

Spatial model of land use change related to sediment yield (case study: Cipeles and Cilutung watershed, West Java)

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Abstract. Land use changes (LUC) as a result of increasing human need for space are likely to destroy the hydrological function of the watershed, increase land degradation, stimulate erosion and drive the process of sedimentation. This study aimed to predict LUC during the period 1990 to 2030 in relation to sediment yield in Cilutung and Cipeles Watershed, West Java. LUC were simulated following the model of Cellular Automata-Marcov Chain, whereas land use composition in 2030 was predicted using Land Change Modeler on Idrisi Selva Software. Elevation, slope, distance from road, distance from river, and distance from settlement were selected as driving factors for LUC in this study. Erosion and sediment yield were predicted using WATEM/SEDEM model based on land use, rainfall, soil texture and topography. The results showed that the areas of forest and shrub have slightly declined up to 5% during the period 1990 to 2016, generally being converted into rice fields, settlements, non-irrigated fields and plantations. In addition, rice fields, settlements, and plantations were expected to substantially increase up to 50% in 2030. Furthermore, the study also revealed that erosion and sediment yield tend to increase every year. This is likely associated with LUC occurring in Cipeles and Cilutung Watershed.

1. Introduction

Land use (LU) is defined as a series of people's activities on a land, the purpose of these activities are to get product and/or benefit through the utility of natural resources of the land. Land use can be reflected human interactions with environment on earth [1] and the social-economy characteristic of people in a certain geographical space [2]. The increase of quantity of inhabitant and the economy demand on an area of earth make the change of rapid land use as one of the most environmental issue globally [3]. The land use change (LUC) is a complex interaction between structural factor and human behavior with technology, demand, and social interaction [4]. LUC in a watershed, especially showed by the decrease of forest area and the increase of rice fields, at one side, and variability of rain intensity on the other, these cause changes in hydrology balance in the watershed system that triggered land level increasing and soil erosion [5]. The results are the decreasing of land fertility, the extent of critical area, and degraded land in the watershed [6,7]. Spatially, the patterns of LUC on earth are variable and the dynamic in geographic scale is very complex. These also influence the natural process of atmosphere, lithosphere, hydrosphere, and biosphere difference in intensity between geographical spaces [3].

Spatial modeling the LUC on a watershed will assist the understanding of complicated system and produce valuable information about configuration of LU in the future [1]. These information definitely very important in watershed management, especially to land resource management. For examples cases in Cipeles and Cilutung Watershed, West Java, we analyze the LUC and simulate the change in the future with integration of Markov-Cellular Automata method. Then, we integrate with WATEM-SEDEM model (Water and Tillage Erosion Model and Sediment Delivery Model) to predict sediment yield and its spatial distribution. Markov-Cellular Automata method has been used widely as model and to predict LUC in numerous room scale [8-10].



Cipeles and Cilutung Watershed are part of subsystem of Cimanuk Watershed. Since Jatigede Dam operated on August 2015, Cipeles and Cilutung River have important role to maintain balance of sediment supply to the Java sea. Base on identification of BPDAS Cimanuk- Citanduy, in 2003 critical land in Cimanuk Watershed was dominated at outside of forest area about 132,665 hectares. This high level of critical area will trigger quality degradation of watershed environment. This will lead to increasing of soil erosion and sedimentation in the river, more over in the lake, in the dam and irrigation channels. In this study, we predict the LUC in 2030, which is the same time with the end of Rencana Tata Ruang Wilayah (RTRW) of Regencies in the study area.

2. Method

2.1. Study Area

The research location is situated in Cipeles and Cilutung watershed. Both are sub system of Cimanuk watershed. Geographically Cipeles and Cilutung lies between $6^{\circ}38'09.5''$ – $7^{\circ}04'04.6''$ South and $107^{\circ}45'44.7''$ – $108^{\circ}24'17.4''$ East. Administratively, Cipeles watershed is in Sumedang Regency, and Cilutung watershed is in Majalengka Regency.

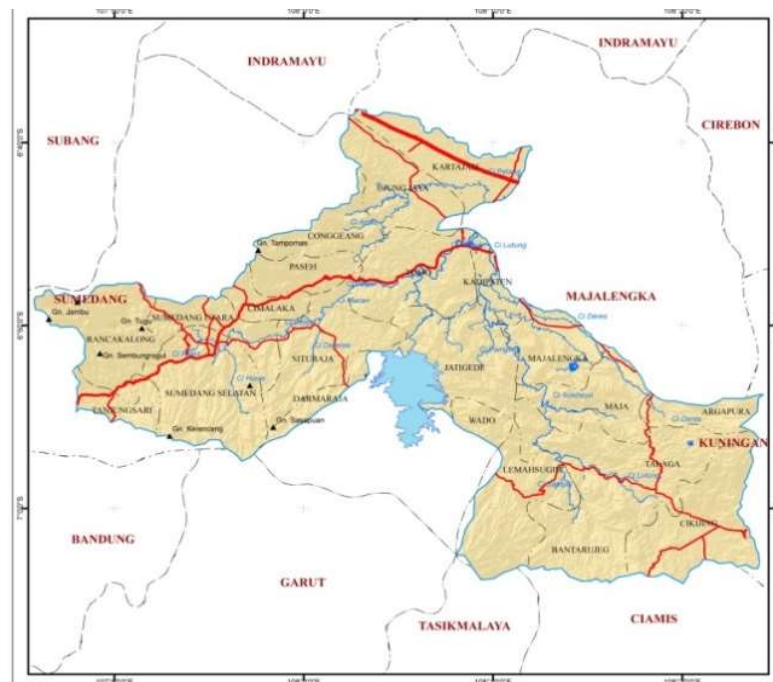


Figure 1. Map of the study areas (Cipeles and Cilutung Watershed).

2.2. Data and Materials

- Landsat images of path/row 121/065; Landsat 5 TM for the year 1990 and 2010, Landsat 7 ETM for the year 2000, and Landsat 8 OLI for the year 2016. The satellite acquisition date for the images was July to October.
- Digital Elevation Models Shuttle Radar Topography Mission (DEM SRTM).
- Land use of Sumedang and Majalengka Regency scale 1: 50,000 (year 1990, 2000, 2010, and 2016), obtained from Ministry of Agricultural dan Spatial.
- Annual Rainfall Data obtained from Meteorology, Geophysics, and Climatology Agency (BMKG)
- Soil Texture of West Java Province obtained from Puslitanak.
- Software: Arc GIS. 10.1, ENVI 5.1, Idrisi Selva, and WATEM/SEDEM version 2004.

2.3. Data Processing and Analysis

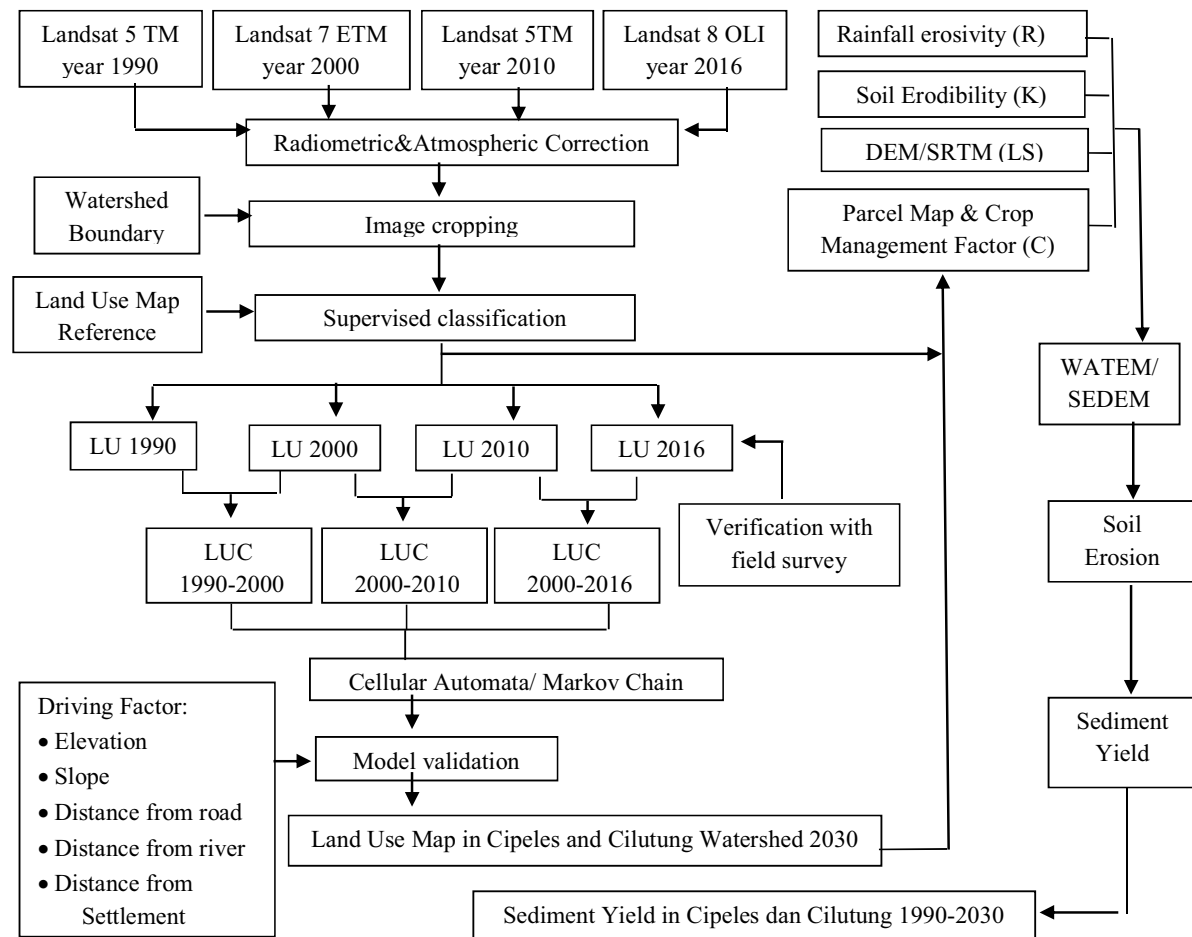


Figure 2. Landuse classification and sediment yield analysis process.

LUC Analysis was done with menu land change modeler (LCM) on software Idrisi 17 Selva. The prediction of LU in 2030 was acquired by observing the LUC on year 2000 and 2016 as a reference years. Potential Transition Accuracy test was done to count how much influence of each driving factor to LUC. In this study driving factors were consider as the factors that influence the LUC which are consist of: the slope, elevation, distance from road, distance from river, and distance from settlement [8,9]. The prediction of LUC was done using Business As Usual scenario, which means this model calculate without obstructive and supportive factors that influence the LUC.

Analysis the effect of LUC on sediment yield was using WATEM-SEDEM model version 2004. The result of this modeling was a spatial imaging of soil erosion that can be used to detect part of watershed which the most endangered by soil erosion. This model consists of three stages which are: calculation of soil erosion with RUSLE equation, calculation the capacity of sediment transportation, and sediment flow to the river [11]. Software WATEM/SEDEM version 2004 was built based on RUSLE equation, which is $E = R \times LS_2D \times K \times C \times P$, where E represent annual soil erosion; R for rainfall erosivity; K for soil erodibility; C for crop management factors; P for erosion control practice; and LS_2D for two dimensional topography factor. The results are value and the spread of erosion, and sediment deposition. All input layers were generated in Idrisi Selva with a resolution of 20x20m. The resolution of 20x20m

was applied because the WATEM/SEDEM model was calibrated with resolution 20x20m. The input layer consisted of rainfall erosivity (R), soil erodibility (K), crop cover (C), and parcel map. In WATEM/SEDEM model, P factor was considered to be 1, because the conservation practices are mostly in small scales that cannot be detected by Landsat satellite images [12].

3. Result and Discussion

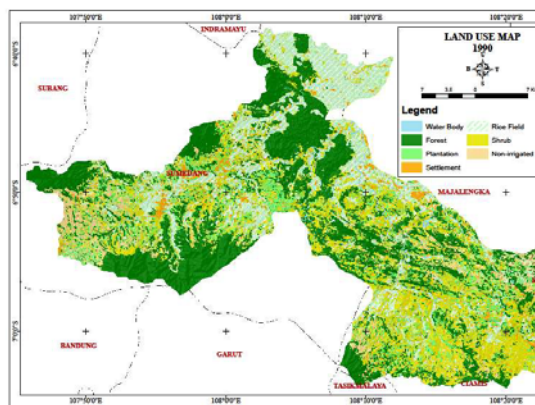
3.1. The Land Use Change in Cipeles and Cilutung watershed between 1990 to 2016

The land use in Cipeles and Cilutung watershed classified as water body, forest, plantation, rice fields, settlements, shrub, and non-irrigated fields. Each class of land use will change dynamically in extent, more or less in size. This land use dynamics were effects of human activities in the watershed. In detail, the extent of land use in 1990, 2000, 2010, and 2016 are reveals in Table 1.

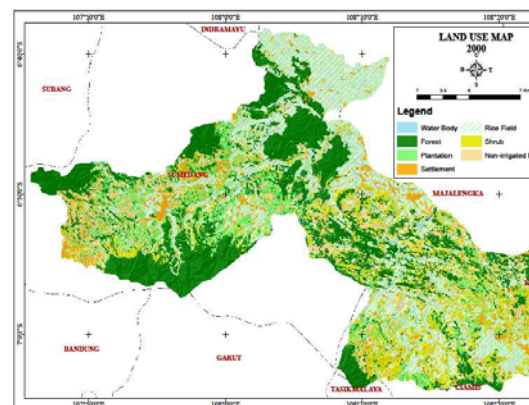
Table 1. Land Use Change between 1990 to 2016.

No	Land Use	1990		2000		2010		2016	
		Hectares	%	Hectares	%	Hectares	%	Hectares	%
1	Water body	1,226	0.88	1,226	0.88	1,226	0.88	2,487	1.79
2	Forest	49,019	35.31	42,303	30.48	35,834	25.82	28,111	20.25
3	Plantation	14,422	10.39	14,578	10.50	18,825	13.56	18,235	13.14
4	Settelments	4,243	3.06	7,447	5.36	9,970	7.18	12,625	9.10
5	Rice Fields	28,284	20.38	42,682	30.75	43,820	31.57	49,585	35.72
6	Shurb	32,625	23.50	19,909	14.34	17,505	12.61	13,547	9.76
7	Non-irrigated fields	8,990	6.48	10,665	7.68	11,628	8.38	14,219	10.24
	Total area	138,809	100.00	138,809	100.00	138,809	100.00	138,809	100.00

In 1990, forest had dominated in Cipeles and Cilutung watershed with area of 49,019 Ha or 35.31% of the watershed. But in 2000, 2010 and 2016, the forest areas were reduced into 5% per 10 years. Shurb area was significantly reduced. In 26 years proportion of Shurb in Cipeles and Cilutung watershed had decreased from 23.50 % in 1990 became 9.76 % in 2016. The increasing of settlement area in 26 years (1990 to 2016) was 8,382 Ha. The water bodies (river, lake) had the area extent relatively the same from 1990 to 2010, which was 1.226 Ha or 0.88 % of the extent of Cipeles dan Cilutung watershed. But, in 2016 the extent was increase into 2,487 Ha or 1.79 % of watershed. This increasing was because of Jatigede Dam that had been operated since August 2015.



(a)



(b)

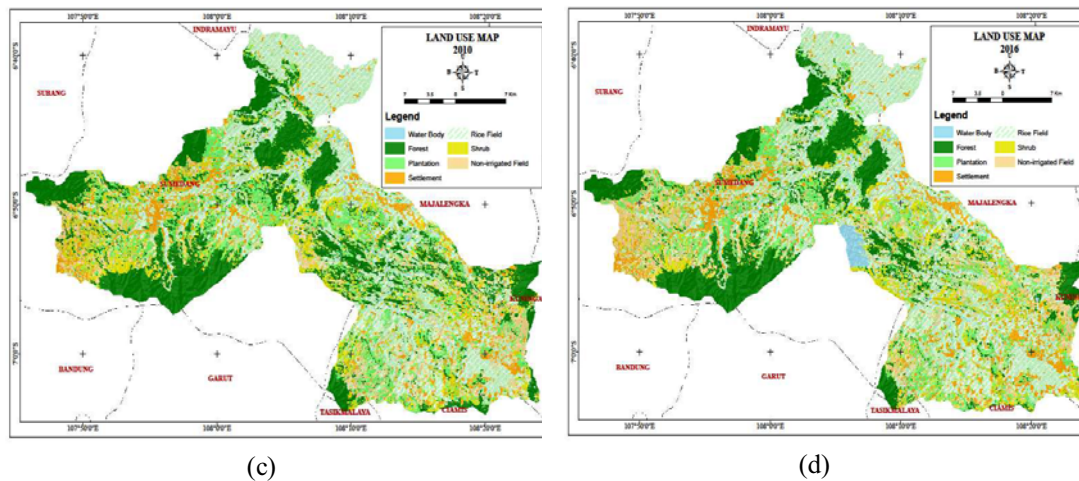


Figure 3. Land Use Change in Cipeles and Cilutung Watershed Map (a) 1990 (b) 2000 (c) 2010 (d) 2016

3.2. Factors that Affect Land Use Change

The driving factors of LUC that used in this study were the slope, elevation, distance from the road, distance from the river, and distance from the settlement. The level of strength of each driving factor to each utility was measured by Cramer's value. The higher of the Cramer's value, means the higher the effect of driving factors on LUC. Elevation had the highest Cramer's value of 0.246 (Figure 3). This showed that elevation factor had affect more to the chance of land use on Cipeles and Cilutung watershed. Commonly, the elevation of less than 500m had more likely to LUC. The second higher value (0.233) is the distance from the settlement. This showed that the closer to the settlement, the higher the possibilities of LUC. The change commonly were became settlement, rice field, and non-irrigated field. And the last one is the slope of mountain with Cramer's value of 0.216. The slope of mountain had become the border of LUC. The areas which were too steep had become the limit of development area.

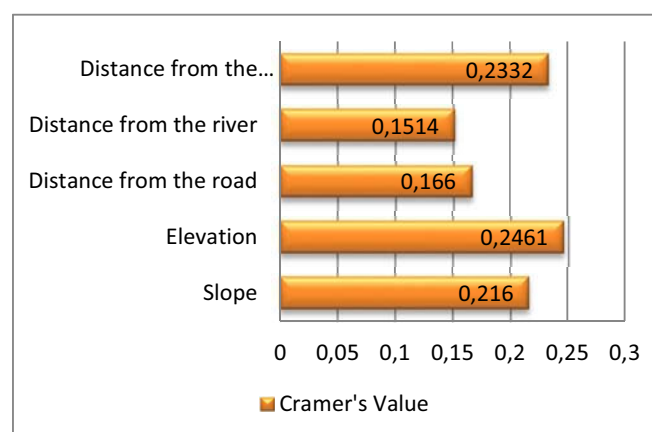


Figure 4. Cramer's Value for each Driving Factors

3.3. Prediction of Land Use in 2030

Kappa Value as results of cross tabulation between actual LU of 2016 with simulated LU of 2016 was 0.7256. This value reveals that the model that had been used had good synchronization. In other words, model of LUC that already arranged can be used to predict LUC in 2030. The result of LU in 2030 is shown in Figure 4. The use of water body, forest, shrub, and non-irrigated field were predicted will change into other form, this will decrease the extent in 2030. Compared with 2016, the extent of forest and shrub decrease each 108 Ha (29% of watershed) and 5,081 Ha (38%). Meanwhile, rice fields, settlements, and plantation were predicted will increasing in extent. The plantation increase into 4,446 Ha or increased proportionally into 24 % of the extent of the watershed in 2016. The settlement was predicted will be the most extensive change of 6,292 Ha or increase the proportion 50% of the extent of settlement in 2016.

Tabel 2. Land Use change between 2016 and 2030.

No.	Land Use	2016	2030	Change	
		Hectares	Hectares	Hectares	%
1	Water body	2,487	2,440	-47	-2%
2	Forest	28,111	20,003	-8,108	-29%
3	Plantation	18,235	22,681	4,446	24%
4	Settelments	12,625	18,917	6,292	50%
5	Rice Fields	49,585	53,419	3,834	8%
6	Shurb	13,547	8,466	-5,081	-38%
7	Non-irrigated fields	14,219	12,883	-1,336	-9%
Total area		138,809	138,809		

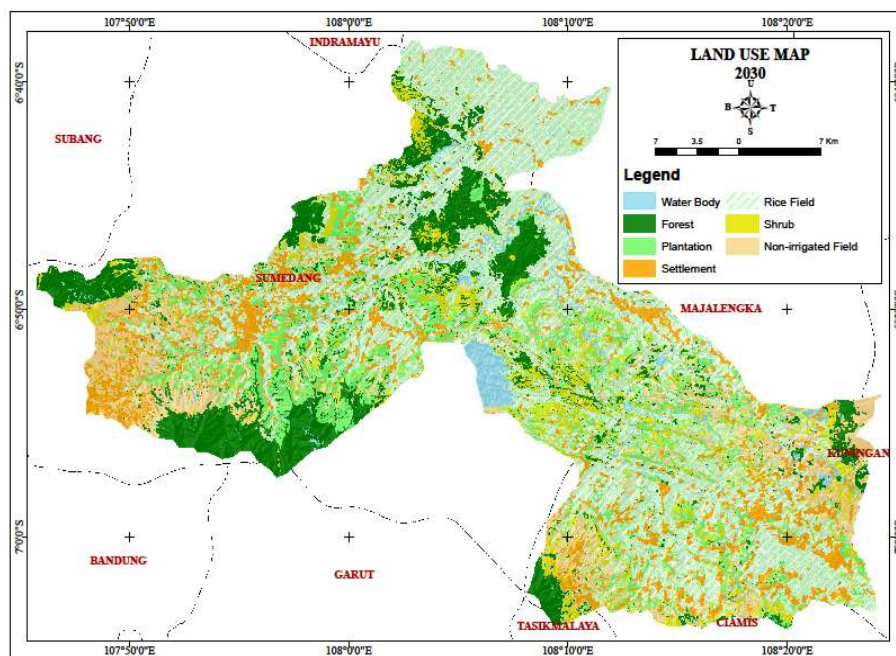


Figure 5. Land Use Change in Cipeles and Cilutung Watershed Map year 2030.

3.4. Model of Soil Erosion and the Sediment yield

Table 3 shown the summary of WATEM-SEDEM model results. Along with prediction of LUC, total of sediment yield in study area in 2016 was 10.51×10^6 tons, increased almost 24.38% from the LUC in 2010. The modeling results show that in 2030 total production of sediment yield predicted will be 13.1×10^6 ton, increase about 2.6×10^6 ton from year 2016. Most of sediment yield (75%) was deposit in the watershed and only 12% drifted by Cipeles and Cilutung River. The low value of sediment delivery ratio (SDR) affected by geomorphology of watershed [14]. Along with the increase of sediment production, the sediment yield that drifted by Cipeles and Cilutung river were also increasing. In 1990 total of drifted sediment was 454,269 ton and increased into 1,225,726 tons in 2016 and predicted will be around 1,542,140 tons in 2030.

Tabel 3. Summary of the WATEM/SEDEM model results.

WATEM/SEDEM output	1990 (ton/year)	2000 (ton/year)	2010 (ton/year)	2016 (ton/year)	2030 (ton/year)
Total sediment production	4,832,039	6,925,720	8,450,038	10,510,259	13,095,628
Total sediment deposition	3,705,019	5,092,698	6,317,254	7,854,479	9,818,185
Total sediment export	1,127,020	1,833,022	2,132,784	2,655,780	3,277,443
Total River export	454,269	820,642	1,007,341	1,225,726	1,542,140

3.5. Spatial Distribution of Soil Erosion and Sediment Deposition

The percentage of deposition in Cipeles and Cilutung watershed tends to increased (Table 4). Area with level of deposition 10 tons/Ha per year (classified as high – severe) has increased significantly. In 1990 the proportion was only 11% of the watershed, increased into 18% in 2016 and predicted will be 20% of the watershed in 2030. Spatially, the area with deposition category high and severe found in non-irrigated fields, plantation, and rice fields. This is because the management of non-irrigated fields, plantation, and rice field causes the capacity of soil particle transportation had become higher.

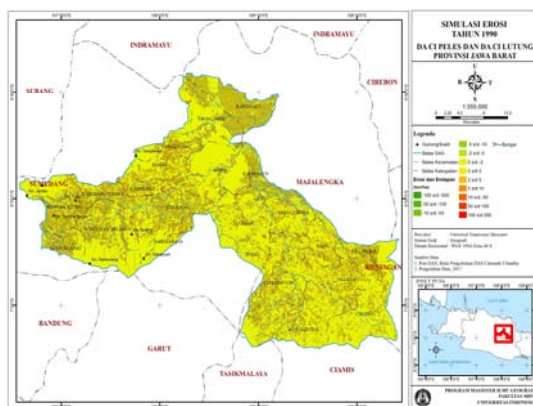
Tabel 4. The deposition classification.

Deposition rate (ton/ha/year)	Deposition classes	Coverage of the deposition affected area (%)				
		1990	2000	2010	2016	2030
0 s/d 2	Very Slight	1.84	2.36	2.53	2.70	2.84
2 s/d 5	Slight	0.06	0.09	0.11	0.14	0.19
5 s/d 10	Moderate	3.79	5.01	5.38	5.76	6.06
10 s/d 50	High	8.24	11.12	12.17	13.54	14.57
50 s/d 100	Severe	2.63	3.31	3.75	4.47	5.10
100 s/d 500	Very severe	0.06	0.08	0.11	0.13	0.19

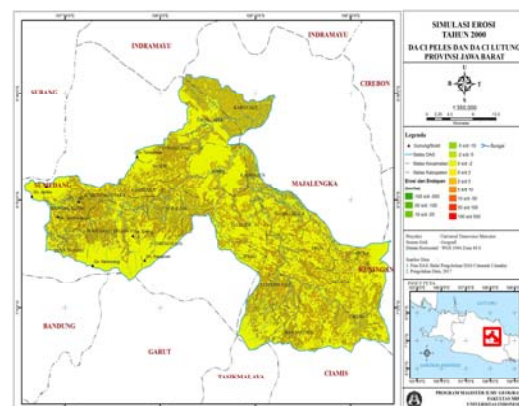
Based on the erosion rate, study area dominated with the slight erosion class (less than 2 tons/Ha per year). However, along with LUC, the slight erosion class will getting smaller. In 1990 the proportion was 66% of the watershed, but in 2016 became 46% and predicted will be 41% in 2030. The decreasing of slight erosion class was followed by the increasing of area with level of erosion more than 10 tons/Ha per year (classified as high to severe). In 1990, it was only 9.6% of the watershed and will increasing into 17.3% in 2030. The more extensive erosion area with high to severe classification was due to the decreasing of forest and shrub area, converted into non-irrigated field.

Tabel 5. Soil erosion classification.

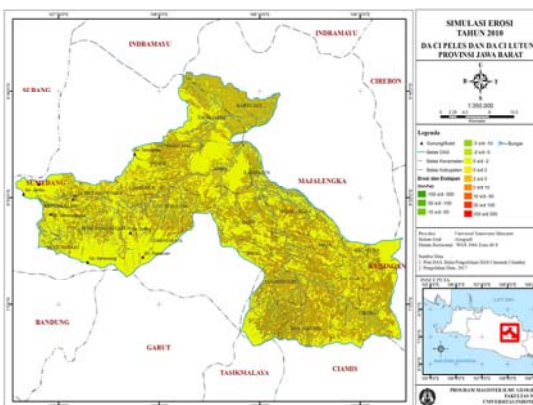
Erosion rate (ton/Ha/year)	Erosion classes	Coverage of the erosion affected area (%)				
		1990	2000	2010	2016	2030
-100 s/d -500	Very severe	0.48	0.60	0.70	0.89	1.11
-50 s/d -100	Severe	1.81	2.29	2.58	3.10	3.47
-10 s/d -50	High	9.63	12.90	14.29	15.82	17.27
-5 s/d -10	Moderate	5.03	6.55	7.00	7.42	7.77
-2 s/d -5	Slight	0.05	0.08	0.10	0.13	0.18
0 s/d -2	Very Slight	66.36	55.60	51.28	45.91	41.27



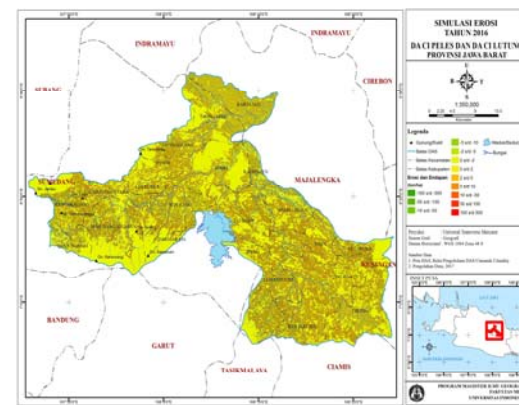
(a)



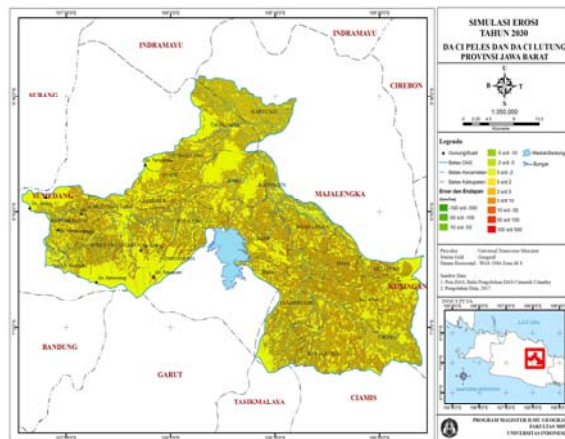
(b)



(c)



(d)



(e)

Figure 6. Erosion/deposition in Cipeles and Cilutung Watershed Map (a) 1990 (b) 2000 (c) 2010 (d) 2016 (e) 2030.

4. Conclusions

The land use change model using integration of Markov-Cellular Automata method with business as usual scenario, had been done successfully in Cipeles and Cilutung watershed. The LUC period from 1990 to 2016 showed that there were decreasing in forest and shrub area up to 5% every 10 years. Its commonly change into rice field, settlement, non-irrigated field, and plantation. These were caused by the increasing of human demand of field and settlement. The prediction of soil erosion and sediment yield in Cipeles and Cilutung watershed tend to increase every year due to the LUC. Spatial distribution showed that area with high erosion and sediment yield were in forest and shrub area which changes into non-irrigated field because the non-irrigated field is the source of soil erosion.

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