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The Impact of Land Use on Hydrological Characteristics in Kaligarang Watershed

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***Abstract** - The increasing number of population in Kaligarang watershed will cause population pressure that will have a direct impact on land-use change and in turn will have an impact on watershed hydrological characteristics. Watershed management planning as an integral part of land-use and conservation based development is very important and need to be applied. The aims of this research were to analyze land-use changes in Kaligarang watershed, and the impact of land-use changes on watershed hydrological characteristics in Kaligarang. The results of this research showed that in Kaligarang watershed, there was a decrease in forest area of 2.28% and rice field of 13.96%, an increase in resident area of 2.14%, dry land farming of 5.82% and mixed dry land farming of 10.03%. The decreasing forest area caused an increase in runoff coefficien (C_{RO}= 147.5 – 7.06F), an increase in average daily maximum discharge (Q_{max}(cms) = 79.33 – 4.23 F) and a decrease in baseflow (BF (cms) = -1.65 + 0.36 F).*

Keywords—*Land-use change, hydrological characteristics, runoff coefficient, maximum discharge, baseflow and watershed.*

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INTRODUCTION

Watershed is operationally defined as a region above a river point that topographical boundaries made it drain water into the same river (Arsyad, 2010). Watershed management is an effort to rationally use natural resources in a watershed to obtain maximum production in unlimited time and reduce potential damage to a minimum, as well as to obtain water yield evenly throughout the year. In wathershed management, it should be viewed as a unity of upstream and downstream areas, because of the interdependence (Sinukaban, 2008).

Watershed management as an integral part of regional development is still facing various complex and interrelated problems. These problems including erosion and sedimentation, flooding and drought, water pollution of river, unintegrated management, poor coordination, unsteady institutions, sectoral/ activity conflicts and overlapping regulations (Brooks, et al., 1990). Complexity of issues in watershed management requires involvement of stakeholders to conduct strategic steps in integrated watershed management with the rule: one watershed, one plan, and one management (Sinukaban, 2008).

Increasing number and mobility of population that increased the need for food, clothing and energy will directly affect land use change (Barbieri, 2006). Factors affecting land use change is very complex. In general, these factors are land demand, changes in population, land allocation and changes in the yield of agriculture (Verburg, et al., 2011). It was further explained that land use change analysis used variables such as land cover demand, location suitability, and land conversion characteristics (Fox, et al., 2011).

Runoff is water flowing over ground surface and is part of rainfall flowing into the river or canal, lake, and sea. Runoff takes place when the amount of rainfall exceeds the rate of water infiltration into the ground. Runoff would not happen before evaporation, interception, infiltration, depression saving, surface detention and channel detention occurs (Arsyad, 2010).

The impact of land use change on the hydrological response was observed and shown at the daily discharge, the total annual runoff and the peakflow (Friedrich, et al., 2012). Furthermore (Nejadhashem, et all, 2011) explain that impacts of land use changes overall increase overland flow and overall decrease in the amount of baseflow and water yield were observed.

Land-use change from high to low coverage level will increase runoff coefficient (Peng, et al., 2013) resulting in increase of runoff and flooding frequency (Ashraf, et al., 2014). Land-use changes, which mainly exhibited as the increased forests, might be the main factor affecting the increase of runoff (Liu, et al., 2012). Land-use change was primarily from majority evergreen to majority deciduous forest, experienced increases of 20–40% in total runoff. Land use conversion from prairie grasslands to row agriculture crop, resulting in a 20–30% decrease in total runoff (Dazhi M and KA Cherkauer, 2009). Furthermore (Bonell and Bruijnzeel, 2005) explains that land use change will affect some hyd,rology aspects, namely (1) land-use change increases erosion; (2) increasing erosion and land coverage change increases sedimentation rate; (3) water yield monthly distribution decreases along with decreasing evapotranspiration of vegetation; (5) seasonal water flow especially baseflow decreases along with decreasing infiltration capacity of ground and increasing surface runoff; (6) peakflow will increase along with decreasing ground cover; and (7) groundwater will decrease.

MATERIAL AND METHODS

Research was conducted in watershed Kaligarang located in three (3) Regency/City of Central Java province, namely Semarang District, Kendal and Semarang that lies between 06°.57′ - 07°11’ S dan 110°15’ - 110°.23’ E. Kaligarang watershed covers 20 thousand hectares area, consisting of 4 subwatershed, i.e.: upper Kaligarang, Kreo, Kripik, and downstream Kaligarang.

Material and Instruments

The materialsusedinthis study includeland use mapsin 2000, 2003, 2006, 2009, and 2011. The instruments usedin this study include: GeographicalPosition System(GPS), clinometer, cameras and software fordata processing, such as Microsoft Excel, ARCGIS10.1. and Statistical Product and Service Solutions (**SPSS).**

Methods

Land Use. Land use data was obtained from land use map image analysis followed by ground check/field observation in sample locations to observe the existing land-use change development. Land use data in the past 10 years (2000, 2003, 2006, 2009 and 2011) was analyzed.

Rainfall. Secondary rainfall data was obtained from the climatological station around watershed. It was data series for 10 years (2001-2010).

Kaligarang River Discharge. Discharge data collected was daily data series of Kaligarang river discharge in the past 10 years (2001-2010). The data was used to analyze the impact of land use on hydrological characteristics of Kaligarang watershed.

Analysis

Analysis of land use change in Kaligarang watershed was conducted using ArcView Geographical information system (GIS) software and the results were presented in descriptive form and map.

Analysis of land use changes (forest, plantations, dryland farming, mixed dryland farming, rice fields, and settlements) was conducted using regression analysis assuming area of each land use as time function (t). The tendency of land use changes over time was allegedly exponential following regression equation $\mathbf{A_i t = A_i o e^{rt}}$, where $A_i t$ was area of each type of land use at the time t, $A_i o$ was area of each type of land use at the time to, e was natural logarithm, r was the rate of land use type change, t was time value of 1, 4, 7, 10 and so on, i was type of land use such as forest, plantation, mixed farming, rice fields, and settlements.

Effect of land use change on hydrological conditions in Kaligarang watershed was analyzed based on land use data, rainfall (years 2001-2010) and discharge (2001-2010) using decision criterias: maximum discharge (Q_{max}), minimum discharge (Q_{min}) or baseflow (BF) and runoff coefficient (C_{RO}).

Runoff coefficient was a number indicating ratio of runoff volume to rainfall volume. Runoff was obtained from Kaligarang river discharge data by separating streamflow from base flow. Base flow was determined based on minimum discharge of Kaligarang River. Surface flow coefficient was calculated using equation $\mathbf{C_{RO} = (Q/R)}$, where C_{RO} was surface flow coefficient (%), Q was runoff (m^3) and R was rainfall volume (m^3).

Effect of land use change on hydrological conditions (Q_{max}, BF/Q_{min} and C_{RO}) in Kaligarang watershed was analyzed using multiple regression with equation $\mathbf{Y = \beta_o+\beta_1 x_1+\beta_2 x_2+\beta_3 x_3+ \ldots\ldots + \beta_n x_n+\acute{\varepsilon}}$, where x_1, x_2, x_3..... and x_n was proportion of each type of land use, β_o, β_1, β_2, β_3..... and β_n was regression coefficient of each variable x. $\acute{\varepsilon}$ was assumed to be normally distributed residuals with a mean approaching 0 and certain standard deviation.

Stepwise regression was conducted if multiple analysis results of each predictor variable (land use) interplay with response variable (VIF>5). The expected result was only one land use variable influences response variable most.

RESULTS AND DISCUSSIONS

Analysis of land use

Kaligarang watershed land use was divided into six types of use: forest, plantations, dryland farming, mixed dryland farming, rice fields and settlements. The states of forests in Kaligarang watershed were natural and conversion forest.

Analysis of Kaligarang watershed land use map from 2000-2011 showed that forest area and rice fields had decreased, while setllements, dry land farming, and mixed dry land agricultures were increased. Area of each type of land use in Kaligarang watershed as presented in Table 1.

Regression analysis of forest cover and rice fields changes during 2000-2011 showed that forests area and rice fields decreased exponentially over time. Regression analysis on Kaligarang watershed land area percentage of forest use followed exponential equation $\mathbf{y_{ht} = 14.43\ e^{-0.02x}}$, while the rice fields percentage followed exponential equation $\mathbf{y_s = 25.71\ e^{-0.10x}}$ (y_h was percentage of forest area in particular year, y_s was percentage rice fields coverage in particular year, x was particular year that x = 1 for 2000, and e was natural logarithm value 2.7182818).

Regression analysis on percentage changes pattern of forest and rice fields area in Kaligarang watershed is presented in Figure 1.

Table 1. Development of Kaligarang watershed land use in 2000-2010

Land Use	2000		2003		2006		2009		2011	
	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Forest	2758	14.20	2612	13.45	2516	12.96	2315	11.92	2315	11.92
Plantations	566	2.91	208	1.07	208	1.07	208	1.07	208	1.07
Settlements	3131	16.12	3308	17.04	3486	17.95	3545	18.26	3545	18.26
Dryland farming	5512	28.39	5913	30.45	6580	33.89	6663	34.31	6663	34.31
Mixed dryland farming	2985	15.37	3642	18.76	4190	21.58	4932	25.40	4932	25.40
Rice fields	4451	22.92	3720	19.16	2423	12.48	1740	8.96	1740	8.96
Water body	15	0.08	15	0.08	15	0.08	15	0.08	15	0.08
Total	19418	100.0	19418	100.0	19418	100.0	19418	100.0	19418	100.0

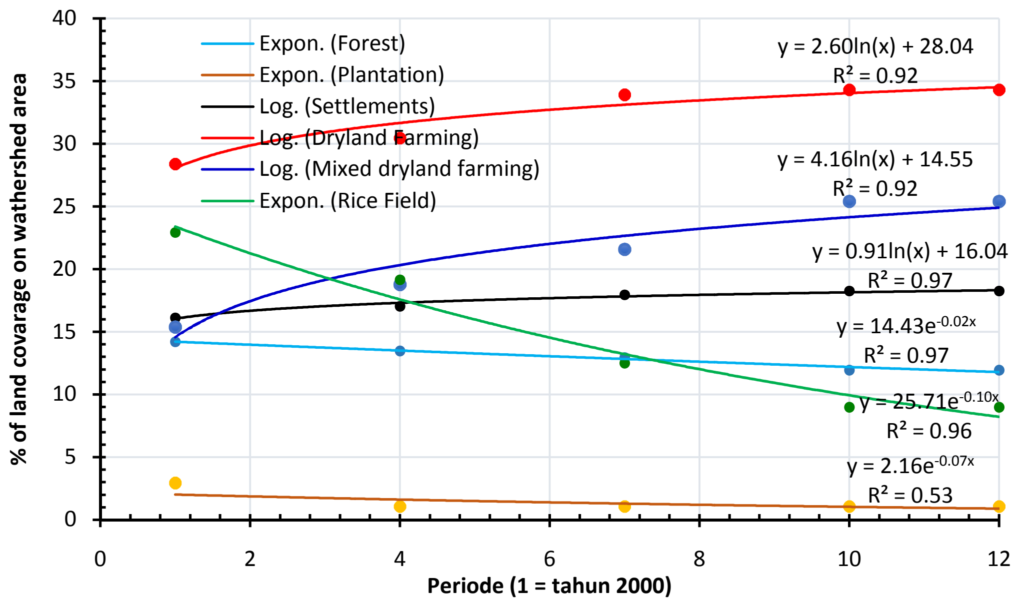

Figure 1. Percentage change tendencies of rice fields change in Kaligarang watershed (years 2000-2011)

Expansions of settlements, dryland farming, and mixed dyland farming were impacts of forest and rice fields decrease. Regression analysis on settlements, dryland farming, and mixed dyland farming changes in Kaligarang watershed during 2000 to 2011 as presented in Table 3.1 showed an increase over the years. Regression analysis on settlement expansion, dryland farming, and mixed dyland agriculture over the years showed a logarithmic increase. Regression analysis showed a logarithmic expansion of settlements following equation y_{pm} **= 0.91 Ln (x) + 16.04**, while dryland farming coverage change followed equation y_{lk} **= 2.60 Ln (x) - 28.4** and mixed dryland farming coverage change followed equation y_{lkc} **= 4.16 Ln (x) – 14.55**. Regression analysis on percentage change pattern of settlements, dryland farming, and mixed dryland farming in Kaligarang watershed is presented in Figure 1.

Reduction of forest and rice fields in Kaligarang watershed occurred due to pressure or the increasing population of Kaligarang watershed and thereby increased demands for settlements. Along with the increasing number of population and incomes, the effort of land conversion from non-residential into residential areas became evident. These conditions resulted in diminishing of rice fields, as it was suitable for settlements. Rice fields was usually flat, had higher water holding capacity as well as excellent accessibility. Such condition was very good for settlement location. In addition to the increasing demand for settlement as an impact of increased population, other factors affecting changes of forest and rice fields into settlements was carrying capacity of land that was reduced due to declining soil fertility and ultimately reduced land productivity (Maltima, et al., 2010). On the other hand, the increasing population pressure on land led to higher land value. Furthermore Wainger, Rayburn and Price (2007) suggested that the change in land use was influenced by energy needs, especially bio-energy coming from agriculture. Changes in land use were influenced complex results of interaction between human and environmental factors (Schaldach and Priess, 2008).

Effect of Land Use on Hydrology Characteristics

Analysis results of average daily discharge, maximum daily discharge and minimum daily discharge using arithmetic average approach over the last 10 years showed that monthly distribution of average daily discharge, maximum daily discharge and minimum daily discharge had the same tendency. The highest maximum daily discharge occurred in January at 34.60 cms, and the lowest in August at 4.48 cms. The highest average daily discharge occurred in February at 16.83 cms and lowest in August at 2.36 cms. While the highest average daily discharge occurred in January at 24.68 cms and the lowest occurred in August at 3.27 cms.

Effect of land use change on hydrological conditions in Kaligarang watershed was focused on runoff coefficient, maximum discharge and base flow. Runoff coefficient ($C_{RO} = Q/R$) was calculated using average rainfall and Kaligarang river discharge data. Runoff coefficient, maximum discharge, base flow of Kaligarang watershed subzone is presented in Table 2.

Table 2 shows that runoff coefficient increased in line with time accumulation (years) due to a decrease in proportion of forest and rice fields followed by an increase in proportion of dryland farming, mixed dryland farming, and settlements. Runoff coefficient increased following exponential equation: $\mathbf{C_{ro} = 47.275e^{0.035x}}$. In contrast, baseflow decreased over time (years) following exponential equation: $\mathbf{BF = 3.487e^{-0.034x}}$. Maximum discharge had the same trend with runoff coefficient and followed exponential equation: $\mathbf{Q_{max} = 18.961e^{0.050x}}$.

Kaligarang watershed hydrological characteristic was influenced by land use change especially the dominant land use such as forest, dryland farming, mixed dryland farming, rice fields, and settlements. But in this case, as agro-technology was the only aspect examined, analysis of land use for settlements was not the main study. Analysis of variance due to land use change in Kaligarang watershed affected runoff coefficient, base flow, maximum discharge values as presented in Table 3.

Table 2. Runoff coefficient, base flow, maximum discharge and minimum discharge values of Kaligarang runoff in 2002-2010

Parameter	Year								
	2002	2003	2004	2005	2006	2007	2008	2009	2010
CRO	50.98	54.62	50.70	58.55	53.31	62.72	62.38	66.01	64.77
BF	3.25	3.24	3.21	2.68	2.52	2.83	2.77	2.81	2.36
Q_{max}	21.13	22.90	22.92	23.35	22.77	27.41	25.88	34.60	27.06

Regression analysis of correlation between parameter and cumulative time (year= x)

C_{ro} **(%) =** $\mathbf{47.275e^{0.035x}}$ BF(m^3/sec) **=** $\mathbf{3.487e^{-0.034x}}$ $\mathbf{Q_{max}}$(m^3/sec) **=** $\mathbf{18.961e^{0.050x}}$

Table 3. Percentage of forest (F), dryland farming (DF), mixed dryland farming (MD), rice fields (RF), settlements (S), base flow (BF), and runoff coefficient (C_{RO}) in Kaligarang watershed Period 2000-2011.

Periode	BF (m^3/sec)	C_{RO} (%)	Q_{max} (m^3/sec)	F (%)	DF (%)	MD (%)	RF (%)	S (%)
2000-2002	3.29 ^{a}	50.21 ^{a}	21.37 ^{a}	14.20	28.39	15.37	22.92	16.12
2003-2005	3.08 ^{ab}	54.62 ^{ab}	23.05 ^{ab}	13.45	30.45	18.76	19.16	17.04
2006-2008	2.71 ^{ab}	60.12 ^{bc}	26.52 ^{b}	12.96	33.89	21.58	12.48	17.95
2009-2011	2.52 ^{b}	66.25 ^{c}	31.64 ^{c}	11.92	34.31	25.40	8.96	18.26

Table 3 shows land coverage percentage change from 2000-2002 periods to 2009-2011 periods. Forest area was reduced from 14.20% to 11.92% and rice fields was reduced from 22.92% to 8.9692%, dryland farming was increased from 28.39% to 34.31%, mixed dryland farming was increased from 15.37% to 25.40% and settlement was increased from 16.12% to 18.26%. Declining forest and rice fields areas as well as increasing dryland farming, mixed dryland farming, and settlements led to an increase in runoff coefficient from 50.21% (2000-2002 period) to 66.25% (2009-2011 period), an increase in maximum discharge 21.37 cms to 31.64 cms and baseflow reduction from 3.29 cms to 2.52 cms.

The increasing runoff coefficient, maximum discharge and a decrease in baseflow indicated the occurrence of a decrease in forest coverage or in water absorption functions; so that most of rainwater falling to the ground was flowing above the ground. Land coverage was associated with leaf area index (LAI) of which size was determined by age of stand, stand management and area of canopy stand. Land coverage in watershed had water transmission, water buffer and release of water functions. The decline in land cover was indicated by reduction of forest, while decline in absorption function could occur due to soil and water conservation aspects or inadequate soil management (Farida and Noordwijk, 2004). This was in accordance with Arsyad (2010) statement that runoff coefficient value was influenced by several factors, namely (1) rainfall amount, intensity and distribution, (2) soil topography and types, (3) watershed area, (4) ground coverage vegetations, and (5) land management.

Multiple regression analysis between percentage of forest, rice fields, dryland farming, mixed dryland farming and settlements against runoff coefficient (C_{RO}) in Kaligarang watershed used linear equation C_{RO} (%) = -4424 – 10.9 F + 0.54 RF – 11 DF – 75 MD + 376 S with R-sq value = 91.9 and VIF>5. Based on these equations, land use change in Kaligarang watershed was shown to cause changes in runoff coefficient. Runoff coefficient value decreased with an increase in percentage of forest, dryland farming and mixed dryland farming as well as a decrease in percentage of rice fields and settlements. The decline in forest area, dryland farming area, and mixed dryland farming area as well as an increase in percentage rice fields area and settlements area had direct impacts on the increase in runoff coefficient.

Multiple regression analysis resulted in VIF value > 5 that proved an attraction between predictors, so that data processing was continued using Stepwise Regression method and resulted in regression equation as follows: **C_{RO} (%) = 147.5 – 7.06 F** with R-sq value = 89.09 (Figure 2.). Based on the equation, runoff coefficient was a negative function of forest area percentage, which meant that higher forest area percentage in a watershed area will be decreased runoff coefficient. This was in accordance with Yuwono (2011) statement that the decrease inpercentage offorest cover (5%) inthe watershedWay Betungwill be increasedsurface runoffcoefficient (7%). This fact shows that forest use change contributed greatly to the increase in runoff coefficient and in turn increased runoff volume.

Multiple regression analysis between maximum discharge and land coverage percentage change showed that forest area, dryland farming, mixed dryland farming and settelments percentage change had an impact on maximum discharge (Q_{max}) in Kaligarang watershed as the following multiple linear equation **Q_{max}(cms) =- 5211 - 7.9 F+0.58 RF-115 DF–56.0 MD +584 S**with R-sq value = 90.0 and VIF > 5. The equation illustrates that maximum discharge value (Q_{max}) will be increased if there is a decrease in percentage of forest area, dryland farming, mixed dryland farming and an increase in percentage rice fields and settlements area. It was caused by multiple regression analysis result that has VIF value > 5 which proved the existence of attraction between predictors, so that data processing was continued with Stepwise Regression method that resulted in the following regression equation: **Q_{max}(cms) = 79.33 – 4.23 F**with R - sq value = 79.94 (Figure 2.)

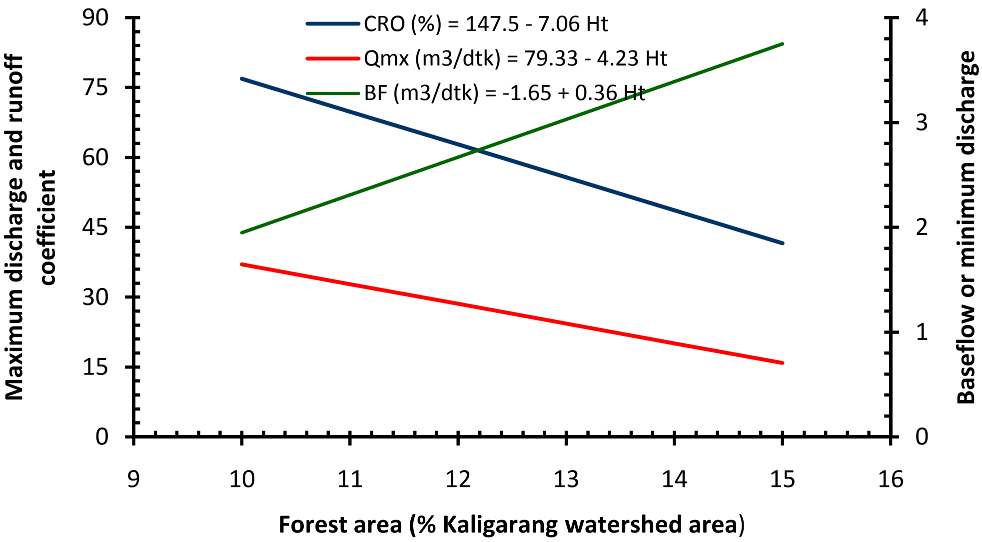

Figure 2. Graphic of correlation between runoff coefficient, maximum discharge and baseflow of Kaligarang river against percentage of forest area.

Based on these equations, it could be concluded that maximum discharge was a negative function of forest area percentage which meant that the higher forest area precentage in watershed area will be decreased maximum discharge and vice versa. This fact shows that land use change greatly contributed to the increase in average maximum discharge and runoff volume. Land coverage by trees in every form affected water discharge. Land coverage affected water flow in various stages such as: (1) interception, (2) protection of soil aggregates, 3) infiltration, 4) water uptake (Noordwijk et al., 2004)

Land use change also affected baseflow or minimum discharge. Land use changes that occurred from 2002 to 2010 caused baseflow value to decrease. Forest coverage, dryland farming, mixed dryland farming, and settlements percentage changes will affect magnitude of maximum discharge (Q_{max}) in Kaligarang watershed follong equation: **BF (cms) = 99 + 0.43 F + 0.020 RF – 26.4 DF**

+9.80 MD + 30.8 Swith R-sq value = 82.7 and VIF > 5.

The above equation demonstrates that baseflow value will be higher if there was an increase in forest coverage, rice fields, mixed dryland farming, and settlements area percentage as well as the decrease in dryland farming area percentage. Multiple regression equation of baseflow showed different trend from the observations, which was a decrease in forest coverage and rice fields, the increase in dryland farming, mixed dryland farming and settlements area will reduce baseflow or minimum discharge. It was because multiple regression analysis gave VIF value > 5 which proved the existence of attraction between predictors, so that data processing must be continued using Stepwise Regression method that resulted in the following regression equation: **BF (cms) = -1.65 + 0.36 F** with R-sq value = 77.48 as presented in Figure 2.

Based on this equation, baseflow value or minimum discharge was a positive function of forest area percentage which meant that the higher forest cover percentage in a watershed area will be increased the baseflow or minimum discharge and vice versa. The increasing percentage of forest cover caused baseflow to increase due to a decrease in runoff coefficient so that rainwater falling above the ground will mostly flow into the ground as infiltration water. It was because forests had relatively thick litter and contributed to soil organic matter. The ability of soil to absorb and store water was determined by organic matter content. Forestland with high organic matter could store more water compared other land uses such as mixed garden or dry land agriculture (Yusnaini, et al., 2008).

Equation above indicated that the larger a forest area will be decreased runoff coefficient, maximum discharge and increasd baseflow or minimum discharge, or in other words the larger a forest area will be increased hydrological function and vice versa. Therefore, efforts to improve hydrological functions could be executed through expansion of forest plantation when possible. In this case, forest expansion in Kaligarang watershed could not be done thus; soil and water conservation measures were necessities. Soil and water conservation measures could be applied in agronomy, vegetative, engineering and management.

CONCLUSIONS

1. There were land use changes in Kaligarang watershed over the last 10 years, i.e: decreasing forest area (2.28%) and rice fields (13.96%) and increasing settlements (2.14%), dryland farming (5.82%) and mixed dryland farming (10.03 %).
2. Land use change that had the most impact on hydrological condition was the decreasing forest area that caused an increase in runoff coefficien (C_{RO}= 147.5 – 7.06F**)**, an increase in average daily maximum discharge (Q_{max}(cms) = 79.33 – 4.23 F) and a decrease in baseflow (BF (cms) = -1.65 + 0.36 F**)**.

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