi-temporal land use mapping. Machine learning is about computer programming to optimize performance criteria by using sample data or experience [5][6].

2.3. Data Processing Algorithm

Machine learning algorithms aim to study a sample pattern and then generalize it to a new sample. Kotsiantis [7] divides supervised machine learning into 5 groups: logic-based algorithms, perceptron-based techniques, statistical learning algorithms, instance-based learning, and supports vector machines. All processing and analysis of satellite images are carried out using machine learning algorithms in Google Earth Engine where the stages in this section include: (a) problem identification, (b) literature study, (c) data collection, (d) inundation source mapping, (e) validation and verification, and (f) correlation of land use and tidal inundation. This study uses DEM data from SRTM as elevation data, Landsat 5 (1996-2000), Landsat 7 (2005-2010), and Landsat 8 (2015-2020) satellite imagery as land use change data, water occurrence data from Global Surface Water as data on potential inundation. Testing the results of the analysis of machine learning algorithms for mapping land use and water events was carried out in two stages, namely the verification stage and the validation stage. The verification stage is an action to get the truth, accuracy, or reality of a data that is owned, it is obtained from observations in the field (site visit). While data validation is an action to get the correct conclusion based on the requirements that have been set, this is done in the analysis of satellite imagery using the confusion matrix method [8]. After testing the results of machine learning algorithms for classifying land use and water events, then calculating the correlation between land use changes and the potential for inundation in the downstream area of the Cipunagara watershed.

3. Results and Analysis

3.1. Slope of the Cipunagara Watershed

The slope and length of the slope are the two topographic elements that have the most influence on runoff and erosion. In addition to increasing the amount of runoff, the steeper the slope also increases the surface runoff velocity, thereby increasing the energy of water transport. The slope of the Cipunagara River Basin can be seen in Figure 1, dark green is a flat area, bright green is a sloping area, yellow is a slightly steep area, orange is a steep area, and red area is a very steep area.

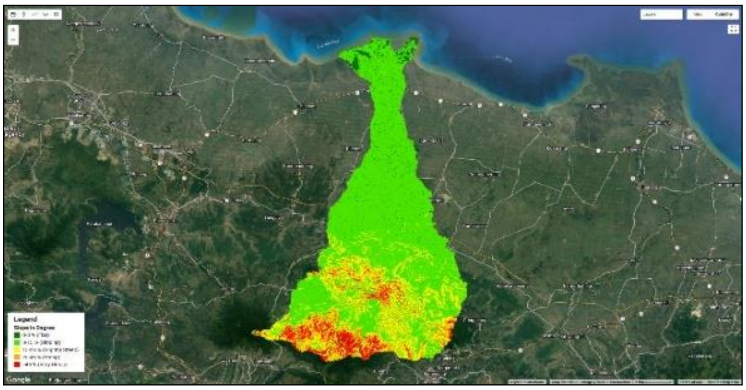


Figure 1. Slope map of the Cipunagara watershed.

The slope of the slope in this study is expressed in percent. Cipunagara watershed is generally dominated by sloping topography and rather steep, Cipunagara watershed has a contour that is quite varied with various levels of slope. Slope classes vary widely from flat to very steep categories where each class has a different function. The slope of the slope is divided into several classes, namely the flat category (0-8%) with an area of 52.67 km^2, the sloping category (8-15%) covering an area of 823.98 km^2, rather steep (15-25%) covering an area of 226.79 km^2, steep (25-45%) covering an area of 126.02 km^2, and very steep (≥ 45%) covering an area of 74.96 km^2. The classification of the slopes of the Cipunagara watershed and its area is presented in Table 1.

Table 1. Classification of the Cipunagara watershed.

Grade Slope	Interval	Classification	Area (km^2)
1	0 – 8 %	Flat	52.67
2	8 – 15 %	Sloping	823.98
3	15 – 25 %	Slightly steep	226.79
4	25 – 45 %	Steep	126.02
5	> 45 %	Very steep	74.96

3.2. Land Use Condition of Cipunagara Watershed

Land use is one of the parameters of the level of land use in an area. The land use classified in this study only consists of 4 classes, namely open land, forest vegetation, water, and rice fields. Open land cover includes settlements, roads, fields, and non-water land. Forest vegetation includes mangroves, shrubs/grass, and trees. Waters include seas, rivers, and lakes. Meanwhile, the cover of paddy fields includes rice fields that are still productive, ponds, and wetlands. Land use mapping in the Cipunagara watershed in this study uses machine learning Classification and Regression Tree (CART).

The land use distribution map in 1996 and 2000 is presented in Figure 3 and the land use area is presented in Table 2. The dominant land use in 1996 was forest vegetation which reached 304.11 km^2 (43%) of the total area of the Cipunagara watershed. The next dominant land use is built-up land 304.11 km^2 (23%), while the minimal land use is rice fields/wetlands 233.20 km^2 (18%) and water 205.52 km^2 (16%).

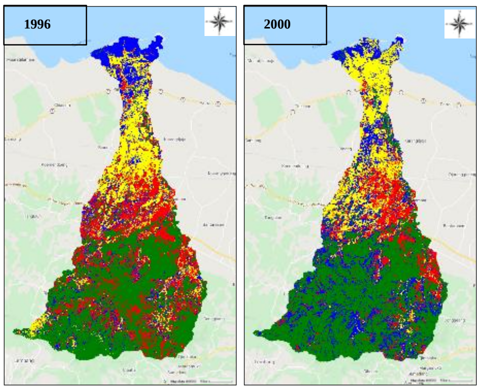


Figure 2. Map of land use in the Cipunagara watershed 1996-2000.

The land use of the Cipunagara watershed in 2000 saw a reduction in built-up land with a change of -120.73 km^2 (-9%) from the conditions in 1996. Meanwhile, land use of forest and water increased +4% and respectively +5 % of conditions in 1996. The most rapid changes occurred in the upstream part of the Cipunagara watershed, an area with a gentle slope (8-15%). Changes in built up land decreased by -9% because in 1996 there was land clearing for plantations and land clearing for ponds so that in 2000 land use for forest and water/water vegetation increased by +9%. The increase in land occurred due to the conversion of other lands in the upstream area of the Cipunagara watershed.

Table 2. Land use area in 1996 and 2000 Cipunagara watershed.

Land Use	1996		2000		Change	
	km^2	%	km^2	%	km^2	%
Built-up Land	304.11	23	183.38	14	-120.73	-9
Forest Vegetation	561.69	43	617.42	47	+55.75	+4
Water	205.52	16	270.82	21	+65.30	+5
Rice Fields/Wetlands	233.10	18	232.82	18	-0.28	0
Total	**1,304.42**	**100**	**1,304.44**	**100**		

The land use distribution map in 2005 and 2010 is presented in Figure 3 and the land use area is presented in Table 3. The dominant land use in 2005 was forest vegetation which reached 615.98 km^2 (47%) of the total area of the Cipunagara watershed. The next dominant land use is water/water 292.42 km^2 (22%) and rice fields/wetland 268.35 km^2 (21%), while the minimal land use is built-up land 127.34 km^2 (10%).

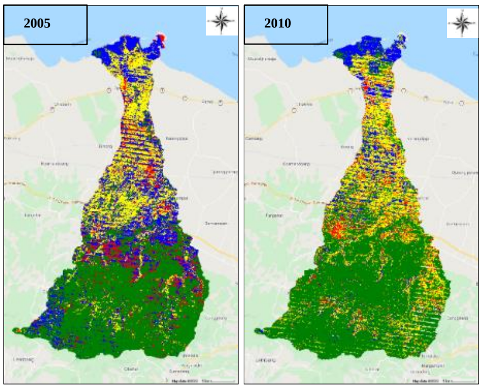


Figure 3. Map of land use in the Cipunagara watershed 2005-2010

The land use of the Cipunagara watershed in 2010 saw a reduction in two classes of land use, namely water by -146.76 km^2 (-11%) and built-up land by -42.19 km^2 (-3%) from the conditions in 2005. forest vegetation and paddy fields/wetlands respectively experienced an increase of +11% and +3% reduction in water and built-up land, respectively, from conditions in 1996. Changes in water decreased by -11% due to conversion other land in the upstream area of the Cipunagara watershed.

Table 3. Land use area in 2005 and 2010 Cipunagara watershed.

Land Use	2005		2010		Change	
	km^2	%	km^2	%	km^2	%
Built-up Land	127.34	10	85.15	7	-42.19	-3
Forest Vegetation	615.98	47	754.23	58	+138.25	+11
Water	292.42	22	145.66	11	-146.76	-11
Rice Fields/Wetlands	268.35	21	306.00	24	+37.65	+3
Total	**1,304.09**	**100**	**1,291.04**	**100**		

The land use distribution map in 2015 and 2020 is presented in Figure 4 and the land use area is presented in Table 4. The dominant land use in 2015 was forest vegetation which reached 880.68 km^2 (69%) of the total area of the Cipunagara watershed. The next dominant land use is paddy field/wetland 224.93 km^2 (17%), while land use which is less than ten percent is built-up land 123.70 km^2 (9%) and water 74.96 km^2 (6%).

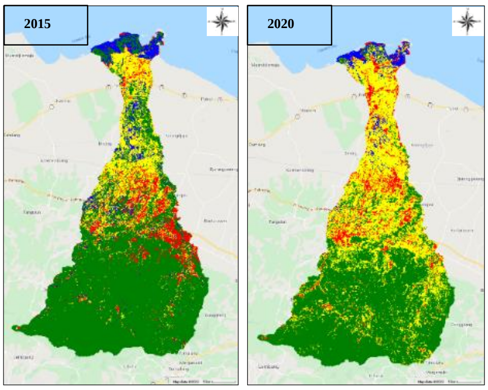


Figure 4. Map of land use in the Cipunagara watershed 2015-2020

The land use of the Cipunagara watershed in 2020 saw an increase in paddy fields/wetlands by +224.28 km^2 (+17%) from the conditions in 2015. Meanwhile, the use of forest, water, and open land vegetation decreased by -173.21 km^2 (-13%), -34.40 km^2 (-3%), and -16.51 km^2 (-1%) from 1996 conditions. The largest land change occurred in forest classes that experienced a reduction due to deforestation into other land uses, such as rice fields and mangrove areas submerged in seawater. The increase in paddy fields/wetlands is the conversion of forest land, waters, and built-up land in the middle to downstream areas of the Cipunagara watershed.

Table 4. Land use area in 2015 and 2020 Cipunagara watershed.

Land Use	2015		2020		Change	
	km^2	%	km^2	%	km2	%
Built-up Land	123.70	9	107.19	8	-16.51	-1
Forest Vegetation	880.68	69	707.47	54	-173.21	-13
Water	74.96	6	40.56	3	-34.40	-3
Rice Fields/Wetlands	224.93	17	449.21	34	+224.28	+17
Total	**1,304.27**	**100**	**1,304.43**	**100**		

The results of the overall accuracy test of the land use map are classified as very good so that they can describe the actual conditions with an average Kappa Accuracy (KA) value of 0.95. Meanwhile, the overall test value for the accuracy of land use mapping with an average value of 96.17%, shows a good level of accuracy with a very good predicate [8]. This is in line with the agreement table [9], which is at an acceptable kappa agreement interval of 0.81-1 with a very good agreement strength (almost perfect). According to the assessment [10], the overall accuracy value generated by the level of agreement is 86-96.98% (almost perfect).

Table 5. Confussion matrix of land use in the Cipunagara Watershed.

Image Class		Sampel (User)				Total pixels	User Accuracy	User Error
		Built-up Land	Forest Vegetation	Water	Rice Fields/Wetlands			
Interpretation Results (Maker)	Built-up Land	148	0	1	1	150	98%	2
	Forest Vegetation	0	148	2	0	150	99%	0,67
	Water	4	4	134	8	150	91%	9,33
	Rice Fields/Wetlands	1	0	2	147	150	97%	3,33
Total pixels		153	152	139	155	600		
User Accuracy		97%	96%	96%	96%	OA	96.17%	
User Error		3.29	4.49	3.55	3.97		KA	0.95

Info:

Error/False Pixels

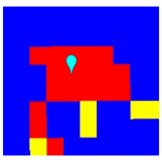
True/Fair Pixels

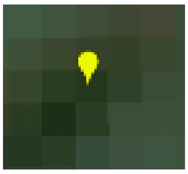
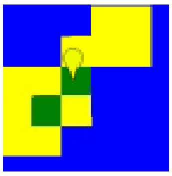
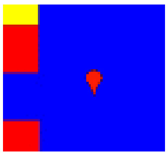
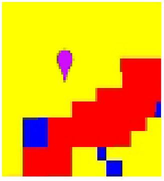
Overall Accuracy

Kappa Accuracy

The results of the field verification test were inserted (site visit) which was carried out for 2 days in the field, namely on 29 & 30 January 2022 for land use classes consisting of open/residential land use classes, forest/mangrove vegetation land use classes, and aquatic land use classes. Water, and finally the rice field/pond land use class shows the suitability of the visual interpretation of land use using the 432 band combination (RGB) [11]. Verification is done by taking the same coordinates between the interpretation results of RGB Band 432 Landsat 8 Imagery in 2020, the results of the CART algorithm analysis, and the results of field verification based on the coordinates taken. This is done to get the truth, accuracy, or reality (truth, accuracy, reality) from a data that is owned. From the results of the field verification test, it was found that the land use class was in accordance with the results of the CART algorithm analysis used on the google earth engine. The results of the land use verification test based on analysis of Landsat 8 satellite imagery and field inspections are presented in Table 6.

Table 6. Comparative image of land use class visualization.

Land Use Class	Coordinate	RGB Band 432 Landsat 8 imagery 2020	CART Algorithm Analysis Results	Field Photo	Land use description
Built-up Land	107.78 BT -6.21 LS				In the field, open land in the form of settlements is found on the coast or the coast of Mayangan village

Land Use Class	Coordinate	RGB Band 432 Landsat 8 imagery 2020	CART Algorithm Analysis Results	Field Photo	Land use description
Forest Vegetation	107.77 BT -6.20 LS				In the field, forest vegetation, which is mangrove, is found on the beach of Pondok Bali which is directly opposite the North Sea of Java.
Water	107.78 BT -6.20 LS				In the field found open water (North Java Sea) which is at the end of Pondok Bali beach.
Rice Fields/ Wetlands	107.81 BT -6.23 LS				In the field, there are areas of productive rice fields that stretch widely in Bobos Village.

3.3. Potential Inundation in the Downstream Area of the Cipunagara Watershed

Data on potential inundation from the Global Surface with data coverage is global, which means it covers the entire surface of the earth with a time span of 37 years between 1984-2020. It has a 30-meter resolution because based on Landsat 5, Landsat 7, and Landsat 8 images, more than 3 million of them are processed to get monthly and annual statistics on the presence or absence of water on the earth's surface [12][13]. In this study, an analysis of water events for the last 25 years (1996-2020) was carried out based on the results of image recording on the google earth engine platform using machine learning algorithms to obtain the potential area of tidal flood inundation and inundation sources in the downstream area of the Cipunagara watershed. In the process of analyzing the area of inundation and the source of the tidal flood, the first stage is water event analysis to determine the percentage of water occurrences in the study area, analysis of the intensity of changes in water events to see changes in water events in the study area, transition analysis of water events to obtain sources of tidal flood inundation. Based on transitions of seasonal water events (areas that are inundated during the rainy season/due to river runoff) and transitions of permanent water events (areas that are inundated every day/due to tides).

3.3.1. Water Occurrence 1996-2020

The occurrence of water in the Cipunagara watershed in the last 25 years (1996-2020) especially the downstream area is depicted in Figure 6. The dark blue color indicates that the occurrence of water in the area is 100% occurrence which means it is a permanent body of water with an area of 1,700.60 Ha. Then when it fades and becomes pinker, it means that the area has fewer occurrences or only 1% of events with an area of 3,573.41 ha. While the white one symbolizes land or no puddles with an area of 6,430.61 ha.

Figure 6. Map of water occurrence in the downstream Cipunagara watershed for the 1996-2020 period.

3.3.2. Intensity of Changes in Water Occurrence

The map of the intensity of changes in water occurrence can be seen changes in the intensity of water occurrence in the three time periods between (1996-2000, 2005-2010, and 2015-2020) and compares the three periods to see which areas have an increase in the incidence of surface water decreasing, remaining the same, and increase. From Figure 7, it can be seen that the bright green area is the area where there has been a large loss on the surface of the water, covering an area of 472.32 ha, the black area is the location that has not changed with an area of 1,982.55 ha, and the red area is the location where there is an increase in surface water or this area is a new irrigation area with an area of 3,961.15 ha. Meanwhile, the gray area indicates land that is not affected by tidal inundation or river runoff with an area of 5,288.60 ha.

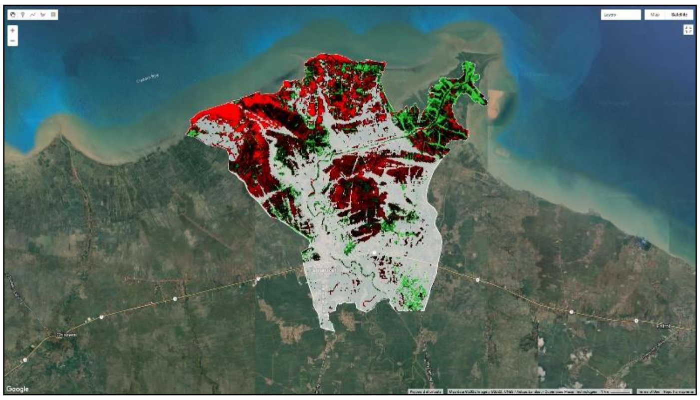


Figure 7. Intensity map of changes in water occurrence in the downstream Cipunagara watershed for the 1996-2020 period.

The intensity of changes in water events in the downstream area of the Cipunagara watershed from 1996-2020 from the results of machine learning algorithm analysis shows that there is an increase in inundation, with the highest frequency of 15,000 with an incidence percentage of 10%. Histogram of the intensity of the change in surface water inundation is presented in Figure 8.

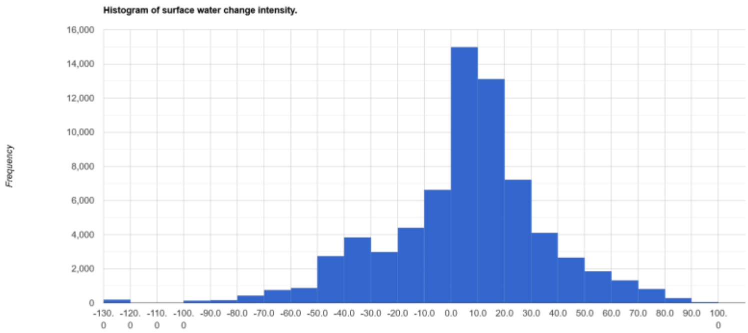


Figure 8. Histogram of changes in water occurrence in the downstream Cipunagara watershed for the period 1996-2020.

3.3.3. Water Occurrence Transition

The next map is very important, namely the water transition map, in Figure 9 you can see the changes between the data for the first and last years, and can analyze classes of non-water, seasonal water (river runoff), and permanent water (tidal runoff). Based on the map, the dark blue area is the tidal inundation area of 2,214.56 ha. Areas inundated by tidal water include Tegalurung Village, Mayangan Village, Legon Wetan Village, Legon Kulon Village Pangarengan Village, and Patimban Village. Areas in light blue are areas of seasonal water or river runoff which means that this area gets flooded from time to time, the area of river runoff is 1,982.09 ha. The villages included in this area are almost all villages. While the gray areas are land areas or minimal water occurrences such as Lengkong Jaya Village, Pamanukan Hilir Village, Pamanukan Village, Rancasari Village, Mulyasari Village, Mundusari Village, Pusakaratu Village, Pusakajaya Village, and Gempol Village.

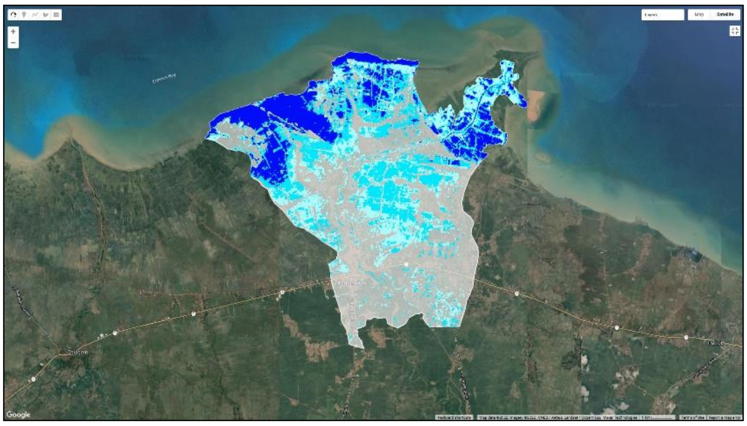


Figure 9. Transition map of water occurrence in the lower Cipunagara watershed for the period 1996-2020.

3.3.4. Water Occurrence Validation

The occurrence of water transitions from inundation of rivers/ponds to tidal areas can be seen in Figure 10, in 1996-2004 the southwest coast area of Mayangan Village was still a land/pond area, in 2005-2007 there was a shift in coastline towards land, and in 2008-present the southwest coast area of Mayangan Village which was once a land area (tambak) has been inundated by sea water or has become an intertidal zone (tidal area).

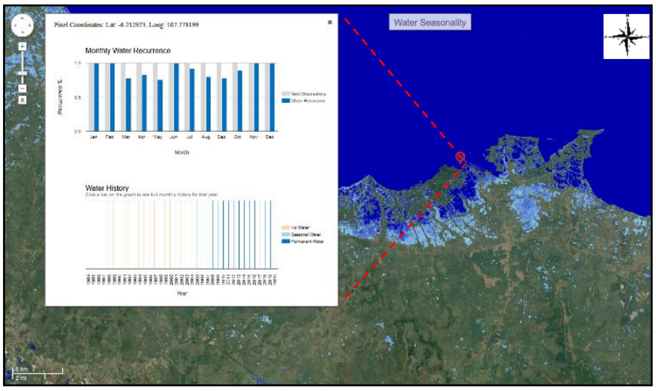


Figure 10. Map of the occurrence of seasonal to permanent water transitions for the period 1996-2020.

The transition of water from the tidal area to the river inundation area (seasonal) can be seen in Figure 11, in 1996-2008 the northeast coast of Patimban Village was a permanent inundated area (sea area), over time in 2009-2010 the area began to occur sedimentation from the mouth of the Cipunagara watershed and slowly the area has become an area of seasonal water events (river runoff). So that in 2011-present the area becomes a new 100% land area.

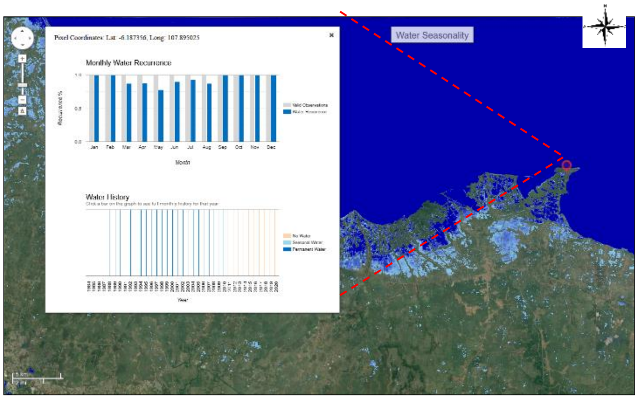


Figure 11. Map of the occurrence of permanent to seasonal water transitions for the period 1996-2020.

The transition of water from land to seasonal water occurrence areas (flood subscription areas) can be seen in Figure 12, in 1996-1999 the northern part of Bobos Village was a 100% land area, in 2000-2015 there was a transition from land to seasonal inundated areas. 73%, and in 2016-present has become an area of 100% seasonal water events (river runoff). This is due to several factors, namely in the area there has been clearing of rice fields and poor irrigation of rice fields, causing the area to become a waterlogging area.

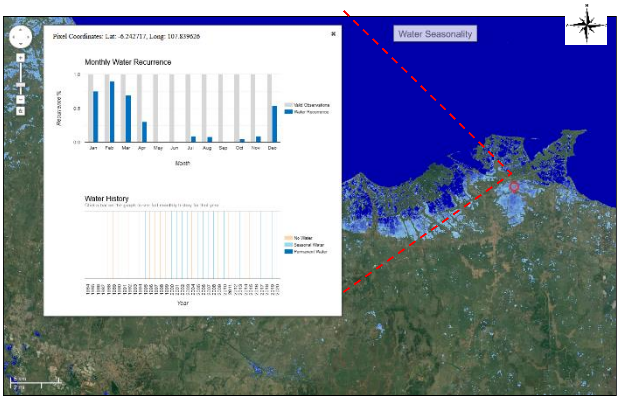


Figure 12. Map of the occurrence of land to seasonal water transitions for the period 1996-2020.

3.3.5. Percentage of Inundation Source

The percentage of tidal flood inundation area per village based on the source of inundation per village in the Downstream Area of the Cipunagara Watershed is presented in Table 7.

Table 7.a. Percentage of Inundation Area by Inundation Source in each Village

No	Village	Total Inundation Area (ha)	Tidal Inundation Area (ha)	% Flood	River Inundation Area (ha)	% Flood
1	Tegalurung	229.78	138.42	60%	91.36	40%
2	Mayangan	385.92	340.41	88%	45.51	12%
3	Legon Wetan	605.82	507.45	84%	98.37	16%
4	Legon Kulon	201.72	95.04	47%	106.68	53%

No	Village	Total Inundation Area (ha)	Tidal Inundation Area (ha)	% Flood	River Inundation Area (ha)	% Flood
5	Pangarengan	1,145.54	660.04	58%	485.5	42%
6	Bobos	175.66	1.22	1%	174.44	99%
7	Karangmulya	206.19	0.03	0%	206.16	100%
8	Patimban	685.16	471.32	69%	213.84	31%
9	Rancadaka	438.61	0	0%	438.61	100%
10	Gempol	3.64	0	0%	3.64	100%
11	Pusakaratu	8.62	0	0%	8.62	100%
12	Mundusari	2.16	0	0%	2.16	100%
13	Rancasari	1.82	0	0%	1.82	100%
14	Pamanukan Sebrang	83.3	0	0%	83.3	100%
15	Mulyasari	5.9	0	0%	5.9	100%
16	Pamanukan Hilir	0	0	0%	0	0%
17	Pamanukan	0	0	0%	0	0%
18	Ranca Hilir	9.87	0	0%	9.87	100%
19	Lengkong Jaya	0.25	0	0%	0.25	100%
20	Pusakajaya	5.97	0	0%	5.97	100%
	Total	**4,195.93**	**2,213.93**	**53%**	**1,982**	**47%**

Based on the analysis of Table 7, the percentage of tidal flood inundation in the downstream area of the Cipunagara watershed is obtained. Overall, the percentage of tidal inundation source area is 53% and the percentage of river runoff source area is 47%. The percentage of the area with the highest tidal inundation area is in Mayangan Village, which is 88% and the lowest percentage of tidal inundation is in Legon Kulon Village, which is 47%. Meanwhile, the percentage of river inundation area is found in Bobos Village, Rancadaka Village, Karangmulya Village, Lengkong Jaya Village, Pamanukan Sebrang Village, Gempol Village, Mundusari Village, Rancasari Village, Mulyasari Village, Ranca Hilir Village, and Pusakajaya Village with a percentage of 100% inundation sources from river runoff. Spatially, the percentage of inundation source area per village in the downstream area of the Cipunagara watershed can be seen in Figure 13.

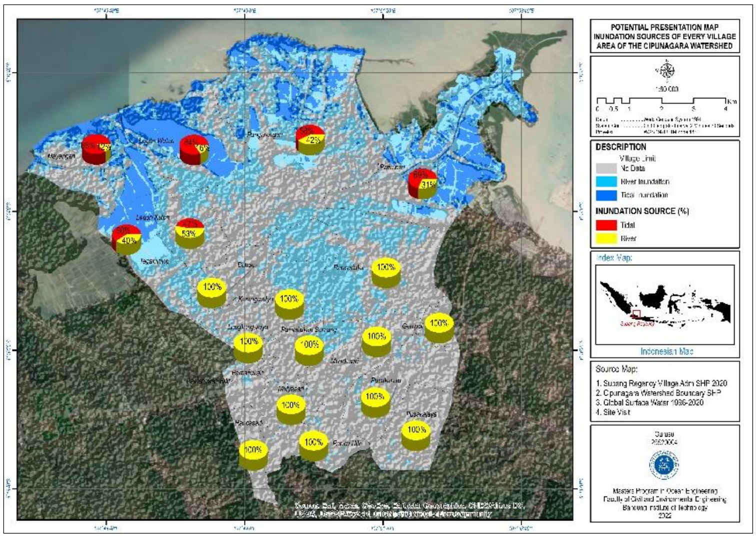


Figure 13 Percentage map of potential inundation sources of rob in each village.

3.3.6. Percentage of Inundation Source

The graph below, the pattern of changes in the occurrence of river runoff in the Downstream Area of the Cipunagara watershed follows the pattern of changes in open land, forest vegetation, and rice fields. In 1996 there was an increase in the incidence of river runoff followed by an open land pattern, while in 2000-2005 there was a decrease in river runoff followed by a decrease in open land and an increase in forest vegetation and rice fields/wetlands. In 2010-2015 the pattern of river water runoff increased again, which was followed by an increase in the use of paddy fields and open land in the Cipunagara watershed area. In 2020 the incidence of river water runoff in the downstream area of the Cipunagara watershed decreased, this was due to changes in productive paddy fields into wetland areas or permanently inundated. The graph in relation to land use change and river runoff is presented in Figure 14.

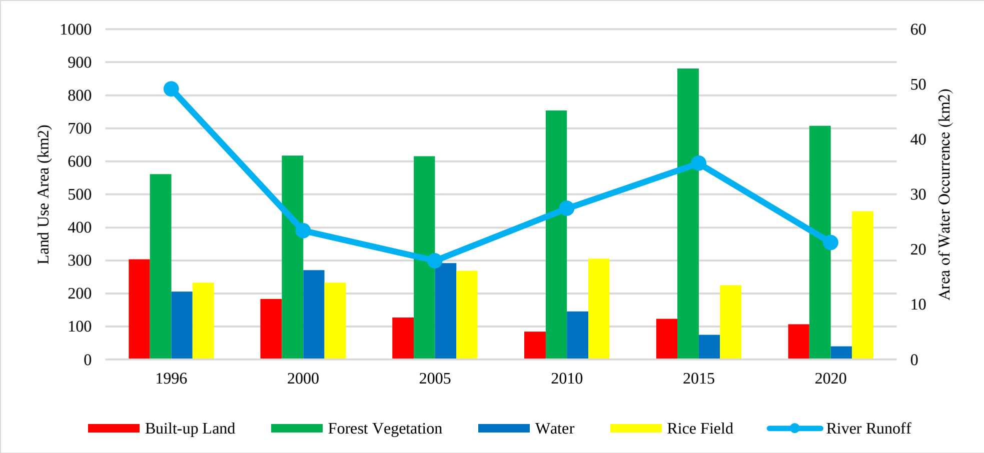


Figure 14. Graph of the relationship of land use change and river runoff occurrence in the downstream area of the Cipunagara watershed.

The graph presented in Figure 15 below shows the relationship between the pattern of changes in the occurrence of tidal water (sea water intrusion) and the pattern of land use changes in the Cipunagara watershed. The graphic pattern of permanent water events follows the pattern of changes in water land use. In the period 1996, 2000, and 2005 the area of water occurrence in the downstream area of the Cipunagara watershed experienced an increase in area along with the addition of the area of water/water in the catchment area of the Cipunagara watershed. While in the period 2010 and 2015 the incidence of seawater intrusion in the downstream area of the Cipunagara watershed showed a decrease in area, this was because the catchment area of the Cipunagara watershed experienced a decrease in water land.

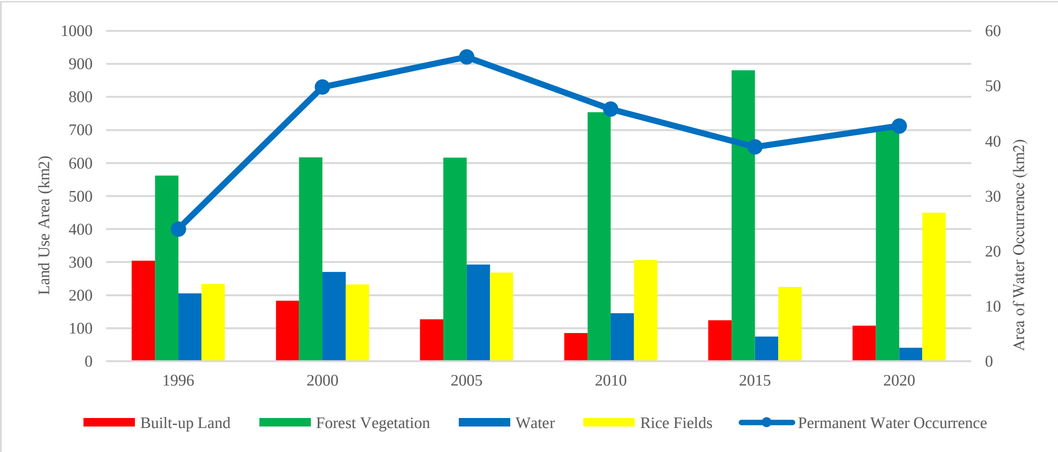


Figure 15. Graph of the Relationship between land use changes and permanent water occurrence (sea water intrusion) in the downstream area of the Cipunagara watershed

In 2020 in the downstream area of the Cipunagara watershed, the occurrence of permanent water (sea water intrusion) again experienced an increase in area (Figure 15), due to the transition of paddy fields into waterlogged areas due to runoff from the Cipunagara River. This happened in several villages, namely Bobos Village, Rancadaka Village, Gempol Village, Mundusari Village, Karangmulya Village, and Mundusari Village. Based on the results of interviews with local communities and measurements of inundation salinity data conducted at the site visit, information was obtained that the Northeastern part of Bobos Village has become a permanent inundation area.

4. Conclusion

The results of the slope analysis in the Cipunagara watershed are divided into five classes, namely the flat category with an area of 52.67 km^2, the sloping category covering an area of 823.98 km^2, slightly steep covering an area of 226.79 km^2, steep covering an area of 126.02 km^2, and very steep covering an area of 74.96 km^2. Spatial changes in land use from 1996 to 2020, namely for open land/settlements decreased by -15% (-196.92 km^2), forest vegetation increased by +11% (+145.78 km^2), waters decreased by -13% (-164.96 km^2), and paddy fields/ponds increased by +17% (+216.11 km^2). Analysis of the potential for tidal inundation (river runoff) downstream of the Cipunagara watershed correlates with changes in use of open land, forest vegetation, and rice fields with an area of 1,982 ha (47%). Meanwhile, the potential for tidal inundation (tidal events) correlates with changes in land use for paddy fields and waters/water with an area of 2,213.93 ha (53%).

Acknowledgements

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