International Journal of Technology (2017) 1: 145-159
ISSN 2086-9614

WATER QUALITY INDEX FOR DETERMINING THE DEVELOPMENT THRESHOLD OF URBANIZED CATCHMENT AREA IN INDONESIA

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(Received: May 2016 / Revised: January 2017 / Accepted: January 2017)

ABSTRACT

The findings of numerous studies on the responses of stream quality indicators to different levels of watershed development have been integrated into an impervious cover model. The focus on one development stressor, namely the impervious cover, allows the decision makers to use the impervious cover model as a watershed planning tool to forecast stream response. In evaluating stream quality, the studies used various indicators such as pollutant loads, habitat quality, aquatic species diversity and abundance, and others. This study aims to test the applicability of the impervious cover model as a tool to set the threshold of catchment area development based on the targeted water quality index. The model is represented by a linear relationship between the water quality index as a response variable and catchment area imperviousness as an explanatory variable. The study area is an urbanized catchment area of a cascade-pond system located at the campus of Universitas Indonesia, Depok, West Java. Estimation of catchment area imperviousness is based on digital globe imagery and digitized based on identified rooftops. The water quality data to compute the water quality indices are collected from previous studies and related reports. The targeted water quality index is determined based on water use suitability referring to the Indonesian government regulation number 82/2001. Based on the available data, an increasing tendency of temporal variation of catchment area imperviousness for each pond can be recognized, while water quality index of each pond tends to decrease over time. In accordance with land cover distribution, spatial tendency indicates that imperviousness is decreasing in downstream direction, while water quality index is increasing in downstream direction, in line with the characteristics of cascade ponds. The results demonstrate that despite the fact that the available data are very limited, it is possible to use the linear relationship between catchment area imperviousness and water quality index as a tool to set the threshold for future development on the catchment area of the cascade-pond system at the campus of Universitas Indonesia with a minimum water quality index suitable just for recreation activities.

Keywords: Development threshold; Imperviousness; Urbanized catchment area; Water quality index

1. INTRODUCTION

The increasing amount of impervious surfaces in the catchment area as a consequence of urbanization generates the term “urban stream syndrome.” Syndrome of streams in urban areas

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Permalink/DOI: https://doi.org/10.14716/ijtech.v8i1.3971

covering the following symptoms: higher and faster flood peak, higher nutrient and contaminant concentration, disruption of channel regime, and degrade the integrity of aquatic life (Bellucci, 2007).

Schueler et al. (2009) summarize the findings of numerous studies on the responses of stream quality indicators caused by different levels of catchment area development, showing a reasonably strong relationship between the imperviousness of a drainage basin and various indicators for evaluating stream quality such as pollutant loads, habitat quality, aquatic species diversity and abundance, and others. The focus on just one development stressor, namely the impervious cover, allows the decision makers to use it as a basis for watershed planning to forecast stream response.

The Center for Watershed Protection (CWP) was the first organization to publish the Impervious Cover Model (ICM) in 1994. This model is actually not intended to predict the exact score of an individual indicator, but only to predict the average behavior of the group of indicator responses over a range of impervious cover (IC). Four categories of urban streams were defined based on the IC existing in their contributing area and on the threshold of degradation level, namely: sensitive (0–10% IC), impacted (11–25% IC), non-supporting (26–60% IC), and urban drainage (61–100% IC). The stream quality in general is grouped into “excellent,” “good,” and “fair” (CWP, 2003). Schueler et al. (2009) reformulate the ICM, which covers three important changes to the original conceptual model: first, the IC/stream quality relationship is expressed as a “cone” rather than a straight line, that is widest at lower levels of IC and progressively narrows at higher IC; second, the cone width is greatest for IC values less than 10%, which reflects the wide variability in stream indicator scores observed for this range of streams; and third, the reformulated ICM now expresses the threshold between stream category as a band rather than a fixed line. There is no change in the stream category. The term “threshold” is used in the study to discuss the relationship between imperviousness and stream quality indicator(s) in regard to the degree of imperviousness, by which the level of degradation will change the category of stream quality. The stream quality is defined as “poor,” “fair,” “good,” and “excellent.” The development of the ICM, as well as the reformulated ICM, is, among others, based on the following studies:

Klein (1979) is the first study to publish the correlations between development and aquatic-system conditions. Based on the data of small watersheds in Maryland Piedmont, the study shows that the first evidence of stream quality impairment occurs when watershed imperviousness reaches 12%, but stream quality is not considered severe until imperviousness reaches 30%. Todd et al. (1989) state that projected total phosphorus concentrations and loading rates exceed eutrophic levels at imperviousness levels of 30–40% based on extensive land use, nonpoint sources, and lake water quality data in the Lake Austin watershed. From a wide variety of lowland streams and wetlands in King County, western Washington State, Booth and Reinelt (1993) state a remarkably clear and consistent threshold of aquatic system degradation, approximately 10% imperviousness in a watershed typically yields demonstrable, and probably irreversible, loss of aquatic system functions. The loss is reflected by measured changes in channel morphology, fish and amphibian populations, vegetation succession, and water chemistry. Arnold and Gibbons (1996) define an average range of 10% imperviousness at which degradation first occurs, and 30% at which degradation becomes so severe that it becomes almost unavoidable based on the data of the Anacostia river watershed. Arnold and Gibbons (1996) further define three broad categories of stream health based on these thresholds, namely: “protected” (less than 10%), “impacted” (10–30%), and “degraded” (over 30%). Later, Bellucci (2007) refers to the Connecticut Water Quality Standards in stating that the 12% IC threshold represents a level of imperviousness in the upstream watershed. Beyond this value, streams will not likely be able to support a macroinvertebrate community.

Booth and Jackson (1997) discuss the fundamentals of “threshold,” arguing that changes imposed on the natural system are a continuum and believing that to define a strict threshold would be naïve. They also emphasize that the compendium compiled by Schueler (1994) limits the ability to draw precise conclusions because the geographic scope is largely restricted to streams of the mid-Atlantic seaboard, the Pacific Northwest, and a few other humid regions, in addition to the fact that the terminology “imperviousness” is not well defined in most of the studies. Brabec et al. (2002) raise three emerging issues regarding thresholds, including the following: first, variation exist in what is considered to be degraded; second, thresholds might be locally specific; and third, thresholds vary depending on the endpoint used (physical, chemical, or biological metric). Typically, thresholds of impacts on biological metrics are lower (3–15% IC) than for chemical measurements, such as contaminant concentrations, which do not typically reach levels of concern until IC is 30–50%. The limitation of the ICM is that a single set of thresholds may not accurately represent the behavior of all aquatic ecosystems (CWP, 2003). Walsh et al. (2005a) declare that the ecological condition, as indicated by concentrations of water-quality variables, algal biomass, and several measures of diatom and macroinvertebrate assemblage composition, declined with increasing effective imperviousness (EI) until a threshold of 1–14% was reached, and no further degradation was observed beyond the threshold. They also report that the streams of eastern Melbourne are in good condition up to 12% of total imperviousness (TI) and beyond this threshold are consistently in poor condition. However, this relationship declined linearly to a threshold when EI was used. Apparently, the threshold was a function of the proportion of impervious surfaces connected to the stream.

Although the majority of studies reviewed by Schueler et al. (2009) prove that the increasing level of land development will degrade stream quality, most of the studies state that the relationship between IC and declining stream quality is rather ambiguous and appears to vary regionally in response to climate and geologic factors, as well as water and sewer infrastructure (CWP, 2003).

The National Sanitation Foundation Water Quality Index (NSFWQI) was developed to provide a standardized method for comparing the water quality of various bodies of water, and it is widely used in North America because of its simplicity (Zandbergen & Hall, 1998). The merits of NSFWQI, as stated by Poonam et al. (2015), among others, are: it summarizes data into a single index value in an objective, rapid, and reproducible manner; it enables evaluation between areas and identification of changes in water quality; the index value relates to a potential water use; and it facilitates communication with lay persons.

This study aims to test the applicability of the impervious cover model as a tool to set the catchment area development threshold based on targeted water quality index. The model in this study is represented by a linear relationship between water quality index as a response variable and catchment area imperviousness as an explanatory variable. Considering the statement by Poonam, the water quality index used in this study is the NSFWQI.

The case study, catchment area of a cascade-pond system in the Universitas Indonesia (UI) campus at Depok, West Java, is dominated by a high density residential area. Based on several studies conducted in the last decade concerning the water quality variation in the pond system, which was built in the nineties, it is suspected that the condition of the aquatic ecosystem is deteriorating. To prevent further deterioration of water quality in the pond system, a tool to limit the development in the catchment area is urgently needed. The water quality index is representative of the cascade-pond ecosystem quality, and the target of water quality index is determined based on the Indonesian Government Regulation Nr. 82/2001 Concerning Water

Quality Management and Water Pollution Control (State Secretary of the Indonesian Republic, 2001).

2. METHODOLOGY

2.1. Framework of Study

This study is conducted in four steps: (1) analysis of temporal variation of catchment area imperviousness; (2) analysis of temporal variation of water quality index in water body; (3) analysis of catchment area imperviousness and water quality index relation; and (4) determination of imperviousness threshold for future development on catchment area.

2.2. Description of Study Area

UI Campus in Depok is located at the boundary of Jakarta Special Capital Region and Depok City, West Java Province, Indonesia. A cascade-pond system in the campus area was built in the nineties. The total catchment area of the cascade-pond system is around 580 Hectares, where around 305 Hectares (the northern part) is located inside the campus area (Figure 1), and the rest (the southern part) is located at two sub districts of Depok City. The campus area was designed with better landscaping to preserve the topography as well as the water bodies, while the outside of the campus is dominated by improperly planned, fast growing, and high density residential areas.

Figure 1 Catchment area of cascade-pond system at the campus of Universitas Indonesia, Depok, West Java (Google Map, 2015)

2.3. Estimation of Catchment Area Imperviousness

According to Kelly and McGinnis (2002), there are three methods applicable at the sub watershed level; namely: (1) direct measurement; (2) measurement based on specific land use categories; and (3) measurement based on a correlation between development and road length. The decision of which methodology to use should be based on: the time, labor, and funding available; the accuracy needed; and the ability to predict future imperviousness. The selected methodology should also consider three basic attributes of the required information: relatively accurate, easy to be conducted, and easily derived and readily available. Referring to those considerations, estimation of impervious surface for the study area was based on the digital globe imagery from the year 2005, 2011 and 2015. Considering the typical land use characteristic, which is dominated by high density residential build up (Figure 2a) without any rainwater management practices (Figure 2b), the digitation using ArcGIS was focused on the identified rooftops.

Figure 2a Bird-eye view of catchment area outside the campus (Google Map, 2015)

Nr. 1: Jl. Labu Nr. 2: Jl. Kembang Beji Nr. 3: Jl. Turi III

Figure 2b Example of directly-connected rooftops (Google Map, 2015)

The result is presented on Figure 3 and Table 1.

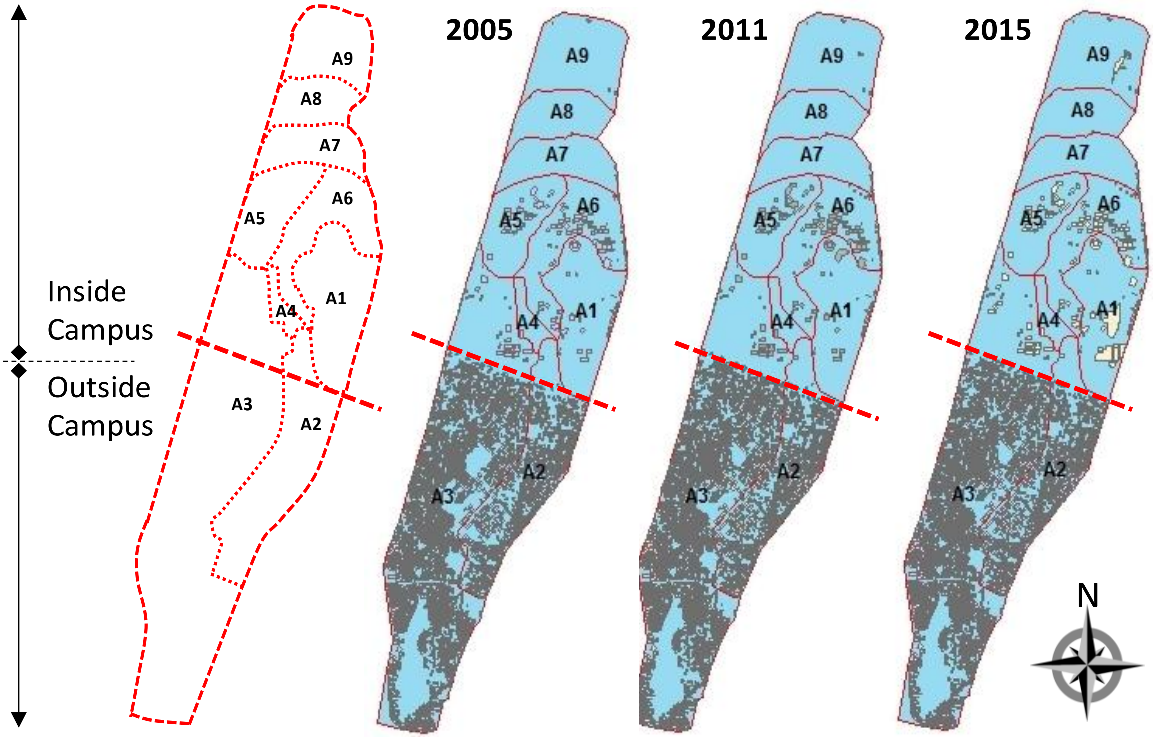


Figure 3 GIS-derived Impervious Cover Intensity Maps of Catchment Area of Cascade-pond System at UI Depok Campus

Table 1 Catchment area imperviousness

Pond (Point of Interest)	Coordinates of Point of Interest	Total Area*	Total Area (Ha)	Catchment Imperviousness (%)		
				2005	2011	2015
Kenanga	(6.3658) S; 106.8297 E	A1	54.40	5.1%	7.2%	22.4%
Agathis	(6.3687) S; 106.8248 E	A2 & A4	87.15	68.2%	75.5%	76.9%
Mahoni	(6.3599) S; 106.8280 E	A1 up to A6	472.04	38.9%	41.2%	44.2%
Puspa	(6.3569) S; 106.8296 E	A1 up to A7	503.50	36.5%	38.6%	41.5%
Ulin	(6.3535) S; 106.8290 E	A1 up to A8	531.88	34.6%	36.5%	39.3%
Salam	(6.3493) S; 106.8307 E	A1 up to A9	578.86	31.8%	33.6%	36.2%

* As indicated on Figure 3

Comparison of estimated percentages of impervious surface area for high-density residential land use as derived by various workers ranged from 25 up to 60% (Brabec et al., 2002), and from 21 up to 65% (Shuster et al., 2005).

2.4. Water Quality Index and Water Quality Rating

As stated by Tyagi et al. (2013), the use of individual water quality parameters in order to describe the water quality for the common public is not easily understood. The water quality index (WQI), which has the capability to reduce the bulk of the information - in this case, the water quality parameters into a single value to express the data in a simplified and logical form, has become a handy tool for public communication. Various water quality indices reviewed among others by Landwehr and Deininger (1976), Stoner (1978), United Nations Environment Programme Global Environment Monitoring System/Water Programme (UNEP GEMS/Water) (2007), Poonam et al. (2015), and Tyagi et al. (2013), indicate that there is no globally accepted composite index of water quality. Landwehr and Deininger (1976) compared five approaches to calculate the WQI, namely: arithmetic water quality index (WQIA), multiplicative index (WQIM), unweighted arithmetic index (WQIAU) and unweighted multiplicative index (WQIMU), and index by Harkins, which is based on Kendall's nonparametric multivariate ranking procedure. Stoner (1978) states that all developers of indices face the problem of subjectivity, which is usually solved using DELPHI method. The United Nations Environment Programme Global Environment Monitoring System/Water Programme (UNEP GEMS/Water, 2007) developed global water quality indicators, and ultimately, a global water quality index, which is an index that assesses the global status of drinking water in source water supplies. Poonam et al. (2015) review 13 types of water quality indices that are frequently used for water quality assessment, such as NSFWQI (National Sanitation Foundation Water Quality Index), CCMEWQI (Canadian Council of Ministers of the Environment Water Quality Index), and WQI (Water Quality Index). Through this review, Poonam states that most of the developed water quality indices are surface water specific.

This study uses the National Sanitation Foundation Water Quality Index (NSFWQI), which was developed in the seventies by Brown et al. using the DELPHI method of asking 142 people representing a wide range of positions at the local, state, and national level to consider which parameters should be included in an index from about 35 surveyed water quality tests. The NSFWQI was developed to provide a standardized method for comparing the water quality of various bodies of water, and its use is widespread in North America because of its simplicity (Zandbergen & Hall, 1998). Nine water quality parameters were selected to be included in the index (BASIN, 2005).

$$WQI = \sum_{i=1}^{n} Q_i W_i \tag{1}$$

where Q_i is the sub-index for i-th water quality parameter, W_i is the weight associated with i-th water quality parameter, and n is the number of water quality parameters.

Table 2 NSF water quality parameters & associated weight

No.	Water Quality Parameters (WQP)	Weight associated with WQP
1.	Dissolved Oxygen (DO)	0.17
2.	Fecal Coliform	0.16
3.	pH	0.11
4.	Biochemical Oxygen Demand (BOD)	0.11
5.	Temperature change	0.10
6.	Total Phosphate	0.10
7.	Nitrate	0.10
8.	Turbidity	0.08
9.	Total Solids	0.07
	Total	1.00

The NSFWQI are rated according to the following categories:

Table 3 Water quality index and water quality rating

Water Quality Index (WQI)	Water Quality Rating (WQR)
90–100	Excellent
70–90	Good
50–70	Medium
25–50	Bad
0–25	Very Bad

Water Research Center (2014) also provides an NSFWQI online calculator based on Equation 1. Using this calculator, it is possible to calculate WQI with incomplete/missing data, as demonstrated by Srivastava and Kumar (2013), although the uncertainty of the index value increases with the number of missing properties (Stoner, 1978). According to Kaswanto et al. (2012), the use of WQI could be of particular interest for developing countries because it provides cost-effective water quality assessments as well as the possibility of evaluating trends.

2.5. Existing Water Quality Data

There are several studies regarding the water quality dynamic of the UI cascade-pond system as listed in Annex (Table A). The tested parameters vary because the objectives of the works also vary. Table A presents the compliance of parameters of each study with nine parameters according to NSFWQI.

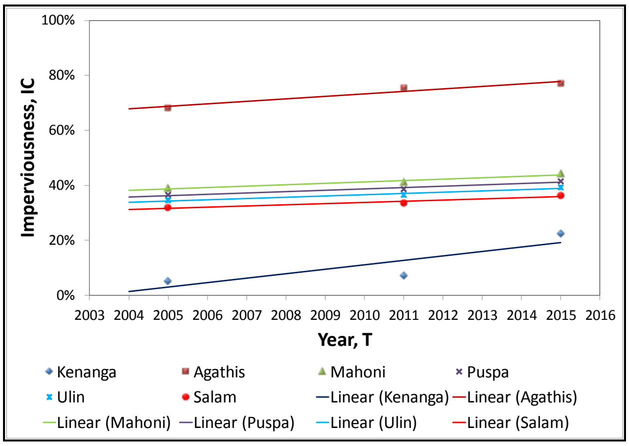
3. RESULTS AND DISCUSSION

3.1. Imperviousness and Water Quality Index Dynamics

Available water quality data were collected from previous studies (Supriadi et al., 2008; Sutopo, 2008; Sutjiningsih & Anggraheni, 2011; Isnaini, 2011; Suwartha & Pramadin, 2012; Suwartha & Priadi, 2013), and related reports (Unit Pelayanan Teknis Kesehatan, Keselamatan Kerja, dan Lingkungan Universitas Indonesia (UPT K3LUI), 2015; Badan Perencanaan, Pengembangan dan Pengendalian Universitas Indonesia (BP3UI), 2015) (See Table A in Annex), while the available map for estimating catchment imperviousness were based on the images from the year 2005, 2011 and 2015. Therefore, the catchment imperviousness in the years 2004, 2006, 2007 and 2012 was estimated based on its relation to the data from the year 2005, 2011 and 2015, as listed in Table 1. The complete series are listed in Table B in Annex.

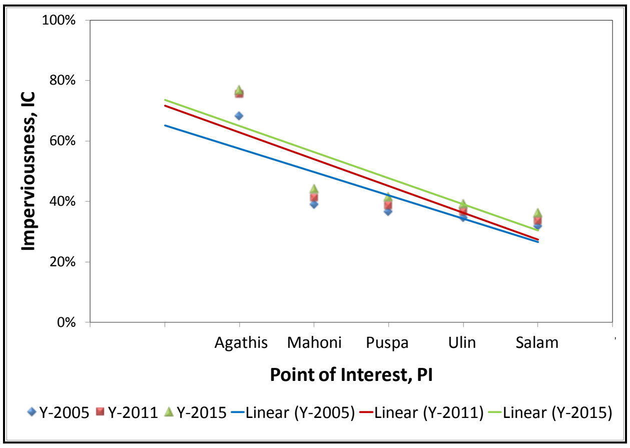
Temporal and spatial trends of catchment area imperviousness are presented in Figure 4a and

4b. The increasing temporal trend based on data from 2005, 2011, and up to 2015 as shown by Figure 4a represents the rapid development in the catchment area outside the campus, while the decreasing spatial trend as shown by Figure 4b represents the maintained green open space in the northern part inside the campus area. Kenanga was not included in the spatial trend analysis since the imperviousness of its catchment area in 2015 is still below the threshold of severe degradation (Klein, 1979).



Point of Interest	Trend line
Kenanga	$IC = 0.8792T - 1761.2$ $(r^2 = 0.7425)$
Agathis	$IC = 0.7866T - 1517.2$ $(r^2 = 0.9369)$
Mahoni	$IC = 2.4220T - 4673.4$ $(r^2 = 0.9574)$
Puspa / Ulin	$IC = 2.4271T - 4683.6$ $(r^2 = 0.9577)$
Salam	$IC = 2.4974T - 4824.5$ $(r^2 = 0.9522)$

Figure 4a Temporal trend of catchment area imperviousness of individual pond from year 2004 up to 2015



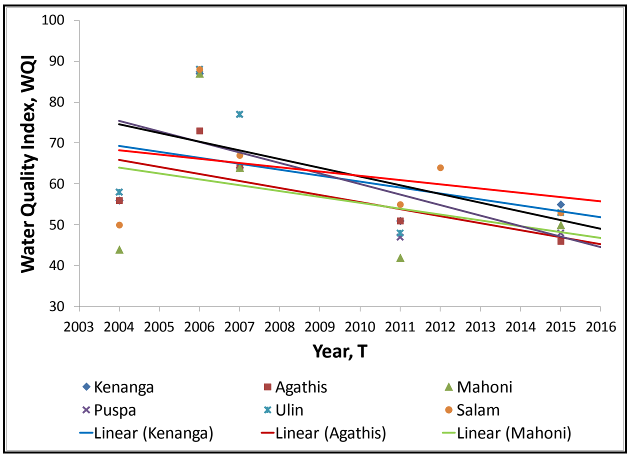
Year	Trend line
Y-2005	$IC = -0.0771PI + 0.7286$ $(r^2 = 0.6733)$
Y-2006	$IC = -0.0884PI + 0.8043$ $(r^2 = 0.6583)$
Y-2007	$IC = -0.0864PI + 0.8217$ $(r^2 = 0.6729)$

Figure 4b. Spatial trend of catchment area imperviousness from upstream (Agathis) to downstream (Salam) pond

Temporal and spatial trends of water quality indices are presented on Figure 5a and 5b. Figure 5a shows a declining temporal trend of WQI from year 2004 up to 2015 (See Table C in Annex), as well as an inclining spatial trend of WQI from Agathis downward up to Salam is detected on Figure 5b.

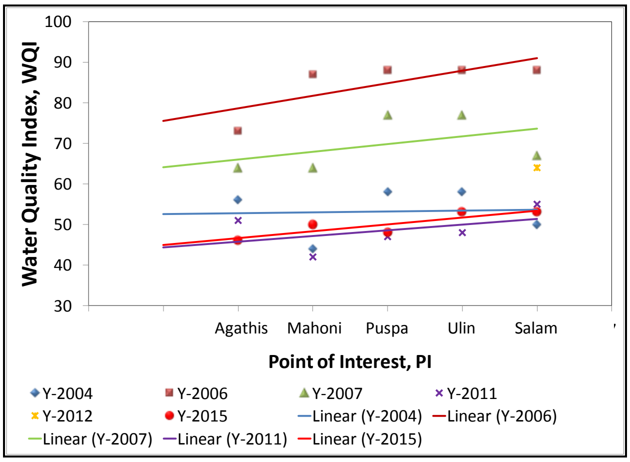
The unique phenomenon of the cascade-pond system at UI Depok-Campus is that the catchment area of individual ponds is actually a cumulative one, where there is less occupied area inside the campus in the downstream part of the catchment. The increasing catchment area imperviousness temporally represents the rapid development in the catchment area outside the campus, while the decreasing spatial trend represents the maintained green open space in the northern part inside the campus area. On the other hand, the WQI shows an inverse tendency, where it tends to decline over time, but in terms of space it tends to incline. These phenomena are aligned with the increasing imperviousness over time and decreasing imperviousness over space. It is important to note that a temporal trend is observed within a time frame of 2004–

2015, while a spatial trend is observed from the upstream (Agathis) to the downstream (Salam) pond.



Point of Interest	Trend line
Kenanga	$WQI = -1.4482T + 2971.4$ $(r^2 = 0.1943)$
Agathis	$WQI = -1.7228T + 3518.4$ $(r^2 = 0.5003)$
Mahoni	$WQI = -1.4275T + 2924.6$ $(r^2 = 0.1131)$
Puspa	$WQI = -2.5751T + 5236$ $(r^2 = 0.3863)$
Ulin	$WQI = -2.1295T + 4342.2$ $(r^2 = 0.3032)$
Salam	$WQI = -1.0461T + 2164.6$ $(r^2 = 0.0975)$

Figure 5a Temporal trend of water quality indices of individual ponds from year 2004 up to 2015



Year	Trend line
Y-2004	$WQI = 0.2PI+52.4$ $(r^2 = 0.0027)$
Y-2006	$WQI = 3.1PI + 72.4$ $(r^2 = 0.5498)$
Y-2007	$WQI = 1.9PI + 62.2$ $(r^2 = 0.2019)$
Y-2011	$WQI = 1.4PI + 43$ $(r^2 = 0.2103)$
Y-2015	$WQI = 1.7PI + 43.2$ $(r^2 = 0.7605)$

Figure 5b. Spatial trend of water quality indices from upstream (Agathis) to downstream (Salam) pond

3.2. Determining the Threshold of Development on Catchment Area

The approach used in determining the development threshold on the catchment area is using a linear relation between catchment area imperviousness and water quality index. The linear equation representing the relationship was determined based on the scatter diagram between those two variables. The threshold is the intersection between the linear equation and the minimum target of water quality index.

The minimum target for WQI is determined based on water use suitability. Isnaini (2011) suggests that the UI campus water should be used for water-related recreation because it does not meet the requirements for drinking water or fishing. This refers to the Indonesian Government Regulation No. 82/2001, which requires that there should be no content of fecal coliform in raw water sources for drinking water, while for fisheries it is required that phosphate content should not exceed 0.1 mg/l. High phosphate content will lead to eutrophication which can reduce the dissolved oxygen level. Thus WQI for the development threshold is set at a value of 50, which is the minimum limit of medium water quality rating (50–70).

The linear relationship between the two variables indicates that the trend of water quality index in each individual pond decreases as shown in Figure 6. Furthermore, the threshold value was compared with the condition of the existing imperviousness on the catchment area.

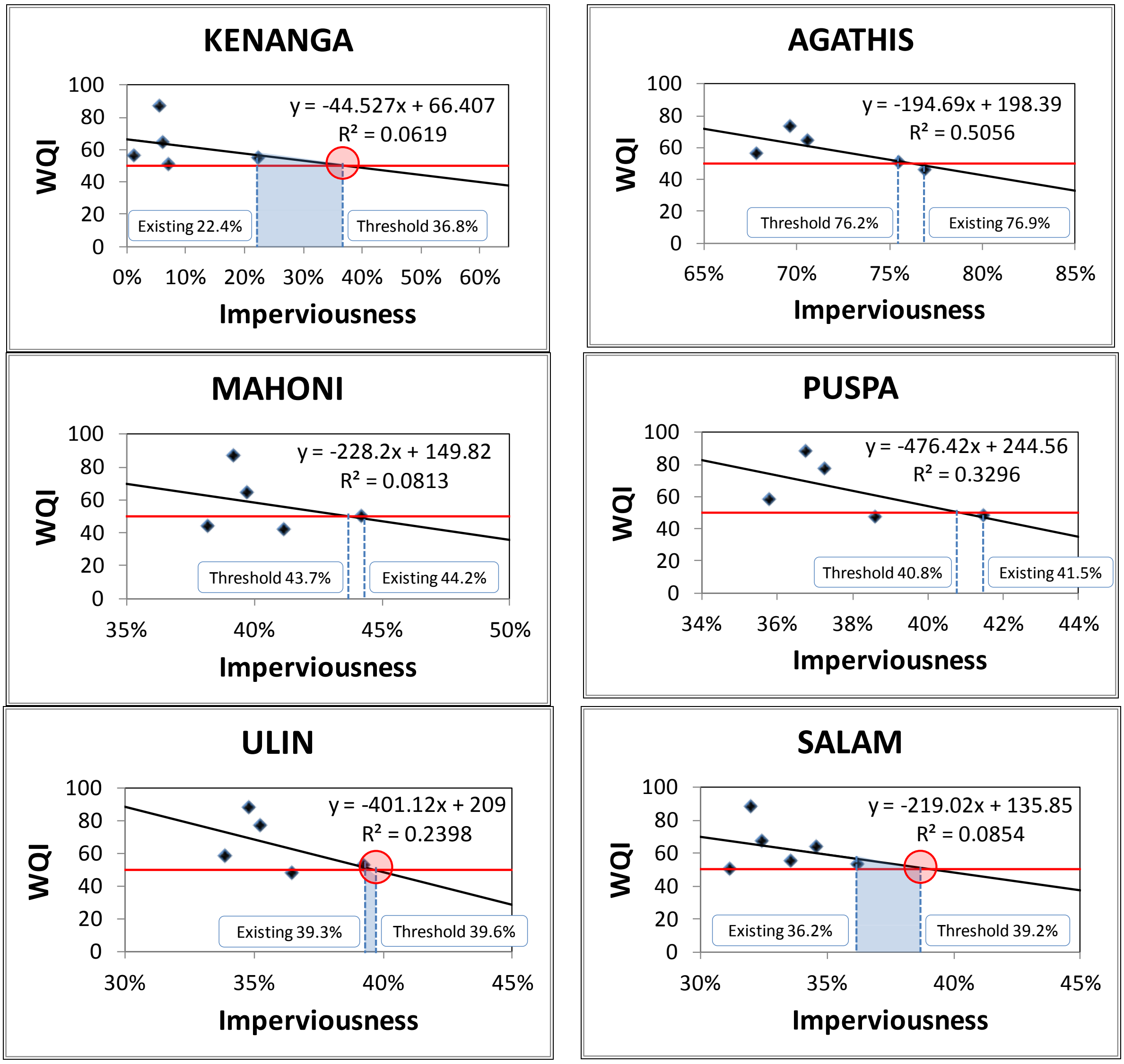


Figure 6 Estimation of imperviousness threshold for further development on the catchment area based on trendline of individual pond

According to CWP (2003), a common characteristic of IC and stream quality indicator relationships is that the data is scattered. The overall trend of indicators is decreasing, although considerable variation exists. Mostly, the linear relation between IC and stream quality indicators shows modest correlation coefficients (r^2 = 0.3–0.7), which are considered moderately strong. The scatter plots of individual ponds in Figure 6 show that only the relationship between IC and WQI for catchment area of Agathis, Puspa, and Ulin are meeting those criteria.

Although the results are still debatable, due to limited data, the relational equation between IC and WQI for an individual pond is tested to estimate the threshold of development on the catchment area, considering the findings of Hwang et al. (2016). Based on their investigation at 527 sampling sites on five major river systems in Korea, Hwang states that the linear relationships only confirmed the findings of previous studies in moderate land use conditions with 1.1–31.5% urban land use. The relationships were different in very low and/or very high urbanization conditions. Even with sufficient data, Hwang was still not able to identify the cause of the unexpected pattern. The results of development threshold estimation are summarized on Table 4.

Table 4 Estimation of imperviousness threshold for further development

Point of Interest	Existing Imperviousness*	Estimation of Imperviousness Threshold for Further Development	Remarks
Kenanga	22.4%	36.8%	Space available
Agathis	76.9%	76.2%	Already beyond the threshold
Mahoni	44.2%	43.7%	Already beyond the threshold
Puspa	41.5%	40.8%	Already beyond the threshold
Ulin	39.3%	39.6%	Very limited space available
Salam	36.2%	39.2%	Limited space available

** Based on 2015 data*

Although it seems that there is still space for development available in the catchment area of Kenanga, Ulin, and Salam, a constraint exists due to the condition of Mahoni, which is already beyond the threshold. Mahoni receives inflow from outside the campus area and also from the outlet of Kenanga and Agathis. Additionally, it receives waste water from the buildings inside the campus as well. Therefore, the decision makers must be careful in deciding to push the development in Kenanga, ensuring consideration of the possible impact on Mahoni. On the other hand, development in the catchment area of Puspa, Ulin, and Salam is actually impossible, since development in the conservation area is strictly prohibited.

4. CONCLUSION

Available data are very limited, and not all of the causal relationship between the impervious cover as an explanatory variable and the water quality index as a response variable on the individual pond can be explained, but the results demonstrate that it is possible to use the linear relationship between catchment area imperviousness and water quality index as a tool to set the future development threshold at UI Depok-Campus. However, since this case involves a cascade-pond system, the decision makers should be careful in interpreting the threshold of individual ponds, since all of the ponds are interconnected. In fact, the built-up area on the catchment zone outside the campus cannot be developed any further, since the imperviousness is already beyond the threshold, as detected on the catchment area of Agathis, Mahoni, and Puspa. Undoubtedly, development in the conservation area inside the campus is strictly prohibited. Therefore, additional development either on the built-up area or on the conservation area will bring the same result, since the water quality ranking in the cascade-pond system will drop below the target of medium category as set for recreation activities based on the Indonesian Government Regulation No. 82/2001. To establish effective water quality management policies, understanding the true nature of the relationship between water quality and urban land use therefore becomes essential.

5. ACKNOWLEDGEMENT

My special gratitude goes to the Head of University Planning, Development and Control Universitas Indonesia (BP3UI), Professor Nandy Putra, for supporting this study. Special thanks are extended to Ardi and Evi, who have dedicated their time and energy to provide me with land use analysis of UI Depok-Campus Catchment Area.

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ANNEX

Table A List of Existing Data/Information for Calculating NSFWQI

Sampling Date	DO	Fecal C.	pH	BOD	T-change	Phosphate	Nitrate	Turbidity	TDS/TSS	Objectives of the Works	Source
03-Jun-04	-	-	√	-	-	-	√	√	√	Assessing the physical, chemical and biological feasibility of water in the cascade-pond system as water supply for recharge-pond located at the downstream of the system.	Supriadi et al. (2008).
03-Jun-04	-	√	√	-	-	-	√	√	√		
16-Apr-06	-	√	√	-	-	-	√	√	√		
16-Apr-06	-	√	√	-	-	-	√	√	√	Analysis of the dynamics and water quality status of cascade-pond as water supply for recharge-pond located at the downstream of the system.	Sutopo (2008).
01-Feb-11	-	-	-	√	-	√	-	-	-	Determine the level of Situ KAMPUS-UI System effectiveness as a series of ponds to reduce COD (Chemical Oxygen Demand) concentration.	Sutjiningsih and Anggraheni (2011).
Apr-11	√	√	√	√	√	√	√	√	√	Determine the quality of water in Situ Salam based on NSFWQI.	Isnaini (2011).
Jun-11	-	-	√	-	-	-	-	√	√	Understand the recharge rate, and evaluate existing quantity and water quality of the pond during dry and rainy season.	Suwartha and Pramadin (2012).
Nov-11	-	-	√	-	-	-	-	√	√		
11-May-12	-	-	√	-	√	-	-	√	√	Identify the characteristic of recharge pond covers the Eigen value, transfer function, assimilation factor, residence time, and response time. Evaluate the surface water quality changes over time.	Suwartha and Priadi (2013).
5-Jul-12	-	-	√	√	√	-	-	√	√		
8-Oct-12	-	-	√	√	√	-	-	√	√		
22-Oct-12	-	-	√	√	√	-	-	√	√		
31-Oct-12	-	-	√	√	√	-	-	√	√		
23-Sep-15	√	√	√	√	√	√	√	-	√	Water Quality Monitoring in Cascade-pond system.	UPT K3LUI (2015).
18-Dec-15	√	-	√	-	√	√	√	-	√	Determine the Water Quality Rating in Cascade-pond system based on NSFWQI.	BP3UI (2015).
18-Dec-15	√	-	√	√	√	√	√	-	√		

Table B Imperviousness of UI Depok-Campus Catchment Area.

Point of Interest	Catchment Area Imperviousness (%)						
	2004*	2005	2006*	2007*	2011	2012*	2015
Kenanga	1.3%	5.1%	4.5%	6.2%	7.2%	14.2%	22.4%
Aghatis	67.9%	68.2%	69.7%	70.6%	75.5%	75.1%	76.9%
Mahoni	38.2%	38.9%	39.2%	39.7%	41.2%	42.3%	44.2%
Puspa	35.8%	36.5%	36.8%	37.3%	38.6%	39.7%	41.5%
Ulin	33.9%	34.6%	34.8%	35.3%	36.5%	37.6%	39.3%
Salam	31.1%	31.8%	32.0%	32.4%	33.6%	34.6%	36.2%

**estimated based on 2005, 2011 and 2015 data*

Table C Water Quality Index of Cascade-pond System at UI Depok-Campus

Parameter	KENANGA						AGATHIS						MAHONI					
	2015	2012	2011	2007	2006	2004	2015	2012	2011	2007	2006	2004	2015	2012	2011	2007	2006	2004
DO	67.39						41.01						60.21					
Fecal Coli	12,667			815	2	4,000	11,950			900	30	4,000	21,349			305	2	13,000
pH	7.77			6.86	6.40	5.23	6.99			6.69	6.61	5.20	6.77			6.79	6.48	5.20
BOD	48.68		0.97				65.46		0.98				61.87		2.05			
T-change	2.29						1.98						1.34					
PO4	2.98		20.86				8.67		22.85				6.11		20.08			
NO3	0.35			0.19	0.16	0.91	2.24			0.14	0.12	1.15	0.95			1.27	0.10	0.65
Turbidity				13.30	0.90	1.10				12.00	16.50	1.10				3.00	1.30	62.00
TSS	64.75			240.00	84.00	93.00	49.60			150.00	150.00	92.00	33.35			135	116.00	90.00
WQI	55	-	51	64	87	56	46	-	51	64	73	56	50	-	42	64	87	44

Parameter	PUSPA						ULIN						SALAM					
	2015	2012	2011	2007	2006	2004	2015	2012	2011	2007	2006	2004	2015	2012	2011	2007	2006	2004
DO	52.95						71.44						61.50		61.00			
Fecal Coli	58,413			50	2	1,400	16,500			50	2	1,400	6,950		819	240	2	13,000
pH	6.86			6.79	6.54	5.50	6.72			6.79	6.54	5.50	7.37	6.92	6.57	6.64	6.45	5.69
BOD	31.58		1.60				26.61		1.50				23.84	28.24	3.02			
T-change	0.97						1.15						1.85	2.69	1.00			
PO4	5.03		23.82				6.89		26.57				4.68		14.53			
NO3	1.03			1.90	0.35	0.89	0.93			1.90	0.35	0.89	1.46		1.47	2.49	0.34	0.10
Turbidity				1.70	0.90	3.00				1.70	0.90	3.00		9.19	13.31	12.40	0.90	20.00
TSS	36.18			140.00	95.00	90.00	37.67			140.00	95.00	90.00	29.45	114.58	650.78	125.00	92.00	230.00
WQI	48	-	47	77	88	58	53	-	48	77	88	58	53	64	55	67	88	50