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Urban Drainage System Review Based on Regional Spatial Planning in Madiun City Area

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ABSTRACT

This study evaluates the urban drainage system in the Madiun City area through the lens of regional spatial planning. It highlights the impacts of land-use changes on drainage congestion and flooding, emphasizing the need for sustainable spatial policies. The research identifies key factors contributing to drainage issues, such as the closure of primary waterways and inadequate maintenance. Utilizing a combination of qualitative and quantitative analysis, the study assesses hydrological conditions and the effectiveness of proposed eco-drainage solutions, including infiltration wells and retention ponds. The findings underscore the importance of integrating drainage management with spatial planning to mitigate flood risks, especially in the context of climate change.

KEYWORDS *Flood mitigation, regional spatial planning, urban drainage system*

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INTRODUCTION

Land-use changes due to spatial use are an important phenomenon to analyze because they significantly impact various environmental, economic, and social aspects (Baso et al., 2019). Spatial planning, regulated by the government or local authorities, aims to optimize land use according to its function and designation, but its implementation often leads to drastic land-use changes (Andhika, 2017).

Regional spatial changes also have a significant impact on urban drainage systems (Asdak, 2022). The creation of suboptimal green open spaces, the closure of primary waterways, and development without proper planning can hinder rainwater flow and cause bottlenecks in drainage systems (Andawayanti, 2019). Urban drainage system congestion can be interpreted as a condition where drainage channels are unable to effectively drain rainwater, causing inundation or flooding on roads and residential areas (Sirishantha & Rathnayake, 2017).

The main causes of drainage system congestion include the closure of primary waterways by garbage and sediment, lack of routine maintenance, and infrastructure development without considering drainage capacity (Asmorowati et al., 2021). In addition, suboptimal spatial changes, such as the reduction of green open spaces that serve as water catchment areas and construction on former waterways, can inhibit rainwater flow and exacerbate drainage problems (Cahyaningrum, Zakaria, & Jamal, 2025; Maizir, 2017; Pariartha, Tonyes, Arsana, & Widyaastuti, 2023). Moreover, changes in land use are often associated with the risk of natural disasters. According to research by Fajarini, Barus, & Panuju (2015), land-use changes increase vulnerability to floods and landslides. Therefore, a comprehensive and integrative analysis is necessary to formulate sustainable and climate-resilient spatial policies.

IDN Times, through its news portal, reported that heavy rain that struck Madiun City on Wednesday night (10/01/2025) caused flooding in several areas. Several main roads experienced waterlogging, including Jalan Kemuning in Klegen Village, Jalan Punthuk, Jalan Sawo Barat in Manisrejo Village, Jalan Halmahera in Gang Sendang Barat, Jalan Imam Bonjol in Rejomulyo, Jalan Sri Rejeki, and Jalan Perintis (Riyanto, 2025). This incident highlights the vulnerability of urban drainage infrastructure in Madiun City to heavy rain and underscores the need to repair and improve drainage systems to address frequent flooding (Fitri & Kurniawan, 2017).

This incident further stresses the urgency to improve the urban drainage system in Madiun City, especially amid increasingly extreme rainfall patterns driven by climate change (Ruminta & Nurmala, 2016). Additionally, it highlights the importance of integrating drainage system management with regional spatial planning. Given rapid urban growth and ongoing spatial changes, an integrated strategy is essential to optimize drainage infrastructure and reduce flood risks. In the past year, Madiun City has shown rapid development, particularly in its transformation toward becoming a smart city (Madiun City Government, 2019). This effort, pioneered by the local government since 2019, has made Madiun City a model for other regions in Indonesia.

In the context of smart city development, the Madiun City Government has adopted the concept of eco-drainage as one of its strategies for environmentally friendly rainwater management. The relationship between smart cities and eco-drainage closely relates to water management and sustainable urban planning (Haji et al., 2016; Hijah & Eliawati, 2021; Indarto, 2010; Irawan et al., 2017). The drainage concept in a smart city involves applying technology and smart strategies to efficiently manage rainwater and urban drainage systems. Key elements include weather monitoring systems and sensors, data management and analytics, adaptive infrastructure, early warning systems, good drainage system management, and community involvement (Prawati, 2019). Eco-drainage in smart cities aims to manage rainwater runoff by mimicking the natural water cycle through permeable surfaces, retention ponds, and infiltration systems (Juleha et al., 2023). This approach reduces flooding and water pollution risks while enhancing groundwater recharge and creating green urban ecosystems (García & Santamarta, 2022).

Design must promote environmentally friendly development, participate in maintaining ecosystem sustainability, use energy efficiently, and emphasize renewable natural resources through recycling (Saragi et al., 2021; Soplantila et al., 2023). This approach supports ecosystem survival and preserves soil, water, and air quality while ensuring human welfare, comfort, and sustainability in physical, social, and economic terms. Proper building planning produces environmentally friendly buildings that balance aesthetics, meet current needs, and maintain natural conditions for future safety and comfort (Istiningsih & Poerwodihardjo, 2018).

Based on this background, the study's problem formulation includes evaluating the Madiun City drainage system relative to hydrological conditions, planned rainfall, and urban drainage network arrangement in line with regional spatial planning policies. It also examines environmental aspects tied to the development of infiltration well and retention pond models as environmentally friendly drainage structures. The study aims to assess the drainage system by considering these factors and to explore environmental impacts through infiltration well and retention pond modeling (Rahmat Irawan, 2017; Ruminta & Nurmala, 2016). .

This research offers authenticity through a holistic approach that examines the urban drainage system alongside regional spatial planning policy directions, aiming to evaluate drainage infrastructure effectiveness in flood management and its alignment with the urban spatial pattern plan for 2043. The environmental focus seeks to understand how applying the eco-drainage concept affects drainage use, contributing to sustainable urban drainage management in Madiun City. Previous studies have shown that land-use changes increase flood discharge and cause drainage problems like sedimentation and garbage buildup that reduce channel capacity. Some research has emphasized the importance of analyzing existing drainage systems to ensure capacity for increased discharges from land-use changes. Additional studies highlight the need for channel repairs and infiltration wells to reduce waterlogging. Consequently, this study is expected to aid better drainage system planning and management and to support flood mitigation efforts in urban areas.

METHOD

This research employed a mixed-method approach combining qualitative and quantitative descriptive analysis to comprehensively evaluate the urban drainage system in Madiun City. The study was conducted in Madiun City, East Java, Indonesia, which covers an area of approximately 33.92 km² with a relatively flat topography and alluvial soil composition. The city was selected as the research location due to its ongoing transformation toward a smart city and its vulnerability to flooding events, particularly following the recent January 2025 flood incident.

The research population encompassed all primary drainage channels in Madiun City and their associated catchment areas. A purposive sampling technique was employed to select specific drainage channels and measurement stations based on their strategic importance in the city's drainage network and their history of flooding problems. The sample includes four rainfall measurement stations (Rejo Agung Station, Klegen Station, Kanigoro Station, and Madiun Office Station) and 11 primary drainage channels identified as critical for flood management.

Data collection was conducted through multiple techniques to ensure comprehensive analysis. Primary data were obtained through direct field measurements including channel dimensions (length, base width, surface width, depth), water levels, sediment heights, and flow velocities. Field observations were also conducted to assess current drainage conditions and identify problematic areas. Secondary data were collected from relevant institutions, including daily rainfall data from 2011 to 2021 from the Water Resources Irrigation Technical Implementation Unit, regional spatial planning documents from the Madiun City Regional Development Planning Agency, and soil permeability data indicating alluvial soil characteristics with medium permeability of 1.5×10^{-2} cm/second.

The data analysis techniques employed in this study include both qualitative and quantitative methods. Qualitative analysis was used to describe field conditions, spatial planning compliance, and environmental aspects of drainage management. Quantitative analysis was conducted through several stages: (1) hydrological analysis including rainfall data validity tests (trend absence test using Spearman Method, stationarity test using F Distribution

Method, persistence test, and outlier test), average rainfall calculation using the algebraic mean method, and frequency distribution analysis; (2) hydraulic analysis to calculate channel discharge capacity using Manning's equation; (3) eco-drainage modeling to determine infiltration well requirements based on SNI 06-2459-2002 specifications and retention pond dimensions; and (4) spatial analysis to assess conformity between drainage network arrangement and regional spatial planning policies up to 2043. All statistical calculations were performed following established hydrological standards, with critical values determined at 95% and 99% confidence levels as appropriate for each test.

RESULT AND DISCUSSION

Technical Aspect Analysis

1. Hydrological Analysis

Hydrological analysis aims to calculate the planned rainfall in a given rainy period. To determine the rainfall, the plan carried out various tests, including data validity tests and distribution suitability tests. This study uses daily rain data with an observation period from 2011 to 2021 recorded at 4 (four) rainfall measuring stations in Madiun, namely Rejo Agung Station, Klegen Station, Kanigoro Station and Madiun Office Station. The following is rainfall data obtained from 4 (four) rainfall measuring stations for the period 2011 – 2021.

Table 1. Daily Maximum Rainfall Data at Each Station

No	Year	Madiun City Station	Rejo Agung Station	PG Kanigoro Station	Klegen Station
1.	2011	144	110	85	100
2.	2012	100	83	93	114
3.	2013	158	82	135	109
4.	2014	60	73	75	62
5.	2015	128	104	113	125
6.	2016	125	171	180	120
7.	2017	153	150	75	155
8.	2018	85	79	63	82
9.	2019	95	92	113	94
10.	2020	122	114	80	75
11.	2021	114	97	82	65

Source : Water Resources Irrigation Technical Implementation Unit, 2025

2. Statistical Analysis of Rainfall Data

1) Trend Absence Test

The Absence of Trend test is carried out to find out whether there is a trend or variation in the data. If there is trend data, then the data is not recommended for analysis. Good data is homogeneous data that comes from the same population. In this study, the absence of trend test was carried out using the Rank Correlation Test (KP) with the Spearman Method. The following are the results of the Trend Absence Test using the Spearman Method for each rainfall measuring station as shown in Table 2.

Table 2. Analysis of the Correlation Test of the Spearman Method at the Madiun City Rainfall Measurement Station

No	Year	Madiun City	Time rating (Tt)	Variable rating (Rt)	German	Dt2
1	2011	144	1	3	2	4
2	2012	100	2	8	6	36
3	2013	158	3	1	-2	4
4	2014	60	4	11	7	49
5	2015	128	5	4	-1	1
6	2016	125	6	5	-1	1
7	2017	153	7	2	-5	25
8	2018	85	8	10	2	4
9	2019	95	9	9	0	0
10	2020	122	10	6	-4	16
11	2021	114	11	7	-4	16
Sum						156
Lots of data						11
KP						0,291
Stuttgart						0,912
tkritis						1,796
Conclusion						**No trend**

2) The Stations Test

The stationary test was carried out using the F Distribution Method by dividing the data into 2 (two) or more groups. Each group will be tested using the F distribution. But if the value of the variant is unstable, there is no need to carry out a stability test of the average value. The following are the results of the calculation of the Variance Stability Test – F Test for 4 (four) rainfall measurement stations in the Madiun City area as presented in Table 3.

Table 3. Analysis of Variant Stability Test – F Test at the Madiun City Rainfall Measurement Station

No	Group 1	Group 2
1	144,00	153,00
2	100,00	85,00
3	158,00	95,00
4	60,00	122,00
5	128,00	114,00
6	125,00	
Lots of data (N)	6,000	5,000
Rerata	119,167	113,800
Std Dev (Sd)	34,942	26,395
N1S12. (N2-1)	175.819,20	
N2S22. (N1-1)	87.087,50	
Calculation	2,019	
Fkritis (dk = 5)	5,05	
Fkritis (dk = 4)	6,26	
Conclusion	**Stable Variant Value**	

3) Persistence Test

The following are the results of the Persistence Test of each Rainfall Measurement Station as presented in Table 4.

Table 4. Analysis of Persistence Test at the Madiun City Rainfall Measurement Station

No	Year	Madiun City	Data rating	of	of2
1	2011	144	3	-	-
2	2012	100	8	5	25
3	2013	158	1	-7	49
4	2014	60	11	10	100
5	2015	128	4	-7	49
6	2016	125	5	1	1
7	2017	153	2	-3	9
8	2018	85	10	8	64
9	2019	95	9	-1	1
10	2020	122	6	-3	9
11	2021	114	7	1	1
Sum					308
Lots of data					11
m					10
KS					- 0,8667
Thitung					- 4,9135
Tkritis					1,860
Conclusion					**Data Is Not Dependent**

4) Outlier Test

The last test that is carried out before the Distribution Analysis is the Abnormality Test to find out whether the maximum and minimum data of the data set are suitable for use. The following are the results of the Outlier Test from each Rainfall Measurement Station as presented in Table 5.

Table 5. Analysis of Outlier Test at Rainfall Measuring Stations of Madiun and PG Stations. Rejoagung

No	Yrs	Madiun City	Log R
1	2011	144	2,158
2	2012	100	2,000
3	2013	158	2,199
4	2014	60	1,778
5	2015	128	2,107
6	2016	125	2,097
7	2017	153	2,185
8	2018	85	1,929
9	2019	95	1,978
10	2020	122	2,086
11	2021	114	2,057
Rerata			2,052
Standard deviation			0,124

No	Yrs	PG Rejo Agung	Log R
1	2011	110	2,041
2	2012	83	1,919
3	2013	82	1,914
4	2014	73	1,863
5	2015	104	2,017
6	2016	171	2,233
7	2017	150	2,176
8	2018	79	1,898
9	2019	92	1,964
10	2020	114	2,057
11	2021	97	1,987
Rerata			2,006
Standard deviation			0,116
Kn - from the table			2,088

Kn - from the table	2,088
YH upper limit	2,312
YL lower limit	1,792
Conclusion	**Data Not Outlier**

YH upper limit	2,249
YL lower limit	1,764
Conclusion	**Data Not Outlier**

Graphically, this Outlier Test can be seen in Figure 1 as follows:

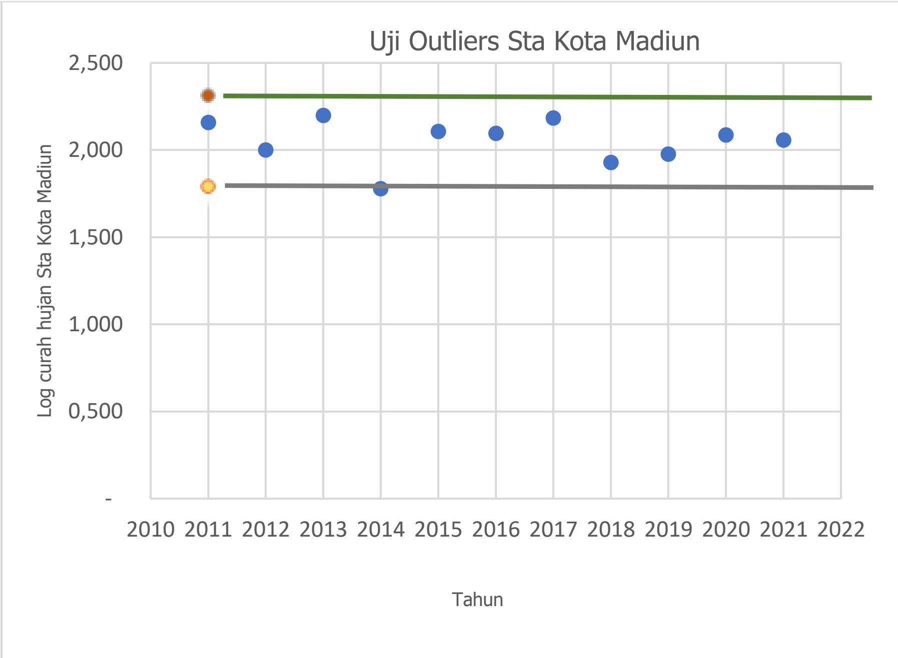

Figure 1. Outlier Test Results at Madiun Station Rainfall Measurement Station

From the various types of data validation tests above, the rainfall data obtained from 4 (four) rainfall measurement stations in this study can be concluded as presented in the following Table 6:

Table 6. Results of data validation test for 4 (four) rainfall measuring sites

No	**Rain Station**	**Data Validity Test**	**Correlation / Trend Dependence Test**	**Stationarity Test**		**Persistence Test**	**Abnormality Test**
		Mass Curve Test	Spearman Rank Correlation (α=5%)	F Test (α=5%)	T Test (α=5%)	Serial Correlation Spearman (α=5%)	Outlier Test
1	Madiun City Station	Meets requirements	No trend	Stable Variance Value	Stable Mean Value	Data Not Dependent	No Data Outliers
2	PG Rejo Agung Station	Meets requirements	No trend	Stable Variance Value	Stable Mean Value	Data Not Dependent	No Data Outliers
3	PG Kanigoro Station	Meets requirements	No trend	Stable Variance Value	Stable Mean Value	Data Not Dependent	No Data Outliers

4	Klegen Station	Meets requirements	No trend	Stable Variance Value	Stable Mean Value	Data Not Dependent	No Data Outliers

So that data from 4 (four) rainfall measuring stations can be used in the calculation of the next analysis.

5) Consistency Test of Debit Data with RAPS (Rescaled adjusted partial Sums)

The RAPS method is carried out by calculating the cumulative value of the deviation from the mean value. If the Q/n obtained from the calculation results is less than the critical value for the corresponding confidence level year, then the data is declared to be oppressive. (Soewarno, 1995). The following are the results of the discharge data consistency test with the RAPS method as presented in Table 7.

Table 7. Results of the discharge data consistency test with the RAPS method

No	Tahun	Curah Hujan	Curah Hujan (sort besar ke kecil)	R_{rerata}-Ri	Yi - Yrerata	Sk*	[Sk*]^2	Dy^2	Dy	Sk**	|Sk**|
1	2011	109.75	148.00	-43.68	4.43	4.43	19.64	1.79	32.28	0.137	0.137
2	2012	97.50	133.25	-27.93	-7.82	-3.39	11.47	1.04	32.28	- 0.105	0.105
3	2013	121.00	121.00	-15.68	15.68	7.86	61.84	5.62	32.28	0.244	0.244
4	2014	67.50	117.50	-12.18	-37.82	-22.14	490.02	44.55	32.28	- 0.686	0.686
5	2015	117.50	109.75	-4.43	12.18	-25.64	657.22	59.75	32.28	- 0.794	0.794
6	2016	149.00	98.50	6.82	43.68	55.86	3,120.75	283.70	32.28	1.731	1.731
7	2017	133.25	97.75	7.57	27.93	71.61	5,128.51	466.23	32.28	2.219	2.219
8	2018	77.25	97.50	7.82	-28.07	-0.14	0.02	0.00	32.28	- 0.004	0.004
9	2019	98.50	89.50	15.82	-8.82	-34.89	1,217.06	110.64	32.28	- 1.081	1.081
10	2020	97.75	77.25	28.07	-7.57	-14.39	206.97	18.82	32.28	- 0.446	0.446
11	2021	89.50	67.50	37.82	-15.82	-23.39	546.92	49.72	32.28	- 0.725	0.725
Jumlah		1,158.50						1,041.856		2.219	
Rerata		105.32									
n		11									
Stdev		24									
Sk** maks.		2.219									
Sk** min.		-1.08									
Q = Sk** maks		2.219									
R = Sk**maks - Sk**min		3.299									
Q/(n$^{0.5}$)hitung		0.669									
R/(n$^{0.5}$)hitung		0.995									

At 99% probability, from the calculation results, the value of $Q/(n^{0.5})$ calculation = 0.669 < from $Q/(n^{0.5})$ table = 1.303 while for $R/(n^{0.5})$ calculation = 0.995 < from for $R/(n^{0.5})$ table = 1.402.

6) Average Rainfall Analysis

According to Supirin (2004), the area with the location of the existing rainfall stations is quite evenly distributed and the area of the watershed < 500 km^2 can be used using the algebraic average method. This method is used in flat areas with an adequate number of stations (more than two) and evenly distributed rainfall between rainfall measuring stations. The condition of Madiun City is a flat area with more than two stations and a watershed area of < 500 km^2, so that in analyzing the average rainfall in the primary drainage system, the algebraic average method can be used.

The following are the results of the calculation of average rainfall using the algebraic average method as presented in Table 8.

Tabel 8. Results of the calculation of average rainfall using the algebraic mean method

Year	Madiun City	PG. Rejoagung	PG Kanigoro	Klegen	Average
2011	144	110	85	100	109.75
2012	100	83	93	114	97.50

Year	Madiun City	PG. Rejoagung	PG Kanigoro	Klegen	Average
2013	158	82	135	109	121.00
2014	60	73	75	62	67.50
2015	128	104	113	125	117.50
2016	125	171	180	120	149.00
2017	153	150	75	155	133.25
2018	85	79	63	82	77.25
2019	95	92	113	94	98.50
2020	122	114	80	75	97.75
2021	114	97	82	65	89.50
		Average / x			105.32

7) Frequency Distribution Analysis and Re-Period Rainfall

The purpose of the analysis of the frequency distribution of hydrological data is to find a correlation between the magnitude of extreme events and the frequency of occurrences using probability distributions. In statistics, there are several types of frequency distributions and 4 types of distributions used in the field of hydrology, namely normal distribution, normal log, pearson III and Gumbel logs.

8) Channel Discharge Hydraulic Analysis

Hydraulic analysis is carried out to analyze the existing capacity of the channel by calculating the slope of the talud, the cross-sectional area of the channel, the wet cross-section of the channel, the radius of the hydraulic and the slope of the channel.

The data needed for the calculation were obtained from measurements in the field (primary data) and from related institutional documents (secondary data) in the form of data on channel length, channel base width, channel surface width, channel depth, water height, sediment height and flow speed in the water. The shape of most of the primary channel cross-sections in the Madiun City area is trapezoidal in the shape of a pair of river stones which has a coarseness coefficient value of 0.017 as shown in the following Manning Coefficient table.

Table 9. Manning Coefficient Table

No	Channel Material	Roughness Coefficient n
1	Smooth plastered brick masonry	0.010 - 0.015
2	Unplastered brick masonry	0.012 - 0.018
3	Smoothed river stone masonry	0.017 - 0.030
4	Unsmoothed river stone masonry	0.023 - 0.035
5	Smoothed concrete (finished)	0.011 - 0.015
6	Unsmoothed printed concrete (unfinished)	0.014 - 0.020
7	Concrete on neat concrete trenches	0.017 - 0.020
8	Concrete on uncompacted concrete trenches	0.022 - 0.027
9	Neat excavated soil	0.016 - 0.020
10	Compacted grassed excavated soil	0.022 - 0.030
11	Slightly overgrown excavated soil with grass	0.022 - 0.033
12	Trenches on hard rock	0.025 - 0.040

The following is an example of calculation on the Semar Mendem Channel with each component that affects the discharge of the trapezoid-cross-sectional channel in existing conditions where there is still sedimentation in it.

Channel slope (m) =

$$m = \frac{b - B}{2\ x\ h} = \frac{6{,}22 - 5{,}62}{2\ x\ 1{,}70} = 0{,}176$$

Wet cross-section area of the channel (A) =

$$A = \left(B + (m\ x\ h_{air})\right) x\ h_{air}\ = \left(5{,}62 + (0{,}176\ x\ 0{,}85)\right) x\ 0{,}85 = 4.905\ m^2$$

Channel circumference (P) =

$$P = B + (\ 2\ x\ h_{air}\ ) x\ \sqrt{1 +\ m^2} = 5{,}62 + (2\ x\ 0{,}85) * \sqrt{1 +\ 0{,}176^2} = 7{,}35\ m$$

Hydraulic radius (R) =

$$R = \frac{A}{P} = \frac{4{,}905}{7{,}35} = 0{,}67$$

Slope of the channel base (So) with value n = 0.017 (Table 5.50)

$$S_o = \left(\frac{v\ x\ n}{R^{2/3}}\right)^2 = \left(\frac{1{,}42\ x\ 0{,}017}{0{,}67^{2/3}}\right)^2 = 0{,}0010$$

Slope will be used for the calculation of the plan's discharge.

Furthermore, the number of discharges of existing channels is calculated with the following calculation example:

Channel discharge ($Q_{Channels}$) = A x v
= 4.905 x 1.42
= 6,969 m3/s

From the results of the calculation, the results were obtained that the discharge that could be accommodated in the Semar Mendem Channel was 6,969 m^3/second.

Environmental Aspect Analysis

The analysis of environmental aspects is carried out by analyzing the need for retention ponds and infiltration wells as environmentally sound construction for the handling of areas that often experience inundation.

1. ***Utilization of Environmental Carrying Capacity (Soil Absorption) in Handling Inundation Discharge***

The analysis of environmental aspects is carried out with the aim of utilizing the carrying capacity of the existing environment in overcoming inundation discharge. The city of Madiun has a relatively flat topography, so if there is an overflow of the primary channel, it is certain that there will be inundation around the channel.

Madiun City has the characteristics of soil that is quite fertile and able to absorb water quite well, because the type of soil in the Madiun City iKota area is alluvial soil. (Madiun City Regional Development Planning Agency, 2016). Alluvial soil itself has a fine sand texture which is classified as a type of soil with medium permeability, where the type of soil with a medium class is able to absorb water of 1.5 x 10-2 cm/second or 1.5 x 10-4 m/second.

In addition, Madiun City has a groundwater depth of more than 15 m from the ground level (Madiun City Regional Development Planning Agency, 2015). So that the construction of infiltration wells in order to handle inundation discharge and as a groundwater filling medium can be fulfilled.

The carrying capacity of the environment will be used to absorb and accommodate inundation discharge. And one of the alternatives that can be implemented in Madiun City is the creation of infiltration wells and retention ponds. This effort includes a groundwater conservation effort to ensure water balance due to changes in the use of agricultural land to residential land. This infiltration well functions to accommodate and absorb the inundation discharge contained in it.

2. Infiltration Well Needs

The planned infiltration well refers to type III infiltration wells in accordance with SNI 06-2459-2002 concerning Specifications for Infiltration Wells in the Yard with the following specifications:

a. Shape and size
   1) The cross-section of the rainwater infiltration well is circular in shape;
   2) The cross-sectional size is at least 150 cm in diameter;
   3) The size of the inlet pipe is 110 mm in diameter;
   4) Overflow pipe size 110 mm;

b. Construction materials
   1) The well cover is a non-reinforced concrete plate, 10 cm thick, a mixture of 1cement : 2 sand : 3 gravel with a slab and no load on it
   2) The bottom and upper walls of the well are precast reinforced concrete, porous dinsdng. 150 cm
   3) 10 – 20 cm ukurab crushed stone for well filler
   4) PVC pipe and its accessories 110 mm diameter

c. Construction type

Type III with porous concrete buar walls, which at the end of the joint are given a hole gap and can be applied with maximum depth up to the groundwater level

d. Rainwater distribution system

The distribution of rainwater to rainwater infiltration wells or to rainwater channels can be seen in figure 2.

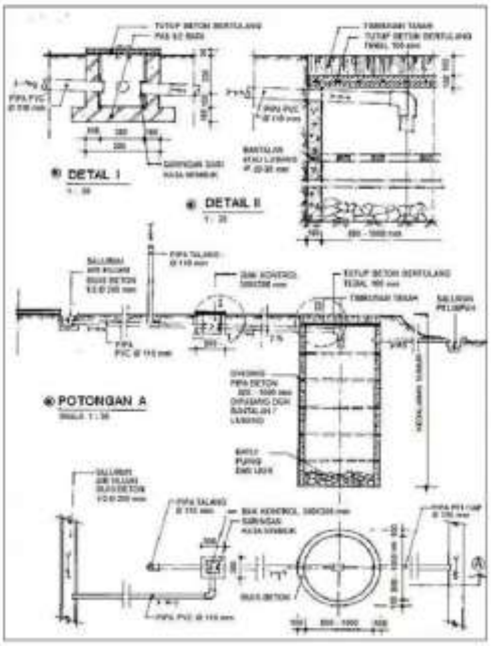

Figure 2. Rainwater distribution system image to rainwater infiltration wells

The following is an example of the calculation of infiltration well needs as presented below:

1) Data on the dimensions of the planned well
2) Infiltration well diameter (D) = 1.2 meters
3) Depth (H) = 6.0 meters
4) Cover thickness = 0.10 meters
5) Thick porous gravel = 0.40 meters
6) Effective depth (L) = 5.5 meters
7) Dominant rain duration (T) = 7200 seconds (2 hours)
8) Soil permeability (k) = 0.00015 m/s (for the type of soil in Madiun City, namely alluvial soil with a fine sand texture)

Hydraulic Radius

$$R = \frac{A}{P} = \frac{\pi . r^2}{\pi . r^2 + 2.(2.\pi . r)} = \frac{\pi . 0{,}60^2}{\pi . 0{,}60^2 + 2.(2.\pi . 0{,}60)}$$

$$R = 0{,}1304$$

Well discharge (Qo)

$$Qo = \frac{2.\pi . L.H.k}{ln\left[\frac{L}{R}.\sqrt{1} + \left(\frac{L}{R}\right)^2\right]} = \frac{2\ x\ \pi x\ 5{,}5\ x\ 6\ x\ 0{,}00015}{ln\left[\frac{L}{0{,}60}.\sqrt{1} + \left(\frac{L}{0{,}60}\right)^2\right]}$$

$$Qo = 0{,}006861\ m3/dtk$$

Geometry factor (F)

$$F = \frac{Q_o}{k.H} = \frac{0{,}006861}{000015\ x\ 6}$$

$$F = 7{,}6238$$

Well capacity (Qsumur)

$$Q_{well} = \frac{H.k.F}{1 - e^{\left(\frac{F.k.T}{\pi.R^2}\right)}} = \frac{6\ x\ 0{,}00015\ x\ 7{,}6238}{1 - e^{\left(\frac{7{,}6238x\ 0{,}00015\ x7200}{\pi.0{,}60^2}\right)}}$$

$$Q_{well} = 0{,}006866$$

The construction of this infiltration well has been regulated in the Madiun City Regional Regulation Number 04 of 2023 concerning the Madiun City Regional Spatial Plan for 2023-2043. In the regional regulation, it is stated that infiltration wells are built in the following locations.

1) Densely populated areas as an effort to handle moderate flood disasters in Article 82 paragraph (2.e).
2) The development of infiltration wells and biopore holes as a manifestation of the drainage network system in Article 46 paragraph (6.d); the realization of urban infrastructure in Article 47 paragraph (2.f)

Based on applicable regulations, the alternative location of infiltration wells is on land owned by the Madiun City Government such as city parks, government office areas and other government-owned public facilities.

In addition, infiltration wells can be built in the yard of houses and newly built land. These infiltration wells are placed in areas lower than other areas so that inundation can flow into the infiltration well. In this study to support the policies of the Madiun City Government and also as a pilot project, in each inundation-prone area it is planned to create infiltration wells as many as 100 location points where the location points are prioritized in the environment and/or assets owned by the Madiun City Government such as in offices owned by the Madiun City government and Green Open Space (RTH).

3) Retention Pond

Retention ponds or reservoir ponds are used to protect the downstream area of the channel from damage caused by the condition of the downstream channel is not able to accommodate the discharge of the upstream channel, where the excess discharge is accommodated in the retention pond. In this study, in overcoming inundation, in addition to making infiltration wells, it is also planned to make retention ponds so that they do not remember the downstream channels.

From the calculation of inundation management using pumps and infiltration wells for channels without sediment, there are still 8 channel sections that will be planned to be made retention ponds as the next inundation handling, namely in the West Terate Channel Hilir, the East Terate Hulu Channel, the Banjarejo II Channel, the Mojorejo Channel, the Pelitatama Channel, the Rejomulyo Channel, the Nambangan Kidul Channel and the Nambangan Lor Channel. The following is an example of the calculation of the capacity needs of the retention pond in the Rejomulyo Channel as follows:

Data from the calculation after the addition of pump capacity and the construction of infiltration wells in the Rejomulyo channel without sediment:

Qinundation	=	4,378 m3/sec
Tc	=	0.70 hours

	=	0.70 x 60 minutes x 60 seconds
	=	2512.98 seconds
Qinundation	=	$\frac{Volume}{Concentrated\ period\ (t_c)}$
Volume	=	Qinundation x concentration time (tc)
	=	4.378 m3/s x 2512.98 sec
	=	11.002.20 m3

Simulation of pool dimensions = W x H x W

	=	(80 x 40 x 3.5) meters
	=	11.200.00 m3
Qinundation	<	Qpool retention (Pool dimension x tc)
Qinundation	<	$\frac{Volume}{Concentration\ Period\ (t_c)}$
4,378 m3/sec	<	$\frac{11.200}{2512,98}$ m3/sec
4,378 m3/sec	<	4,457 m3/s

After simulating the dimensions of the retention pool, then a re-check is carried out on the Qinundation, where the Qinundation must be smaller than the Qinundation pool. It is hoped that the construction of infiltration wells and retention ponds can overcome the problem of inundation that may occur due to changes in the spatial pattern plan of Madiun City in 2043. The construction of infiltration wells and retention ponds, in addition to reducing inundation discharge, is also expected to be able to fill groundwater, so that during the rainy season Madiun City is not flooded and during the dry season local residents who are not served by PDAM do not dry out of water.

CONCLUSION

Analysis indicates that by 2043, the runoff coefficient (C) is projected to increase across all catchment areas of Madiun City due to land-use changes from open spaces to built environments, with the West Terate Channel showing the highest increase from 0.64 to 0.76. Drainage capacity is compromised by sediment accumulation in 11 primary channels and inadequate capacity in 9 sediment-free channels, leading to inundation risks. Efforts to reduce flood discharge include sediment dredging and flood control pump operation, while environmentally, 100 type IIIa infiltration wells and retention ponds are planned to enhance groundwater recharge and mitigate flooding. Recommendations for the Madiun City Government emphasize regular canal maintenance, expansion of pump capacity, and the development of green spaces via retention ponds on government land, coupled with supportive policies and community involvement to sustain drainage system resilience. Future research could focus on assessing the long-term effectiveness and community acceptance of these green infrastructure interventions and modeling climate change impacts on drainage system performance under various urban growth scenarios.

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