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Assessment of hydrological alteration from 1996 to 2017 in Brantas watershed, East Java, Indonesia

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Abstract

Climate, land use, and land cover change can propagate alteration to the watershed environment. The interaction between natural and human activities probably accelerates the change, a phenomenon that will generate serious environmental problems. This study aims to evaluate the change in the hydrological regime due to natural and human-induced processes. The study was conducted in Brantas watershed, Indonesia, which is the largest watershed in East Java. This area is populated by more than 8 million inhabitants and is the most urbanized area in the region. An analysis of rainfall time series use to shows the change in natural phenomena. Two land-use maps at different time intervals were used to compare the rapid development of urbanization, and the discharge from two outlets of the sub-watersheds was employed to assess hydrological changes. The indicator of hydrological alteration (IHA) method was used to perform the analysis. The daily discharge data are from 1996 to 2017. The research results show an increase in flow (monthly, 1-day, 3-day, 7-day, 30-day, and 90-day flows) in the two sub-watersheds (Ploso and Kertosono) from the pre-period (1996–2006) to the post-period (2007–2017).

Key words: *Brantas watershed, hydrological alteration, land use, rainfall*

INTRODUCTION

Climate, land use, and land cover change can influence the watershed environment. The interaction between natural and anthropometric factors may accelerate this change, and this phenomenon will probably generate serious environmental problems. This study aims to evaluate the change in the hydrological regime due to natural and human-induced processes.

The study was conducted in Brantas watershed, which is the largest watershed in East Java. The area is populated by more than 8 million inhabitants and is the most urbanized area in the region [JATIM 2017]. The rapid development of population, urbanization, industrial sites, food services, energy, and tourism have significantly converted the natural landscape to a human-influenced one over the last two decades, which has led to the change in the hydrological regime on the river. This change will probably also exacerbate the risk of erosion, sedimentation, and landslide.

The water resource management problems faced in the watershed are a lack of water availability to supply water users and for irrigation purposes; problems related to water quality, which is below standard; environmental problems related to the presence of domestic waste in the river body and irrigation channels; rapid erosion; and sedimentation processes. The risk of flood and drought events has also increased. This preliminary study analyses the change in this watershed over the last two decades and asks if the change is related more to natural phenomena or is triggered by human activities?

According to LOUCKS and VAN BEEK [2017], the changes in streamflow in a watershed (the maximum, minimum, average and other statistical values) can be observed through the hydrological cycle and by a statistical measure of the streamflow during a specific period.

The indicators of hydrologic alteration (IHA) methodology was initially developed by the Nature Conservancy [RICHTER et al. 1996] to quickly process daily hydrologic records in order to enable characterisation of natural water conditions and facilitate evaluations of human-induced changes to flow regimes [MATHEWS, RICHTER 2007]. The descriptions of IHA methodology can be found in paper by RICHTER et al. [1998]. MATHEWS and RICHTER [2007] also presented more detail of the IHA software features and its application in environmental flow-setting processes.

Furthermore, OPPERMAN [2006a] used IHA to study hydrological alteration in the Patuca River. SHIEH et al. [2007] made a similar study. In Croatia, ŽGANEC [2012] applied the IHA method to analyse long-term trends of hydrological and temperature conditions in five connected karst rivers, before the closing of a large new dam. Furthermore, MINEA and BĂRBULESCU [2014] applied the IHA method to study the hydrological alteration of Buzău River induced by Siriu Dam (Romania). The application of the IHA method in Balkan regions was reported by PAPADAKI et al. [2016].

Similar studies (including the application of Environmental Flow Component (EFC), flow duration curve (FDC), range of variability approach (RVA), and integration of IHA methodology with other applications) were also conducted in the Mekong River Basin, as reported by DAMING et al. [2006]. Also, the IHA tool was used to compare historical (pre-assessment) and contemporary (post-assessment) discharge from the Yarlung River [CHEN 2012]. The IHA method also applied to study the influence of climate change on river ecology [MOHAMMED et al. 2017]. Finally, the IHA method is also used to develop water resource management strategies to maintain future water flow in areas of Rhine and Elbe River basins [PFEIFFER, IONITA 2017].

METHODS

STUDY AREA AND INPUT DATA

Two sub-watersheds at Kertosono (6414 km^2) and Ploso (8848 km^2) were used as the study site. The AWLR (automatic water level recorder) placed at the outlets of Kertosono and Ploso. The choice of these sub-watersheds as samples was due to the completeness of the data series. In this region, it is usually difficult to have a complete and continuous data series for an extended period of time. Therefore, the availability of long-term data is the main constraint of this study.

LAND USE CHANGE

Two editions of maps were used to calculate the change in land use during the two periods. The first map (Fig. 1) was used to represent the land use of the watershed from 1996 to 2005 and was obtained from RBI (Rupa Bumi Indonesia) Digital Maps. Editions of RBI maps range from 1999 to 2002.

The second land use map (Fig. 2) was obtained from Landsat image interpretation (Tab. 1). This map was processed by standard image processing, following the procedure published in the Multispec Documentation [LANDGREBE, BIEHL 2011].

The classification process was then conducted using the supervised method by means of a maximum likelihood algorithm. This classification process identifies five significant classes of land use: (1) built-up areas, (2) paddy fields, (3) rural areas, (4) forests and/or plantations, and (5) water bodies. Based on the OIF (optimal index factor) method, the image treatment employed a composite Landsat band, i.e., Band 2, Band 5 and Band 6. About 2,500 points based on surveys and Google Earth were used as
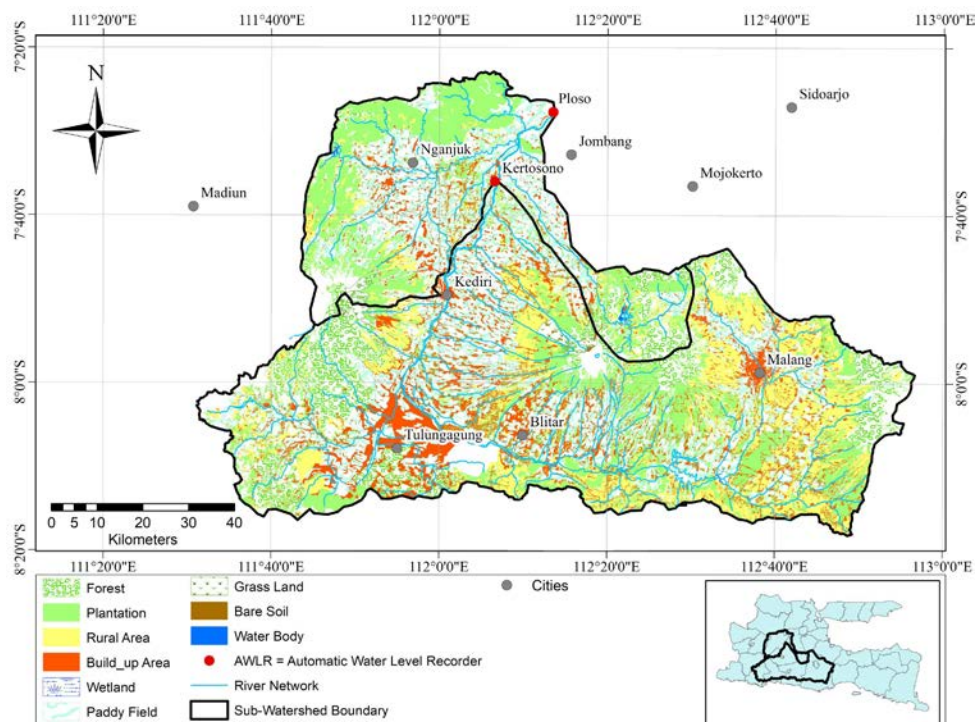

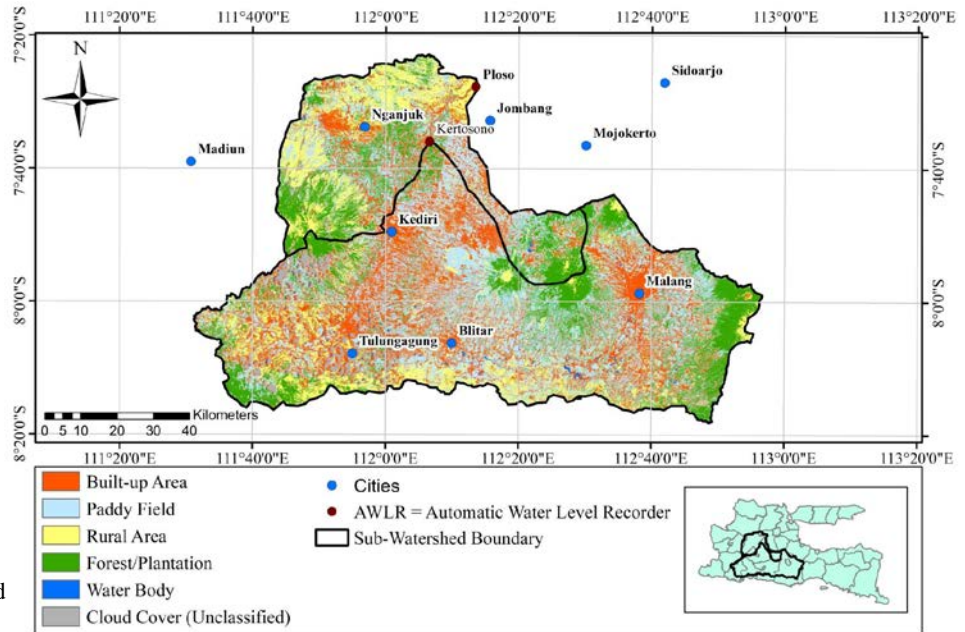Fig. 1. Land use map for period 1996–2005; source: BIG 2019

Fig. 2. Land use map for period 2006–2018; source: own elaboration

Table 1. Landsat images raw data

Date acquired	Path/row	Cloud cover (%)	Land cloud cover (%)	Data type/ category	Orbit
28.09.2018	118/66	3.50	1.11	L1TP/T1	ascending
05.10.2018	119/65	9.75	10.31	L1TP/T1	ascending
05.10.2018	119/66	5.24	3.46	L1TP/T1	ascending

Source: own elaboration.

training areas. Furthermore, the process produced 92.44% overall and 90.11% kappa accuracy for all the areas of East Java. The detailed classified map was then clipped with the sub-watershed boundary.

Finally, the proportion of land use class (in % of the total area occupied) from the two maps was calculated and compared. In this study, classification was simplified to just five classes, i.e. built-up areas, paddy fields, rural areas, forest-plantations, and water bodies. It is challenging to separate forests and plantations using Landsat because the two classes appear the same as the annual vegetation. Therefore, they are regrouped together to represent one major vegetation feature.

RAINFALL CHANGE

An analysis of the annual rainfall data series was elaborated to represent the change in natural phenomena. The annual data were obtained from the cumulative daily rainfall data for one year. It should be noted that many rainfall stations are available in the region.

However, only seven measurement sites have a continuous recording period of ≥20 years, so these were used in this study (Tab. 2).

The location of the seven stations also constrained the analysis of rainfall data series. The stations are located mainly in the lower-middle area of the region investigated (Fig. 3). These stations are used only to show if the annual rainfall during the two periods is changing?

Table 2. Stations for Rainfall Analysis; Period: 1996–2015

Station	Annual rainfall (mm)
Dingin	785–2397
Kedungrejo	1287–2524
Kertosono	665–2584
Minggiran	1080–2932
Papar	987–2617
Perak	1017–3022
Woromarto	662–2587

Source: own elaboration.

The rainfall series was divided into two periods: the pre-assessment (pre-evaluation) period from 01.01.1996 to 31.12.2005 and the post-evaluation (post-assessment) period from 1 01.01.2006 to 31.12.2015.

Non-parametric statistical tests were conducted using Mann–Kendall and rank sum tests. Mann–Kendall (MK) is one of the non-parametric tests recommended by WMO (World Meteorological Organization) to test the trends in meteorological data [CHIEW, SIRIWARDENA 2005]. For $n > 10$ (i.e., a data series of more than ten years), it is assumed to be under normal distribution, and the Mann–Kendall test Z value is calculated by Equation (1):

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var\,(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & S < 0 \end{cases} \qquad (1)$$

Where: n = number of years; S = tendency statistical test ($S = P - M$); Var (S) = Variance of S (Var (S) = $n(n-1)$ ($2n + 5)/18$); P = number of events where $y_i > y_j$; M = number of events $y_i < y_j$, i = the sequence of data to 1 to $n - 1$; and j = data order $i + 1$ to n.

The Z value follows the normal distribution, and the positive Z value represents the rising trend. The null hypothesis (H_0) is rejected if $Z > Z_{(1-\alpha:2)}$, then there is a trend for rainfall data series. The significance level used is $\alpha = 0.05$.
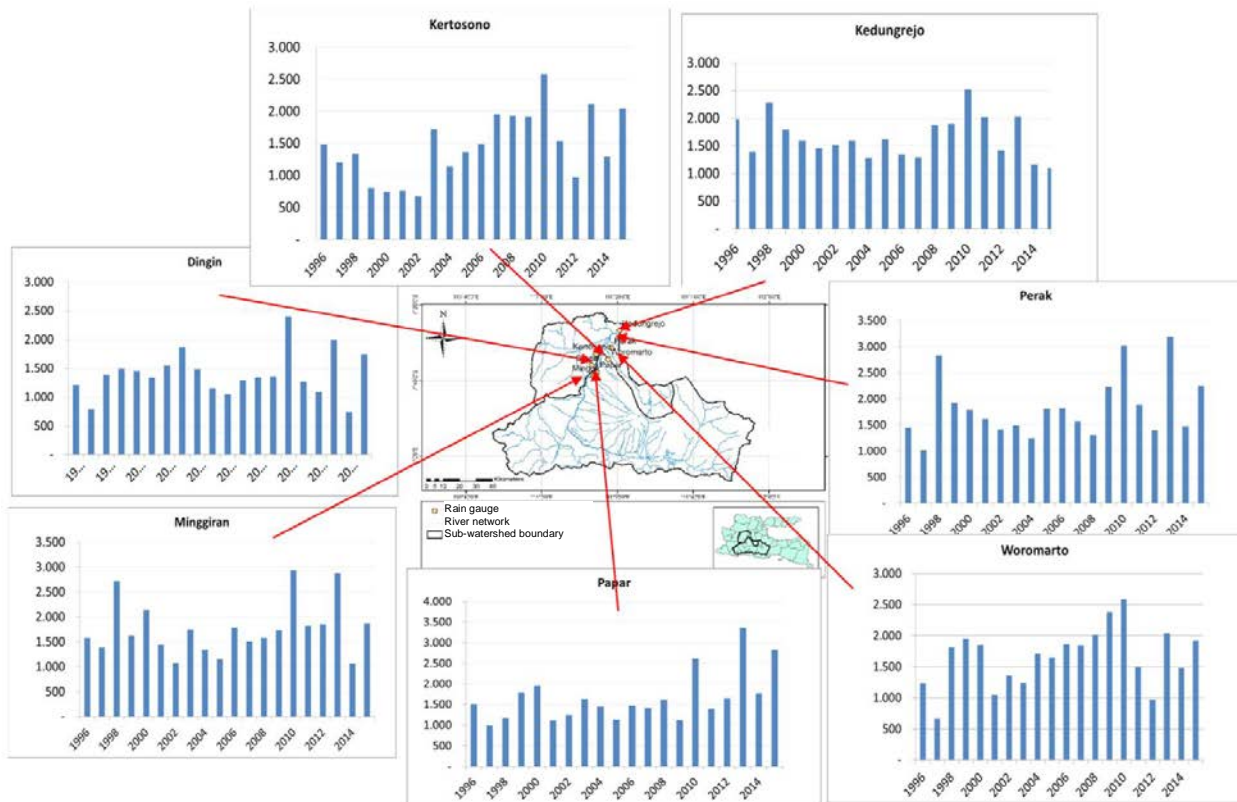
Fig. 3. Annual rainfall (mm) recorded by the seven stations from 1996 to 2015; source: own elaboration

The rank sum (RS) test was used to test the changes or differences between two periods of data series. The division of the first and second periods was made by dividing the data series of each location into two periods. The value of Z in the RS test was calculated by Equation (2).

$$Z = \begin{cases} \frac{W - 0.5 - \mu}{\sigma} & W > \mu \\ 0 & W = \mu \\ \frac{W + 0.5 - \mu}{\sigma} & W < \mu \end{cases} \qquad (2)$$

Where: W = number of ranks in data n; N = number of years of rainfall data; n = number of first data groups; m = number of second data groups; μ = average $(\mu = \frac{n(N+1)}{2})$; σ = Var $(\sigma = \sqrt{\frac{nm(N+1)}{12}})$.

The Z value follows the normal distribution. If the Z value is positive, it indicates that the median of the first (pre-evaluation) period is higher than the median of the second period (post-evaluation). The null hypothesis (H_0) is rejected if $Z > Z_{(1-\alpha/2)}$, which shows the changes or differences between the first and second periods. The level of significance used in this study is $\alpha = 0.05$.

HYDROLOGICAL ANALYSIS

The discharge from the two outlets of the sub-watershed (from 1 January 1996 to 31 December 2017) was used to evaluate the impact of the changes (land use and rainfall changes) on hydrological regimes. The period was the longest record available for the study. Then, the streamflow data series is divided into two periods: the initial (pre-assessment) period from 1996 to 2005 and the final (post-assessment) period from 2006 to 2017. It is noted that the availability of time series data is the main constraints of this study. The separation to the two periods (pre- and post-assessment) chosen based on the availability of discharge data series. The objective of the separation is simplified to evaluate if the annual rainfall and the land-use changes have an impact on hydrological processes during the two periods.

First, the formatted streamflow data was imported to RAP (river analysis package) [MARSH 2004] for further statistical analysis. Then, the streamflow data from the two outlets were used to derive a statistical summary of daily discharge (i.e. maximum, minimum, mean, median, mean daily baseflow (MDBF), percentile 10, 25, 33, 66, 75, 90, and percentile 95). All these values were calculated using the RAP time series module [MARSH 2004].

Second, IHA software was used to evaluate the alteration in hydrological properties by using: (1) the range of variability approach (RVA); (2) the environmental flow component (EFC); and (3) the flow duration curves (FDC) tools [The Nature Conservancy 2009]. The IHA method comprises 33 parameters grouped into five categories to describe the flow components. The five classes are (1) monthly flow (median value of 12 months); (2) the smallest and largest flow for the period (1, 3, 7, 30, and 90 days) and the baseflow which occurs weekly; (3) date of the flow occurrence (date of occurrence of the smallest 1-day and largest 1-day); (4) frequency and duration of high flow and low flow (the low and high flow rates each year, and the median duration of low and high flows (days); and (5) the average and frequency of flow changes (the rise and the

fall of the hydrograph) [MATHEWS, RICHTER 2007]. The IHA analysis consists of four steps.
A. The streamflow data series is divided into two periods.
B. The 33 IHA parameters are calculated. Each parameter is calculated for the pre- and post-evaluation period.
C. The annual values of the IHA parameters are calculated. Then, based on these values, the trend and distribution of the data series are determined.
D. The IHA parameter values are used to compare the pre- and post-evaluation periods. All the results are then displayed based on percentile and standard deviation.

RANGE OF VARIABILITY APPROACH (RVA) ANALYSIS

Changes or alteration in the hydrological parameters was evaluated using the RVA. This was used to detect the differences or hydrological alterations between the two periods, pre-assessment (from 1996 to 2005) and post-assessment (from 2006 to 2017). The RVA determines any change by simultaneous analysis of the 33 hydrological parameters between the time series. The results were displayed in three percentile classes: percentile 0–33, percentile 34–67, and percentile 68 to 100.

The alteration between the two periods was calculated as follows:

$$HA = \frac{Of - Ef}{Ef} \qquad (3)$$

Where: Of = observed frequency; Ef = expect frequency.

ENVIRONMENTAL FLOW COMPONENT (EFC) ANALYSIS)

Analysis of the five EFC components was based on all the available streamflow data records. EFC uses three filters to select and classify the streamflow data into one of the EFC components. The first phase, all daily streamflow data, was identified and classified as low flow (1st class) or high flow (2nd class). The second phase, each high flow, was separated as high flow (2.1 class), small flood (2.2 class), or large flood (2.3 class). The third phase, each low flow, was then re-classified as extreme low flow (class 1.1) or low flow (1.2 class).

The five flow components of EFC acc. to the definition given by MATHEWS and RICHTER [2007], as follows:
A. The extreme low flow component is defined as all flow below the 10th percentile of flow.
B. The low flow threshold is defined as daily streamflow having a magnitude in the range of the 10th up to the 75th percentile.
C. The high flow component is defined as streamflow that has passed (is more than) the low flow threshold. High flow is determined as flow ranging from the 76th to the 89th percentile.
D. The small flood threshold is considered as all streamflow data whose peak is greater than the high flow level. Usually, streamflow greater-than or equal to percentile 90 every two years.
E. The large flood is defined as a streamflow event having a peak higher than a small flood. Usually, a large flood

occurs when streamflow greater-than percentile 99; the frequency of large flood is greater-than or equal to 10 years.

FLOW DURATION CURVES (FDC) ANALYSIS

FDC is a simple method to visualize the frequency of stream-flow occurrence. The FDC graphic is composed of an *X*-axis, which shows the bin-class or percentage of flow equal or more than the ($\geq$) specific threshold, and a *Y*-axis that shows the daily flow ($m^3 \cdot s^{-1}$) [INDARTO 2016]. The FDC graphic is constructed using procedures as published in the Nature Conservancy [2009] manual. Finally, the hydrological alteration between the two periods (initial and final) can be compared and visualised through FDC. The FDC results are shown in a flow duration curve table, with flow values (ranked from highest to lowest) and exceedance probabilities for the annual and monthly FDC. Results can also be displayed graphically. Any selection of yearly or monthly FDCs can be visualised on the same graph [The Nature Conservancy 2009].

RESULTS AND DISCUSSION

LAND USE CHANGE

The change in land use of the Kertosono watershed is presented in Table 3. Build-up areas or urban pavements significantly increased, from 17.50% to 29.05% (a $\pm$11.6% change). An increase was also found for paddy fields, which matched the increase in water bodies (+0.41% change). The development of reservoirs for irrigation and consumptive use has taken place significantly between 1996 and 2015. On the contrary, rural areas decreased by – 8.58%, and similarly, the areas occupied by forests and plantations significantly decreased (–13.68%). The change in land use for the whole area of the Ploso sub-watershed is presented in Table 3.

The change in land use related to built-up areas saw a 9.1% increase, in paddy fields of 7.7% and water bodies

Table 3. Change in land use in Kertosono and Ploso watersheds

Land-use	1996–2005		2006–2017		Change	
	km^2	%	km^2	%	km^2	%
Kertosono						
Built-up areas	1119.7	17.46	1819.0	29.00	699.40	11.60
Paddy fields	1816.5	28.32	2415.1	38.60	598.60	10.25
Rural areas	1421.1	22.16	850.2	13.58	–571.00	–8.60
Forests and plantations	2036.3	31.75	1131.1	18.10	–905.00	–13.70
Water bodies	20.59	0.32	45.6	0.73	25.03	0.41
Total	6414	100	6261	100	–153	–2.39
Ploso						
Built-up areas	1489	16.8	2256	25.9	766.6	9.1
Paddy fields	2592	29.3	3219	37.0	626.5	7.7
Rural areas	1757	19.9	1446	16.6	-311	–3.2
Forests and plantations	2983	33.7	1723	19.8	-1260	–14.0
Water bodies	26.4	0.3	53.3	0.6	26.9	0.3
Total	8848	100	8697	100	–151	–1.7

Source: own study.

0.3%. On the contrary, rural areas experienced a –3.2% decrease, then followed by decreases in forests and plantations (–14%). The four yellow cells in Table 3 represent the area of cloud cover on the Landsat image and unclassified by the image treatment processes. The unclassified pixels are probably located under the permanent cloud cover in the mountainous tropical areas.

The rapid growth of the population from 1996 to 2015 in the centre of the East Java region meant demand for more land to serve houses and other urban facility infrastructures. Note that the overall Brantas watershed area covers the majority of big cities in East Java province, i.e., Surabaya, Sidoarjo and Mojokerto in the down-streams areas below the Ploso outlet, followed by the cities of Jombang, Kediri, Nganjuk and Kertosono located in the centre, and Blitar, Tulungagung, Malang, and Batu located in the upstream areas of the watersheds. The last two cities are known as centres for education and mass tourism destinations in Indonesia. This situation has accelerated the conversion of the natural and rural environments to built-up areas.

Furthermore, higher populations need more food and agricultural areas to produce it. Therefore, conversion from the natural environment to paddy fields also marked the pre- (1996–2005) to post-periods (2006–2017). The government has also built several reservoirs and intake-dams during the last 20 years in this region.

RAINFALL CHANGE

Five of the seven stations observed saw no significant change in annual rainfall between the first and the second periods, as shown in Table 4.

A change in annual rainfall series only occurred locally at two stations, Kertosono and Papar. The other five stations experienced no difference in the median of annual rainfall between the pre- and post-evaluation periods (Tab. 5).

Table 4. Mann–Kendall test results

Station name	Critical value	Z value	Result
Dingin	1.862	0.23	insignificant
Kedungrejo	1.862	–0.55	insignificant
Kertosono	1.862	2.24	significant
Minggiran	1.862	1.20	insignificant
Papar	1.862	2.04	significant
Perak	1.862	1.20	insignificant
Woromarto	1.862	1.72	insignificant

Source: own study.

Table 5. Rank sum test results

Station name	Critical value	Z value	Result
Dingin	1.862	0.34	indifferent
Kedungrejo	1.862	–0.11	indifferent
Kertosono	1.862	–2.91	different
Minggiran	1.862	–1.47	indifferent
Papar	1.862	–1.62	indifferent
Perak	1.862	–1.32	indifferent
Woromarto	1.862	–2.08	different

Source: own study.

From the seven rainfall stations evaluated, we can conclude that insignificant change was observed in the annual rainfall series from the pre- to post-periods.

DISCHARGE PROPERTIES

Table 6 presents the statistical analysis results of daily discharge data from 1996 to 2017. The flow unit is cubic meter per second.

Table 6. Statistical summary of flow

| Statistical parameter | Flow ($m^3 \cdot s^{-1}$) | |
	Ploso	Kertosono
Minimum	0.73	1.99
Maximum	5063.98	1289.81
Mean	319.96	204.02
Median	216.04	154.35
Coefficient of variance	1.28	0.85
Standard deviation	410.26	173.01
Skewness	1.48	1.32
Variability (Var)	–3.38	–2.66
Percentile 10	23.84	37.80
Percentile 20	44.21	56.20
Percentile 30	81.66	78.92
Percentile 40	149.00	111.23
Percentile 50	216.04	154.35
Percentile 60	268.75	203.07
Percentile 70	343.80	261.00
Percentile 80	468.82	334.87
Percentile 90	754.33	448.73
Percentile 100	5063.98	1289.81
Lanes	0.60	0.44

Source: own study.

The mean daily flow measured at Kertosono was 204.2 $m^3 \cdot s^{-1}$ and at Ploso 319.96 $m^3 \cdot s^{-1}$. The skewness of the hydrograph was 1.32 at Ploso and 1.48 at Kertosono.

RANGE OF VARIABILITY APPROACH (RVA) RESULTS

The graphs in Figure 4 show the monthly flow alteration by comparing monthly values for the pre- and post-assessment periods. Figure 4 also shows that most of the monthly flow values (both at Ploso and Kertosono) increased from the pre- to the post-period. The median value in the post-period exceeds the median of the pre-period. This median value signifies an increase in the discharge quantity in most months; the increase in discharge occurs from January to December both at Ploso and Kertosono.

Figure 5 shows the alteration in hydrological values generated by the RVA by comparing the pre- and post-assessment periods. The RVA in Figure 5 shows that the hydrological values increased at the two outlets. Furthermore, the increase in values is higher at Kertosono than at Ploso.

Figure 6 shows the minimum and maximum of 1-day, 3-day, 7-day, 30-day, and 90-day flows. The extreme values (minimum and maximum) of these flows increased in the Ploso sub-watershed from the pre- to post-period (Fig. 6). These may occur due to the regulation of river stream-flows by the existing reservoirs in the upstream area. The
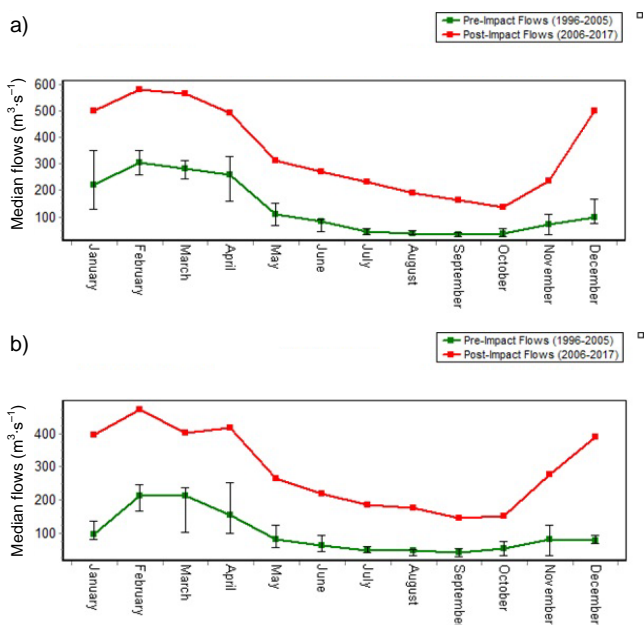
a)

b)

Fig. 4. Monthly Flow Alteration : a) Ploso, b) Kertosono;
source: own study

reservoir collects water during the rainy season, but most of the water should be released after its capacity is reached. This will be observed at Ploso as the increase in water during extreme flood conditions. The increase of flow at Ploso is more accentuated, which is also probably due to the contribution of flow from the downstream river tributaries.

On the other hand, during the dry period, the water at Ploso is exploited more for irrigation and therefore reduces the low flow of the river.

The baseflow index (*BFI*) is defined as the baseflow portion per total flow of the river at a specific time interval [INDARTO 2016]. The index of the Kertosono sub-watershed increased in the post-period, which is also an impact of the reservoir, which maintains the water level of the rivers.

ENVIRONMENTAL FLOW COMPONENT (EFC)

The threshold in the EFC analysis can be interpreted as the value of a discharge limit that refers to the five components of environmental flow.

First, Figure 7 visualizes the EFC analysis results at Ploso (a) and Kertosono (b). Extreme low flow occurs below the 10th percentile threshold each year; the high flow component (Tab. 7) is calculated each year for flow that exceeds the 75th percentile. Finally, the median value is obtained from the middle value of the entire year.

High flow EFC analysis (Tab. 7) produces six parameters. A high flow peak is the overall peak value that occurs throughout the flow periods. The median of high flow peak is 616.8 $cm^3 \cdot s^{-1}$ at Ploso and 372.5 $cm^3 \cdot s^{-1}$ at Kertosono. High flow duration refers to the duration of the occurrence of high flow each year. The median value is calculated from the yearly data.

The duration of high flow in both sub-watersheds has the same median value of 2 days. The median value of high flow timing for Ploso occurred at the 46th percentile and for Kertosono at the 67th. High flow frequency shows the frequency of high flow events every year. High flow rise rate and high flow fall rate refer to the level of increase and decrease in high flow hydrographs [GUL 2015].
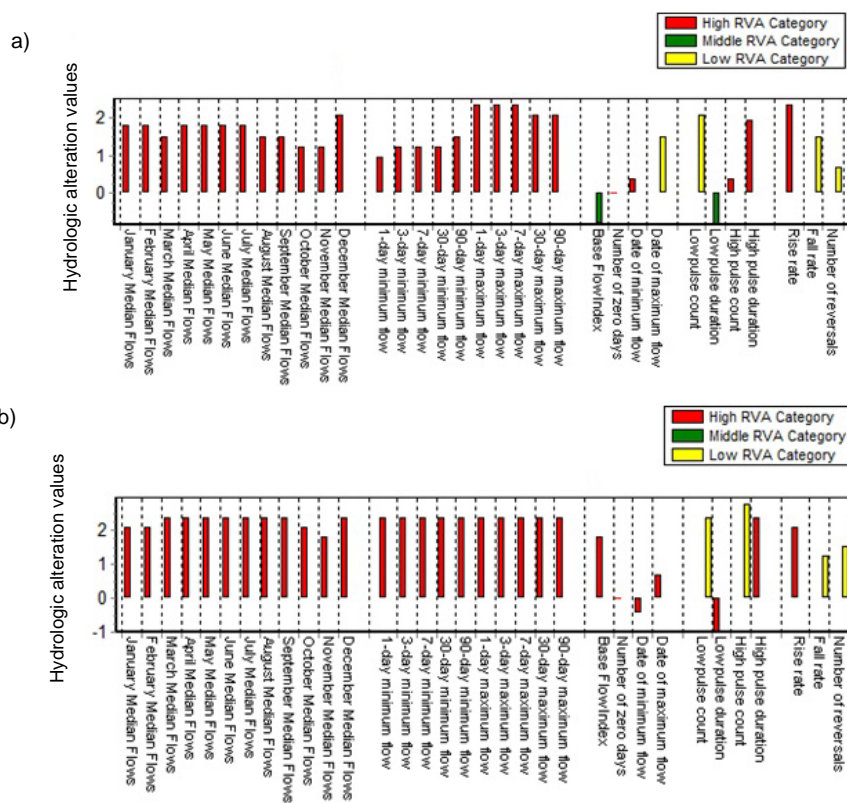
a)

b)

Fig. 5. Hydrological Alteration Based on 33 parameters: a) Ploso, b) Kertosono; source: own study
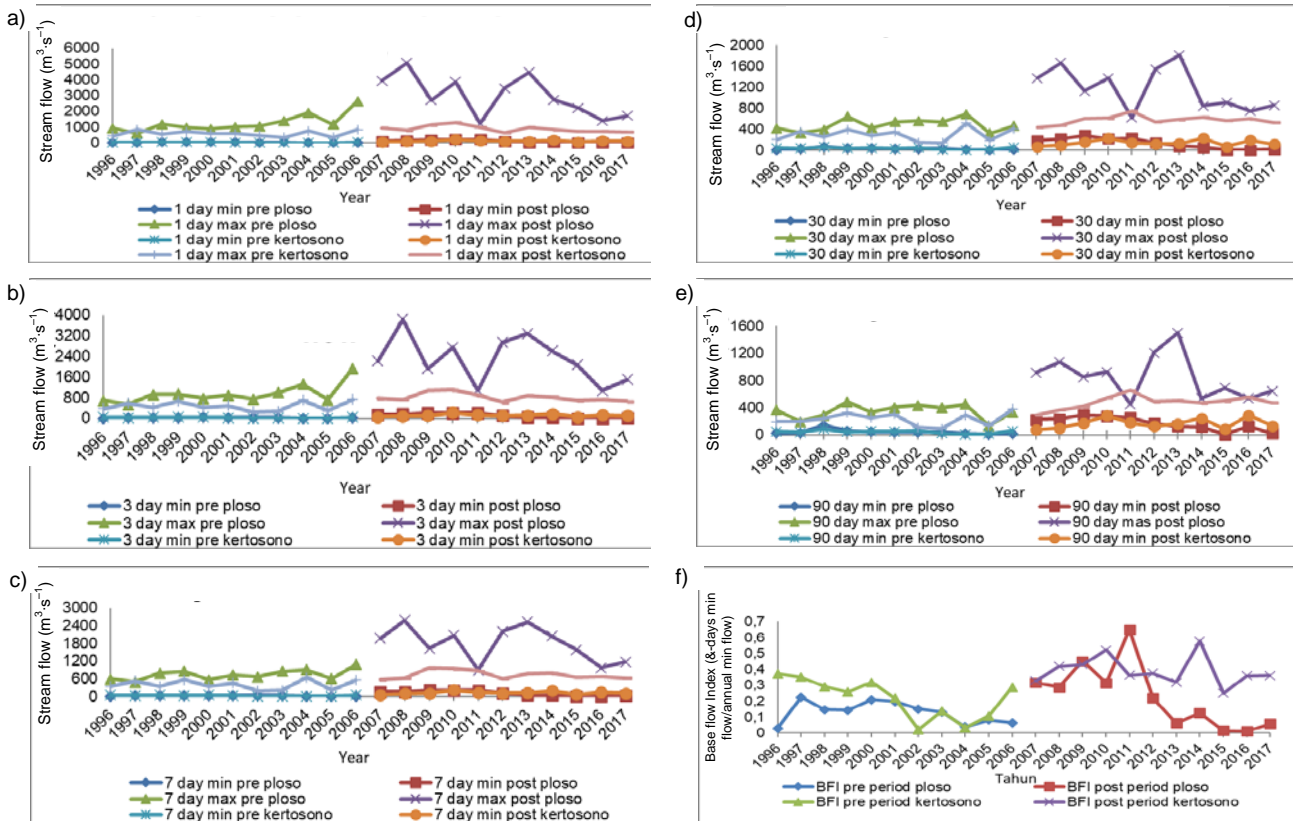
Fig. 6. Flow for Ploso and Kertosono of: a) 1-day, b) 3-days, c) 7-days, d) 30-days, e) 90-days, f) Baseflow Index (*BFI*);
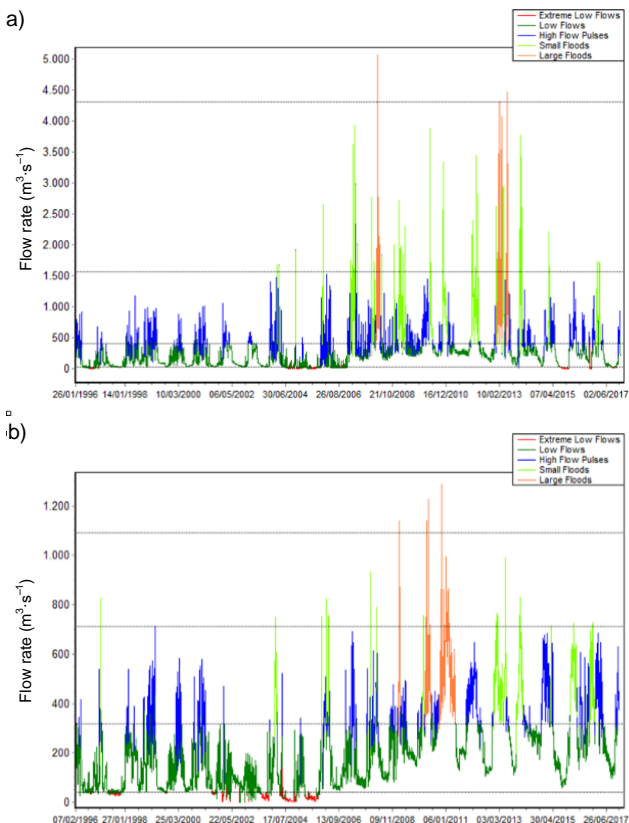source: own study

Fig. 7. Environmental Flow Component (EFC) results from:
a) Ploso, b) Kertosono; source: own study

Table 7. EFC Analysis for High flow pulses

EFC parameter	Ploso		Kertosono	
	median	*CV*	median	*CV*
High flow peak	616.8	0.25	372.5	0.16
High flow duration	2	1.12	2	1.5
High flow timing	46	0.31	67	0.25
High flow frequency	13	0.59	8	1.25
High flow rise rate	174.6	0.84	58,41	1.56
High flow fall rate	–131.5	–0.89	–66.25	–0.91

Explanation: *CV* = coefficient of variance.   Source: own study.

The small flood parameters (peak, duration, timing, frequency, rise rate, and fall rate) are calculated for flows greater-than or equal to the 90th percentile every two years (Tab. 8). The median value is obtained from the middle value of the entire year. The median value of the small flood peak is 2469 $cm^3 \cdot s^{-1}$ at Ploso and 789.6 $cm^3 \cdot s^{-1}$ at Kertosono.

Table 8. Environmental flow component (EFC) analysis for small floods

EFC Parameter	Ploso		Kertosono	
	median	*CV*	median	*CV*
Small flood peak	2469	0.57	789.6	0.16
Small flood duration	19	1.70	24	5.54
Small flood timing	35	0.23	56	0.19
Small flood frequency	0.5	5.5	0	0
Small flood rise rate	422.7	1.44	33.56	7.46
Small flood fall rate	–237.5	–3.02	–46.07	–1.93

Explanation: *CV* = coefficient of variance.   Source: own study.

Table 9 shows the results of the six parameters of the EFC analysis for large flood events in both sub-watersheds.

Table 9. Environmental flow component (EFC) analysis

EFC parameter	Ploso		Kertosono	
	median	*CV*	median	*CV*
Large flood peak	4766	0.124	1199	0.100
Large flood duration	48	0.416	103.3	1.438
Large flood timing	120.5	0.210	135.3	0.44
Large flood frequency	0	0	0	0
Large flood rise rate	228.8	0.113	31.82	0.873
Large flood fall rate	−157.2	−0.38	−48.04	−1.39

Explanation: *CV* = coefficient of variance.
Source: own study.

Flow is categorized as a large flood event if it exceeds the threshold of the 99th percentile every ten years.

A large flood peak is the peak value of a large flood that has occurred. The median value of a large flood peak is 4766 $m \cdot s^{-1}$ at Ploso and 1199 $m \cdot s^{-1}$ at Kertosono. The frequency of large floods refers to the frequency of large flood events every ten years. The median value of frequency in the two sub-watersheds is 0 because large floods are calculated every ten years, therefore the annual median value = 0. Large flood rise rates and a large flood fall rates indicate the number of increases and decreases in large flood hydrographs.

FLOW DURATION CURVES (FDC)

Figure 8 shows a graphic of the FDC results. The FDC curves show the high flow category of flow from the 20th to the 50th percentile. Then, from the 51st to the 80th percentile, the curve of the low flow category of flow is shown. The graphics show the differences between the pre-

a)

b)

Fig. 8. Flow duration curve (FDC): a) Ploso, b) Kertosono

and post-assessment periods for both sub-watersheds. The green and red lines (Fig. 8) indicate the FDC for the pre- and post-periods. The FDC curves for the two sub-watersheds show an increase in discharge from the pre- to post-period. The red line is always above the green line.

The availability of discharge has increased over the post-period. The increase is mainly explained by the change and conversion in land-use. The rapid land-use conversion and change from a natural to a built-up environment result in more runoff and less infiltration during the rainy seasons. Therefore, the streamflow on the river tends to increase in the post-period. The regulation of streamflow by several reservoirs in the upstream areas can compensate for low flow during the dry seasons.

It may be asked why the FDC of the low flow zone at Ploso is less than that at Kertosono. It is because of the higher number of irrigated and built-up areas located downstream of the watershed. The demand for water supply is critical in the downstream area.

CONCLUSIONS

The research results show an increase in flow in the two sub-watersheds (Ploso and Kertosono) from the pre-period (1996–2006) to the post-period (2007–2017). RVA analysis shows the increase in all monthly flow parameters from the pre- to post-period. The minimum and maximum daily flows parameters (1-day, 3-day, 7-day, 30-day, and 90-day) also increased for both sub-watersheds. The increase in flow from the pre- to post-period has also been proven by the FDC analysis. This hydrological alteration is caused more by the change in land use on the upland areas of the watershed and the water resources management policy (human-induced) than by a change in rainfall data series (a natural phenomenon). However, this study is limited by the availability of the data series used. The idea was to show that rapid change in land use and conversion from a natural to the human-induced environment can propagate hydrological alteration.

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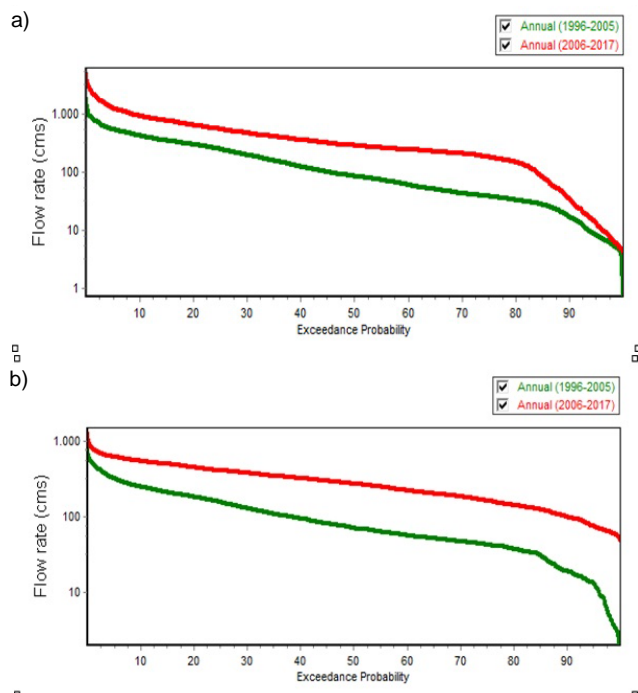
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