LID Prototype of Runoff Management Model in Sub-Catchment Area for Urban Water Sustainability: Case Study of Tegal City

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Abstract

In the city of Tegal, the tributaries are in critical condition as indicated by several indicators, including an average flow velocity of 0.002 mm/second, an average depth of 1.2 cm, heavy pollution, 2 – 3 m average width, and there is no vegetation at all. It is necessary to develop a hydrological model for controlling runoff using a low-impact development module to cope with flooding and to increase the rate of water infiltration through permeable structures. Hydrological data at six observation points in the Gung sub-watershed and other supporting data such as rainfall intensity were used to design a prototype model based on LID parameters. The prototype of the designed model was validated using the PEST technique on the components and elements of the model. The research resulted in a prototype runoff water control management model (RMM) which includes: 1 permeable structure, 1 river vegetation area, 1 infiltration trench.

Keywords: Prototype; Runoff Management Model; Sub-catchment Area; Urban Water Sustainability

INTRODUCTION

Rainwater runoff is a problem in the City of Tegal and its surroundings due to the increased volume of rainfall, reduced porous surface area, which reduces infiltration capacity, the high content of materials and pollutants in it, and river water overflow as well which is degraded and decreased its carrying capacity and ecosystem services. Development activities can alter the natural hydrological cycle and the movement of runoff water above the ground surface. Geomorphological changes and loss of vegetation cover along watersheds (DAS), reduced infiltration surfaces in residential, office, business, and industrial areas can turn runoff water into flooding. (Recanatesi et al., 2017). The potential hydrological impacts of urban development on the watershed include: (i) changes in the geomorphology and flow regime of the watershed; (ii) sedimentation and siltation; (iii) degradation of the quantity and quality of river water; (iv) decline in ecosystem services and carrying capacity. An effective way to control runoff is to apply a Best Management Practice (BMP) approach. This method can prevent flooding while increasing the ability of the soil to absorb and store water and is cost-

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effective (Hunt et al., n.d.). The application of BMP in urban scale is based on the concept of Low Impact Development (LID), which consists of three sub-contexts, namely: (i) integrating governance; (ii) designing LID-based control models and practices; (iii) monitoring and evaluation of runoff water management performance (Shojaeizadeh et al., 2021; Seo et al., 2017; Jusić et al., 2020). The current conventional method is only focused on disposing of runoff water into the sea or storing it in retention ponds. Apart from being less effective, this practice is relatively expensive and incomplete because it does not touch the root of the problem, namely the hydrological function of the system.

Research Material

The materials used in the study include primary and secondary data. Primary data is collected by field observation, survey, and Focused Group Discussion (FGD), while secondary data is collected from official data from relevant agencies in tegal city. Field observations were made to obtain an overview of the actual situation and conditions of runoff water control practices in the city of Tegal, in relation to urban water resource management and watershed management as an integrated system entity. The survey was conducted to obtain a descriptive overview of the opinions of actors, stakeholders, and communities about practices, while Focused Group Discussion (FGD) and interviews were conducted to obtain an overview of the main points of mind about LID-based runoff water control.

Research Methods

This study is a foundational study aimed at exploring opportunities to apply new approaches, methods, or models in runoff water management practices in the city of Tegal. The research approach is qualitative that aims to reveal and explain the relationships and interactions of various factors that affect the occurrence of phenomena or problems (Creswell, 2007, 2014; Kothari, 2004; Denzin & Lincoln, 2005). The collected data is analyzed with PEST tools to determine the tendency of the influence of key external factors: politics, economy, social, and technology. The output of pest analysis is a description of the dominant external factors that influence decision-making over runoff water control practices in the city of Tegal. The output is obtained after an evaluation of the results of the PEST analysis as illustrated in the following figure:

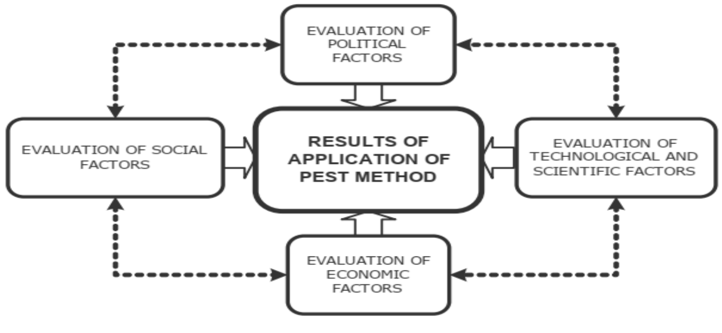

Figure 1. Results of PEST Analisis

Research Resuklts

Table 1. Scores of PEST Indicators based on FGD Results (2020)

FACTORS	SUBJECTS	SCORE
Politics (P)	There is no specific policy for stormwater runoff management	-2
	Policy incoherence of urban water management	-1
	Bad policy on land use management	-2
	There is no policy on payment for environmental services	0
Economy (E)	Carrying capacity based water utilization and control	+2
	Cost-benefit ratio of integrated sormwater runoff control	+2
	High contribution of sormwater runoffs control to economic growth	+1
Social (S)	Low integration of stormwater runoff control practices	-1
	Partial and sectoral practices of the sormwater runoff management	-1
	Single, linear, short-term, and unsustainable planning	-1
	Weak coordination on sormwater runoff control at all level	-1
	There is no innovation in sormwater runoff control	-1
	High conflict of interest in runoff water management	-2
	Non-participatoric stormwater runoff management	-2
Technology (T)	Hybrid technology for controling stormwater runoff	+2
	Application of bioretention technology	+2
	Application of porous pavement technology	+2
	LID model of stormwater runoff management	+2

PEST analysis output is a description of the tendency of external factors that affect the management of runoff water. FGD results on PEST factors in the table above indicate two trends, namely positive and negative. Negative or positive tendencies related to runoff water management in the city of Tegal can be summed up as follows:

Analysis of key factors with negative tendencies:

Strong negative tendencies in the political aspect are the absence of specific policies regarding runoff water control, as well as poor soil use. The two are closely related because poor land use management has implications for the difficulty of making the right policies. In addition, the tendency of urban water resource policy incoherence in various sectors also negatively affects runoff water control efforts. Keterbatasan anggaran adalah There is a strong negative tendency on social aspects, namely high conflicts of interest and non-participatory runoff water management. The river border is occupied for settlement, business and industry which makes the width of the waterway narrower and shallower. Vulnerability to flood risk increases in line with the degradation of watershed infrastructure. Problems become more complex and difficult to solve because the intervention action tends to be linear, sectoral, and partial. Coordination is weak and not integrated with other cognate intervention actions, such as the management of watersheds and urban water resources. In addition, there has been no innovation in water resource management practices including runoff water control. Overall it can be concluded that factors with negative tendencies that affect the management of runoff water and urban water resources include: the absence of an integrated policy on urban water resource management and runoff water control, as well as unsustainable intervention practices. All negative tendencies have a significant effect on intervention actions carried out by the Tegal City Public Works Office and other related agencies.

Analysis of key factors with positive tendencies:

Pressure to maximize the value of urban water resources has a strong positive influence on runoff water management practices. It is based on the reality that water is a vital resource for life, so its quantity and quality must be preserved. Given that water is a fundamental component of the hydrological system, runoff water should be absorbed by the soil and/or flowed into the ocean. On the other hand, Analysis of the cost-benefit ratio becomes important as basic information for making decisions regarding runoff water control. In line with that thinking, the analysis of the cost-benefit ratio becomes important as basic information for making decisions regarding runoff water control. Furthermore, runoff water control is believed by stakeholders can give positive contribution to economic growth. These three positive factors are driving for the Tegal city Public Works Office to implement runoff water control. There are several strong positive factors concerning technology aspect that are driving the implementation of runoff water control. These factors include hybrid technologies that combine conventional technology with new technologies, bioretention techniques, LID-based runoff water management, the application of porous infrastructure, and the engineering of runoff water management models.

Evaluation of primary data of FGD results with PEST analysis technique can be described as follows:

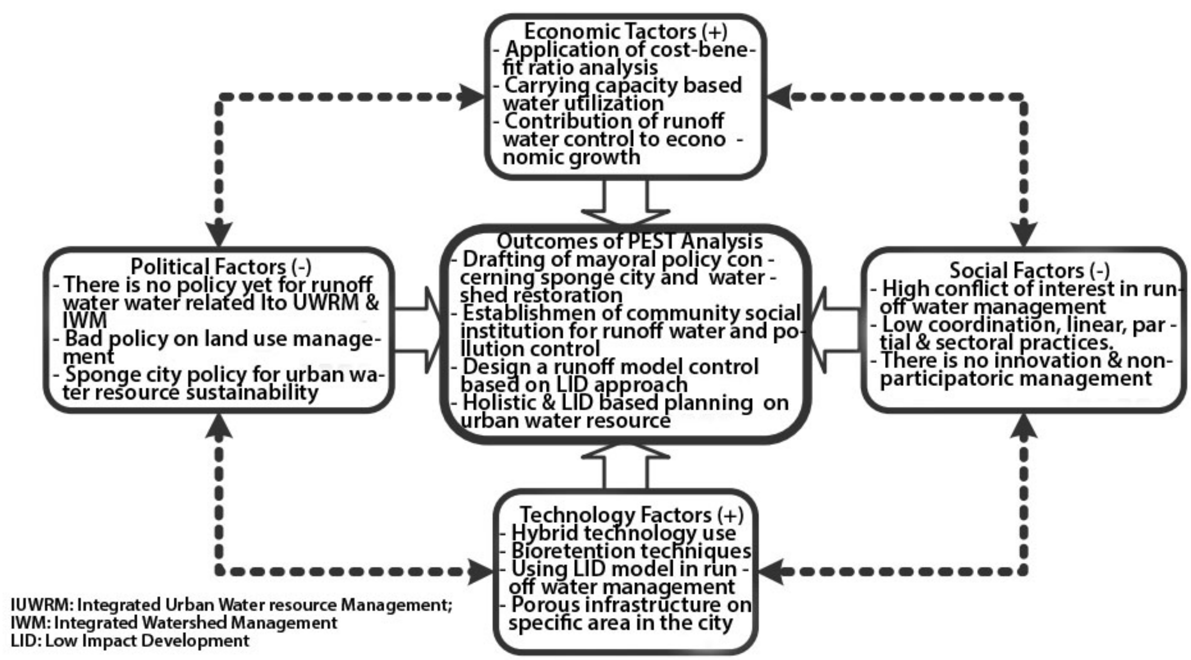

Figure 2. Outcomes of PEST Analysis

Roof Runoff Water

One source of runoff water is roof runoff. During this time the roof runoff water is always discharged directly into the soil so it relies heavily on the drainage system and the ability of soil catchment. Pada area dengan kepadatan tinggi dimana permukaan tanah banyak tertutup dengan struk non permeabel, dan infrastruktur drainase tidak baik, maka air limpasan berpotensi besar berubah menjadi banjir. In line with the LID principles, roof runoff water can be managed in two ways, namely: (i) accommodated on drums and used for bathing, washing, and others; (ii) it is distributed to the nearest LID facilities (rain garden, permeable infiltration trench, and underground storage tank).

Ground Catchment Area

In urban areas, the land surface is generally converted into non-porous hard surfaces such as roads, settlements, buildings, parking lot, and so on. This increases flood puddles and reduced water infiltration power into the soil. LID practices such as rain garden, wetlands, vegetation roof, permeable infiltration trench, underground storage tank, grass swale, and others can reduce the risk of flooding and lack of water so that the sustainability of urban water resources can be maintained. Based on the FGD results, rainwater capture practices that can be implemented in the near future in the city of Tegal are; (i) rain water harvesting; (ii) bioretention; (iii) grass swale; (iv) vegetation cover & canopy; (v) rain garden; and permeable pavement at the specific area such as roads and parking lot.

The Obstacles of LID pRactices in the city of Tegal

LID is essentially a nature-based development practice so the negative impact is very low and therefore sustainable. However, its implementation in urban areas is not easy because there are a number of obstacles, among others: (i) limited land to practice LID; (ii) the absence of standard standards on LID practices; (iii) low knowledge of actors, stakeholders, and the community about LID technology; (iv) low linkage between programs/projects and LID practices; and (v) lack of budget or resources to implement LID

The research results based on the opinion of actors and stakeholders concerning the challenges of LID practice are as follows:

Table 2. Obstacles and Its Solution of LID Practices

Obstacles	Yes	Solutions
Land limitation	-3	Multiple use of land
There is no standar for LID practices	-1	Designing operatonal model for LID practice
Low knowledge on LID technology	-3	Seminar, workshop, education and training
Low linkage betwen program/project with LID practice	-1	Integration of LID practice into development planning
Lack budget or resources to implement LID practice	-2	Using non-conventional budget and resources
-1 = low negative impact; -2 = medium negative impact; -3 = high negative impact		

The comparison survey between existing conditions and expected conditions about the management of runoff water is as follows:

Table 3. Comparation of Exixting and Expected Condition Concerning LID Practice

Source	Existing Condition	Expected Condition	Reflection
Roof runoff water	Ground surface, drainage system, rain barrel, ditch, tributuries, canal, river	LID facilities (rain garden, wetlands, green roof, permeable infiltration trench, underground storage tank)	LID facilities is the urgently required needs and demand of the majority
Groundwater runoff	Ground surface, drainage system, trench, tributaries, canal river	Centralized sewer system, LID facilities, (rain garden, wetlands, vegetation roof, permeable infiltration trench, underground storage tank, grass swale)	
Specific Area (road, parking lot, etc)	Ground surface, drainage system, trench, tributaries, canal, river	Centralized sewer system, LID facilities (permeable pavement, , vegetation cover & canopy)	
Single House Area	Ground surface, drainage system, ditch, tributaries, canal, river.	Rain barrel, LID facilities , (rain garden, wetlands, vegetation roof, permeable infiltration trench, underground storage tank, grass swale)	

Prototype of LID Based Stormwater Runoff Management (SWRM)

Table 4. Conceptual Framework of LID BasedStormwater Runoff Management Model (SWRM)

Component	Description
Tittle	LID Based Stormwater Runoff Management Model
Principal	Public Works Office of Tegal Municipality
Research Partner	Diponegoro University Semarang
Project Site	Gung sub-watershed in Tegal city
Principles	**Use existing natural system:** consiser regional and watershed scale contexts, objectives and targets; Look for stormwater management opportunities and constraints, Identify and protect environmentally sensitive resources **Focus on runoff prevention:** Minimize impervious cover, application of permeable pavement, incorporate grees roof and harvesting system, drain roofs to pervious areas. **Treat the stormwater at the closest source:** maintain natural flow paths, decentralized lot level and conveyance stormwater management **Create multifunctional landscape:** integrate stormwater runoff management into IUWRM and IWM, utililize facilities that provide filtration, inflitration and water conservation, design landscaping to reduce runoff, heat island effect, and enhancing aesthetic. **Education and traing:** education and training on LID technology for stormwater Runoff Management (SWRM)

Table 4. (continued)

Component	Description
POLICY	Specific Mayoral Policy concerning Stormwater Runoff Management (SWRM) that included in the Mayor’s Regulation for Sponge City, Integrated Urban Water resource Management (IUWRM) and Integrated Watershed Management (IWM)
INITIATIVE	Designing LID Based Stormwater Runoff Management Model
STRATEGY	**Conserving the Vital Hydrologic Features and Functions:** (i) Expanding buffer stream area that provide filtration, infiltration, flood control, and river bank stability; (ii) Restoring area that its integrity of soil and vegetation cover were fefected; (iii) Avoiding development on permeable soil; (iv) Grreening any place in the city with trees or trre clusters where possible. **Siting and layouting the urban development:** (v) Fiiting the design of development to the terrain; (vi) Using open space or clustered development; (vii) Innovative street network design; (viii) Reduce roadway setback and lot frontage. **Reducing the impervious area:** (ix) Reduce the building and parking footprints, unnecessary sidewalks and driways: (x) promoting pervious pavement at the specific site such as road and parking lot. **Using natural drainage systems:** (xi) Disconnect the impervious area; (xii) creating micro-tophographic area; (xiii) Extending the drainage flow paths **Adapting LID practice in the city of Tegal:** (xiv) Specific site selection for adapting the LID practice; (xv) Designing an operational model for implementing LID practice; (xvi) Applying, iterating, and scalling up the model at multiple spatial and temporal implementation
DESIGN PROCESS	1. Designing the environmental criteria for LID practices: a. Preserve groundwater and baseline of the flow regime b. Prevent geomorphic and integrity changes of the hydrologif system c. Reduce the vulnerability to the risk of flood and draught d. Protect water quantity and quality, integrity and helath of watershed, and biodeversity 2. Screening the potential of Best Management Practice for LID Based SWRM 3. Selection suitable model of the Best Management Practice (BMP) using computerized modelling 4. BMP sizing and valuation 5. Assessing the effectiveness of the selected suitable model of BMP 6. Calculating the cost-benefit ratio of LID based BMP for SWRM 7. Monitoring and evaluation
COMPONENT & ELEMENT	**Structural component of LID based Stormwater Runoff Management (SWRM):** (i) Rainwater harvesting; (ii) Green roofs; (iii) Soakaways, infiltration trench and chamber; (iii) Bioretention; (iv) Vegetated filter strips; (v) Permeable pavement; (vi) Grass swales; (vii) Rain garden; (viii) Wetlands; (ix) Perforated pipe system. Non-Structural component of LID based SWRM: (i) Policy network; (ii) Legal framework; (iii) institutional framework; (iv) Good Environmental Governance practices; (v) Participatoric involvement of the communities; (vi) Cross sectoral and muli level inter-organizational collaboration for LID based SWRM

Discussion

The current runoff water control practices in the city of Tegal are conservative, meaning they don't change over time relying on existing infrastructure: drainage systems, floodgates, water pumps, and retention ponds. The technology is relatively conventional and not innovating both in the management aspect and the use of technology. Viewed from the perspective of Holling's adaptation cycle, the existing condition of runoff water control is trapped in a rigidity trap making it difficult to change. Krative destruction of the status quo is needed by adopting new paradigms and approaches, namely lid practices in the control of runoff water. Focused Group Discussion (FGD) in 2020 analyzed with PEST techniques shows the facts of the findings that there are two key problems, namely: the absence of specific policies and partial, sectoral and un terpadusized governance practices. At the same time there is an opportunity that runoff water control in accordance with LID principles can contribute to local economic growth, as well as opportunities for the application of LID-based hybrid technologies that can protect water sustainability.

There is no standard standard for LID practices so careful and in-depth identification and analysis of the comonents and effective elements of the LID-based SWRM model is required. This is necessary because the LID-based BMP model is not one fit for all, but is influenced by domain problems, context, location, population, infrastructure, vulnerabilities, and key external factors such as: politics, economy, social, and technology (PEST). A specific model is needed that suits the situation and conditions of the city of Tegal. This paper reports the results of investigations into external factors that are key determinants for efforts to formulate a conceptual model of LID-based SWRM practice.

Conclusion

Based on the results of the analysis of the research findings, it can be concluded that: (i) there is a need to implement LID practices in the implementation of development in the city of Tegal; (ii) Mayor Tegal's response to create a LID-based SWRM policy integrated into the Mayor's Regulation on Porous Cities, IUWRM, and IWM; (iii) the initiative of the Tegal city Public Works Office to design a prototype conceptual model of LID-based SWRM practice; (iv) conduct research collaborations with researchers from Diponegoro University Semarang; (v) Components of LID-based SWRM practice model include: structural components including: permeable structure, river vegetation area, infiltration trench, bioretentin etc, and non-structural compound: policy network, legal framework, institutional framework, participatoric involvement of the community.

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Ethical Issue

The author ensures that there are no ethical conflicts concerned with the conduct of research.

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