Bioretention Basin, Rain Garden, and Swales Track Concepts through Vegetated-WSUD: Sustainable Rural Stormwater Management in Klaten Regency

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Abstract. The rural area is one area with a vital function as a food producer towards food security which urgently needs sustainable stormwater management. However, the challenge of sustainable stormwater management is climate change. WSUD is one of the most influential sustainable stormwater because WSUD can control the hydrological cycle and water quality through local facilities. Vegetated WSUD is a practical application of WSUD in regulating stormwater management because it is easy to apply. Vegetated-WSUD consists of a bioretention basin, rain garden, and swales track. Klaten Regency is an area in the province of Central Java that is ranked 9th in the highest drought level in Indonesia, and eleven sub-districts are prone to flooding. On the other hand, Klaten Regency is the largest producer of rice suppliers in Central Java which requires sustainable stormwater management. The research aims to formulate a design simulation model through bioretention, rain garden, and swales track through WSUD to achieve sustainable rural stormwater management. The research method used is quantitative with map overlay and design mapping. The research outputs determine the location feasibility and design model application of vegetated-WSUD in the Klaten Regency. The two-dimensional and three-dimensional design model consists of space requirements, placement, and vegetation types from each bioretention basin, rain garden, and swales track.

Keywords: bioretention, sustainable rural settlement, rain garden

1. Introduction

Widespread climate change jeopardizes world food security, including the rural agricultural sector, because of the widespread drought and flood disasters in stormwater management. Climate change in the context of stormwater has led to changes in livelihoods, degradation of ecosystems, lack of availability of food and water, and economic degradation of the region [1–4]. The impact of climate change on people's livelihoods is due to excessive human activities in using natural resources that affect the environment. It triggers an increase in stormwater frequency. Therefore, the livelihood security of rural households relates to climate, economic and social development [5]. In the context of climate change, stormwater focuses on the hydrological risks of flooding and drought. It's part of the same hydrological cycle, where the watershed must face both flooding and drought [6]. Stormwater is
a consequence of human development. It has an impact on land cover for the built-up area [7]. Rainwater runoff causes hydrological changes in water catchment areas that alter the health of water bodies, and disrupt aquatic habitats, as a recreational and aesthetic function. It has an impact on environmental, social, and economic losses [8]. Stormwater management in rural areas is a priority. It's because poverty in areas prone to water disasters often occurs in rural areas. So, rural people are more vulnerable to natural disasters such as floods and droughts, which have an impact on the socio-economic vulnerability of rural communities [9]. Drought and flood phenomena affect agricultural production and the rural ecological environment. It's a formidable challenge for sustainable rural development [10]. The challenge of ineffectiveness in stormwater management can increase the risk of runoff. Therefore, stormwater management must accommodate interactions between hydrological, biophysical, infrastructure, social, and population systems in rural areas [11]. Sustainable stormwater management emphasizes water quality in creating a healthy and well-being ecosystem that can control higher river flow dynamics, nutrient flow, and various water quality indicators [12]. Sustainable Urban Stormwater Management (SUSM) is an effective method for managing floods and droughts globally. There are various forms of SUSM such as green infrastructure (GI), low-impact development (LID), sustainable urban drainage systems (SUDS), alternative techniques, compensatory techniques, best management practices (BMPs), storm-water control measures, source control, water-sensitive urban design (WSUD), integrated urban water management (IUWM), sustainable urban water management (SUWM), and low-impact urban design and development (LIUDD) [13]. Water Sensitive Urban Design (WSUD) is the most effective stormwater management in rural areas because it can control the hydrological cycle and water quality through local facilities [14]. WSUD can connect stormwater management with a sustainable framework through the built form (landscape) and the water cycle. WSUD models such as bioretention, rain garden, and swales track can synergize architectural context, aesthetics, amenities, built environment, open space, and streetscapes in an urban environment [15]. Bioretention can control the volume, rate and quality of runoff from stormwater. In addition, bioretention is also able to create aesthetic value and social benefits [16]. Rain gardens can also increase the infiltration of rain runoff and temporary storage into the subsoil of an area. Rain gardens are built on various types of site characteristics such as river zones, squares, parking lots, yards, open spaces of building blocks, roads, etc. Swales track as a green infrastructure that can replace the part of conventional sidewalks and ditch drainage to channel rainwater runoff and improve its quality [18] [19]. Therefore, these three WSUD models can be effectively put together in the context of rural stormwater management, especially in locations with characteristics of areas prone to flooding and drought. Based on data from the Central Java Regional Disaster Management Agency (BPBD) for 2016-2020, Klaten Regency is one of the areas in Central Java Province with a high risk of flooding. In 2009, Klaten Regency was also ranked 9th in the national drought disaster. In addition, drought also hit Klaten Regency. Based on data from the Regional Disaster Management Agency (BPBD) in 2020 Klaten, 11 sub-districts are potentially prone to flooding, namely Bayat, Wedi, Gantiwarno, Trucuk, Cawas, and Karangdowo, Wonosari, Juwiring, Prambanan, Pedan, and Kalikotes [20]. It's causing the lack of water supply for agricultural land so that the rice plants that have been planted are threatened with crop failure. In comparison, Klaten Regency is the largest supplier of rice producers in Central Java province [21]. Based on this phenomenon, it is necessary to intervene in overcoming floods and droughts in Klaten Regency through the WSUD concept. Therefore, the research aim is to formulate a design simulation model through bioretention, rain garden, and swales track through WSUD to achieve sustainable rural stormwater management. The research output is a design simulation model in the two-dimensional and three-dimensional form of bioretention, rain garden, and swales track in Klaten Regency through the WSUD approach.

2. WSUD for Sustainable Stormwater Management
The sustainable stormwater management context is related to proper water use as an element of their life support. [22]. Stormwater management can hold, harvest, absorb and filter runoff to manage rainwater. Stormwater management can maximize water as a resource and not as a waste product. The
context of stormwater management is related to resilience and sustainability in maximizing the urban security strategy. It's done by maintaining natural water ecosystems and green spaces [23] [24]. One example of implementing practical aspects of effective watershed management is Australia's Water Sensitive Urban Design (WSUD). The benefits of WSUD are reducing the impact of the climate channel, increasing the use of water resources, mitigating the risk of flood disasters, and reducing the risk of water scarcity due to drought. WSUD approach in stormwater management through increased flood control and rainwater harvesting. WSUD designs are integrated into spaces accessible to the general public, such as parks and median pathways. The WSUD facility has vegetation to increase recreational and aesthetic use, increase public awareness about rainwater management, and provide habitat for urban wildlife [15].

Several WSUD models, such as bioretention and wetlands, can process rainwater harvesting compatible with urban landscapes [26]. WSUD has two main principles: regulating stormwater runoff (erosion control, permeable pavement, rainwater, and others) and mitigation in overcoming stormwater runoff [27].

**Figure 1.** Flood Management Concepts [25]

**Figure 2.** WSUD Model Design as Water Treatment Function [28]

**Figure 3.** WSUD Model Design as Green Infrastructure [29]
3. Bioretention, Rain Garden, and Swales Track For for Sustainable Stormwater Management

Vegetated-WSUD is used as a strategic tool in reducing stormwater management's natural carbon footprint directly or indirectly. Vegetate-WSUD plays a role in production, transportation, and construction processes contributing to the carbon footprint. It can help the process of realizing sustainable stormwater management. The technology in Vegetated-WSUD is designed to control and treat rainwater runoff in design models in the form of bioretention basins, vegetated swales, green roofs, rain gardens, and stormwater ponds. The basin design in the vegetated-WSUD is based on functional units and services that are capable of being sustainable [30].

Bioretention is a form of vegetated-WSUD functions to manage the volume, rate, and quality of rainwater runoff through filter media and underground channels before being stored for reuse or discharged into receiving waters as much as 27-86% of the runoff volume. The mechanism of bioretention is through infiltration, temporary retention, and removing pollutants through plant uptake [31] [32]. Bioretention can also function as an aesthetic value and social benefit for the environment by combining it with a green open space system [16] [33]. Bioretention is located along the road or parking lot, which is part of the road landscape. Bioretention basins have different sizes and shapes that affect the space placement flexibility [34] [35]. The bioretention design model has several parameters: size, media depth, surface storage depth, underdrain configuration, situ soil type, media type, and vegetation [36] [38].

Rain gardens are Vegetated-WSUD models with vegetated basins designed to capture runoff to be drained [39] [41]. Rain gardens are a solution to reduce water flow and total rainwater runoff, which can reduce the pollutant load carried by runoff even though it only looks like an ordinary garden [39].
Rain gardens have benefits and functions, including lowering conventional drainage loads, rainwater pollution, reducing water pollutant loads, eliminating plant pathogens, and storing soil nutrients. The rain gardens work through shallow basins vegetated above the ground that receives and absorbs rainwater and filter pollutants from rainwater using porous filter media planted with one or more vegetation species. Vegetation and soil play an essential role in the design elements of rain gardens planted with trees or shrubs that can improve well-being and retain water and pollutants. Native plants are most suitable for rain gardens due to their adaptability. Rain gardens are easy to place in various locations such as green spaces, stream zones, squares, parking zones, open areas of building blocks, and along the street.

Vegetated swales are part of Sustainable Urban Drainage Systems (SUDS). Vegetated swales slow down the rainwater runoff rate and reduce pollutants to improve water quality. In addition, vegetated swales are widely used as a substitute for conventional sidewalks and gutter drainage to reduce rainwater runoff by enhancing its quality. The mechanism of action of vegetated swales in stormwater management is the principle of sedimentation, which plays a role in removing particulates. Slope in vegetated-swales increases the retention volume, which depends on the infiltration capacity of the media, soil moisture deficit, and slope length. Vegetated swales are located along the road or parking lots. The type of vegetation placed on vegetated swales depends on the design. Swales for stormwater conveyance and volume reduction require vegetation that is a blend of species with tall and stiff grass blades. While swales for sediment reduction, use vegetation that is a blend of species with tall and stiff grass blades.

The scope of this research location is Klaten Regency which has physical characteristics that are prone to flooding and drought. The Klaten Regency area consists of three plains; north is the slopes of Mount Merapi, the east is a lowland longitudinal, and the south is a limestone mountain plain. This condition causes each sub-district to have different regional characteristics.
5. Result and Discussion

5.1. Location Assessment of Bioretention, Rain Garden, and Swales Track

The priority location assessment for the Vegetated WSUD intervention in Klaten Regency was carried out in flood risk and drought areas. Spatial analysis of flood risk zone to assess Klaten Regency. It is because Klaten Regency is located around the Bengawan Solo river border, which passes through Cawas, Bayat, and Wedi Districts. Spatial analysis of drought to assess areas with the highest drought potential in the Klaten Regency. Based on the results of the analysis, it is known that Bayat District is the highest drought potential. Therefore, the Bayat district is the highest drought and flood risk zone in Klaten Regency.
Figure 11. Location Assessment Vegetated WSUD in Klaten Regency.

After location selection analysis at the Klaten Regency scale, it was found that Bayat District has the highest potential for drought and flooding, with concentration points in Krikilan and Jotangan Villages. The concentration point is then reduced to 1-2 km. Therefore, the location of the WSUD intervention is on the Krikilan village and Jotangan village border.

Figure 12. Location Assessment Vegetated WSUD in Bayat District.

Scoring and overlays are based on several criteria, especially in determining the appropriate location for applying the Vegetated WSUD principle. Based on the scoring results, it is known that Krikilan Village and Jotangan village have the highest need for WSUD intervention. It is supported by the fact that both villages are areas of scarce groundwater, potential soil types, productive land cover in agriculture and settlements, and very high levels of drought and flood vulnerability. The WSUD intervention location finds in the border area of Krikilan Village and Jotangan Village, which is a potential area seen from the land cover, which is a combination of agricultural land, potential vacant land, and settlement areas.
Table 1. Scoring Overlay of Location Assessment Vegetated WSUD in Bayat District.

| Village | soil                  | Hydrogeology  | Land cover    | Drought | Flood Risk | Total Score |
|---------|-----------------------|---------------|---------------|---------|------------|-------------|
| Krikilan| Gray alluvial and Mediterranean | 3             | Rare Ground Water Zone | 5       | High       | 5           | 23          |
| Jotangan| Gray alluvial         | 4             | Rare Ground Water Zone | 5       | High       | 5           | 23          |
| Pasaban | Grumosol              | 2             | Rare Ground Water Zone | 5       | High       | 5           | 2            |

Figure 13. The Simulation Model Location of Vegetated WSUD.

5.2. The Design Needs of Bioretention, Rain Garden, and Swales Track

Design requirements in the implementation of Vegetated WSUD through Bioretention basins, rain gardens, and swales tracks are seen from the area of space requirements, vegetation type, placement, and detailed size dimensions. The need for bioretention basins at the Vegetated WSUD intervention sites in Krikilan Village and Jotangan Village is based on the availability of vacant land with moor functions, non-productive rice fields, and vacant land. It can be a medium for increasing groundwater absorption in the area with the help of grass cover, diverse vegetation so that residents can still use it for farming, and a combination of gravel and sand so that water absorption in this location can be increased. Meanwhile, the design requirements for rain gardens are based on the condition of the WSUD vegetated intervention site, which is dominated by residential and agricultural land, so the function of the land in the area has undoubtedly decreased. Rain Garden can provide the best solution in Krikilan Village and Jotangan Village to increase groundwater absorption in residential areas with small land requirements. However, it can maximize groundwater infiltration during the rainy season and store some groundwater during the dry season with the help of vegetation media. Sand and gravel. In the context of the swales track applied to Krikilan Village and Jotangan Village, most waterways and drainage channels at this location are still drainage networks as in general, they are covered by concrete/cement (except for rice fields). Facts show that with a high level of flood susceptibility when it rains, runoff water cannot be absorbed and overflows more easily in channels made of concrete (only able to drain). Swales track is expected to ensure that the vegetated beds (green softscape surface
combination of soil, vegetation, and gravel/sand) can control runoff and maximize absorption so that the selection of swales in Krikilan Village and Jotangan Village is very appropriate to realize Vegetated WSUD areas. The design requirements for the bioretention basin, rain garden, and swales track in Krikilan Village and Jotangan Village can be seen in Table 2.

Table 2. Design requirements.

| Vegetated WSUD Type | Land requirements | Laying Point | Vegetation Type | Detail Dimension Size |
|---------------------|-------------------|-------------|-----------------|-----------------------|
| **Bioretention Basin** | 1.94 Ha | 1-2 km from the settlement |  | • **Title Tree**
Title Tree as a shade and foundation to maximize absorption in the Bioretention Basins |
• **Shrubs**
Shrubs have an essential role in the process of filtration of runoff water. Shrubs are the primary filter element in the basin area (filtration area/grasslands) |
• **Flower/ Annual Plants**
Flower plants not only provide an aesthetic element to the basin but also play a role in assisting the absorption and further filtration of runoff water in the basin area. Flower plants also increase biodiversity in the area around the basin. |
| **Rain Gardens** | 0.86 Ha | 1-2 km from the settlement |  | • **Title Tree**
The titled tree functions as a shade, act as a foundation and maximizes absorption in the Rain Garden area. |
• **Shrubs**
Shrubs have an essential role in the process of filtration of runoff water. Shrubs are the primary filter element in the rain garden area (filtration area/grassland). |
• **Perennials and Ferns**
Flower plants not only provide an aesthetic element to the rain garden but also play a role in |
|  |  |  |  | • **Total Area of Rain Garden:** 0.86 Ha |
• **Total Area of the green zone:** 0.80 Ha |
• **Area of buffer path (grass):** 0.06 Ha |
### Vegetated WSUD Type

| Vegetated WSUD Type | Land requirements | Laying Point | Vegetation Type             | Detail Dimension Size |
|---------------------|-------------------|--------------|-----------------------------|-----------------------|
| Laying Point Vegetation Type | Size  | helping further absorption and filtration of runoff water in the basin area. Flower plants also increase biodiversity in the area around the rain garden. The community can also use other annual plants for cultivation needs. |
| **Swales Track**    | 1.46 Km           | along the Krikil-Jotangan Highway | **Tree titled** The tree with the title functions as a shade and acts as a foundation, and maximizes stormwater absorption in swales | **Total track length**: 1.46 km |
|                     |                   |              | **Shrubs** Shrubs have an essential role in minimizing the occurrence of inundation and runoff. Shrubs also play a significant role in the filtration and absorption of runoff water into the soil surface. | **Total vegetation track**: 1.46 km |
|                     |                   |              |                             | **Total basin track**: 1.46 km |
|                     |                   |              |                             | **Width of vegetation path**: 1 m |
|                     |                   |              |                             | **Basin width (Waterway)**: 0.5 m |

### 5.3. The Model Simulation of Bioretention, Rain Garden, and Swales Track

Based on the analysis of WSUD's vegetated design needs implemented in Krikilan Village and Jotangan Village, a two-dimensional and three-dimensional design model simulation was produced. Bioretention Basin, Rain Garden, and Swales Track Design Simulation Model at the WSUD Vegetated intervention site in solving flood and drought problems in Klaten County in the form of two-dimensional can be seen in Figure 14.
**Figure 14.** The Simulation Model Design Two Dimensional Vegetated WSUD in Klaten Regency.

While the three-dimensional of the WSUD vegetated design simulation model, consisting of axonometry and cross section bioretention basin, rain garden, and swales track can be seen in Figure 15 - 18.

**Figure 15.** The Axonometry and Cross Section of Bioretention Basin.
Figure 16. The Axonometry and Cross Section of Rain Garden

Figure 17. The Axonometry and Cross Section of Swales Track.

Figure 18. The Simulation Model Design Three Dimensional Vegetated WSUD in Klaten Regency.
6. Conclusion

Vegetated WSUD can maximize stormwater management areas sustainably. It is not only able to absorb and regulate rainwater run-off optimally but also provides social, economic, and aesthetic benefits to the area. Areas prone to flooding and drought need WSUD vegetated intervention, including the Klaten district. The vegetated forms of WSUD that can be applied to the Klaten Regency are bioretention basins, rain gardens, and swales tracks. The bioretention basin, rain garden, and swales track area consist of two main elements: softscape (green land/grass, vegetation, flowers, and annual vegetation, as well as tree canopy) and hardscape elements in the form of permeable paving. It will create a maximum blend in the Vegetated WSUD landscape in sustainable stormwater management.

7. References

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