Integrated assessment of highly urbanized catchment using geographic information system (case study: cascade-pond system Universitas Indonesia campus catchment area)

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Abstract. This study is assessing the ecological integrity of landscape condition to maintain freshwater biodiversity at highly urbanized catchment using geographic information system (GIS). GIS tools were used to calculate the percentage of land use types i.e. impervious cover, vegetation cover, and water body at 6 sub-catchments of Universitas Indonesia (UI) Depok campus. In order to evaluate freshwater biodiversity, 478 samples of macroinvertebrates were collected from the cascade-pond system. Each of pond was calculated using macroinvertebrate indices namely Singscore and The Shannon Diversity Index. Nine parameters of water physics-chemistry were also collected from each pond and calculated based on The National Sanitation Foundation - Water Quality Index. The highest percentage of impervious cover is located in the upper of catchment and simultaneously reduce the percentage downward. The impervious cover affects the pattern of freshwater biodiversity and water quality of cascade-pond system. The most diverse and highest score of aquatic organism was found at Salam sub-catchment that located in the lower part of UI catchment. Integrated assessment of UI catchment area using GIS-based multiple criteria decision analysis shows that the term of “end-of-pipe” at cascade-pond system affecting the ecological status of each catchment.

1. Introduction
Over the last two decades until now, researcher is trying many methods to determine the state of catchment health, from simple to complex methods. The health of catchment can be assessed simply by its land use characteristics [1,2,3]. More complex and sophisticated assessment was developed by The United States Environmental Protection Agency (US EPA) that combining many variables. US EPA argues that there are six assessment components to describe the healthy catchment. The systems
approach of healthy catchment is based on an integrated evaluation of 1) Landscape Condition, 2) Habitat, 3) Geomorphology, 5) Water Quality, and 6) Biological Condition [4]. The systems approach of health catchment needs interdisciplinary work from different fields i.e. geographer, civil engineer, landscape architect and biologist. Integrating and connecting all of catchment health variables into a simple understanding is one of purpose of this study. Geographic information system (GIS) believed as powerful, efficient, low-cost tool for integrating and connecting the systems approach to health catchment [5,6,7]. Multiple criteria analysis is common method to decision analysis in GIS platform [8,9,10]. GIS-based multiple criteria analysis can be a tool to accommodate the system thinking of geographer. This study is using GIS-based multiple criteria analysis as a spatial decision support system tool for integrated assessment of catchment health.

The case study is located in Universitas Indonesia (UI) campus catchment area that dominated by high imperviousness. Previous study by Sutjiningsih [11] found that the current state of imperviousness in UI catchment is classified from impacted to heavily damaged. Three from six sub-catchments of UI campus is already beyond the threshold of impervious cover development [11]. Another study by Zulkarnain et al [12] investigated the biological condition derived from macroinvertebrate indices of the cascade-pond system that located in UI campus catchment. In order to develop more integrated assessment of UI catchment, this study is using the same impervious cover and macroinvertebrate indices data in previous studies [11,12] with some additional variables namely water quality, road network and vegetation cover. GIS based multiple criteria analysis is being used for incorporating all of variables into a simple understanding of catchment health assessment.

2. Area of Study

Universitas Indonesia (UI) catchment is located at two administrations, Special Capital Region of Jakarta and Depok City, West Java. The total area of UI catchment is around 580 hectares, 305 hectares is located inside the UI campus and 275 hectares is located outside the UI campus. UI catchment can be divided into 6 sub-catchments based on its point of interest which are 6 ponds of the cascade-pond system (see figure 1).

![Figure 1. Universitas Indonesia’s sub-catchments](image)

A cascade-pond system that located inside the campus area makes a distinctive hydrologic condition of UI catchment. A cascade-pond system known as “KAMPUS”, short form of *Kenanga-Agathis-Mahoni-Puspa-Ulin-Salam*, is an artificial stormwater pond system that connecting one to the another, from the upper to the lower part then flowing to the bigger stream, Ciliwung river. A cascade-pond system is also known as term of the “end-of-pipe” [13]. “End-of-pipe” term is last stage process of pollutants removal from water before the stream is released to the bigger system or environment [14]. In cascade-pond
system case, pollutants removal in cascade-pond system mostly is coming from settling mechanism while the others are coming from infiltration and biological uptake [13]. Although its main function, a study by Sutjiningsih and Anggraheni [13] stated that the cascade-pond system is ineffective to maintain the water quality of UI campus.

3. Data Collection Technique
478 samples of macroinvertebrates were collected from the cascade-pond system in Universitas Indonesia (UI) catchment. All of the ponds were divided into three stations which is inlet, middle, and outlet. Macroinvertebrate was caught during the rainy season (January to March 2017) from all of the microhabitat particularly macrophytes, stones, and sediment/mud by using dip net within two replicates. This technique was applied because mostly macroinvertebrate was found near its microhabitat [15,16,17,18,19]. For delaying the decomposition rate, all macroinvertebrate samples were preserved with 4% formaldehyde and was identified by microscope. The other primary data is water quality sample of 6 ponds. Each ponds were also divided into three stations. Water quality samples were taken within three replicates during rainy season. The national accredited laboratory was hired for testing 8 parameters of water quality. Impervious cover, vegetation cover, and road network data were generated from high-resolution image processing. Imagery data then was digitized using ArcGIS 10.3 to extract the impervious cover, vegetation cover, and road network in 1:5,000 map scale.

4. Data Processing
4.1 Impervious Cover and Vegetation Cover Percentage Calculation
The total area of imperviousness and vegetation cover was digitized using ArcGIS 10.3 and calculated with a UTM projection. Road network density is another variable that been used in this study. Road network density is known as one of indicator for urban development and also a trigger for land use change [20]. Road network is also causing landscape fragmentation that may impact negatively related to the ecological diversity of certain region [21,22]. Road network data was digitized using ArcGIS 10.3 and calculated with projected projection.

4.2 Macroinvertebrate Indices & The Shannon Diversity Index ($H'$)
The Shannon Diversity Index ($H'$) is an index that has been widely used for assessing the macroinvertebrate diversity [23,24]. Morris et al. [25] stated that using The Shannon Diversity Index has the greatest relationship to the ecological traits rather than other diversity index [26]. Public Utilities Board (PUB) of Singapore developed the Singscore as a bioindicator based on macroinvertebrate existence [27]. This study is applying Singscore for calculating the macroinvertebrate indices, assumes that the characteristics of macroinvertebrates abundance between Singapore and Indonesia are quite similar [27]. Singscore can describe the categories of likely water quality based on aquatic macroinvertebrate existences (see table 1).

| Singscore | Likely water quality |
|-----------|----------------------|
| 0 - 79    | poor                 |
| 80-99     | fair                 |
| 100-119   | good                 |
| 120+      | excellent            |

4.3 The National Sanitational Foundation – Water Quality Index
The National Sanitational Foundation – Water Quality Index (NSF-WQI) was used to determine the current state of cascade-pond system’s water quality. The NSF-WQI consists of nine water quality parameters. Each parameter has its own weight based on Brown et al [28, 29]. The NSF-WQI has 6 categories:
Table 2. Water quality rating of NSF-Water Quality Index

| Water quality index | Water quality rating |
|---------------------|----------------------|
| 90-100              | Excellent            |
| 70-90               | Good                 |
| 50-70               | Medium               |
| 22-50               | Bad                  |
| 0-25                | Very bad             |

5. Data Analysis
Impervious cover, road network, vegetation cover, biological conditions, water quality were divided into two big categories i.e. physical catchment properties and pond environment characteristics. There are 4 classifications of impervious model based on Center for Watershed Protection [1]. Classes are: sensitive (imperviousness less than 10%); impacted (imperviousness between 10 to 25%); non-supporting (imperviousness between 25 to 40%); and urban drainage (imperviousness between 60 to 100%). Road network and vegetation cover were also classified into three classes based on natural break. Natural break methods was used because there is no specified threshold classification on those variables based on previous studies. Each class of impervious cover, road network, and vegetation cover got a quantitative score from 0 to 3. Another two variables for assessing the pond environment characteristics were also classified into a quantitative score. Macroinvertebrates were assessed by two methods (Singscore [27] and The Shannon Diversity Index [26]). Categories of Singscore and The Shannon Diversity Index also got quantitative scores from 0 to 3. Water quality was assessed by NSF-WQI and also got quantitative scores for each class (“excellent” and “good” got 3 points; “medium” got 2 points; “bad” got 1 point; and “very bad” got no point. Weighted overlay analysis from ArcGIS 10.3 was used to simplify three variables of physical catchment properties into a simple single score. The integrated assessment of UI catchment was also coming from superimposing of physical catchment properties assessment and pond environment assessment using weighted overlay analysis.

6. Result and Discussions
6.1 Impervious and Vegetation Cover in UI Catchment

Table 3. Impervious cover in UI sub-catchment

| Outlet  | Catchment area (ha) | Imperviousness (ha) | % imperviousness | Classification    | Score |
|---------|---------------------|---------------------|------------------|-------------------|-------|
| Kenanga | 54.7                | 15.8                | 29%              | Nonsupporting     | 1     |
| Agathis | 86.9                | 48.6                | 56%              | Nonsupporting     | 1     |
| Mahoni  | 389.4               | 186.1               | 48%              | Nonsupporting     | 1     |
| Puspa   | 505.9               | 235.4               | 47%              | Nonsupporting     | 1     |
| Ulin    | 532.3               | 235.8               | 44%              | Nonsupporting     | 1     |
| Salam   | 575.1               | 238.2               | 41%              | Nonsupporting     | 1     |

Table 4. Vegetation cover in UI sub-catchment

| Outlet  | Catchment area (ha) | Vegetation cover area (ha) | Vegetation cover | Score |
|---------|---------------------|-----------------------------|------------------|-------|
| Kenanga | 54.7                | 34.7                        | 63%              | 3     |
| Agathis | 86.9                | 21.0                        | 24%              | 1     |
| Mahoni  | 389.4               | 135.0                       | 35%              | 1     |
| Puspa   | 505.9               | 162.3                       | 32%              | 1     |
| Ulin    | 532.3               | 184.2                       | 35%              | 1     |
| Salam   | 575.1               | 219.7                       | 38%              | 2     |
All of the sub-catchments in UI catchment area found as “non-supporting” class (see table 3). It means that it is no longer support their designated uses in terms of hydrology, channel stability, habitat, water quality and biological diversity [1]. The highest percentage of imperviousness is Agathis sub-catchments with 56%. The total imperviousness of UI catchment based on Salam pond outlet is about 41% that still categorized as “non-supporting” and got 1 point. Vegetation cover of UI sub-catchments is shown in table 4. Kenanga pond sub-catchment has the biggest vegetation cover over another sub-catchments. Only Kenenga pond sub-catchment got 3 points while the other sub-catchments only got 1-2 point(s).

6.2 Road Network in UI Catchment

Ulin and Salam sub-catchments got the highest point for road network density because it has the less density. On the other hand, Agathis, Mahoni, and Puspa sub-catchments got the lowest point. Road network is causing landscape fragmentation that may impact negatively related to the ecological diversity of certain region [21, 22]. Look further, the most density road is located in the southern part of UI Catchment (table 5).

| Outlet | Catchment area (ha) | Length (km) | Road network density (km/ha) | Score |
|--------|---------------------|-------------|------------------------------|-------|
| Kenanga | 54.7                | 7.4         | 0.13                         | 2     |
| Agathis | 86.9                | 14.5        | 0.16                         | 1     |
| Mahoni  | 389.4               | 60.3        | 0.15                         | 1     |
| Puspa   | 505.9               | 61.8        | 0.12                         | 1     |
| Ulin    | 532.3               | 63.3        | 0.11                         | 3     |
| Salam   | 575.1               | 67.6        | 0.11                         | 3     |

6.3 Macroinvertebrate Indices in Cascade-pond System

6.3.1 Singscore and The Shannon Diversity Index

| Score | Cascade-Pond System |
|-------|----------------------|
|       | Kenanga  | Agathis | Mahoni | Puspa | Ulin  | Salam |
| Singscore | 26     | 101     | 58     | 75    | 86    | 113   |
| Likely Water Quality | Poor | Good | Poor | Poor | Fair | Good |
| Score | 0 | 2 | 0 | 0 | 1 | 0 |

| Cascade-pond system | Shannon diversity index | Diversity | Score |
|---------------------|-------------------------|-----------|-------|
| Kenanga             | 0.69                    | low       | 1     |
| Agathis             | 1.84                    | medium    | 2     |
| Mahoni              | 1.38                    | medium    | 2     |
| Puspa               | 1.43                    | medium    | 2     |
| Ulin                | 1.44                    | medium    | 2     |
| Salam               | 2.06                    | medium    | 2     |

Singscore of Kenanga pond that located in the upper of the cascade-pond system is poor with no point. The other upper pond, Agathis pond has a better score than Kenanga pond with score worth for two points. Mahoni pond that located after Agathis pond, classified as poor water quality and got no point. The middle part of the cascade-pond system, Puspa pond has similar characteristics of macroinvertebrates with Mahoni pond. Puspa pond is slightly better than Mahoni pond although still
classified as poor and got no point. The lower ponds of cascade-pond system, Ulin and Mahoni pond are relatively better than the upper ponds. The results obtained from The Shannon Diversity Index calculation show considerable variation in the cascade-pond system. The Shannon diversity index values of the cascade-pond system ranges from 0.69 to 2.06 with an average 1.47. Only Kenanga pond is included in the classification of low diversity with overall score is worth for 1 point while others belong to medium diversity with an overall scores is worth for 2 points.

6.4 Water Quality in UI Catchment

| Parameter                  | Kenanga | Agathis | Mahoni | Puspa | Ulin | Salam |
|----------------------------|---------|---------|--------|-------|------|-------|
| Dissolved Oxygen (%saturation) | 53.36   | 42.57   | 47.08  | 47.07 | 52.62| 52.90 |
| Temperature Changes (Celcius) | 1.2     | 1.3     | 1.55   | 2.9   | 3.4  | 2.8   |
| Total Suspended Solid (mg/l) | 49.45   | 23.27   | 25.33  | 15.72 | 27.03| 20.90 |
| pH                         | 6.87    | 6.80    | 6.56   | 6.38  | 6.50 | 6.82  |
| Turbidity (NTU)            | 3.89    | 1.27    | 1.54   | 2.04  | 1.75 | 3.06  |
| Nitrate (mg/l)             | 0.66    | 1.98    | 0.84   | 1.21  | 1.04 | 1.07  |
| BOD (mg/l)                 | 30.95   | 55.21   | 89.04  | 29.05 | 26.42| 10.08 |
| Total phosphate (mg/l)     | 4.57    | 11.43   | 9.89   | 8.08  | 9.24 | 7.13  |

**Table 8. NSF-WQI in cascade-pond system**

The “end-of-pipe” term of the cascade-pond system creates the water quality index better from upper to lower sub-catchments. Two ponds on the upstream side, Kenanga and Mahoni pond have 61 and 56. Lower pond on the downstream, Salam has the best state of WQI.

6.5 Integrated Ecological Assessment using GIS technology

Lower catchment in UI catchment is relatively better and healthier than the upper catchment based on GIS-based multiple criteria decision analysis (table 9 and figure 2). Kenanga and Agathis pond sub-catchments that located in the upper of UI catchment has 1.6 and 1.5 points out of 3 points. Mahoni pond sub-catchment which located in the middle of UI catchment has the lowest score. Puspa and Ulin pond sub-catchment which located after Mahoni pond sub-catchment is getting better than Mahoni. Salam pond sub-catchment that located in the “end-of-pipe” of UI catchment has the best score.

| Sub-catchment | Impervious cover | Road density | Vegetation cover | Physical properties | Singscore | Shannon Diversity | Biological Water Quality | Pond environment | Integrated ecological assessment |
|---------------|------------------|--------------|------------------|---------------------|-----------|-------------------|-------------------------|-------------------|---------------------------------|
| Kenanga       | 1                | 3            | 2                | 2                   | 0         | 1                 | 0.5                     | 2                 | 1.25                            |
| Agathis       | 1                | 1            | 1                | 1                   | 2         | 2                 | 2                       | 2                 | 1.5                             |
| Mahoni        | 2                | 1            | 1                | 1                   | 0         | 2                 | 1                       | 2                 | 1.5                             |
| Puspa         | 1                | 2            | 1                | 1                   | 0         | 2                 | 1                       | 2                 | 1.5                             |
| Ulin          | 1                | 3            | 1                | 1                   | 1         | 2                 | 1.5                     | 2                 | 1.75                            |
| Salam         | 1                | 3            | 2                | 2                   | 2         | 2                 | 2                       | 2                 | 2                               |

**Table 9. Integrated ecological assessment of UI catchment**
7. Conclusion and Recommendation
Integrated assessment of UI catchment area using GIS-based multiple criteria decision analysis shows that the term of “end-of-pipe” at cascade-pond system affecting the ecological status of each catchment. The lower catchment is relatively better and healthier than upper catchment. Integrated ecological assessment using GIS technology offers effective, simple, and easy methods for interdisciplinary study of catchment health. Sophisticated variables of catchment health based on US EPA components can be more simple by implementing GIS-based multiple criteria decision analysis. For the next study, authors will improve the GIS-based multiple criteria decision analysis by modifying weighted method using fuzzy analytical hierarchy process (fuzzy AHP) method to get more objective assessment based on expert judgment.

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