Application of water-sensitivity assessment procedure for outlining the urbanized Ciliwung watershed restoration plan

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Abstract. Various studies show a close relationship between imperviousness and various biotic/abiotic elements of aquatic ecosystem. This phenomenon has been adapted to assess the water-sensitivity of a regional spatial plan at regency/city level. A generic assessment procedure based on the experience in Upper Ciliwung watershed is ready for application in other regions. The objective of this study is to apply the assessment procedure in set of subwatersheds, which covers all stream classifications, as specified in the reformulated impervious cover model. Using family biotic index as indicator of aquatic ecosystem quality, water quality index and habitat score as dependent variables, and impervious cover as independent variable, the regression equations are derived based on the data of 17 subwatersheds of Ciliwung watershed with imperviousness ranges of 5.23-91.10%. Based on the assessment result an outline of restoration plan can then be developed.

1. Introduction
Based on application of water-sensitivity assessment for existing and forecasted future conditions in Upper Ciliwung, West Jawa, a synthesized generic assessment procedure is ready for application in other watershed [1]. The procedure consists of 11 steps, which relies on the following concept: expansion of impervious cover, IC will increase surface flow that in turn change the stream morphology as the biotic habitat, HAB and change its level. Expansion of IC might also directly change the HAB level due to morphologic-physical alteration. The water quality index, WQI will also get worse. The degraded HAB and WQI will further impair the quality of aquatic ecosystem, in this case shown as tendency of family biotic index, FBI deterioration [2].

Schueler et al., 2009 [3] reformulated Impervious Cover Model (ICM) published by Center for Watershed Protection by adding one stream classification based on its imperviousness level become: sensitive, impacted, non-supporting and urban drainage. Moreover, they expressed IC-stream quality relationship as a cone, with the greatest width for IC values less than 10%, and the transition between stream quality classifications as a band. There are three important things to consider in applying the ICM: the watershed scale should be restricted to first to third order streams, no extensive impoundings nor major pollutant discharge points, and the subwatersheds under study located in the same physiographic region. They also stated that by controlling the development of built area that dominated by impervious cover the authorities are able to predict stream response as well as to manage the impact of development on aquatic ecosystem quality.

This study aimed to apply the water-sensitivity assessment procedure in set of subwatersheds of Ciliwung, which covers all stream classifications as specified in the reformulated impervious cover
model. Outline of restoration plan for selected subwatersheds in Ciliwung was developed based on the resulted regression equations between correlated variables.

2. Method and Material

2.1. The Method
The method adopts the water-sensitivity assessment procedure that consists of eleven steps as follows:
1. Delineate subwatershed boundaries [4].
2. Determine the existing imperviousness in each subwatershed [4].
3. Water sampling refers to Indonesian National Standard number SNI-6989.57-2008 [5], calculate water quality index based on NSF-WQI using online calculator [6] and apply at subwatershed outlet.
4. Assess habitat condition at subwatershed outlet and its surroundings [7, 8].
5. Macroinvertebrates sampling at subwatershed outlet, identify the sample in situ and in the laboratory and calculate the family biotic index (FBI) [9].
6. Determine the existing aquatic ecosystem quality at subwatershed outlet based on its FBI values.
7. Test the significance of the correlation between variables using the Spearman Rank-Order Correlation method [10].
8. Derive the linear regression equation(s) between variables that correlate significantly.
9. Determine the extent of impervious cover in the watershed and subwatersheds according to spatial plan or any other growth scenarios.
10. Forecast the aquatic ecosystem quality according to spatial plan or any other growth scenarios using the derived linear regression equation(s) for each subwatershed.
11. Compare the existing aquatic ecosystem quality with the forecasted condition, the IC expansion is predicted based on spatial plan or any other growth scenarios.

The relationship that explain the impact of imperviousness IC expansion on the aquatic ecosystem quality FBI, as described in step number eight, has three possibilities:

First,

\[ FBI = a_0 + a_1 IC \]  \hspace{1cm} (1)

Second,

\[ FBI = b_{10} + b_{11} HAB \]  \hspace{1cm} (2a)
\[ HAB = b_{20} + b_{21} IC \]  \hspace{1cm} (2b)

Third,

\[ FBI = c_1 HAB + c_2 WQI \]  \hspace{1cm} (3a)
\[ HAB = c_{30} + c_{31} IC \]  \hspace{1cm} (3b)
\[ WQI = c_{40} + c_{41} IC \]  \hspace{1cm} (3c)

The most preferable condition when equation (1) is fulfilled. If this not the case, then either the second or the third possibility is applied [2].

2.2. The Material
The Ciliwung watershed under study is located between 6°22′30″ – 6°46′10″ South and 106°47′30″ – 107°00′15″ East, in West Java. The Table 1 shows the coordinate of the observation points and the area of each subwatersheds.
Table 1. Location of observation points in Ciliwung.

| Subwatershed     | Observation Points | Area (km²) |
|------------------|--------------------|------------|
|                  | S. Latitude        | E. Longitude |      |
| U. Ciliwung 1    | 06°42'15.6"        | 106°58'57.8" | 1.48 |
| U. Ciliwung 2    | 06°41'53.6"        | 106°58'08.0" | 1.62 |
| U. Ciliwung 3    | 06°46'45.5"        | 106°58'11.0" | 4.05 |
| U. Ciliwung 4    | 06°41'45.8"        | 106°58'10.0" | 2.32 |
| U. Ciliwung 5    | 06°41'15.5"        | 106°57'28.9" | 6.61 |
| U. Ciliwung 6    | 06°40'42.1"        | 106°56'39.2" | 2.37 |
| U. Ciliwung 7    | 06°40'00.5"        | 106°55'58.3" | 2.20 |
| Cisarua          | 06°40'23.6"        | 106°55'25.7" | 19.68 |
| Cisuren          | 06°40'15.0"        | 106°53'53.1" | 11.30 |
| Cisukabirus      | 06°39'52.7"        | 106°52'39.9" | 16.46 |
| Ciesek           | 06°39'05.0"        | 106°52'03.6" | 26.36 |
| Cibalok          | 06°38'32.0"        | 106°51'15.6" | 1.37 |
| Ciseuseupan      | 06°38'47.2"        | 106°50'39.0" | 11.23 |
| Cikumpa          | 06°26'36.6"        | 106°49'58.9" | 25.80 |
| Cibuluh-Ciluar   | 06°28'58.5"        | 106°49'13.2" | 33.32 |
| Ciparigi         | 06°32'14.4"        | 106°48'39.7" | 11.92 |
| Sugutamu         | 06°23'37.0"        | 106°50'34.6" | 11.99 |

Figure 1 shows the position of each subwatershed in Upper and Middle Ciliwung. The 17 subwatersheds in Ciliwung cover all stream classifications, as described by Schueler et al, 2009 [3], namely: sensitive streams (Upper Ciliwung 2, Upper Ciliwung 7, Cisukabirus and Cibalok), impacted streams (Upper Ciliwung 3, Cisuren, Ciesek, Upper Ciliwung 5 and Cisarua), non-supporting streams (Upper Ciliwung 1, Ciseuseupan, Upper Ciliwung 6 and Upper Ciliwung 4), and urban drainage (Cibuluh-Ciluar, Cikumpa, Ciparigi and Sugutamu). All four subwatersheds in the Middle Ciliwung are classified as urban drainage.

3. Result and Discussion

The following Table 2 presents the summary of field data processing results.

Table 2. Summary of field data processing results.

| Subwatershed     | IC (%) | WQI | HAB | FBI |
|------------------|--------|-----|-----|-----|
| U. Ciliwung 1    | 23.73  | 72.5| 2.56| 5.16|
| U. Ciliwung 2    | 4.87   | 68.0| 2.44| 4.50|
| U. Ciliwung 3    | 12.20  | 78.0| 2.13| 6.04|
| U. Ciliwung 4    | 40.07  | 72.5| 1.75| 6.72|
| U. Ciliwung 5    | 18.36  | 72.5| 2.38| 3.13|
| U. Ciliwung 6    | 34.66  | 73.5| 1.88| 5.18|
| U. Ciliwung 7    | 5.29   | 70.0| 2.38| 5.77|
| Cisarua          | 19.85  | 79.0| 1.69| 7.61|
| Cisuren          | 12.90  | 78.0| 2.38| 5.04|
| Cisukabirus      | 7.61   | 77.0| 2.88| 4.24|
| Ciesek           | 13.09  | 70.5| 2.31| 5.14|
| Cibalok          | 8.22   | 70.0| 2.56| 4.93|
| Ciseuseupan      | 30.77  | 69.5| 1.56| 5.21|
| Cikumpa          | 75.70  | 65.0| 1.59| 5.95|
| Cibuluh-Ciluar   | 73.60  | 73.0| 1.91| 5.95|
| Ciparigi         | 80.50  | 64.0| 1.63| 5.63|
| Sugutamu         | 91.10  | 58.0| 1.28| 6.00|
3.1. Spearman Rank-Order Correlation Test

The correlation test using Spearman Rank-Order model with two-tailed test for $\alpha \leq 0.05$ and $n$ equal 17, the critical value $r_{\text{critical}}$ is 0.485. If the absolute of obtained value $r_s$ exceeds or is equal to the critical value, the null hypothesis will be rejected, meaning that there is correlation, otherwise the null hypothesis will be accepted or no correlation. The results for five relations of correlation tests are presented on Table 3.

Table 3. The results of spearman rank-order correlation test.

| Dependent Variables | Independent Variables |
|---------------------|-----------------------|
| IC, WQI             | HAB                   |
| Water Quality Index, WQI | $r_s = -0.319 \rightarrow 1, r < r_{\text{critical}}$ |
| Index, WQI          | $H_0$ accepted $\rightarrow$ No correlation |
| Habitat Score, HAB  | $r_s = -0.789 \rightarrow 1, r > r_{\text{critical}}$ |
| Family Biotic Index, FBI | $r_s = 0.519 \rightarrow 1, r > r_{\text{critical}}$ |
| Index, FBI          | $H_0$ rejected $\rightarrow$ Correlated |

3.2. Linear Regression Equation

Though there are two possible relations exist, the agreement made in the procedure is, if the first possibility fulfilled, then the equation (1) applies. Hence the following equation represents the direct relation between the quality of aquatic ecosystem and the dynamic of imperviousness in Upper and Middle Ciliwung:

$$FBI = 0.0122\; IC + 5.0134 \; (R^2 = 0.1248)$$

Refer to [10] $R = 0.3533 \; (R^2 = 0.1248)$ might be considered as moderate correlation coefficient. Predictions of the impact of imperviousness expansion $IC$ on the aquatic ecosystem quality represented by $FBI$ value are presented on Table 4. Only four subwatersheds were not in accordance with the premise, that if the $IC$ increases, the $FBI$ value also increases, meaning that the quality of its aquatic ecosystem deteriorates.
Table 4. The impact of imperviousness expansion on the aquatic ecosystem condition.

| Subwatershed      | IC (%) | FBI Value | Aquatic Ecosystem Condition |
|-------------------|--------|-----------|-----------------------------|
|                   | Existing* | Prediction** | Existing* | Prediction** |
| Upper Ciliwung 1  | 23.73   | 43.47     | 5.16     | 5.54         | deteriorate |
| Upper Ciliwung 2  | 4.87    | 8.91      | 4.50     | 5.12         | deteriorate |
| Upper Ciliwung 3  | 12.20   | 22.35     | 6.04     | 5.29         | -           |
| Upper Ciliwung 4  | 40.07   | 73.40     | 6.72     | 5.91         | -           |
| Upper Ciliwung 5  | 18.36   | 33.63     | 3.13     | 5.42         | deteriorate |
| Upper Ciliwung 6  | 34.66   | 63.49     | 5.18     | 5.79         | deteriorate |
| Upper Ciliwung 7  | 5.29    | 9.69      | 5.77     | 5.13         | -           |
| Cisarua           | 19.85   | 36.35     | 7.61     | 5.46         | -           |
| Cisuren           | 12.90   | 23.97     | 5.04     | 5.30         | deteriorate |
| Cisukabirus       | 7.61    | 13.93     | 4.24     | 5.18         | deteriorate |
| Ciesek            | 13.09   | 23.97     | 5.14     | 5.31         | deteriorate |
| Cihalok           | 8.22    | 15.05     | 4.93     | 5.20         | deteriorate |
| Ciseuseupan       | 30.77   | 56.36     | 5.21     | 5.70         | deteriorate |
| Cikumpa           | 75.70   | 94.30     | 5.95     | 6.16         | deteriorate |
| Cibuluh-Ciluar    | 73.60   | 100.0     | 5.95     | 6.23         | deteriorate |
| Ciparigi          | 80.50   | 100.0     | 5.63     | 6.23         | deteriorate |
| Sugutamu          | 91.10   | 100.0     | 6.00     | 6.23         | deteriorate |

* Year 2017-2018; ** Year 2025-2030

3.3. Restoration Plan Outline

According to [11] the subwatershed is probably the best unit to develop an effective management plan. With the areas ranging from 2 to 15 square mile (5-40 square kilometer) the influence of impervious cover on hydrology, water quality and biodiversity is most strongly felt at those scale. Four examples of restoration plan outline as representative of each stream classification are Cisukabirus (sensitive stream), Ciesek (impacting stream), Ciseuseupan (non-supporting stream), and Sugutamu (urban drainage). Table 5 shows the land use distribution, while the outline of restoration plan for those four subwatersheds are summarized on Table 6.

Table 5. Land use distribution of four subwatersheds in ciliwung (in %).

| Land Use       | Cisukabirus | Ciesek | Ciseuseupan | Sugutamu |
|----------------|-------------|--------|-------------|----------|
|                | Existing*   | Predictions** | Existing* | Predictions** |
|                |             |             |             |           |
| Built-up Area  | 7.6         | 9.7       | 13.1        | 13.6      | 30.8     | 87.6     | 91.1     | 94.0     |
| Cultivated     | 10.5        | 13.2      | 24.5        | 20.8      | 8.5      | 10.9     | 4.4      | 5.0      |
| Forest         | 12.8        | 9.8       | 20.1        | 1.5       | 19.2     | 0.5      | 3.3      | -        |
| Irrigated Area | -           | -         | 0.1         | -         | 0.3      | -        | 1.1      | 1.0      |
| Rainfed Rice   | 10.2        | -         | 1.7         | -         | 41.2     | -        | 0.1      | -        |

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Table 6. Summary of restoration plan outline of four subwatersheds in ciliwung.

| Sub Watershed | Cisukabirus | Ciesek | Ciseuseupan | Sugutamu |
|---------------|-------------|--------|-------------|----------|
| Classification| Sensitive Stream | Impacted Stream | Non-supporting Stream | Urban Drainage |
| Goal          | Maintain predevelopment biodiversity | Limit degradation of stream habitat and quality | Minimize downstream pollutant loads/prevent floods | Restore stream biodiversity to at least impacted stream level |
| Land Use      | Watershed and site impervious cover limits | Upper limit on subwatershed impervious | Redevelopment encouraged | Limited watershed redevelopment with full best management practices |
| Practices     | Maintain | All emphasize | Maximize removal of | Subwatershed restoration |

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| Forest         | 12.8        | 9.8       | 20.1        | 1.5       | 19.2     | 0.5      | 3.3      | -        |
| Irrigated Area | -           | -         | 0.1         | -         | 0.3      | -        | 1.1      | 1.0      |
| Rainfed Rice   | 10.2        | -         | 1.7         | -         | 41.2     | -        | 0.1      | -        |

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Sub Watershed & Cisukabirus & Ciesek & Ciseuseupan & Sugutamu  

| Buffers | Prededvelopment hydrology and recharge, emphasis on infiltration, restrictions on wet ponds, rural drainage | Pollutant removal/channel protection | Phosphorus/metals/toxins, no restrictions on ponds and wetlands | With stormwater management appropriate for urban environment (rwh, urban farming, rain garden, etc) |
| Monitoring Program | Widest stream buffers, protection sensitive areas | Standard three zones, variable width stream buffers | Greenway for recreation/flood protection | Acquisition or easements on stream corridors |
| Other tools | Land acquisition, clearing limits, erosion sedimentation control | Biological, including single species, biological and physical indicators | Water quality trends and loads | Biological monitoring, citizen monitoring |

4. Closure and Remarks

The assessment procedure provides a simple but powerful method to predict the future quality of aquatic ecosystem based on measurable land use change. However, in order to conduct an effective subwatershed management plan there are still many other elements that should be provided, among other by [11]: accurately measure and forecast land use, commit to a continuous watershed management cycle, audit effectiveness of local watershed protection programs, actively engage stakeholders and include public early and often promote intra- and inter-agency coordination.

References

[1] D Sutjiningsih, H Soeryantono and E Anggraheni 2018 Water-sensitivity assessment of regional spatial plan based on the relation between watershed imperviousness and aquatic ecosystem health IOP Conf. Series: Earth and Environmental Science DOI: 10.1088/1755-1315/140/1/012061.

[2] D Sutjiningsih, H Soeryantono, T Saleh. 2018 Pengembangan model korelaso tutupan lahan kedap air dan kualitas perairan pada DAS Ciliwung Final Report: Research Grant Penelitian Terapan Unggulan Perguruan Tinggi

[3] T R Schueler, L Fraley-McNeal, and K Cappiella 2009 Is impervious cover still important?. J. Hydrol. Eng. 14 309

[4] BIG 2009 Data penggunaan lahan se-Jawa (Cibinong : Badan Informasi Geospasial)

[5] Indonesian National Standard number SNI-6989.57-2008.

[6] Water Research Center 2014 Monitoring the quality of surface waters: calculating NSF water quality index (WQI)

[7] Mekong River Commission 2010 Biomonitoring Methods for the Lower Mekong Basin (Vientiane : MRC) 65

[8] Ecoton 2011 Panduan biotilik untuk pemantauan kesehatan daerah aliran sungai (Jawa Timur : Ecoton )

[9] F Haurer, G Lamberty 2007 Methods in stream ecology: second edition (California : Academic Press )

[10] G W Corder, D Foreman 2009 Nonparametric statistics for non-statisticians: A step-by-step approach (A John Wiley & Sons, Inc)

[11] Center for Watershed Protection 2000 Crafting better urban watershed protection plans. The Practice of Watershed Protection. (Ellicot City : Center for Watershed Protection)

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