STRUCTURAL APPROACH IN REVITALIZING URBAN STORMWATER CHANNEL: THE CASE STUDY OF ALUR ILMU, UKM BANGI CAMPUS

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ABSTRACT

Urbanization, economic growth, growing concern of people and regulation demand for clean water has established a niche for sustainable urban stormwater management. Now with more options for best management practice have caused confusion to decision makers and engineers on which practice is suitable to revitalize and manage the urban stream and river according to local needs. This paper aims to provide insights on the structural approach to revitalize urban stream based on the case study in Alur Ilmu stormwater channel. The structural approach consists of two parts, namely water quality assessment to determine spatial distribution of pollutions and on-site water treatment system. Malaysia's Water Quality Index (WQI) is used for water quality classification in Alur Ilmu stormwater, using six water quality parameters which are Dissolved Oxygen (DO), Ammoniacal Nitrogen (NH_3-N), pH, Total Suspended Solid (TSS), Chemical Oxygen Demand (COD), and Biological Oxygen Demand (BOD). The spatial distribution analysis of water quality is developed through interpolation of water quality data using Kriging model, to produce thematic maps of water quality which indicate the point sources of pollution on the map. As a result, a series of on-site water treatment systems, namely constructed wetland, gross pollutant trap, permeable pavement and floating treatment wetland were deployed based on the strategic locations identified through spatial distribution analysis. The structural approach has been deployed since 12th June 2015 and shown significant improvement on WQI from average Class III (68.85) to Class II (79.87) in less than 10 months. The most influential point for source of pollution was detected at AL5 (FST Café), it has improved the most, from Class IV (51.36) to Class III (73.18). Structural approach has successfully improved Alur Ilmu stormwater quality and should be complimented with non-structural approach under integrated stormwater management framework.

Keywords: Integrated stormwater management, on-site water treatment system, structural approach, urban stream revitalization, water quality.

INTRODUCTION

Pristine urban stream water quality of can be achieved if urbanization and economic development incorporate environment consideration into the current practice. Good governance of urban stream through sustainable stormwater management has tapped valuable potentials for many developed countries as cleaner urban stream contributes to alternative water resource, i.e. groundwater recharging and stormwater harvesting [1], fulfilling public demand for better environmental health [2], enhancing their quality of life, and providing nature aesthetic appreciation and gentrification for safe, efficient and greener neighbourhood [3]. Besides, it establishes a niche on revitalizing urban stream through various methodologies and water treatment systems. However, the options available in adopting management and water treatment systems have created ambiguity to decision makers and engineers to suit their local needs. Thus, the current study aims to provide insights on revitalizing urban stream water quality through structural approach based on the case study in Alur Ilmu stormwater channel. In revitalizing urban stream, structural approach is one of the best management practices (BMP) to remove the pollutants from the water body [1,4]. The goal of BMP is to provide sufficient pollution reduction of mass inflow i.e. from point and non-point sources of pollution to meet the targeted mass outflow provided by local standards and guideline [4]. The challenges of structural approach in BMP are the complex urban rainfall-runoff contributing to various types of pollution, myriad of biological, chemical and pollution reactions in the water body, and the reduction of pollution will vary even carefully constructed and hard to achieve same replicated result from previous case studies. Hence, structural approach is designed in a set of action plan that can mitigate pollution close to its source according to standards stipulated by local authorities or government. Similar to most of the developed countries, Malaysia government has outlined a national water quality standard for Malaysia, Water Quality Index (WQI) to identify and classify the level of acceptance of water quality for human use and environmental health [5]. WQI contains six water quality parameters, namely dissolve oxygen (DO), ammonical nitrogen (NH_3-N), total suspended solid (TSS), chemical oxygen demand (COD) and biological oxygen demand (BOD), are calculated into a value that can be classified into five classes and usages. The current present paper studies the technical aspects of structural approach using spatial distribution analysis of WQI in

Alur Ilmu which enable decision makers and engineers to target and apply treatment as close as possible to the source of pollution [8].

METHODS

Study Area

Alur Ilmu is a concreted urban stream traverses 1.79 km long across the main campus of the National University of Malaysia (UKM), Bangi, Selangor, Malaysia before flowing into the Langat River. The first 100 m of Alur Ilmu is located at the lowest elevation point of hilly terrain and flows with normal elevated terrain, closely surrounded by impervious area from building and impervious pavement. It receives water source from the Permanent Reserved Forest and Natural Education Forest (Hutan Simpan Kekal and Hutan Pendidikan Alam) UKM, rain water and stormwater runoff. The urban stream has been reinforced from a natural stream into a concreted urban stream in 1970s concurrent with the construction of the first UKM's faculty buildings without changing its original flow [9]. Alur Ilmu serves as an irrigation system to remove excess water from impervious area nearby the urban stream and avoid flooding. In this study, revitalization of Alur Ilmu water quality was conducted within the upstream (500 m length and 5 m width starting from Ghazali Lake to Silt Collection Tank). Average water depth is about 1.8 m with land coverage of 80% impervious area. The average water velocity of the urban stream is 0.1 ms^{-1} during dry season and increases to an average of 6 ms^{-1} during rain. Figure 1 shows the study area in light blue colour. The area was selected to identify point and non-point sources of pollution in Alur Ilmu and eliminate complication of spatially interpolating within nonconvex, or irregularly shaped regions [10]. The WQI was reported depreciating in value from Class II in 1999 [11], to Class II and III in 2003 [12], and to Class III and IV in 2012 [13].

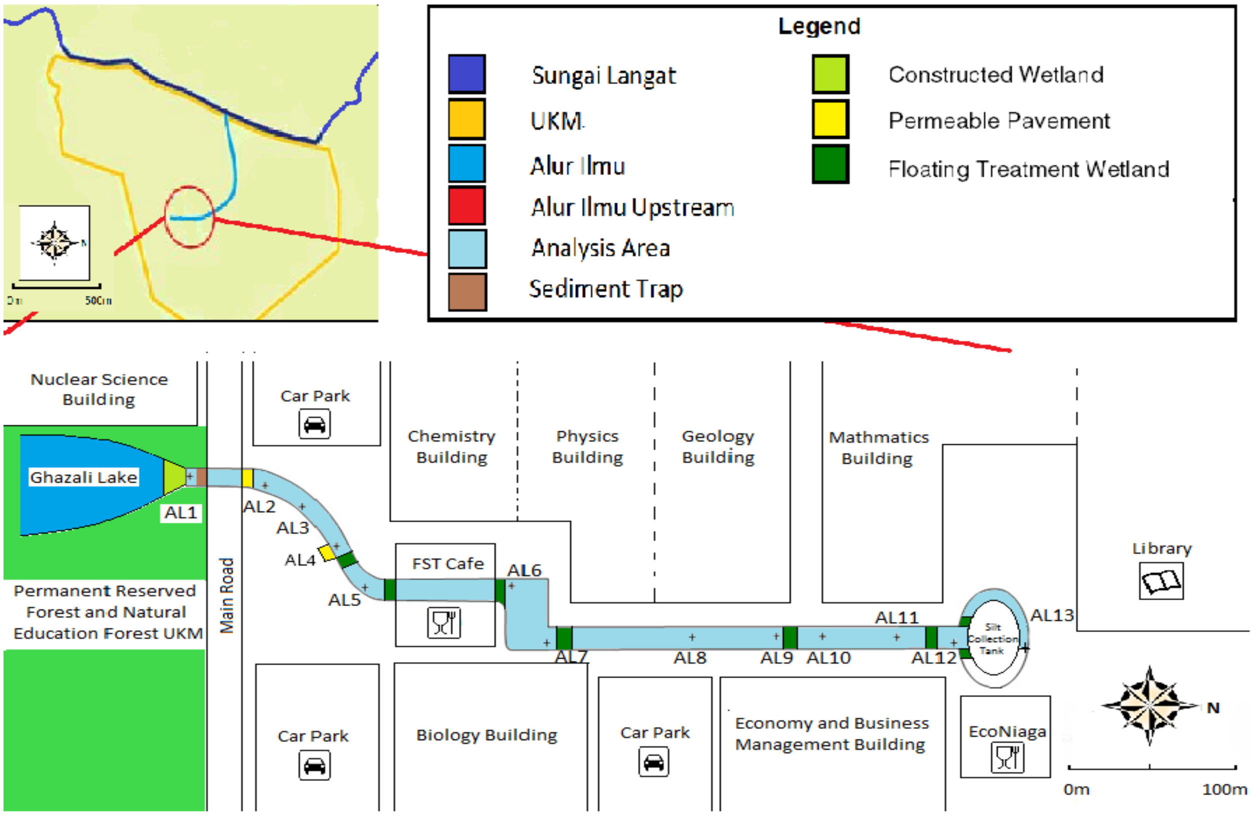

Figure1. Location of Alur Ilmu Stormwater Channel, the sampling sites and on-site water treatment system (treatment train).

Structural Approach

The study of revitalizing Alur Ilmu consists of two steps, namely 1) water quality assessment to determine spatial distribution of pollution 2) on-site water treatment. First, the water quality assessment for Alur Ilmu was conducted through *in-situ* monitoring and *ex-situ* analysis with accordance to National Water Quality Standards for Malaysia [5]. The data obtained was used for spatial distribution analysis to produce a thematic map determining point and non-point sources of pollution entering Alur Ilmu water body as a prerequisite to the development of the on-site water treatment system. The selection of on-site water treatment system was based on two criteria; 1) the site profile for its geomorphology, hydrology, water quality and pollution source, 2) water treatment application, design criteria, specification, operation and maintenance.

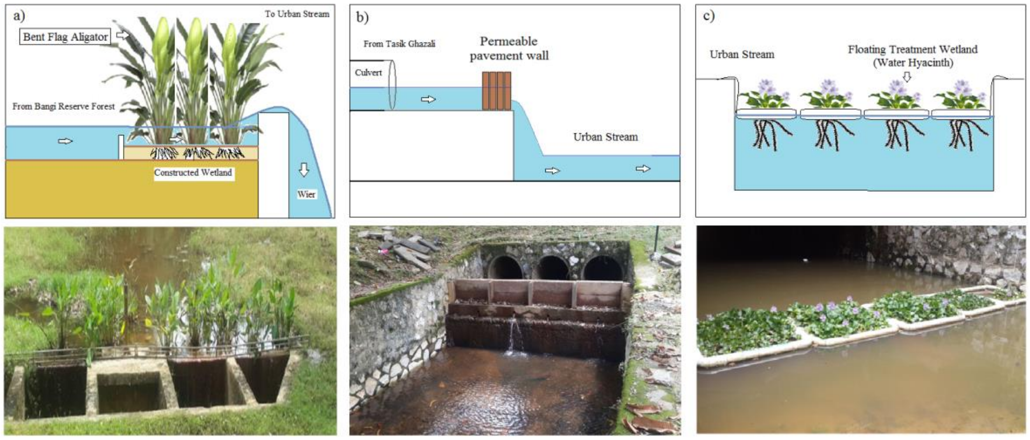

Figure 2. On-site water treatment systems; (a) Constructed Wetland, (b) Permeable Pavement and (c) Floating Treatment Wetland.

Sampling and Analytical Method

Thirteen stations were selected based on inlet identified along the study area and their GPS coordinates were recorded using Garmin Etrex 20. Six water parameters were selected for *in-situ* monitoring and *ex-situ* analysis for the water quality assessment, based on the National Water Quality Standards for Malaysia [5]. The parameter were dissolved oxygen (DO), pH, and Ammoniacal Nitrogen (NH_3-N) for in-situ monitoring and total suspended solid (TSS), biological oxygen demand (BOD) and chemical oxygen demand (COD) for *ex-situ* analysis. The *in-situ* monitoring for DO, pH and NH_3-N were measured using YSI Multiparameter Sonde during mid-day (11 a.m – 1 p.m) and water samples were collected for analysis. For *ex-situ* analysis, TSS parameter was measured using gravimeter method Method 208D [6]. BOD parameter was analysed by BOD_5 Method by incubating the water samples for 5 days under temperature of 20°C in an incubator and analysed using YSI EcoSense Self-stirring BOD Probe. Differences between DO_{first} and DO_{final} were recorded for BOD net value [6]. COD parameter was carried out using 5220B chemical oxygen demand, closed reflux, titrimetric method and was analysed using HACH Spectrophotometer DR3900 [6]. The six water quality parameters for each station in Alur Ilmu were used to calculate WQI value using WQI formula and calculation in Eq. 1. The obtained WQI values of each station were compared to DOE WQI Classification in Malaysia and uses [7] for water pollution level.

$$WQI = (0.22 * SIDO) + (0.19 * SIBOD) + (0.16 * SICOD) + (0.15 * SIAN) + (0.16 * SISS) + (0.12 * SipH) \quad (1)$$

SIDO = Subindex DO (% saturation)
SIBOD = Subindex BOD
SICOD = Subindex COD
SIAN = Subindex NH3-N
SISS = Subindex SS
SipH = Subindex pH

Subindex for DO (In % saturation)
SIDO = 0 for $x \le 8$
SIDO = 100 for $x \le 92$
SIDO = $-0.395 + 0.030x2 - 0.00020x3$ for $8 < x < 92$

SubIndex for BOD
SIDOD = $100.4 - 4.23x$ for $x \le 5$
SIDOD = $108 * \exp(-0.055x) - 0.1x$ for $x > 5$

SubIndex for COD
SICOD = $-1.33x + 99.1$ for $x \le 20$
SICOD = $103 * \exp(-0.0157x) - 0.04x$ for $x > 20$

SubIndex for NH3-N
SIAN = $100.5 - 105x$ for $x \le 0.3$
SIAN = $94 * \exp(-0.573x) - 5 * I\ x - 2\ I$ for $0.3 < x < 4$
SIAN = 0 for $x \ge 4$

SubIndex for SS

SISS = 97.5* exp(-0.00676x) + 0.05x for $x \leq 100$
SISS = 71* exp(-0.0061x) + 0.015x for $100 < x < 1000$
SISS = 0 for $x \geq 1000$

Sublndex for pH
SlpH = 17.02 - 17.2x + 5.02x2 for $x < 5.5$
SlpH = -242 + 95.5x - 6.67x2 for $5.5 \leq x < 7$
SlpH = -181 + 82.4x - 6.05x2 for $7 \leq x < 8.75$
SlpH = 536 - 77.0x + 2.76x2 for $x \geq 8.75$

Table 1.a DOE WQI Classification in Malaysia [7]

	CLASS				
	I	II	III	IV	V
WQI	< 92.7	76.5 – 92.7	51.9 – 76.5	31.0 – 51.9	> 31.0
Pollution level	Clean 100 - 81		Slightly Polluted 80 - 60	Polluted 0 - 59	

Table 1.b Water Classes and Uses [7]

CLASS	USES
Class I	Conservation of natural environment. Water Supply I - Practically no treatment necessary. Fishery I - Very sensitive aquatic species.
Class IIA	Water Supply II - Conventional treatment. Fishery II - Sensitive aquatic species.
Class IIB	Recreational use body contact.
Class III	Water Supply III - Extensive treatment required. Fishery III - Common,of economic value and tolerant species; livestock drinking.
Class IV	Irrigation
Class V	None of the above.

Data Acquisition and Statistics Analysis

WQI before treatment was obtained in June 2015 and WQI after treatment was taken in October 2016 to March 2017. The WQI for the thirteen stations were interpolated to produce thematic maps of spatial distribution of pollution using Kriging model via Surfer® 11 for water quality modelling. Kriging model was chosen in this study because it is the most accurate model to present interpolation of water quality data for liquid flowing in a conduit that does not completely enclose the liquid, i.e concreted stream and river [10]. Below is the general linear regression model (Eq. 2), showing how WQI treated via interpolation (predicted) for notation purposes. {y(s1) , . . . , y(sn)} represent a set of observed WQI at the station expressed by s1 , . . . , sn. Likewise, Y(s0) expresses corresponding water quality at an unsampled (unmonitored) location s0 for interpolation. Weight of the observed data is expressed as w(si) and $\hat{Y}$(s0) represents interpolated value for Y(s0) [14].

$$\hat{Y}(s0) = w(si)y(si) \qquad (2)$$

Kriging is a geostatistic method using statistical optimal spatial interpolation of given values to unsampled location (Murphy et al. 2010). The WQI for thirteen stations in the Alur Ilmu was interpolated using geostatistical Kriging method. Below is the linear equation model of Kriging (Eq. 3).

$$\hat{Y}(s) = \beta 0 + \beta 1X1(s) + \varepsilon(s) \qquad (3)$$

s expresses a generic spatial location expected to be different over some domain of interest, Y(s) is the result of interest measured at s. X1(s) expresses a potential covariate indexed by location s which may have more than one covariates. β1 is the covariate's associated regression effect and ε(s) is the random error term. The current study focuses on WQM-generated concentration of the 6 selected WQI parameters namely DO, NH_3-N, TSS, pH, COD and BOD. Using Kriging method, the parameters can be generated for all locations within the area, representing as the covariate [X1(s)]. The expected value of a parameter (i.e β0 + β1[Modeled DO(s)]) is different by location and is a function of the WQM-generated concentration. Residual error term is accounted for expected value which deviates in value and varies spatially. In Kriging method, accounting for a spatial varying expected value has lessened the concern regarding station in a flowing water body.

On-site Water Treatment System

The selection of on-site water treatment system undergoes screening of two general criteria which are site profile and water treatment application. Site profile is the outline of the intended urban stream and its surrounding location, including geomorphology, hydrology and water quality and pollution source. Geomorphology is the outline of the terrain for its slopes and its land use, hydrology is the water depth of the urban stream and its water velocity, water quality and pollution source are the status of the water in the urban stream and the type of pollution and the location of which it enters the water body. The water treatment applications for revitalizing the urban stream were screened and selected to compliment the site profile. Four categories were considered for the selection; removal efficiency, design criteria, water treatment specification as well as operational and maintenance. Removal efficiency is the ability of water treatment to remove targeted water quality parameters in the water body. Design criteria are the installation and development of the water treatment for on-site operation including the size and mechanism involved. Water treatment specification is the requirement for optimal efficiency and better performance and water treatment management suitability [1,4,15-16].

From the general abovementioned criteria, the selected on-site water treatment systems were constructed wetland, permeable pavement and floating treatment wetland. Figure 2 depicts the selected on-site water treatment systems used to revitalize Alur Ilmu water quality. The three water treatment systems were opt to compliment Alur Ilmu's site profile whereby Alur Ilmu is located close to human development and economic activities, i.e faculty infrastructures, cafe and tarred road, hence the water quality is susceptible to water pollution. Surrounded by impervious hilly terrain, the concreted urban stream received large surface runoff during rain. The constructed wetland is placed at the upstream of Alur Ilmu as it is effective to sink suspended solids using Bent Flag Alligator (*Thalia geniculate)*. Permeable pavement and floating treatment wetland were selected because of flexible design criteria which can be retrofitted into the minimum available space of Alur Ilmu and effective on domestic water pollution and surface runoff. Water Hyacinth *(Eichhornia crassipe)* was used for the floating treatment wetland because it is effective to remove urban stormwater pollution and resilient to urban water dynamic [17].

RESULTS AND DISCUSSION

The site profile of Alur Ilmu shows the geomorphology of the urban stream is bounded with infrastructures and has limited space for large on-site treatment system namely swales, infiltration basin and wetlands. The options available are to exercise major remodelling of Alur Ilmu which may harm the integrity of infrastructures in the vicinity or use Low Impact Development (LID) [17] by retrofitting on-site water treatment system to the urban stream. Based on Figure 3, the first part of Alur Ilmu being AL1 is suitable to use constructed wetland, as it is the only large area available for effective filtration and detention of soil, sediment and large solids, i.e. plastics, dead branches and debris. The area was planted with Bent Flag Alligator (*Thalia geniculate*) and has the predominant removal mechanism for detention system. It enables to hold water for a period of time, allowing for settling of solid pollutants, filtration through vegetation, biological and chemical transformation, i.e. bioabsorptions [4]. As AL2 to AL13 have limited space for large on-site treatment system, the main culverts were built with permeable pavements whereby it is a retrofitted stormwater filtration system engineered to physically reduce the concentration of suspended solids, soil and silt by filtering the water vertically past through the porous medium [4]. Alur Ilmu water body is susceptible to myriad of pollutions from discharged points and surface runoff. The ideal design setup was to use floating treatment wetland with water hyacinth for regional stowmwater control. The regional stormwater control is defined as facilities designed to manage stormwater runoff from multiple inlets for on-site control [4,18]. The floating treatment wetland designed for the regional stormwater control can maximize the utilization of developable land, reduce operation and maintenance cost, retrofit potential and highly visible for enhancing natural aesthetical value. Water hyacinth (*Eichhornia crassipe)* was selected because of its effectiveness in large application of urban water body [15]. The thematic map shows strategic design of floating treatment wetland using water hyacinth was able to improve the WQI.

As shown in Table 1, the average WQI was 68.85 (Class III) in June 2015 (before treatment) and it has been improved to 79.87 (Class II) in October 2016 (after treatment) within 10 months with 16.00% of improvement in WQI. The highest average WQI after implemented structural approach was reported in Feb 2017 being 81.98 (Class II) with 19.07% of improvement in WQI. After implementing treatment, average WQI stables at Class II ranging from 78.60 to 81.98 in WQI. The thematic maps show a general and clear pattern difference of WQI distribution before and after implementing structural approach in Alur Ilmu. All the thirteen stations along 500 m of Alur Ilmu have generally improved spatially in WQI. The highest improvement of WQI was recorded at AL5 with 46.47% of improvement from 51.36 (Class IV, June 2015) J to 75.23 (Class III, Feb 2017).

Figure 3 shows that the structural approach has a positive effect in revitalizing the urban stream's water quality. The overall design of structural approach is depending on the understanding of the complex pollution dynamic from natural phenomenon and anthropogenic factors of physical, chemical and biological forces emanating into the urban stream [4]. Based on the abovementioned methodology, the water quality assessment and spatial distribution analysis are the tools used to understand pollution accumulation and urban hotspot [4] of the land use prior to improve water quality of the urban stream. Alur Ilmu is located at the lowest elevation level of hilly terrain, surrounded by imperious surface area and economic activities. Therefore it is vulnerable to point and non-point sources of pollution. The thematic map before treatment is the superlative example to represent the pollution dynamic in the water body caused by point and non-point sources of pollution. The map indicates that pollutions accumulate at station AL5, AL8 and AL12. In relation to urban hotspot, AL5 and AL12 are both nearby to Cafeteria and AL8 is nearby to car park and faculty buildings. The introduction of pollution into the water body may come from the leakage of pipes and poor maintenance of pipes to channel waste produced into designated water treatment system and discarded properly through schedule waste disposal [9].

CONCLUSION

The result shows that the structural approach using constructed wetland, gross pollutant trap, permeable pavement and floating treatment wetland in revitalizing urban stream's water quality have a positive effect whereby the average WQI was 68.85

(Class III) in June 2015 (before treatment) and it has been improved to 79.87 (Class II) in October 2016 (after treatment) within 10 months with 16.00% of improvement in WQI. However, the structural approach should be complimented with a non-structural approach to control pollution before and after entering the urban stream's water body in view of the increasing of human activities will cause various pollution that can impair the capacity of the on-site treatment system.

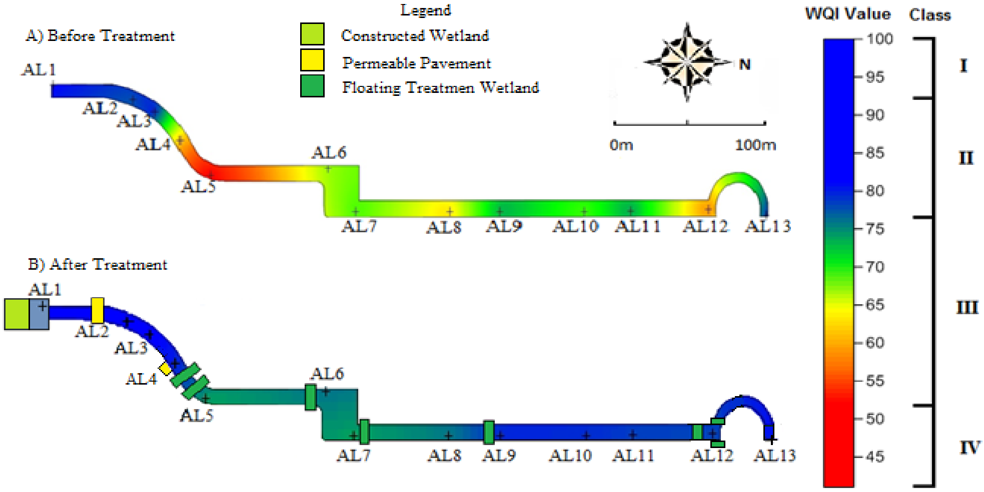

Figure 3. Comparison of spatial distribution of WQI in Alur Ilmu before and after the structural approach

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Table 1 WQI of Alur Ilmu before and after treatment.

Date			Before Treatment			After Treatment																	
			Jun 2015			Oct 2016			Nov 2016			Dec 2016			Jan 2017			Feb 2017			Mar 2017		
Station	Long	Lat	WQI	Class	Status	WQI	Class	Status	WQI	Class	Status	WQI	Class	Status	WQI	Class	Status	WQI	Class	Status	WQI	Class	Status
AL1	2.9219861	101.7817889	79.12	II	S.P	99.15	I	C	99.03	I	C	98.21	I	C	99.00	I	C	99.05	I	C	92.35	I	C
AL2	2.9227833	101.781675	76.34	III	S.P	90.40	II	C	90.61	II	C	92.11	II	C	90.11	II	C	92.90	I	C	90.43	II	C
AL3	2.9226806	101.7817306	78.12	II	S.P	80.81	II	C	81.43	II	C	82.51	II	C	80.68	II	C	81.20	II	C	81.01	II	C
AL4	2.92285	101.7817944	61.26	III	S.P	79.11	II	S.P	79.02	II	S.P	79.87	II	S.P	79.81	II	S.P	81.01	II	C	78.56	II	S.P
AL5	2.9230278	101.7818667	51.36	IV	P	73.18	III	S.P	71.24	III	S.P	71.53	III	S.P	72.91	III	S.P	75.23	III	S.P	70.11	III	S.P
AL6	2.9234722	101.7818139	66.23	III	S.P	75.13	III	S.P	75.36	III	S.P	75.65	III	S.P	75.05	III	S.P	78.23	II	S.P	73.02	III	S.P
AL7	2.923625	101.7819861	68.46	III	S.P	72.94	III	S.P	73.39	III	S.P	72.31	III	S.P	73.47	III	S.P	75.15	II	S.P	71.34	III	S.P
AL8	2.9239780	101.7819970	62.42	III	S.P	74.90	III	S.P	74.22	III	S.P	73.78	III	S.P	75.23	III	S.P	76.24	III	S.P	74.18	III	S.P
AL9	2.9242810	101.7820720	73.13	III	S.P	78.89	II	S.P	79.07	II	S.P	79.54	II	S.P	80.23	II	C	81.67	II	C	78.82	II	S.P
AL10	2.9245940	101.7821030	68.65	III	S.P	78.45	II	S.P	77.36	II	S.P	78.01	II	S.P	79.21	II	S.P	80.48	II	C	78.11	II	S.P
AL11	2.9248440	101.7820580	73.49	III	S.P	77.58	II	S.P	74.66	III	S.P	74.58	III	S.P	77.81	II	S.P	78.86	II	S.P	75.76	II	S.P
AL12	2.9250780	101.7820280	58.88	III	P	77.36	II	S.P	78.28	II	S.P	78.53	II	S.P	79.32	II	S.P	82.56	II	C	79.59	II	S.P
AL13	2.9251780	101.7819190	77.53	II	S.P	80.37	II	C	78.61	II	S.P	78.51	II	S.P	79.57	II	S.P	83.17	II	C	78.53	II	S.P
Average			68.85	III	S.P	79.87	II	S.P	79.40	II	S.P	79.63	II	S.P	80.18	II	C	81.98	II	C	78.60	II	S.P