Sustainable river management: Land use, building coverage, and infrastructure typology of the riverbanks

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Abstract. Surakarta City is intersected by three major rivers which could become the city’s source of clean water. However, pollution of the rivers makes processing this surface water a necessity to create clean water for domestic uses. This study aims to establish a river typology based on the riverbank characteristics and the potential of the surface water to be discharge into clean water. This paper uses spatial analysis to develop typologies and describe the riverbanks characteristics by using the Pepe River in Surakarta as a case study. This is one of the polluted major rivers that flow through Surakarta City. The study found that the Pepe’s riverbanks are dominated by residential and commercial areas. Due to the lack of waste infrastructure, the community (household and small-scale industries) disposes its untreated wastewater directly into the drainage channel. With regard to this problem, five river typologies were established to function as the basis of recommendations to improve the water quality of the river so that it can be used as an urban clean water source. The result shows that all typologies major problems are the lack of wastewater management. The study proposes interventions in waste management, wastewater treatment system, and land use control.

1. Introduction
Water is a basic human need but the world currently faces a critical global freshwater crisis [1]. The need for water has increased considerably along with a rapid urbanization process. Consequently, large-scale clean water provision managed by the government such as networked water is an important source of water provision [2]. Related to the emerging demand for clean water, surface water is one of several important freshwater resources that can be used for the large-scale provision of clean water [3]. Rivers, as one of the water sources under the category of surface water, play many important roles in ecosystems and society [4-5]. However, as cities grow rapidly, many rivers are affected by changes in land use, population density, and urban activities that often occupy the riverbanks. Consequently, rivers are prone to pollution and sedimentation. This is a delicate problem considering the role of surface water as one of the main sources of clean water for cities.

Java, the “urban island” of Indonesia, witnesses the rapid urbanization of its small and medium-sized cities and smaller urban concentrations. Surakarta, as a medium-sized city in Central Java, experiences a similar rapid urbanization process [6]. Concurrent with its rapid urban growth, Surakarta also faces water supply problems, primarily related to raw water availability [7]. As a rapidly
urbanizing medium-sized city, there is a high demand for clean water in Surakarta influenced by urban activities, especially from commercial and construction activities. Rivers are important in fulfilling such demand in Surakarta as the city is crossed by three major rivers: the Pepe, Anyar, and Premulung that flow into the Bengawan Solo River. Based on Indonesian Government Regulation, in order to be used as the source of clean water, the river water quality must be at first class of water quality classification [8]. However, the water quality of Pepe River during year 2011 to 2016 is categorized under the second class qualification or even for several indicators; the river is at a lower classification such as the third or fourth water quality classification [9-13].

Surakarta’s rivers could potentially be a source of clean water for the city to meet the needs of its inhabitants. However, it is necessary to understand the characteristics of each river in terms of its water quality and the characteristics of land use and activities on the riverbanks. These characteristics are important as they affect the quality of the surface water. For instance, many Indonesians drain their untreated wastewater straight into the river. These community characteristics indicate that land use, urban infrastructure, and community activities on riverbanks affect the quality of river water in Indonesia, including in Surakarta. Rivers that flow through urban areas, such as in Surakarta, intersect various types of land use and community activities. As such, the types of land use along the rivers affect water quality [14-15]. Therefore, it is important to analyze the river typology in Surakarta to identify the characteristics and potential of each typology to be used as a source of clean water. Classifying rivers based on their natural channel behavior is a flexible management tool that can be used to determine suitable management for river systems including their foreshore zones [16-17].

The objective of this study is to establish a river typology with the Pepe River as a case study. The typology is formulated based on the river’s infrastructure, land use, and building coverage characteristics. By knowing the river typology, alternative interventions can be formulated as recommendations for government interventions, together with other stakeholders, to ensure that each river typology does not negatively affect the water quality in the river so the surface water can be utilized as a clean water source in Surakarta.

2. Riverbank characteristics
The state of a river is affected by wastewater and the social and cultural traditions of society [18]. Notably, low environmental awareness of communities harms the river quality [19]. Many parts of the river basin, including the riverbanks, are commonly used for social and economic developments that trigger the degradation of the river’s ecosystem services [20]. As such, rapid urbanization and high urban population density will put pressure on the river due to the demand for space for social and economic development. Understanding the triggers put pressure on the river is critical in formulating a strategy for river management.

This paper seeks to understand the river typologies along the Pepe River in Surakarta to reveal to what extent the river is exposed to community and economic development pressures and its underlying causes. In doing so, the river typology in this study is based on infrastructure, land use, and building coverage on the riverbanks. Rivers are influenced by the landscapes they flow through [21]. Therefore, the land use in its surrounding area is important in formulating a river typology because it affects the water entering the river. Changes in land use exacerbated by climate change will affect the quantity and quality of water resources [22]. Specifically, the invasion of housing, government facilities, and industries within river basins causes increased waste and polluted rivers [23]. Changes in land use or land cover affect water quality but can also disturb water availability in the river [24]. Moreover, activities related to the land use on riverbanks can also affect wastewater flowing into rivers. Riverbanks that have green open spaces with high vegetation density will produce a small water flow due to their large infiltration capacity. A lack of green open space resulted in soil compression that will hamper infiltration. The loss of such infiltration will cause a rapid and large discharge of water straight into the river [25]. The important role of landscape along the river indicates that identifying the typology of a riverbank including its extended area is required as one of appropriate strategies for river management.
3. Case study of Malaysia: lesson to learn
The similar case is also occurring in Malaysia which maintains the water quality of the river. This case shows that the water quality can vary according to the surrounding conditions. Therefore control efforts from the government to the activity around the river is indispensable.

3.1. Current quality river in Muar
There are 12 rivers in District of Muar and only five rivers have the observation station for quality monitoring. Monitoring of river quality in District of Muar is very important to have continues raw water supply for Muar. Table 1 shows the Index Level of Water Quality as a guide to monitor the level of quality and status.

| Level | Status     | Index Level | Explanation                                                                 |
|-------|------------|-------------|------------------------------------------------------------------------------|
| I     | Clean      | 81-100      | Natural surrounding conservation Water Sources I – do not need treatment     |
|       |            |             | Fisheries I – Sensitive aquatic species                                    |
| II    | Half-polluted | 60-80      | Water Sources II – Conversional Water Treatment needed Fisheries II - Sensitive aquatic species |
|       |            |             | Recreational purposes that have body contact                                |
| III   | Polluted   | 0-59        | Water Sources III – Complete Water Treatment needed Fisheries III–Value added to economy and moderate toleration Water source for livestock |

Muar River achieved Class II in 2010 and 2014 and maintained Class I from year 2015 to 2017 which shows the river has been protected consistently.

| Year | Class   | Status         | Year | Class   | Status         |
|------|---------|----------------|------|---------|----------------|
| 2010 | 78 (II) | Half-Polluted  | 2014 | 77 (II) | Half-Polluted  |
| 2011 | 80 (I)  | Clean          | 2015 | 84 (I)  | Clean          |
| 2012 | 82 (I)  | Clean          | 2016 | 79 (II) | Half-polluted  |
| 2013 | 84 (I)  | Clean          | 2017 | 81 (I)  | Clean          |
Table 3 shows that quality index for Muar River is in a good and acceptable level compare to other rivers. TSS (Total Suspended Solids) is low and oil & gas recorded less than 5mg/L. However, E-Coli recorded at Level 2 (122 mg/L) shows that Muar River need more frequent monitoring and treatment in future to protect raw water resource.

| Location at West coast of Johor | Station Number | Parameter Index |
|-------------------------------|----------------|-----------------|
| Kukup                         | 1334925        | TSS (mg/L) O&G (mg/L) E-Coli(mg/L) |
| Kuala Sungai BatuPahat        | 1729930        | 27 <5 16         |
| Kuala Sungai Lurus            | 1730962        | 27 <5 7          |
| Kuala Sungai Muar (Muar River)| 2024932        | 28 <5 2          |
| Pantai Punggur                | 1531974        | 17 <5 122        |

3.2. Mitigation Measure for Muar River
Trend analysis shows that quality of river in Muar River is at the acceptable level and suggests that no serious pollution occurred. However, E-Coli level shows immediate action to monitor and overcome the possible increase of E-Coli in the future. Integrated water treatment and management is recommended for the next planning stage to ensure the quality of Muar River is protected especially for raw water usage and treatment. The involvement of Department of Environmental and Department of Irrigation and Drainage are significant to monitor the progress and implement the strategies to protect the river. Besides that, inventory of comprehensive water quality level and source of pollution is being prepared to ensure the cleanliness of river is always at top priority. Strict enforcement and action are needed to punish individual or industries that discharge fluid before being process into the river.

4. Methodology
This study applies a case study approach with observation and interviews with people living and working in the riverbank area. The data was collected for three months from April to June 2019. The case study of the Pepe River is in the middle of the city of Surakarta flowing to the southeast of the city. The Pepe River was selected as a case study because its riverbank is used for various urban activities including high-density housing, industry, and commercial uses. There are also education and health facilities, a bus station, and open space within an extended radius of 700 meters from the river. The riverbanks of the Pepe River are mostly occupied by urban activities. In comparison, the banks Surakarta’s other rivers, the Premulung and Kali Anyar, are characterized by industries and settlements.

As mentioned above, the primary data for this study is collected through observations of the Pepe’s riverbanks. These observations were conducted in a 700-m radius from the river. This buffer area enables the study to include more urban activities near the river that contribute to river pollution. The observations focused on the current availability of infrastructure, particularly which facilitates wastewater and solid waste disposal, land use, and building coverage. The buffer area covers twenty-one kelurahan (urban villages) in Surakarta, i.e., Sangkrah, Kedunglumbu, Kauman, Kampung Baru, Keprabon, Timuran, Ketelan, Punggawan, Mangkubumen, Manahan, Sumber, Nusukan, Gilingan, Kestalan, Setabelan, Kepatihan Kulon, Kepatihan Wetan, Purwodiningratan, Sudiroprajan, Gadegan, and Sewu.

The study area covers the northern and southern riverbanks of the Pepe River. The first phase of observations identifies the land uses and building coverage. Furthermore, the study also observes the infrastructure and community behavior that affects the river directly. This study applies spatial analysis to establish river typologies and to describe the characteristics of the Pepe’s riverbanks.
Spatial analysis in this study is defined as observing the land use composition and building coverage ratio as well as the coverage of wastewater and solid waste infrastructure. The building coverage ratio (BCR) is the ratio of the built-up area divided by the land area. Next, the paper establishes a riverbank typology based on various combinations of the spatial characteristics of land use and infrastructure on the riverbanks and in the 700 m buffer area.

![Figure 2. The Pepe’s riverbanks in Surakarta](image)

5. Results and discussion
The Pepe River is the only of Surakarta City’s three rivers that intersect the city center. The river flows through Surakarta along 7.4 km. The Pepe is bordered by embankments and has a depth of about three meters. The spatial characteristics of its riverbanks are different compared to the banks of the other rivers that flow through Surakarta City. This paper explains the river bank characteristics of the Pepe based on its infrastructure, land use, and building coverage.

5.1. Land use
The Pepe River flows through the city center which is characterized by mixed-use activities. Government regulations stipulate that land on riverbanks should be used for vegetation up to fifteen meters at both sides of the river as a barrier and to provide water infiltration [28]. However, the land use on the Pepe’s riverbanks has developed organically without accommodating the need for vegetation. Only 11,834 m² (2%) of the Pepe’s riverbanks are covered by vegetation as shown in Figure 3. The presence of vegetation on riverbanks is important in creating better spatial quality, it especially offers protection and comfort [29].
Most of the Pepe’s riverbanks are covered by residential and commercial land uses. As the center of an urbanized middle-sized city, those two main land uses have an important effect on surface water quality. Furthermore, those land uses also require more water resources than other land uses. Although the government only regulates land use up to fifteen meters from the river, the land use in a wider radius around the river also must be controlled because it will affect the amount and quality of water flowing into the river. Table 4 presents the land use proportion of the Pepe’s riverbanks in a 700 meters radius from the river.

**Table 4. The Pepe’s riverbanks’ land use proportion.**

| Land Use                | Area (meter²) | %    |
|------------------------|---------------|------|
| Residential            | 2,384,530     | 51.52% |
| Commercial             | 1,118,905     | 24.17% |
| Open Space             | 300,342       | 6.49%  |
| Education Facilities   | 246,094       | 5.32%  |
| Offices                | 245,160       | 5.30%  |
| Recreation             | 178,943       | 3.87%  |
| Urban Infrastructure    | 108,430       | 2.34%  |
| Religious              | 31,836        | 0.69%  |
| Health                 | 14,244        | 0.31%  |
| Industrial             | 297           | 0.01%  |
| **Total**              | **4,628,781** | **100%** |

Industrial land use—although making up only a small proportion of land use, has a direct and significant impact on the river. In the easternmost part where the river empties into the Bengawan Solo River, the Pepe’s riverbanks are used for home industries. A chicken slaughterhouse, a form of small-
scale industry, is located in Kampung Sewu Village. Although this is a small-scale industry, agglomeration is a characteristic of industry. As such, it has the potential to attract other industrial activities. Moreover, the demand for poultry production and consumption is projected to grow rapidly [30-31] which will also expand the scale of the industry. The presence of industry is a crucial environmental factor, especially regarding clean water availability. Its location at only about 400 meters from the river will affect the water quality because of the disposal of waste.

5.2. Building Coverage
The Building Coverage Ratio (BCR) is high along the riverbank. This is critical for water quality because the building coverage strongly affects water infiltration and runoff. Figure 4 shows that most areas of the Pepe’s riverbanks have a BCR of more than 80%, even right adjacent to the river. The high BCR indicates the lack of vegetation that aids water infiltration. This is further evident from the very limited amount of open space (6.5%) on the Pepe’s riverbanks. The Surakarta City Government has stipulated a maximum BCR of 85% although it permits higher BCR of 60-90% in the city center, including in the Pepe River area [32]. Nevertheless, this can cause environmental degradation, especially related to the reduced water infiltration.

![Figure 4. Building Coverage Ratio of the Pepe's riverbanks.](image)

5.3. Infrastructure
The traditional markets on the Pepe’s riverbanks are equipped with temporary dumpsites. The other land uses are provided with a waste management system using garbage carts to collect solid waste. All the solid waste will be sent to the Putri Cempo landfill. Meanwhile, the wastewater flows into the river through the drainage channels as seen in Figure 7. This wastewater originates from the residential areas but also from commercial and industrial areas. With residential and commercial activities as the main types of land use, it is critical to manage wastewater to prevent pollution of the river. Yet, there is no wastewater treatment plant for home industries. In fact, their unprocessed wastewater discharged into the river through the drainage channels. The waste management on the Pepe’s riverbanks comprises only of collecting garbage which is sent to the Putri Cempo landfill.

The waste produced by the chicken slaughter house can be divided into solid waste and wastewater. The solid waste consists of chicken feathers and the remaining chicken pieces. Every afternoon, solid
waste of the slaughterhouse is disposed of directly to the Putri Cempo landfill using a pickup truck. In addition, the slaughterhouse has a wastewater channel that directly leads to an open drainage channel, mixed with household wastewater, which empties into the Bengawan Solo tributary. Waste from chicken slaughtering should not be disposed of without treatment. Although this slaughterhouse is home industry-scale, its waste has environmental impacts such as energy, biowaste, plastic, and paper [33].

The environmental situation along the Pepe indicates that the riverbanks require the provision of infrastructure, especially of a wastewater system, to improve the water quality of the river. Urban infrastructure and waste management on riverbanks are critical in filtering the water that flows into the river. This applies not only to managing disposed waste but also in reducing the waste from each type of land use.

In addition to well-established infrastructure, awareness building is required to change the traditional culture of discharging waste into the river. This is important because, in developing countries, community awareness of environmental impacts is still low. Notably, waste management problems are not only caused by the absence of infrastructure but also by community habits of producing waste, and their ways of disposing of it. The communities on the Pepe’s riverbanks may not realize that the garbage they throw into the drainage channel will affect their clean water supply as well.

![Figure 5. The chicken slaughterhouse](image1)

![Figure 6. Home industry drainage channel](image2)

![Figure 7. Wastewater disposal of the household](image3)

### 5.4. Riverbank Typologies

Based on the characteristics of dominant land use, building coverage, and waste infrastructure, this study found five riverbank typologies of the Pepe. Each typology has characteristics that can affect the river’s water quality. These typologies are used to formulate alternative interventions to achieve better river water quality.

| Typology | Dominant Land Use | BCR  | Waste Infrastructure                  |
|----------|-------------------|------|--------------------------------------|
| 1        | Residential       | Low  | Cart                                 |
| 2        | Residential       | Medium | Cart & Temporary Dumpsite             |
| 3        | Residential-Public facility | Medium | Cart                                 |
| 4        | Commercial-Public facility | High | Cart & Temporary Dumpsite             |
| 5        | Residential (including home industry) | High | Cart & Temporary Dumpsite             |

Typologies 1 and 2 have the same dominant land use (residential) but different BCRs. Typology 1 has a lower BCR because it has some open space in the area. Nevertheless, waste in this typology management consists only of waste carts for picking up garbage and sending it straight to the landfill. Although the riverbanks in typology 2 have a temporary dumpsite besides the waste cart, this
temporary dumpsite is only used for traditional markets. Meanwhile, the residential areas in typology 2 are serviced by garbage carts to collect solid household waste.

Typology 3 has a medium building coverage ratio and contains residential areas and public facilities. The high residential density is offset by the presence of public facilities that can control their BCR because the government manages the development of these buildings. Waste management in typology 3 only relies on garbage carts. Even though typology 3 has public facilities such as a bus station, there is no temporary dumpsite to collect solid waste. In typology 4, most areas have a high BCR although there are public facilities. The high BCR is mostly found in commercial areas, where the government allows a BCR of up to 100%.

Typology 5 has characteristics like typology 2. However, in typology 5, there is a home industry in the form of a chicken slaughterhouse that disposes its wastewater into the drainage channel that empties directly into the river. Moreover, the residential typology 5 has a high BCR which indicates a lack of water infiltration in this area. Nevertheless, parts of the Pepe’s riverbanks in this typology are covered by vegetation which is not found in other typologies.

**Figure 8.** Riverbanks typologies of the Pepe

All typologies face a major problem, i.e., the lack of wastewater management. This problem causes wastewater from each land use on the riverbanks to flow straight into the river through the drainage channel. Consequently, this contaminated water enters the river, affecting the water quality and reducing its potential use as a source of clean water. As such, surface water from the Pepe River must be treated before it is turned into clean water. Specific waste treatment is needed for each type of land use because of the different waste that is produced. Especially for commercial and industrial areas, wastewater flowing into rivers is more polluted than wastewater from residential areas. A case study of model simulation in Galing River Malaysia, which initially all the waste water from nearby residences and industries flows into it, found that waste water treatment plan (WWTP) usage would reduce pollution load and improve the water quality of the river by 80% [32].

Preventive efforts are needed to process wastewater before it flows into the river. If the surface water from the Pepe River were to be used as an alternative source of raw water, the government must consider the quality of water entering the river. The Pepe River has massive embankments on both sides, so the water that flows into the river does not consist of groundwater that has been filtered by
the surrounding soil and plants, but water from drainage channels. In Indonesia, the drainage channels do not only accommodate rainwater (runoff) but also wastewater from each type of land use.

5.5. Recommendations
The government should pay attention not only to the wastewater infrastructure, but also to community development because the community habits of waste disposal require awareness building and regulations to govern these habits. The provision of waste infrastructure is insufficient in solving the waste problem if the community still lacks knowledge of waste management. These efforts are critical in maintaining the water quality in Surakarta because residential and home industry land uses reducing and recycling their waste will offer huge environmental benefits.

Interventions are needed regarding the land use characteristics and the BCR of each typology. The high BCR and the lack of vegetation hamper water infiltration in the soil and cause a large runoff. In Surakarta, much of the land in the buffer area around the rivers is covered by pavement such as cement and asphalt. As a result, rainwater cannot drain into the ground and will flow through the drainage channel into the river. This has led to the reduced availability of groundwater in Surakarta, resulting in a water crisis. Therefore, interventions for typology 4 and typology 5 on the Pepe’s riverbanks should also emphasize land use management. This study recommends the government to increase the proportion of green open space to improve water infiltration. In this case, green space should not only be provided in the form of parks or city forests but also on a smaller scale, one very plot of land. The study found a lack of green space in commercial and residential land uses (shown by the high BCR). The high BCR will lead to a lack of groundwater. As such, the government needs to control the BCR of each land use to increase water infiltration.

6. Conclusion
The strategy of using surface water as a source of clean water cannot only focus on treating the water in the rivers but must also consider the management of its riverbanks. Riverbank management starts with the arrangement of land use and urban infrastructure along the river. Especially infrastructure relating to wastewater and solid waste management is crucial because most rivers in Surakarta are polluted by household and industrial waste. A like city in other developing countries, Surakarta is still unable to provide a comprehensive waste management system. Consequently, the quality of surface water remains low and does not fulfill the quality standards for raw water to be processed and used as a clean water supply for the city. In addition, the dominant land uses - residential and commercial activities - are the urban activities that produce most waste and dispose these pollutants straight into the river.

Based on the five typologies found in this study, different intervention alternatives can be established based on the characteristic of each typology. The typologies that are dominated by residential and commercial land use should focus on waste management and a wastewater treatment system to prevent grey water and black water to flow into the river. Furthermore, interventions in riverbank typologies with high BCR also should emphasize the land use management which relates to the ability of water infiltration. The government should reduce the BCR on along a radius around the river because of their unique characteristics that cannot be generalized with other urban areas. It is also important to build community awareness of waste management because the community needs to build habits to reduce waste and dispose of it in environmentally responsible ways.

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