JOURNAL OF DEGRADED AND MINING LANDS MANAGEMENT
Volume 9, Number 2 (January 2022):3293-3305, doi:10.15243/jdmlm.2022.092.3293
ISSN: 2339-076X (p); 2502-2458 (e), www.jdmlm.ub.ac.id

Research Article

Spatial and temporal distribution of estimated surface runoff caused by land use/land cover changes in the upstream Citarum watershed, West Java, Indonesia

Fajar Yulianto[1*], Muhammad Rokhis Khomarudin[1], Eddy Hermawan[2], Nunung Puji Nugroho[3], Galdita Aruba Chulafak[1], Gatot Nugroho[1], Udhi Catur Nugroho[1], Suwarsono[1], Hana Listi Fitriana[1], Eko Priyanto[3]

[1] Remote Sensing Application Research Center, Aeronautics and Space Research Organization (LAPAN), National Research and Innovation Agency (BRIN), Jl. Kalisari No. 8, Pekayon, Pasar Rebo, Jakarta 13710, Indonesia.
[2] Atmospheric Science and Technology Research Center, Aeronautics and Space Research Organization (LAPAN), National Research and Innovation Agency (BRIN), Jl. Dr. Djunjunan No. 133, Bandung, 40173, Indonesia.
[3] Technology Research and Development Center for Watershed Management. Ministry of Environment and Forestry (KLHK), Jl. Jenderal Ahmad Yani-Pabelan P.O. Box 295 Kartasura Surakarta, Central Java 57102, Indonesia.

[*]corresponding author: fajar.lapan.rs@gmail.com, fajar.yulianto@lapan.go.id

Article history:
Received 15 September 2021
Accepted 26 November 2021
Published 1 January 2022

Keywords:
GIS
hydrology
land use/ land cover
remote sensing
surface runoff

Abstract

In Indonesia, flooding is one of the natural hazards that often occurs during the rainy season. Surface runoff coefficient values are an essential indicator of the supply of regional water resources. The smaller the surface runoff value, the greater the water storage in the ground, and the smaller surface was running water. This study analyses the spatial and temporal distribution of the estimated surface runoff caused by land use/land cover changes in the upstream Citarum watershed. The study area is located in the upstream Citarum watershed, West Java, Indonesia. The site has a long history of flooding and various complex environmental problems. The geographic Information System method was used as a tool in analyzing the spatially and temporally. The research result shows that there has been a change in land cover in several periods of the year in the Citarum upstream watershed. The occurrence of the LULC phenomenon positively affects the surface runoff coefficient. The increasing area of Built land and plantation in the Citarum upstream watershed will further increase the surface runoff coefficient and, in the end, will potentially increase the surface runoff and contribute to flooding in the Bandung basin. This study results can be used to provide input in determining the direction and policies for watershed management, taking into account the varying characteristics of each subwatershed.

To cite this article: Yulianto, F., Khomarudin, M.R., Hermawan, E., Nugroho, N.P., Chulafak, G.A., Nugroho, G., Nugroho, U.C., Suwarsono, Fitriana, H.L. and Priyanto, E. 2022. Spatial and temporal distribution of estimated surface runoff caused by land use/land cover changes in the upstream Citarum watershed, West Java, Indonesia. Journal of Degraded and Mining Lands Management 9(2):3293-3305, doi:10.15243/jdmlm.2022.092.3293.

Introduction

Flood is the most destructive natural hazard in the world. It adversely impacts the environment and human life, especially in flood-prone areas, causing environmental, societal, and economic losses such as water pollution, crop failure, casualties, health problems due to water-borne and vector-borne diseases, infrastructure damages (e.g., buildings, roads, power supplies, telecommunications), and economic activity disruption (Rosyidie, 2013; Bubeck

et al, 2017; Kheradmand et al., 2018; Sholihah et al., 2020; Merz et al., 2021). It was estimated that around 21 million people are affected by river floods worldwide annually, and the number can increase to 54 million people in 2030 due to climate change and socio-economic development (Ward et al., 2013; Winsemius et al., 2013; Luo et al., 2015). However, flood events have also beneficial impacts, especially to the farmers in the floodplain regions who depend on the recurring floods that carry nutrients and sediments, thus enriching the soil for agriculture activities (Bubeck et al., 2017). There are two main categories of flood damages, i.e., tangible (market goods) and intangible (nonmarket goods) damages (Bubeck et al., 2017; Kheradmand et al., 2018). The tangible flood damages, which can be assessed and commonly expressed in monetary values, are classified into two types of damages, i.e., direct (physical impact of floodwaters) and indirect damages (societal impacts outside of the flood zone). Dutta et al. (2003) divided direct and indirect damages into primary and secondary damages.

Flooding can occur due to increasing or high water volume levels that fall to the surface and overflow from water bodies such as rivers, lakes, reservoirs and others (Yulianto et al., 2015). Flood hazards are determined by the atmospheric process (rainfall intensity) and human-induced land surface (overland flow/surface runoff and flood waves in the river networks) (Merz et al., 2021). The occurrence of floods is caused by natural conditions and phenomena (topography, rainfall), geographical conditions of the area, and human activities that have an impact on spatial planning and land-use/land cover (LULC) changes (Rosyidie, 2013). Land-use change/land cover (LULC) results from a long process of interaction, balance and dynamic conditions between human activities on land that has limitations in environmental conditions. LULC conditions in the watershed significantly influence water balance, water quality and organisms in the environment (Dewan and Yamaguchi, 2009; Hassan et al., 2016; Mishra et al., 2020). LULC change, which is a dynamic and complex process caused by natural and anthropogenic factors (Yesuph and Dagnew, 2019), affects surface runoff generation and climate change can increase rainfall intensity, thus determining the flood risk level within the catchment (Merz et al., 2021). In hydrology, surface runoff coefficient values can be used as the most critical indicator in the supply of regional water resources. The smaller the surface runoff value, the greater the water storage in the ground. It means that the region's hydrological system is in the right conditions (Mikoš et al., 2004; Zheng et al., 2016). In addition to LULC conditions, surface runoff is also influenced by river networks, catchment morphology and topography. Deforestation, overgrazing and urbanization can increase surface runoff due to the reduction in interception capability and soil infiltration rate. Some literature also shows that an increase in vegetation cover can significantly increase an area's water storage and infiltration capacity (e.g., Fernandes et al., 2004; Guse et al., 2015; Pradiko et al., 2015; Remondi et al., 2016).

In Indonesia, flooding has been the most frequent natural disaster in the last two centuries. From 1815 to 2019, there were 10,438 flood events, constituting 31% of the total disasters, with 21,932 casualties (8% of the total) (Fitriyani et al., 2021). In 2020, 1,518 flood occurrences were recorded across Indonesian regions, causing 132 deaths and displacing 782,054 people (BNPB, 2021). Based on the analysis of using Aqueduct Flood Analyzer, there are around 635,000 Indonesian people exposed to floods annually, causing Indonesia to rank 6th in the world's largest population affected by flood each year (Luo et al., 2015). High flood occurrences are closely related to watershed degradation (Noordwijk et al., 2017). LULC change, mainly from vegetated cover to built-up area, is the main cause of environmental quality degradation that affects the hydrological characteristics of a watershed (Husodo et al., 2021). Coupled with climate change that triggers high rainfall intensity, LULC change is the key factor in the increasing flood events in Indonesia, particularly in the degraded watersheds. The upstream Citarum Watershed, one of the national priority watersheds, has a long history of flood events (Muin et al., 2015). Previous studies found that LULC change (vegetated cover to built-up land) contributes significantly to the frequent flood occurrences in the upstream Citarum Watershed (e.g. FRosyidie, 2013; Fernandos et al., 2020; Tanika et al., 2020; Yulianto et al., 2020; Atharinafi and Wijaya, 2021; Fadhil et al., 2021; Husodo et al., 2021).

Several studies reported that the built-up land in the upstream Citarum Watershed has decreased significantly. Fadhil et al. (2021) found that during 2009-2018 the built-up land in the upstream Citarum Watershed increased 11,305 ha or 39.7% while the forest cover reduced by around 1,611 ha (5.5%). Husodo et al. (2021) reported that the vegetated cover land in the upstream Citarum Watershed decreased around 35% within 1989-2019. Another study by Yulianto et al. (2020) found that between 1990 to 2016 the extent of urban/built-up area increased by more than 11.000 ha. However, Atharinafi and Wijaya (2021) found that the most significant LULC change in the Cirasea Sub-watershed (part of the upstream Citarum Watershed) between 1999 and 2018 was the conversion of forested land to non-forested land, especially to upland agriculture; whilst the urban expansion was limited. The LULC change results in the increase of surface runoff coefficient from 70.98 in 1999 to 72.04 in 2018. A recent simulation study (2019-2028) indicated that the surface runoff would increase by 1% (of the total rainfall) for every 4,700 ha conversion of vegetated cover to open land (Tanika et al., 2020). Unfortunately, the previous study on the impact of LULC changes on surface runoff in the upstream Citarum Watershed is limited (Atharinafi

and Wijaya, 2021). The availability of remote sensing data can be used to extract LULC classes used to estimate the surface runoff coefficient value. Meanwhile, GIS-based can be used as a tool for spatial mapping and modeling surface runoff distribution. Integrating remote sensing and GIS is a powerful and valuable tool in estimating surface runoff (Zheng et al., 2016; Ahiablame et al., 2017). The novelty of this research is a surface run-off prediction model based on land cover change prediction. In this model, LULC is the main parameter, which reflects the land surface condition, and provides a response in determining the size of the surface run-off. In this model, the LULC parameter, can be described spatially and historically analyzed from multitemporal medium resolution remote sensing image data. This study aimed to assess the spatial and temporal distribution of surface runoff coefficient value based on LULC change dynamics in the study area.

Materials and Methods

Study area

The study area is located in the upstream Citarum Watershed, West Java, Indonesia, which is the catchment area of Saguling Reservoir. Citarum Watershed is one of the national priority watersheds to restore (Tanika et al., 2020; Yulianto et al., 2021). The study area has various complex environmental problems (Muin et al., 2015; Yulianto et al., 2019). Complex issues in the study area occur due to increasing population pressure. One manifestation of population pressure has led to land conversion. LULC change is a significant problem causing an increase in built-up land and a reduction in water catchment land, causing an increase in surface runoff, river flow during the rainy season, and flooding (Yulianto et al., 2019). Upstream Citarum watershed is a landscape area in the form of a sedimentation basin surrounded by hills and mountains. This watersehed is divided into eight sub-watersheds. Sub watershed Cihaur, Cikapundung, and Cikeruh are in the north. Sub watershed Ciwidey, Cisangkuy, and Cirasea are in the soiuth. Sub watershed Citarik is in the East and sub watershed Ciminyak is in the West. Each subwatershed has variations in land cover variation, both in type, area and time or changes. This variation will of course affect the contribution of each subwatershed to the increase in the surface runoff coefficient.

Geographically, the upstream Citarum Watershed, with an elevation ranging from 768 to 2284 m above sea level, is situated between $107^0 30'$-$108^0 00'$ E longitude and $6^0 43'$-$7^0 15'$ S latitude (Yulianto et al., 2018). It has a total area of about 228,109 hectare and consists of eight sub-watersheds, i.e., (1) Citarik, (2) Cirasea, (3) Cisangkuy, (4) Cikapundung, (5) Ciwidey, (6) Ciminyak, (7) Cikeruh, and (8) Cihaur. Administratively, the study area encompasses Bandung Regency, Bandung City, Cimahi City, and Sumedang City. The soil types in the study area are Inceptisols (80% of the total area) and Ultisols (20%) (Tanika et al., 2020). The upstream Citarum Watershed, known as Bandung Basin, has the Am climate type, characterized by one or more dry months annually (Nahib et al., 2021). A map of the study area is presented in Figure 1.

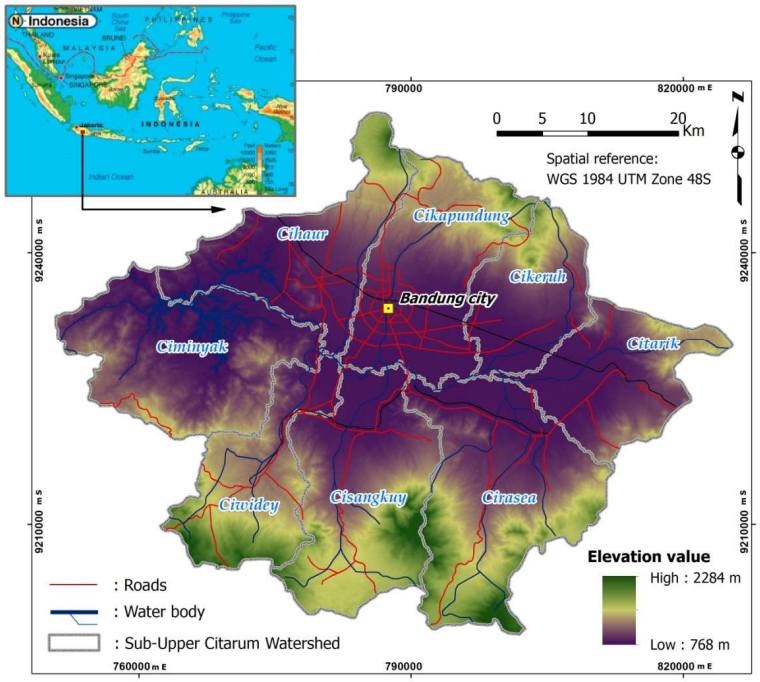

Figure 1. The study area is located in the upstream Citarum, West Java, Indonesia.

Data availability

The multi-temporal LULC data from the year 1990 to 2016 (Figure 2) and its predictions from the year 2025 to 2050 (Figure 3) were obtained from research conducted by (Yulianto et al., 2019; Yulianto et al., 2020). Multi-temporal Landsat data that have a resolution of 30 m were used to input LULC information classification. Landsat data at Level 1 Geometric (L1G) with the sensor TM, ETM+ and OLI/TIRS were used to input LULC in 1990, 1996, 2000, 2003, 2009, and 2016. LULC information from 1990 to 2016 has been classified based on the Maximum Likelihood approach. LULC predictions from 2025 to 2050 have been made based on the Cellular Automata-Markov model (CA-Markov) approach. There are 7 (seven) classes for LULC information was used in this study (Table 1), namely: 1: Built land, 2: Primary forest, 3: Secondary forest and mixed garden, 4: Plantation, 5: Wet agricultural land, 6: Dryland farming, 7: Waterbody.

Land use/ land cover change analysis

The land change modeler in IDRISI software has analyzed LULC changes in various classes from 1990 to 2016. The analysis was carried out to evaluate the transition from one type of LULC to another kind. Furthermore, LULC changes were assessed by gains and losses by different classes. Based on this analysis, it is used to predict the LULC pattern based on previous changing trends.

Table 1. LULC descriptions and surface runoff coefficient were used in this study (Source and modified from Yulianto et al., 2019; Yulianto et al., 2020; and surface runoff coefficient summarised from Schwab et al. 1981; Alijani et al., 2016).

Class	LULC type	Description	Surface runoff coefficient value
1	Build land	It consists of residential, commercial, industrial areas, villages, settlements, transportation infrastructure, etc.	0.60
2	Primary forest	It consists of natural forests that have not been disrupted by human exploitation.	0.01
3	Secondary forest and mixed garden	It consists of industrial plantation forests and some garden plants, coconut, fruits and others.	0.03
4	Plantation	It consists of conservation land, tea plantation and others.	0.40
5	Wet agriculture land	It consists of many lands that require water for planting patterns, irrigated rice fields, rice terraces and others.	0.15
6	Dryland farming	It consists of land that requires little water for cropping, fields, moor and others.	0.10
7	Waterbody	It consists of all water sources, rivers, reservoirs, ponds and others	0.05

Surface runoff estimation

LULC data was used as a basis for spatial and temporal surface runoff estimates. The rational model belongs to the group of grouped hydrological models, which treat the analysis unit (usually a basin or a sub-basin) as a single element, the hydrological parameters (precipitation) of which are taken as average values (Diez-Herrero, 2009). The strength of this model lies in its simplicity and ease of implementation, which is why it is often used to calculate the peak surface runoff for the design of a wide variety of drainage structures (Bengtson, 2010). The rational model converts the precipitation in a catchment area into a runoff by determining the product of the precipitation intensity in the catchment area and its area, reduced by a runoff coefficient (C, between 0 and 1). The runoff coefficient, the most critical parameter in the rational model. The rational model is based on a number of assumptions, which include the following: the entire analysis unit is considered as a single unit, the rainfall is evenly distributed over the catchment area, the peak forecast runoff has the same probability of occurrence (return period) rain intensity (I), the runoff coefficient (C) is constant during the storm. Based on this reason, the rational model is appropriate for estimating surface runoff calculations on 8 sub-watersheds of the upstream Citarum watershed. Estimation of the calculation is carried out by applying the rational method based on Equation (1).

Furthermore, the LULC description and surface runoff coefficient value in Table 1 are used to add the multiplication area of each LULC with the amount of surface roughness for LULC type in the study area. The surface roughness value of each LULC lies between 0 to 1. A value of 0 in surface roughness can indicate no runoff, while 1 indicates maximum runoff. The surface runoff coefficient value can be obtained by tabulating the weight value of the coefficients of each LULC calculated based on Equation (2) (Schwab et al., 1981; Alijani et al., 2016).

$$Q = C * I * A \quad (1)$$

$$C = \frac{\sum A1*C1+A2*C2+A3*C3+\cdots+An*Cn}{\sum A1+A2+A3+\cdots+An} \quad (2)$$

Where Q is the peak flow in cubic meters per second. C is the surface runoff coefficient (weighted). I is the average rainfall intensity in meters per hour. A is the watershed area in square kilometres. $1, 2, 3, \ldots, n$ is the LULC class ID.

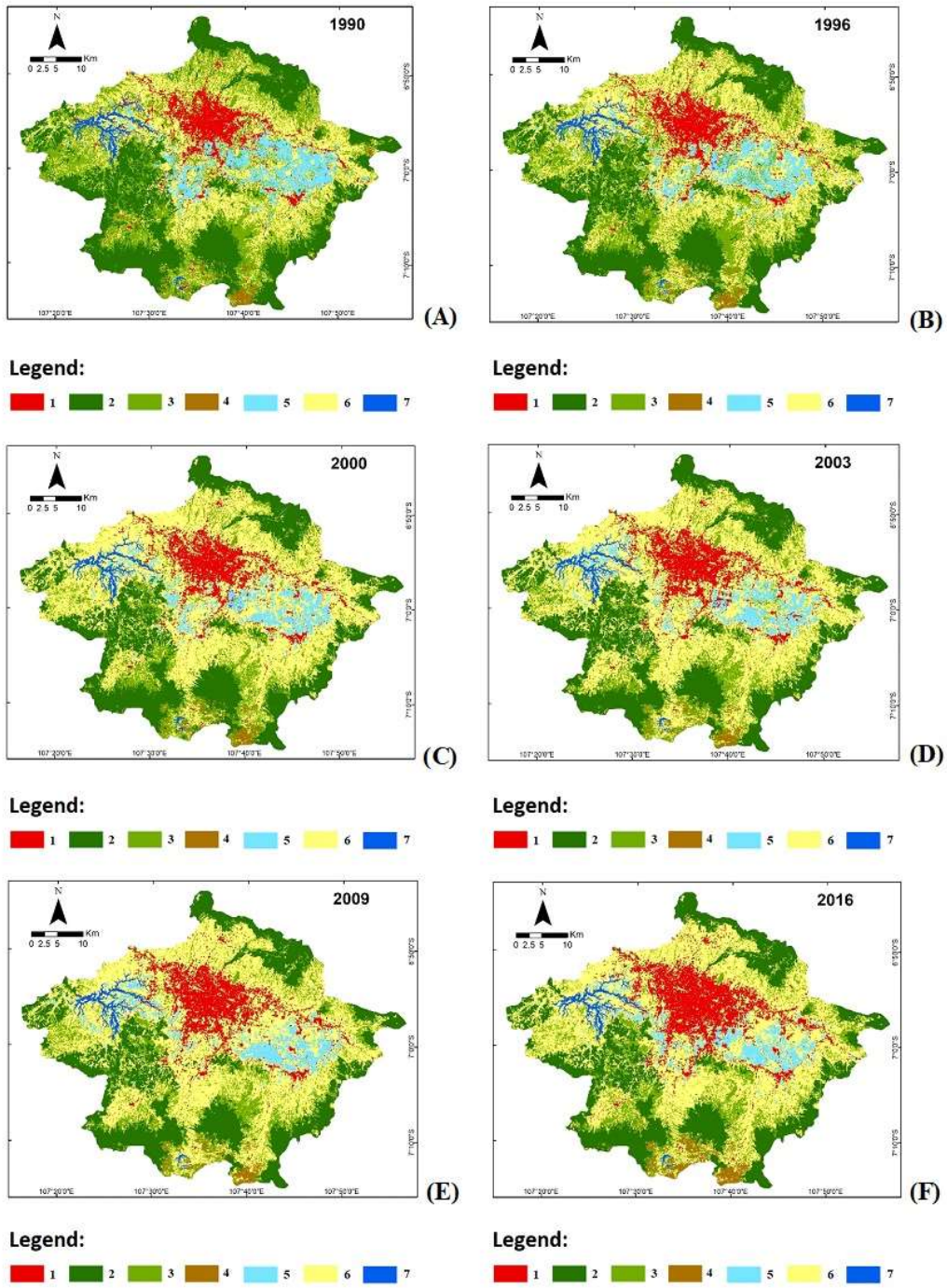

Figure 2. Multi-temporal LULC data and information from the year 1990 to 2016. (a) in 1990, (b) in 1993, (c) in 2000, (d) in 2003, (e) in 2009, (f) in 2016. Class ID for LULC 1: Built land, 2: Primary forest, 3: Secondary forest and mixed garden, 4: Plantation, 5: Wet agricultural land, 6: Dryland farming, 7: Water body (Source and modified from Yulianto et al., 2019; Yulianto et al., 2020).

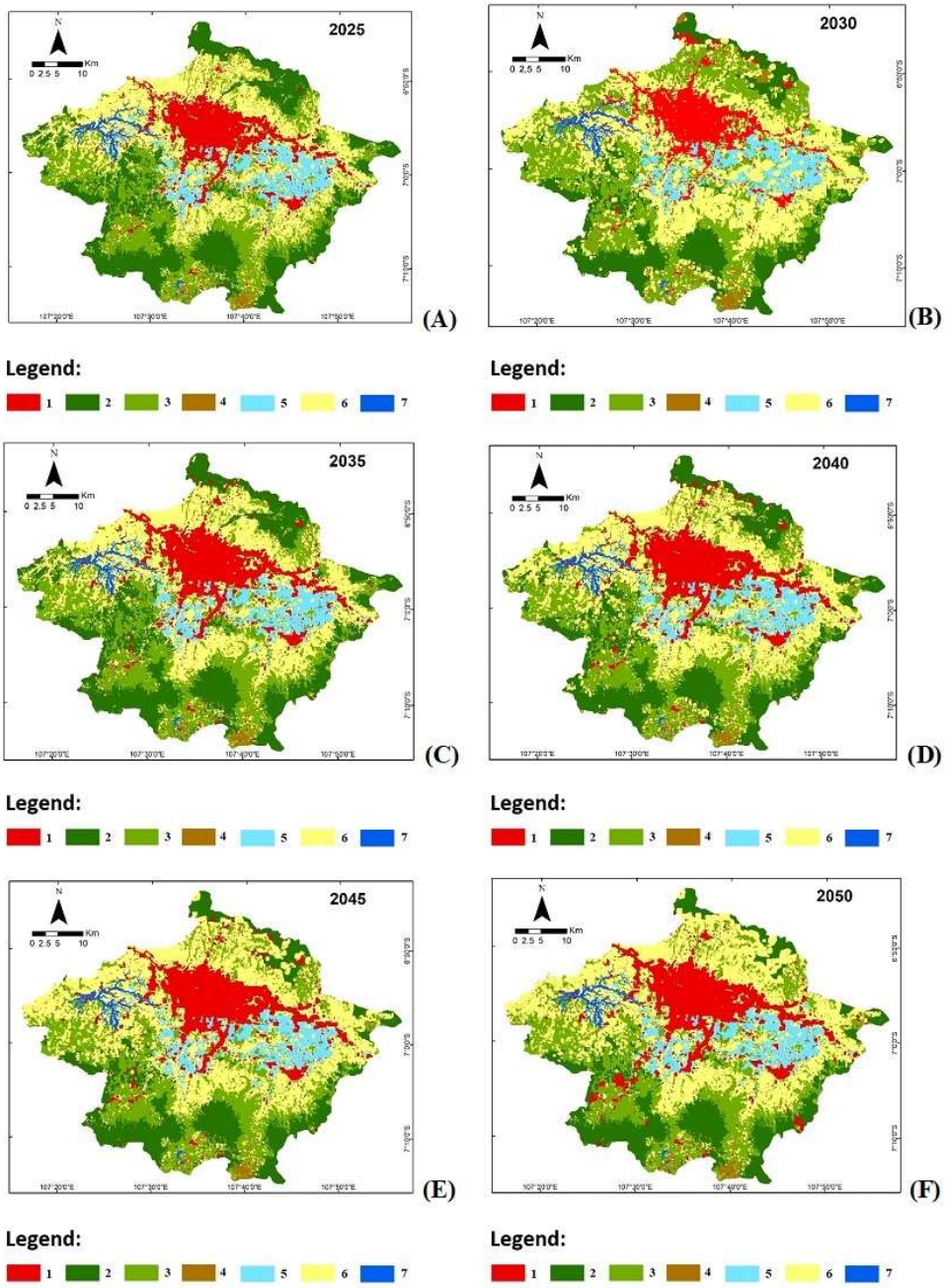

Figure 3. Prediction of the LULC data and information from the year 2025 to 2050. (a) in 2025, (b) in 2030, (c) in 2035, (d) in 2040, (e) in 2045, (f) in 2050. Class ID for LULC 1: Built land, 2: Primary forest, 3: Secondary forest and mixed garden, 4: Plantation, 5: Wet agricultural land, 6: Dryland farming, 7: Water body (Source and modified from Yulianto et al., 2019; Yulianto et al., 2020).

Results and Discussion

Land cover in the upstream Citarum watershed can be grouped into seven classes, namely build land, primary forest, secondary forest and mixed garden, plantation, wet agriculture land, dryland farming, and waterbody. Primary forest, secondary forest and mixed garden, wet agriculture land, dryland farming, and waterbody have a low surface runoff coefficient value. Plantation has a moderate surface runoff coefficient value, whereas built land has a high surface runoff coefficient value. Based on the interpretation and analysis of remote sensing images, there has been a change in land cover in the Citarum watershed, divided into several

periods, starting in 1990 (Yulianto et al., 2019; Yulianto et al., 2020). Figure 4 show gains and losses LULC change in the study area (in hectare), from period 1990 to 1996, 1996 to 2000, 2000 to 2003, 2003 to 2009, and 2009 to 2016 for every landcover class that is Built land, Primary forest, Secondary forest and mixed garden, Plantation, Wet agricultural land, Dryland farming, Waterbody. Based on the graph, it can be seen that in general there has been a change in land cover in several periods of the year.

In general, the Built land tends to increase in the area consistently over all periods. The increase in the built land area has occurred since the 2003-2009 period, with a sharp rise in 2009-2016. An increase in the area also happened at the plantation. The significant increase in plantation area occurred in 1990-1996 and 1996-2000, although it tended to be consistent in subsequent periods. The opposite phenomenon occurs; the Primary forest Secondary class and the forest and mixed garden class experienced a significant decline in all periods.

The LULC phenomenon's occurrence positively affects the surface runoff coefficient in each period (Figure 5). In this case, Built land and plantation are the two class that gives the most significant surface runoff coefficient value. Predictions of land cover conditions from 2025 to 2050 (Yulianto et al., 2019; Yulianto et al., 2020) will show a trend of changes in the surface runoff coefficient LULC (Figure 6). In this case, the increasing area of Built land and plantation will further increase the surface runoff coefficient and, in the end, will have the potential to increase the surface runoff. It is well known that the upstream Citarum watershed is divided into eight sub-watersheds (Cihaur, Cikapundung, Cikeruh, Ciminyak, Cirasea, Cisangkuy, Citarik and Ciwidey). Each subwatershed has variations in land cover conditions, both in type, area and changes. This situation affects the contribution of each subwatershed to the increase in the surface runoff coefficient. Figure 7 show the comparison results of LULC change's effect on the surface runoff coefficient distribution from 1990 to 2016 in the study area. Figure 8 show that the comparison results of LULC changes impact the surface runoff coefficient distribution from 2025 to 2050 in the study area.

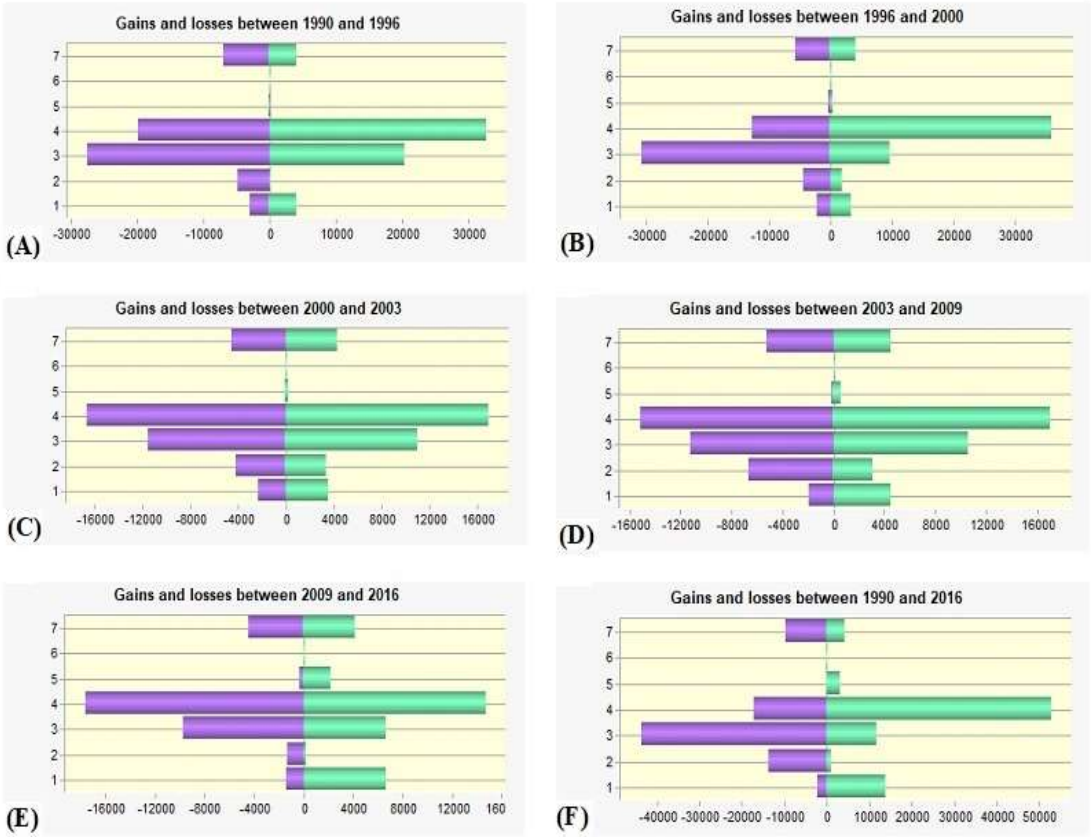

Figure 4. Gains and losses LULC change in the study area (in hectare). (a) 1990 and 1996, (b) 1996 and 2000, (c) 2000 and 2003, (d) 2003 and 2009, (e) 2009 and 2016, (f) 1990 and 2016. Class ID for LULC 1: Built land, 2: Primary forest, 3: Secondary forest and mixed garden, 4: Plantation, 5: Wet agricultural land, 6: Dryland farming, 7: Waterbody.

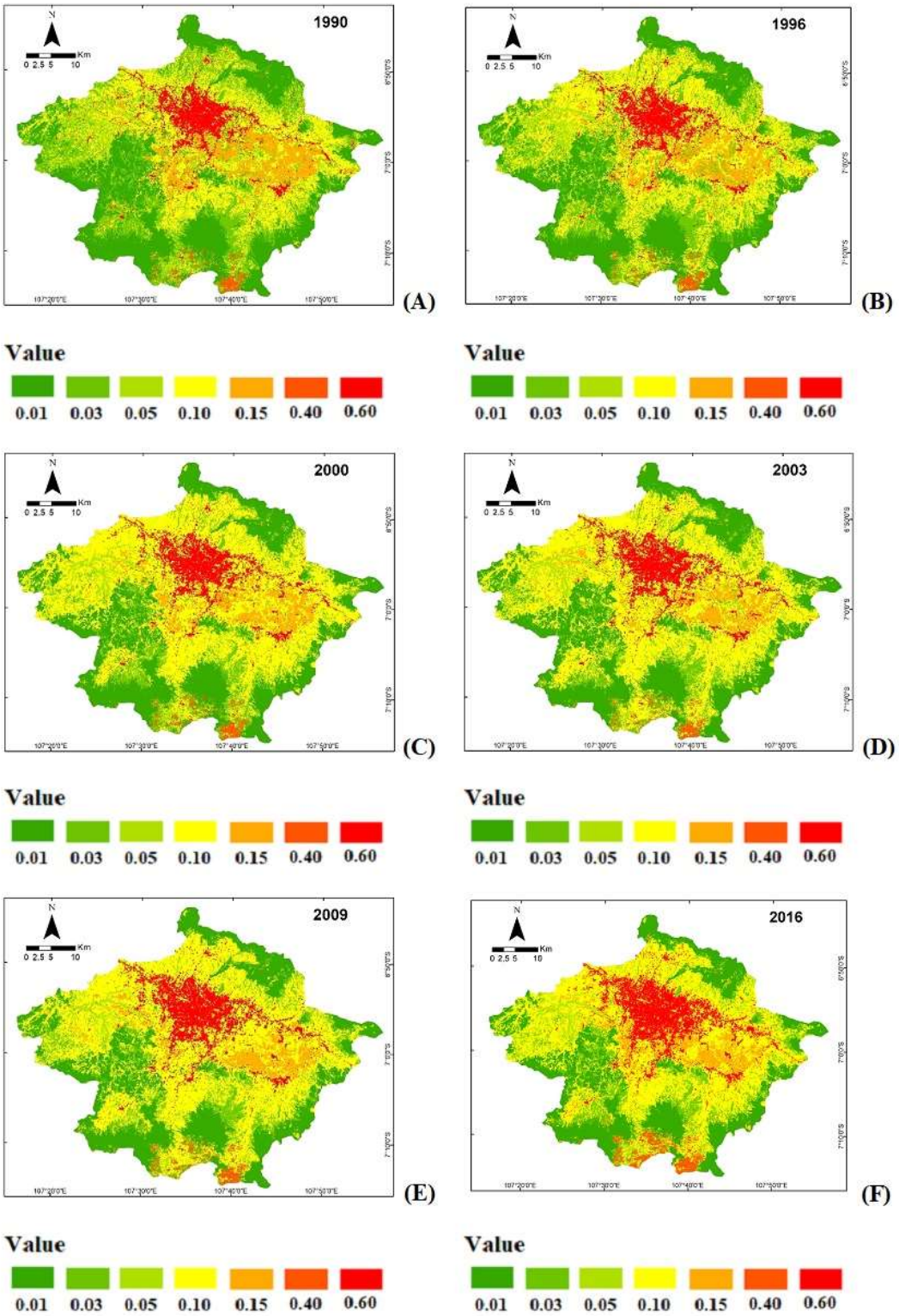

Figure 5. The estimated of surface runoff distribution in 1990 to 2016 were used in this study. (a) in 1990, (b) in 1996, (c) in 2000, (d) in 2003, (e) in 2009, (f) in 2016.

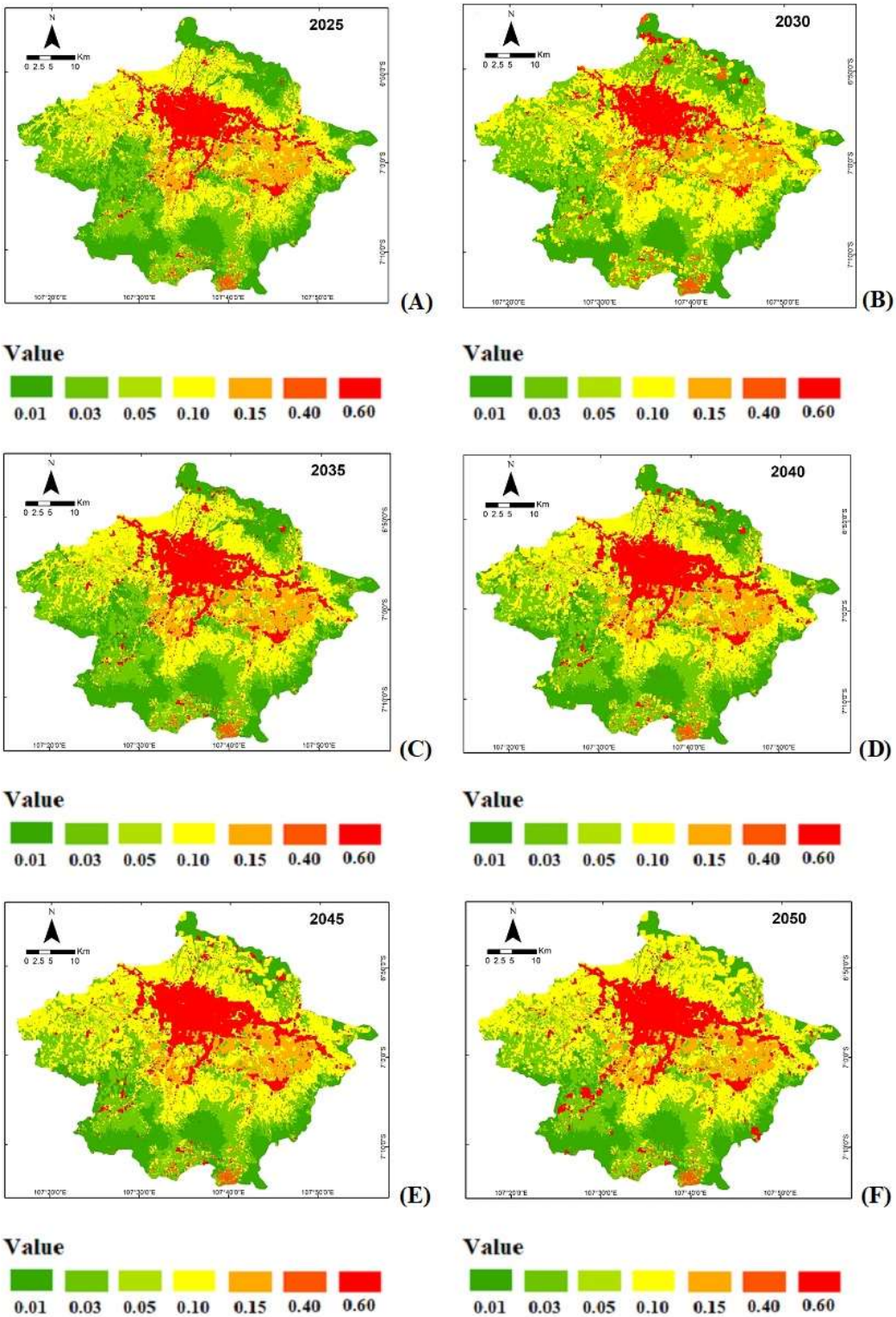

Figure 6. The estimated of surface runoff distribution in 2025 to 2050 were used in this study. (a) in 2025, (b) in 2030, (c) in 2035, (d) in 2040, (e) in 2045, (f) in 2050.

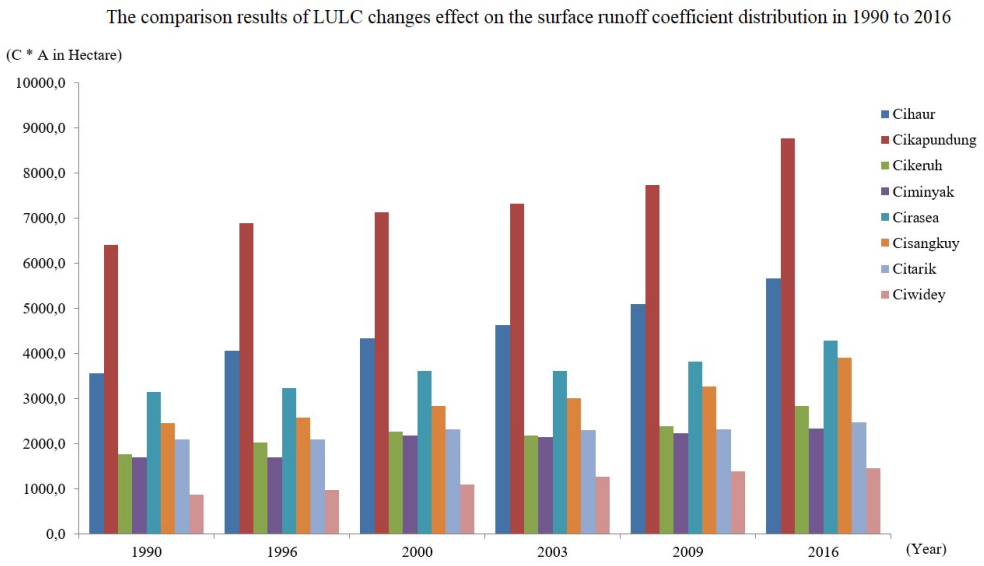

Figure 7. The comparison results of LULC changes effect on the surface runoff coefficient distribution in 1990 to 2016 in the study area.

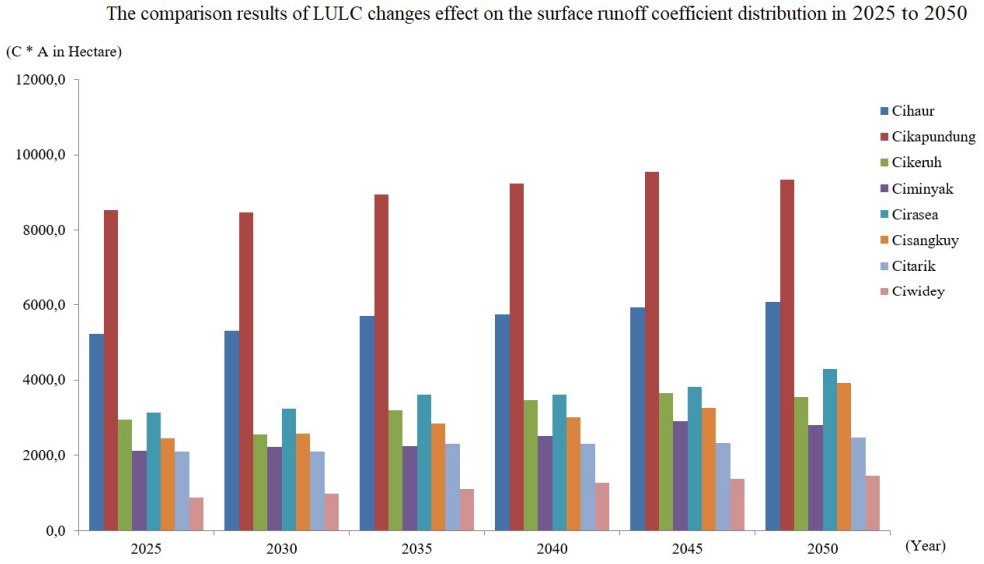

Figure 8. The comparison results of LULC changes effect on the surface runoff coefficient distribution from 2025 to 2050 in the study area.

LULC changes effect on the surface runoff coefficient distribution in 1990 to 2016 varies for each subwatershed. Furthermore, based on the predicted LULC 2025-2050, each sub-watershed contributes to different surface runoff coefficients. Cikapundung and Cihaur are two sub-watersheds that can significantly contribute to the increase in surface runoff. This condition is because these two sub-watersheds cover areas of concentration of settlements (Bandung City and Cimahi City), which have the largest land area and have increased massively.

Based on geographic position, most surface runoff from sub-watershed Cihaur will enter the Saguling reservoir system and flow on the surface of

densely populated residential areas (urban) in Cimahi City. While the surface runoff originated from the Cikapundung sub watershed, most will float on the surface of densely populated residential areas (urban) in Bandung City. This condition causes Bandung City and Cimahi City to receive abundant surface runoff during high rain intensity.

Cisangkuy and Cirasea sub watershed, although the contribution to the increase in surface runoff is still Cikapundung and Cihaur, the total potential surface runoff generated will always significantly contribute to the increase in surface runoff. These two areas are the southern part of the Citarum watershed area, with dynamic land cover changes and a broad surface runoff increasing trend. Geographically, the resulting surface runoff will flow to Bandung basin areas that are geomorphologically and historically the most prone to flooding. Most flood-prone sites are in Rancaekek, Bojongsoang, Solokan Jeruk, Ciparay, Cileunyi, Bale Endah and Cikancung. The area geographically or naturally is a water habitat area (Yulianto et al., 2019). Similar results have also been noted by Atharinafi and Wijaya (2021) who analyze land use change and its impacts on surface runoff in sub watershed Cisarea. Much of LULC change in Cisarea sub watershed has mostly been caused by deforestation.

For other sub-watersheds, the contribution to the increase in surface runoff is still under Cikapundung, Cihaur, Cirasea and Cisangkuy, in terms of the total potential that can be generated, it will even contribute to the increase in surface runoff. The subwatershed also has a reasonably dynamic land cover change and an increasing trend of surface runoff. Different watershed management is required to consider each subwatershed's varying characteristics in terms of area, type of land cover, growth movement and geographical position within the watershed upstream unit of Citarum. This study's results can be used to provide input in determining the direction and policies for watershed management. Atharinafi and Wijaya (2021) propose agroforestry as an implementation of afforestation and reforestation plans, as proposed by RTRW Kabupaten Bandung 2016-2036. Another comprehensive watershed management effort is education and community development to develop non-agricultural economic activity in order to stem deforestation (Rohman, 2014), and integrating built, engineered runoff/flood control works in addition to land-use control (Rosyidie, 2013). The watershed management strategy ultimately leads to improving land cover conditions that have a low surface runoff coefficient so that they will be able to control the increase in surface runoff.

Conclusion

There has been a change in land cover in several years in the Citarum upstream watershed. In general, the Built land and plantation tends to increase in area over all periods. Opposite, the Primary forest Secondary class and the forest and mixed garden class experienced a significant decline in all periods. The occurrence of the LULC phenomenon positively affects the surface runoff coefficient in each period. In this case, Built land and plantation are the two class that gives the most significant surface runoff coefficient value. Predictions will show a trend of changes in the surface runoff coefficient due to LULC. In this case, the increasing area of Built land and plantation will further increase the surface runoff coefficient and, in the end, will have the potential to increase the surface runoff. Cikapundung and Cihaur are two sub-watersheds that can significantly contribute to the increase in surface runoff. The surface runoff originates from the Cikapundung and Cihaur sub-watershed. Most of it will flow on the surface of densely populated residential areas (urban) in Bandung City and Cimahi City. This condition causes Bandung City and Cimahi City to receive abundant surface runoff during high rain intensity. Cisangkuy and Cirasea sub watershed, two areas, are the southern part of the Citarum watershed area, with dynamic land cover changes. It has a massive surface runoff increasing trend and contributes to flooding in the Bandung basin. This study's results can be used to provide input in determining the direction and policies for watershed management, taking into account the varying characteristics of each subwatershed.

Acknowledgements

This paper is a part of the study activities entitled "Integration of Remote Sensing Data for Flood Impact Analysis, Environmental Management and Disaster Mitigation in the Citarum Watershed, West Java Province, Indonesia". The study was funded by the National Innovation System Research Incentive (INSINAS) of 2021, the Ministry of Research Technology, and the Higher Education Republic of Indonesia. Contract number: 13/INS/PPK/E4/2021.Thanks to colleagues at the Remote Sensing Application Center, LAPAN, for their discussions and suggestions. Remote Sensing Technology and Data Center, LAPAN to support the remotely sensed data. The authors thank the anonymous reviewers for their efforts and constructive comments, which have allowed us to improve the manuscript.

References

Ahiablame, L., Sinha, T., Paul, M., Ji, J.H. and Rajib, A. 2017. Streamflow response to potential land use and climate changes in the James River watershed, Upper Midwest United States. *Journal of Hydrology: Regional Studies* 14(August):150-166, doi:10.1016 /j.ejrh.2017.11.004.

Alijani, A., Ghadimvand, N.K., Aleali, M., Espahbod, M.R. and Meysami, A. 2016. Evaluating the amount of erodability and sedimentation by comparing sediment weight model and PSIAC experimental model (Case study: Lali Water Catchment, Khuzestan, Iran). *Open*

Journal of Geology 6(08): 692-702, doi:10.4236/ojg.2016.68053.

Atharinafi, Z. and Wijaya, N. 2021. Land use change and its impacts on surface runoff in rural areas of the Upper Citarum Watershed (Case study: Cirasea Sub-watershed). *Journal of Regional and City Planning* 32(1):36-55, doi:10.5614/jpwk.2021.32.1.3.

BNPB. 2021. Korban dan kerusakan menurut bencana (Data Informasi Bencana Indonesia). Retrieved from https://dibi.bnpb.go.id/kbencana/index. Accessed 1 November 2021.

Bubeck, P., Otto, A. and Weichselgartner, J. 2017. Societal impacts of flood hazards *Oxford Research Encyclopedia of Natural Hazard Science*.

Dewan, A.M. and Yamaguchi, Y. 2009. Land use and land cover change in Greater Dhaka, Bangladesh: Using remote sensing to promote sustainable urbanisation. *Applied Geography* 29(3):390-401, doi:10.1016/j.apgeog.2008.12.005.

Dutta, D., Herath, S. and Musiake, K. 2003. A mathematical model for flood loss estimation. *Journal of Hydrology, 277*(1):24-49. doi:10.1016/S0022-1694(03)00084-2.

Fadhil, M.Y., Hidayat, Y. and Baskoro, D.P.T. 2021. Perubahan penggunaan lahan dan karakteristik hidrologi DAS Citarum Hulu. *Jurnal Ilmu Pertanian Indonesia* 26(2):213-220, doi:10.18343/jipi.26.2.213.

Fernandes, N.F., Guimarães, R.F., Gomes, R.A.T., Vieira, B.C., Montgomery, D.R. and Greenberg, H. 2004. Topographic controls of landslides in Rio de Janeiro: Field evidence and modelling. *Catena* 55(2):163-181, doi:10.1016/S0341-8162(03)00115-2.

Fernandos, Tambunan, M.P. and Marko, K. 2020. Loss levels regarding flood affected areas in the upper Citarum Watershed. Paper presented at the IOP Conference Series: Earth and Environmental Science.

Fitriyani, J., Apriyadi, R.K., Winugroho, T., Hartono, D., Widana, I.D.K.K. and Wilopo, W. 2021. Characteristics of Indonesia's disaster history for the period 1815–2019 based on the number of disasters, deaths, exposures and house damage due to disasters. *PENDIPA Journal of Science Education* 5(3):322-327, doi:10.33369/pendipa.5.3.322-327 (*in Indonesian*).

Guse, B., Pfannerstill, M. and Fohrer, N. 2015. Dynamic modelling of land use changes impacts on nitrate loads in rivers. *Environmental Processes* 2(4):575-592, doi:10.1007/s40710-015-0099-x.

Hassan, Z., Shabbir, R., Ahmad, S.S., Malik, A.H., Aziz, N., Butt, A. and Erum, S. 2016. Dynamics of land use and land cover change (LULCC) using geospatial techniques: a case study of Islamabad Pakistan. *SpringerPlus* 5, Article number: 812 (2016), doi:10.1186/s40064-016-2414-z.

Husodo, T., Ali, Y., Mardiyah, S.R., Shanida, S.S., Abdoellah, O.S. and Wulandari, I. 2021. Perubahan lahan vegetasi berbasis citra satelit di DAS Citarum, Bandung, Jawa Barat. *Majalah Geografi Indonesia* 35(1):54-63, doi:10.22146/mgi.31217.

Kheradmand, S., Seidou, O., Konte, D. and Batoure, M.B.B. 2018. Evaluation of adaptation options to flood risk in a probabilistic framework. *Journal of Hydrology: Regional Studies* 19:1-16, doi:10.1016/j.ejrh.2018.07.001.

Luo, T., Maddocks, A., Iceland, C., Ward, P. and Winsemius, H. 2015. World's 15 countries with the most people exposed to river floods. Retrieved from https://www.wri.org/insights/worlds-15-countries-most-people-exposed-river-floods. Accessed 1 November 2021.

Merz, B., Blöschl, G., Vorogushyn, S., Dottori, F., Aerts, J. C. J. H., Bates, P., Bertola, M., Kemter, M., Kreibich, H., Lall, U. and Macdonald, E. 2021. Causes, impacts and patterns of disastrous river floods. *Nature Reviews Earth & Environment* 2(9):592-609, doi:10.1038/s43017-021-00195-3.

Mikoš, M., Četina, M. and Brilly, M. 2004. Hydrologic conditions responsible for triggering the landslide, Slovenia. *Engineering Geology* 73(3-4): 193-213, doi:10.1016/j.enggeo.2004.01.011.

Mishra, P.K., Rai, A. and Rai, S.C. 2020. Land use and land cover change detection using geospatial techniques in the Sikkim Himalaya, India. *Egyptian Journal of Remote Sensing and Space Science* 23(2):133-143, doi:10.1016/j.ejrs.2019.02.001.

Muin, S.F., Boer, R. and Suharnoto, Y. 2015. Flood modeling and flood financial loss analysis in upper Citarum watershed. *Jurnal Tanah dan Iklim* 39(2):75-84 (*in Indonesian*).

Nahib, I., Ambarwulan, W., Rahadiati, A., Munajati, L., Prihanto, Y., Suryanta, J., Turmudi, T. and Nuswantoro, A.C. 2021. Assessment of the impacts of climate and LULC changes on the water yield in the Citarum River Basin, West Java Province, Indonesia. *Sustainability* 13(7):3919, doi:10.3390/su13073919.

Noordwijk, M.v., Tanika, L. and Lusiana, B. 2017. Flood risk reduction and flow buffering as ecosystem services–Part 1: Theory on flow persistence, flashiness and base flow. *Hydrology and Earth System Sciences* 21(5):2321-2340, doi:10.5194/hess-21-2321-2017.

Pradiko, H., Arwin, Soewondo, P. and Suryadi, Y. 2015. The change of hydrological regime in upper Cikapundung Watershed, West Java Indonesia. *Procedia Engineering* 125:229-235, doi:10.1016/j.proeng.2015.11.033.

Remondi, F., Burlando, P. and Vollmer, D. 2016. Exploring the hydrological impact of increasing urbanisation on a tropical river catchment of the metropolitan Jakarta, Indonesia. *Sustainable Cities and Society* 20:210-221, doi:10.1016/j.scs.2015.10.001.

Rosyidie, A. 2013. Banjir: Fakta dan dampaknya, serta pengaruh dari perubahan guna lahan. *Jurnal Perencanaan Wilayah dan Kota* 24(3):241-249.

Schwab, G.O., Frevert, R.K., Barnes, K.K. and Edminster, T.W. 1981. *Soil and Water Conservation Engineering*. John Wiley Inc., New York.

Sholihah, Q., Kuncoro, W., Wahyuni, S., Suwandi, S.P., and Feditasari, E.D. 2020. The analysis of the causes of flood disasters and their impacts in the perspective of environmental law. Paper presented at the IOP Conference Series: Earth and Environmental Science.

Tanika, L., Lusiana, B. and Hendriatna, A. 2020. Simulation of the impact of land cover and climate change in the Upper Citarum Watershed using the GenRiver Model: Model calibration and sensitivity analysis. Working paper no. 309. Bogor, Indonesia: World Agroforestry (ICRAF) Southeast Asia Regional Program, doi:10.5716/WP20048 (*in Indonesian*).

Ward, P.J., Jongman, B., Weiland, F.S., Bouwman, A., van Beek, R., Bierkens, M.F.P., Ligtvoet, W. and Winsemius, H.C. 2013. Assessing flood risk at the global scale: model setup, results, and sensitivity. *Environmental Research Letters* 8(4):044019. doi:10.1088/1748-9326/8/4/044019.

Winsemius, H., Van Beek, L., Jongman, B., Ward, P. and Bouwman, A. 2013. A framework for global river flood risk assessments. *Hydrology and Earth System Sciences* 17(5):1871-1892, doi:10.5194/hess-17-1871-2013.

Yesuph, A.Y. and Dagnew, A.B. 2019. Land use/cover spatiotemporal dynamics, driving forces and implications at the Beshillo catchment of the Blue Nile Basin, North Eastern Highlands of Ethiopia. *Environmental Systems Research* 8(1):1-30, doi:10.1186/s40068-019-0148.

Yulianto, F., Maulana, T. and Khomarudin, M.R. 2019. Analysis of the dynamics of land use change and its prediction based on the integration of remotely sensed data and CA-Markov model, in the upstream Citarum Watershed, West Java, Indonesia. *International Journal of Digital Earth* 12(10):1151-1176, doi:10.1080/17538947.2018.1497098.

Yulianto, F., Nugroho, U.C., Nugroho, N.P., Sunarmodo, W. and Khomarudin, M.R. 2020. Spatial-temporal dynamics land use/land cover change and flood hazard mapping in the Upstream Citarum Watershed, West Java, Indonesia. *Quaestiones Geographicae* 39(1):125-146, doi:10.2478/quageo-2020-0010.

Yulianto, F., Sofan, P., Zubaidah, A., Sukowati, K.A.D., Pasaribu, J.M. and Khomarudin, M.R. 2015. Detecting areas affected by flood using multi-temporal ALOS PALSAR remotely sensed data in Karawang, West Java, Indonesia. *Natural Hazards* 77(2):959-985, doi:10.1007/s11069-015-1633-x.

Zheng, Z., Ren, J., Li, Y., Huang, C., Liu, G., Du, C. and Lyu, H. 2016. Remote sensing of diffuse attenuation coefficient patterns from Landsat 8 OLI imagery of turbid inland waters: A case study of Dongting Lake. *Science of The Total Environment* 573:39-54, doi:10.1016/j.scitotenv.2016.08.019.