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MODEL LAND COVER INDEX – PEAK DISCHARGE IN MANAGEMENT OF RIVER BASIN

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ABSTRACT: A change of the characteristic of a river basin's component could transform the behaviour of the basin as a whole. In some parts of Indonesia, the land-use changes from forest into settlement, industry, and farming increase the risk of flooding. Therefore, it is important to understand the correlation between the changes of various land uses and runoff discharge in a river basin. This study makes an attempt to formulate the relation between the land-use change indexes and run-off discharge, i.e. the correlation between the changes in the index of covered land in a river basin and the change in the peak run-off discharge. The peak discharge is computed with HEC-HMS software, developed by the Hydrologic Engineering Center (HEC) and US Army Corps of Engineers, which computes the run-off discharge from the precipitation. As for the land cover index (LCI), it is defined as the sum of the land-use index (LUI). The result of the case study in the Beringin river basin (Indonesia) shows the strong correlation between the change in the land cover index and the change in the run-off discharge with such a relation: $DQ = -4E - 05\ DLCI^2 + 0.0788\ DLCI + 6.6187$ or $DLCI = 0.25\ DQ^2 + 6.24\ DQ - 47.40$. DQ is defined as the change in the run-off discharge and DLCI is the change in the land cover index**.**

Keywords: Land-use change, Peak discharge, Land cover index

1. INTRODUCTION

A river basin is an area whose border is its highest topographical feature where falling precipitation will flow to a main river at certain points. As a natural ecosystem, it is a place where biophysical and hydrological processes take place as well as social and economic activities. The mechanism of an ecosystem in a river basin can be understood as natural rainfall acting as an input while river discharge (or run-off discharge) and erosion act as an output.

Flood and drought are basically the result of a distortion in the hydrological cycle. One of the causes of flooding is the decreasing amount of green space where the water can be absorbed. This is closely connected to the change in land use in a river basin. In natural conditions, surface run-off is approximately between 10 and 30 % of the annual rainfall while the infiltration rate can reach 50% of the annual rainfall. For developed land where the percentage of impervious surface can reach 75–100 %, surface run-off can increase to 65% [1].

The effect of land-use change on its resulting flood characteristics has been the subject of research for many years. In 1995, a model of run-off distribution was developed in the Mosel river basin in Italy. The parameters of the model were satellite imagery, digital terrain models, and digital maps. Two scenarios were implemented in this research, i.e. a rapidly developing urban area and all vegetation whose height was above 400 m was assumed to be dead. In both cases, the resulting flood was more severe as its volume increased significantly [2]. In another case, the change in the land use from a paddy field to unvegetated land also increased the flood volume and the percentage of the surface run-off volume, and caused the flood peak to arrive sooner [3]. These examples are in line with the work of Sarminingsih et al [4] who quantified the vulnerability of various land uses to flooding. Indeed, vegetated space such as agricultural farms had the lowest vulnerability while industrialized space was highly exposed to flooding.

A change of land use in a river basin can have a large impact on its surface run-off and flood discharge. A flood simulation conducted in the Nyando river basin [5] showed that the peak discharge in the basin underwent a significant increase, especially in the upstream area where the rate of deforestation was high. In that study, the peak discharge increased by 16% across all 14 subcatchments. In a scenario where the subcatchments consisted of 86% farmland and 5% meadow, the peak discharge increased by 14%, 13%, and 1% for rainfall intensities of 40 mm, 60 mm, and 80 mm, respectively. With those rainfall intensities, subcatchments consisting of 10% farming and 78% forest could increase the peak discharge by 27%, 26%, and 25%, respectively. This is consistent with the results of the simulation of the upper Citarum basin, which saw an increase in its flow duration curve during high flow due to the land-use change [6].

Ranzi et al [7] studied the effect of urbanization on the volume and timing of the flood peak in the Mella river basin in northern Italy. The study was based on two land-use maps, i.e. aerial photographs in 1954 and the interpreted photographs and a survey in 1994. Since 1954, the forest area had expanded by 9% in the upper basin because the firewood consumption had decreased. Meanwhile, the size of the urban area expanded by 252% as the size of the agricultural area and the meadowlands decreased. The consequence was that the surface run-off changed significantly in the catchment area, i.e. a significant drop in the flood's peak and volume (simulated by a distributed hydrological model). Such an outcome is expected as forestation increases infiltration and soil water retention potential [8].

The important hydrological effects of urbanization include: (1) increased water demand, often exceeding the available natural capacity; (2) increased waste water, polluting rivers and threatening the ecosystem; (3) increased peak discharge; (4) reduced infiltration, and; (5) reduced groundwater recharging rate with increased groundwater consumption and reduced river base flow [9]. The flood that hit Chennai's (India) urban area was caused by its increasing population, developing settlement, more paved areas, more waste disposal, a growing number of vehicles, increased water demand etc. The establishment of regulation and control would not be able to prevent urban development unless a proper flood prevention plan existed. The development and constructionthat had been performed would not be able to revert the landscape to its original form [10].

An increased flood risk also occurred in the upper catchment of the River Thames in London. Again, this was caused by the massive urbanization that took place between 1974 and 2000 [11]. There are many factors that have important implications for the future of land use in England that will eventually shape the long-term approach to flood management. They are about land utilization, and balancing economic, environmental, and social demand in such a way that the development will not worsen the risk of flooding. It is about managing the equilibrium between the government and the market in regulating the land-use plan [12].

In the approach to land-use management and flood hazard mitigation, one aspect that can be improved is the judgement of the flood risk temporally and holistically at catchment level. This will result in a more efficient approach as the change in land use in a catchment area can be assessed in a location that is vulnerable to flooding [13].

In 2009–2010, it was estimated that the damage caused by the flooding of the Meuse river (Belgium) could be 1.01–1.04 times greater than in the dry scenario. Urbanization is the only possible explanation as the 100 years return period flood discharge is not supposed to rise. Meanwhile, in the wet scenario, the damage could be 5.4–6.3 times greater with the influence of climate change, which is 3–8 times more influential than urbanization [14]. The study concluded that the projection of climate change is more dominant in affecting flood hazard than that of land-use change. This conclusion is also confirmed by a study of the Brahmaputra river (India), whose peak flow was estimated to increase by 28% due to climate change, much greater than the 9% due to land-use change [15]. In the Brussels-Capital Region, a research was also conducted to appraise how surface run-off corresponded to urbanization and climate change. The result of the simulation showed that change was detectable in the annual series of cumulative surface run-off high flows and the frequency of flood events when imperviousness exceeded 35% [16].

The interaction among vegetation, soil, and water (from rainfall) together with human intervention (through exploitation and management) forms a land-use characteristic in a river basin, thereby forming a classification of land use. The classification of land use is the categorization of the land into several groups to make it is easier to understand the characteristics of the land. In Indonesia, land-use classification as the basis for the mapping of land-coverage maps in a river basin is still not standardized. One of the references [17] of land cover classification is SNI 7645:2010, which is divided into two groups: vegetated area and non-vegetated area. The vegetated area comprises farm and non-farm areas. Meanwhile, the non-vegetated area comprises unused land, settlement, non-farm area, and water.A change in the characteristics of covered land in a river catchment could affect or even transform the whole system. Here, the definition of land-use change is not always necessarily from forest into farmland or settlement etc. In this article, the focus is on the correlation between the changes of peak discharge and the index of land-use change in a river basin.

2. METHOD

The land use in a river basin and its discharge are inseparable features. Therefore, the land cover index in a river basin is integrated with its run-off discharge. Both of them interact with and affect each other. Fig. 1 displays the computation process of the correlation between direct run-off and land covered in this study.

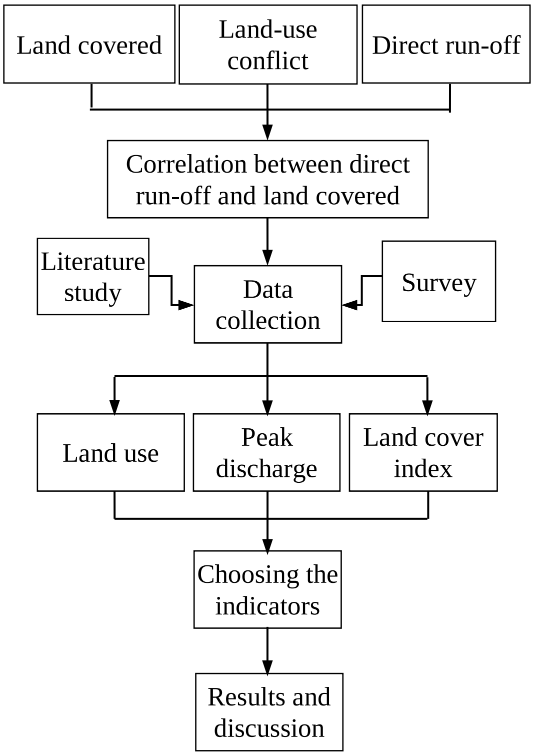

Fig. 1. Flow chart of the correlation between direct run-off and land covered.

2.1 Rainfall – run-off

An empirical approach is commonly used in the calculation of direct run-off, e.g. SCS CN (Soil Conservation Service – Curve Number). The SCS method calculates the effective rainfall using the CN variable, which is a function of river basin characteristics, i.e. land covered, land use, soil category, and humidity. A change in one of those components could potentially transform the characteristics of the river basin as a whole.

The SCS method is about the relation between rainfall and run-off. The total precipitation is classified into three components, i.e. direct run-off, actual retention, and initial abstraction. Equation (1) [18] [19] is the basic equation for calculating run-off (Pe), with P as the rainfall intensity, I_a as the initial abstraction, and S as the potential maximum retention. Meanwhile, Equation (2) shows the relation between the potential maximum retention (S) and the curve number (C):

$$P_e = \frac{(P - I_a)^2}{(P - I_a) + S} \tag{1}$$

$$S = \left(\frac{1000}{CN} - 10\right) x25.4 \text{ mm} \tag{2}$$

This study uses HEC-HMS software (which computes the run-off discharge from the precipitation. It is developed by the Hydrologic Engineering Centre (HEC) and US Army Corps of Engineers.

2.2 Estimating curve number

The curve number is an index that indicates the combination of the hydrologic soil group, land use, and land treatment. Empirically, *CN* is a function of soil classification, land covered, and humidity [19]. Equation (3) is applied to estimate the curve number in every subarea, with Ai as the total area of the specific land use (denoted as i) and CN_i being the curve number for the specific land use (i) in the subarea.

$$CN = \sum_{i=1}^{n} \frac{A_i CN_i}{\sum A_i} \tag{3}$$

2.3 Land cover index

The land cover index (LCI) of an area is defined as the sum of the land-use index (LUI). Meanwhile, the land-use index is the ratio of the area of i land use (Lu_i) divided by the area of i land use in a river basin (Σlu_i). LCI and LUI are determined by Eqs. (4) and (5):

$$LCI = \sum_{i=1}^{n} LUI_i \tag{4}$$

$$LUI_i = \frac{Lu_i}{\sum_{i=1}^{n} Lu_i} \tag{5}$$

2.4 Case study: Beringin river basin

The location of the case study is the Beringin river basin, Semarang, Central Java Province, Indonesia, with an area of ± 33,841 km^2. It is located at 110°17’30” S – 110°21’100” S and 7°4’00” E – 6°50’00” E. To make the calculation easier, the case study location is divided into 31 subareas as displayed in Fig. 2.

The Beringin river is often subjected to overflowing, which causes flooding. A major flood occurred on 9 November 2010 that killed six people, inundated hundreds of houses up to a depth of 0.5—1.25 m, and cut off the Semarang-Kendal road. In May 2016, flooding occurred in some areas up to a depth of 0.6 m.

The land uses in the case study area in 1995, 2005, and 2015 were different. In 1995, the land comprised thicket, farmland, meadowland, settlement, irrigated farmland, rainfed farmland, buildings, and water. Meanwhile, in 2005, the land comprised conservation forests, farmlands, settlements, industry, economic centres, offices, educational areas, mosques, recreational area, roads, reservoirs, and fish farms. The land use in 2015 was for production forest, green space, real estate, industry, economic centre, educational area, office, worshipping area, hospital, farm, road, open space, reservoir, and fish farm.

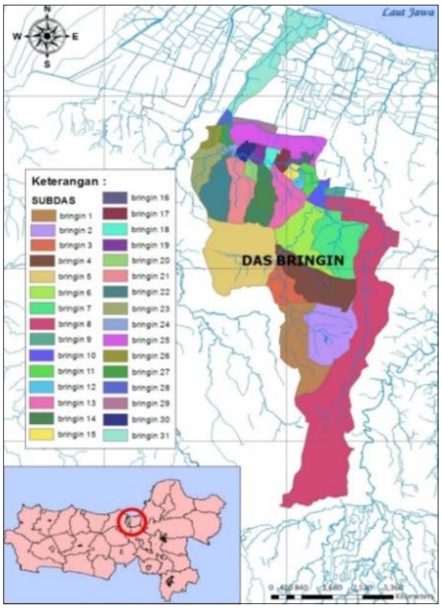

Fig. 2. Map of the Beringin river basin.

Based on the land-use maps in 1995, 2005, and 2015, the land use in the Beringin river basin can be classified into seven classes: (1) forest, consisting of production forest and conservation forest, (2) industry, (3) urban, including economic centre, mosque, market, school, settlement, (4) farmland, including dry and wet farmland, (5) park, which encompasses sport park, recreational park, and public cemetery, (6) non-green open space such as terminal and road, (7) water, such as fish farm and reservoir. Table 1 shows the changes in the area for each land-use class in 1995, 2005, and 2015.

Table 1. The area of each group of land use in the Beringin river basin

No	Land use	Area (%)		
		1995	2005	2015
1	Forest	73.22	27.28	23.54
2	Industry	-	10.59	10.23
3	Settlement	11.72	35.16	46.11
4	Farm	8.10	18.26	15.41
5	Park	4.06	5.84	1.84
6	Non-green open space	-	0.08	0.74
7	Reservoir/fish pond	2.89	2.79	2.12

Table 1 reveals that the land use within the Beringin river basin had been changing from year to year. The forest area in 2015 was reduced by 67.78% compared to the forest area in 1995. Conversely, the settlement area increased. The settlement area had increased by 192.25% in period 1995–2005 and increased by 34.95% in the period 2005–2015. In 2015, there was a 294.27% increase of the settlement area compared to the area in 1995.

3. RESULTS

The land cover index is defined in order to quantify the change in the run-off discharge due to the change in the land use in the river basin. The case study area is the Beringin river basin, which is classified into 31 subbasins. The biggest subbasin is 9202 km^2 while the smallest is 0.083 km^2.

3.1 Curve number

The index that represents the combination of hydrological soil group, land use, and treatment (CN) in the Beringin river basin is depicted in Fig. 3. The value of the average CN in 2005 was 1.88% higher than the average CN in 1995, while the average CN in 2015 was 2.87% higher than in 2005. Within 20 years (1995-–2015), the average CN in the Beringin river basin had increased by 4.8%, with the highest increase in Basin 1, i.e. 16.14%.

As depicted in Fig. 3, the curve number had increased by more than 10% in five subbasins, i.e. B1, B9, B2, B30, and B7. The curve number in Basin 1 in 1995 was 78.83, which then increased to 91.56 in 2015 (15% increase). The second highest increase was in B9 (from 80.73 to 92.84) and in B2 (from 78.54 to 90.10). Both increased by 14.72% within 20 years (1995–2015). The subbasin that relatively did not experience any change was Basin 20, whose CN numbers were 77.00, 77.37, and 77.00 (respectively in 1995, 2005, and 2015).

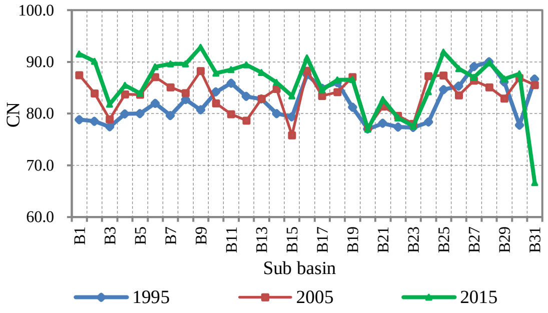

Fig. 3. Curve number in 31 subbasins.

3.2 Peak discharge

The value of the CN acts as a variable that indicates the change of land use in a river basin. It will have an effect on the hydrological aspect. It indicates the conversion rate from rainfall into direct run-off, hence the magnitude of the direct run-off can be estimated. The direct run-off discharge in the case study area will be calculated with rainfall intensities of 23.22 mm, 127.33 mm, 33.1 mm, and 18.48 mm.

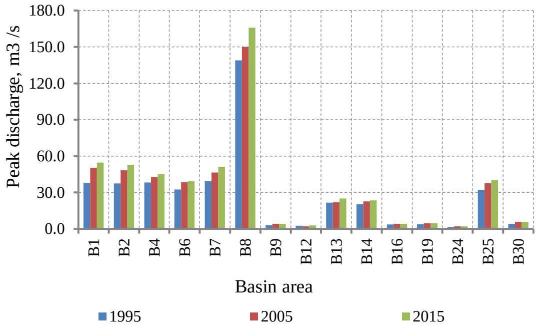

Fig. 4. Peak discharge in 15 subbasins.

An increase in the run-off discharge within 20 years from 1995 to 2015 occurred in almost every basin. There were 15 basins whose peak discharge increased by more than 15% within those years and this is illustrated in Fig. 4. Three basins underwent a 40% increase in the run-off discharge, i.e. Basin 1 (43.57%), Basin 30 (40.48%), and Basin 2 (40.16%). Fig. 4 displays the increasing trend of the run-off discharge in 1995, 2005, and 2015 in 15 basins.

In basins B1, B30, and B2, the run-off discharge increased by more than 40% within the 20-year period. In those three basins, the forest area decreased while the settlement area increased. The forest area in B1 in 2005 was 95% less than in 1995. In 2015, the forest area decreased even more, this time by 42% compared to 2005. On the other hand, the settlement area increased significantly in 2005 and it kept increasing. In 2015, the settlement area was 21.5% larger than in 2005. The forest area in B30 decreased by 61.05% compared to 1995, but in 2015, the forest area increased by 61.55% relative to that in 2005 or decreased by 37.47% relative to that in 1995. There was a conversion from the settlement area into industry. This also occurred in B2 as the forest area in 2015 was 87% less than in 1995 while the settlement area was more than 11 times bigger than in 1995.

To make a correlation between the land cover index and the run-off discharge, the study area is classified into 17 areas, which are marked with junctions, i.e. the intersection where the discharge is the combination of the discharges at the upstream of the junctions. The discharges at each of the 17 junctions were based on the land use in 1995, 2005, and 2015 and their values are displayed in Table 2.

3.3 The correlation between the land cover index and the peak discharge

The correlation between the land cover index and the peak discharge can be seen in Table 2. Figs. 5a to 5d depict the relation between the land cover index and the peak discharge in the Beringin river basin based on the land-use maps in 1995, 2005, and 2015. The trend line that correlates the peak discharge with the LCI in 1995, 2005, and 2015 shows a similar behaviour and suggests a strong correlation between them.

Table 2. Peak discharge in Beringin river basin, Indonesia

Hydrologic Elements	Drainage Area (km^2)	Peak Discharge (m^3/s)		
		1995	2005	2015
Junction 1	1.94	37.60	48.20	52.70
Junction 2	8.00	145.20	169.20	177.80
Junction 3	9.88	239.50	216.30	226.00
Junction 4	13.37	239.50	272.00	283.70
Junction 5	22.57	380.00	424.50	452.20
Junction 6	23.01	340.50	380.90	407.70
Junction 7	23.44	380.60	423.20	449.90
Junction 8	23.74	385.00	429.00	456.40
Junction 9	24.95	383.10	427.60	455.80
Junction 10	26.14	364.60	406.80	434.10
Junction 11	26.51	360.60	400.90	425.20
Junction 12	27.73	371.30	413.70	439.80
Junction 13	28.84	372.50	414.90	441.80
Junction 14	29.71	369.50	411.00	438.10
Junction 15	31.26	364.00	405.10	430.60
Junction 16	31.82	363.00	403.50	429.30
Junction 17	33.84	328.00	362.90	385.40

Mathematically, the relation between the two variables is given by Equation (6) for the land-use map in 1995, Equation (7) for the land-use map in 2005, and Equation (8) for the land-use map in 2015.

$$Q = -29.70\,LCI^2 + 205.55\,LCI + 27.38 \quad (6)$$
$$Q = -18.29\,LCI^2 + 188.59\,LCI - 68.85 \quad (7)$$
$$Q = -19.62\,LCI^2 + 207.52\,LCI - 102.20 \quad (8)$$
$$Q = -17.12\,LCI^2 + 172.44\,LCI - 7.70 \quad (9)$$

Equation (9) shows the relation between the land cover index and the discharge in the Beringin river basin, which is based on the land-use distribution in 1995, 2005, and 2015, where Q is the discharge in the basin and LCI is the land cover index.

The LCI value is calculated by Eq. (4), and the largest value equals the number of land-use classifications. In accordance with Table 1, the LCI from Intersection 14 to the estuary is more than 5. The slope of the river basin from Junction 14 to the estuary is very small and its discharge decreases as a result of sea tides (Table 2). Figures 5a to 5d show that the downward trend line for LCI values is greater than 5.

3.4 The correlation between the change in the land cover index and the change in the peak discharge

To determine the relation between the change in the land cover index and the change in the run-off discharge, the study area is divided into 17 junctions.

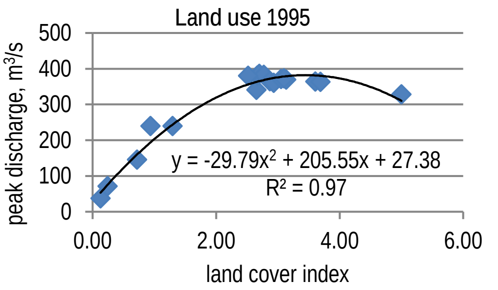

Fig. 5a. The relation between the discharge and the LCI, 1995.

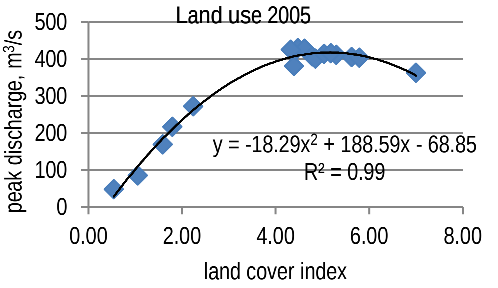

Fig. 5b. The relation between the discharge and the LCI, 2005.

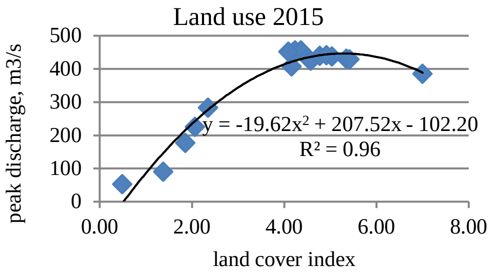

Fig. 5c. The relation between the discharge and the LCI, 2015.

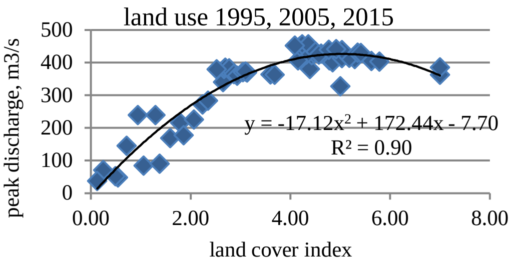

Fig. 5d. The relation between the discharge and the LCI, 1995, 2005, 2015.

The change in the land use is described by the change in the land cover index within 5 years as shown in Equation 11 and the change of the peak discharge as shown in Equation 10.

$$DQ = \left(\frac{Q_{t+1}-Q_t}{Q_t}\right) x\ 100 \qquad (10)$$

$$\mathrm{DLCI} = \left(\frac{\mathrm{LCI_{t+1}-LCI_t}}{\mathrm{LCI_t}}\right) \mathrm{x}\ 100 \qquad (11)$$

DQ is the change of the discharge from year *t* to year *t+1* in per cent. Q_t is the peak discharge in year *t* and Q_{t+1} is the peak discharge 5 years after year t. *DLC* is the change in the land cover index in per cent from year *t* to year *t+1*. LCI_t is the land cover index in year *t* and LCI_{t+1} is the land cover index 5 years after year *t*.

In some areas, DLCI values for 2005 to 2015 are negative because the LCI in 2015 is smaller than in 2005. The following are examples of LCI values in Region 8, from 4.48 to 4.24, with LCI: LCI forests 0.7 to 0.59, LCI open spaces 0.81 to 0.44, LCI settlements 0.84 to 0.82, LCI parks 1.0 to 0.98, but the LCI industry from 0.32 to 0, 59, and LCI farming from 0.64 to 0.66.

Fig 6. Illustrates the relation between the change of the land cover index and the change of the discharge. Mathematically, it is described by Equation (12) or (13).

$$\mathrm{DQ = -4E\text{-}05\ DLCI^2 + 0.0788\ DLCI + 6.6187} \quad (12)$$

$$\mathrm{DLCI = 0.25\ DQ^2 + 6.24\ DQ - 47.40} \qquad (13)$$

DQ is the change of the discharge as in Eq. (10) and *DLCI* is the change of the land cover index as in Eq (11).

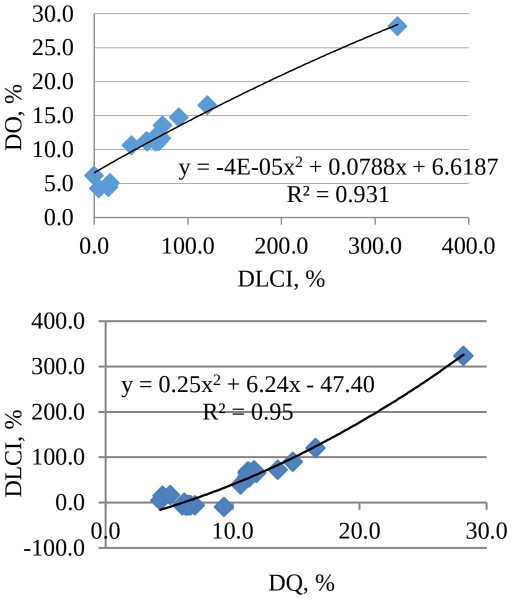

Fig. 6. The relation between the change of DLCI and DQ in the Beringin river basin, Indonesia.

4. DISCUSSION

This study is meant to quantify the relation between the change of land use and the change of run-off discharge through a case study in the Beringin river basin. The land-use change is represented by the land cover index, which comprises seven indicators of land use.

The land-use index is the ratio of land use in subcatchments to land use in the basin. The largest LCI score for 1995 was 5 and the LCI for 2005 and 2015 was 7 according to the land classification for the year.

In this case, the land-use data in 1995, 2005, and 2015 have different classifications. Meanwhile, it is necessary to have a uniform or standardized land-use classification in order to measure the change in the land cover. In future, it is recommended to have a uniform classifying method to assess the land use within a river basin.

The graph of the relationship between LCI and peak discharge as shown in Figure 5 shows a maximum value at the LCI of above 5, and the decrease of the curve is caused by the decrease of discharge from Junction 14 to the estuary (Table 2).

Figure 6 indicates LCI changes and discharge changes in each subarea. The graph equations are approximated by linear equations. Changes in upstream LCI values will also affect the downstream discharge.

The land-use index is the most important aspect in order to measure the change in the land cover index, and the land cover index also plays an important role in assessing flood discharge. This index is meant to be a comprehensive tool for evaluating the land-use distribution in a river basin.

The land cover index can also be used to assess land use in a river basin. As demonstrated in the calculation, a massive change in the land cover index means a massive change in the run-off discharge as well.

5. CONCLUSION

In this study, an evaluation model has already been developed to assess the relation between land use and flood discharge. There is a strong correlation between the land cover index and the peak discharge, although different basins have different characteristics. The correlation between a change in land use and a change in flooding can be formulated by using Equation (12) or (13). This approach can be used as a means of evaluation or as a tool for planning a land-use map in the management of a river basin.

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