

RESEARCH ARTICLE

Sustainable Design of Closed Drainage Infrastructure for Flood Control in Manggala Makassar City, Indonesia

Ritnawati^{1*}, Erdawaty², Yolly Adriati³, Poppy Indrayani¹, Wudi Darul Putra², Muhammad Isya Arrumi Anshari³

¹ Civil Engineering, Universitas Muslim Indonesia, Makassar 90231, Indonesia

² Civil Engineering, Universitas Fajar, Makassar 90231, Indonesia

³ Civil Engineering, Universitas Islam Riau, Pekanbaru 28284, Indonesia

* Corresponding author : ritnawati.ft@umi.ac.id

Tel.: +62 85255350257

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Abstract

Manggala District in eastern Makassar City experiences recurrent urban flooding driven by rapid land-use conversion, undulating topography, and drainage channels whose hydraulic capacity has been degraded by sedimentation and waste. Previous studies in Makassar have largely evaluated open eco-drainage measures, infiltration wells, and retention ponds, but few have provided a reproducible, discharge-based design of a fully closed circular conduit network sized against a defined return period. This study addresses that gap by coupling frequency-based hydrological analysis with hydraulic design of a closed circular drainage system for the Zone 1 catchment of Manggala. Annual maximum daily rainfall from the Makassar station (2014–2024) was fitted to candidate distributions and evaluated with goodness-of-fit tests; the 10-year design storm was propagated to peak discharge using the rational method with land-use-weighted runoff coefficients, and circular reinforced-concrete conduits were sized with the Manning equation. The catchment was delineated into two zones by topography and runoff concentration. Zone I (857.1 ha) requires a conveyance capacity of 0.63–1.57 m³/s and 1.86 km of closed channel, whereas Zone II (272.4 ha) requires 0.35–0.80 m³/s and 14.39 km. Circular conduits of 600–1200 mm diameter provide full-flow capacities of 0.43–2.76 m³/s at velocities of 1.5–2.4 m/s, satisfying the self-cleansing range while remaining below the scouring limit. Field observation confirmed that inundation develops when rainfall persists beyond one hour in low-lying, obstructed reaches. The main novelty of the study is a zone-specific, return-period-referenced closed circular drainage model in which conduits are placed beneath the road corridor, releasing surface land for urban functions while maintaining hydraulic efficiency and reducing sediment retention relative to the trapezoidal open channels currently in service.

Keywords: Closed drainage system; Circular conduit; Rational method; Urban flood mitigation; Inundation

1. Introduction

Urban flooding has become an increasing challenge in rapidly developing cities, particularly where land-use conversion, impervious surface expansion, and inadequate stormwater infrastructure increase runoff generation and hydraulic pressure on drainage networks. Recent studies have emphasized the need to improve the reliability of urban drainage systems through integrated hydrological and hydraulic assessment, particularly under increasing rainfall variability and climate-related changes in extreme precipitation (Rohith & Sudheer, 2023; Tamm et al., 2023; Simpson et al., 2023; Schlef et al., 2023). Urban drainage performance is also strongly influenced by the interaction between land-use characteristics, runoff generation, drainage connectivity, and the hydraulic capacity of conveyance systems (Oswald et al., 2023; Farina et al., 2023).

In Indonesia, urban flood risk is particularly pronounced in rapidly urbanizing areas where land conversion reduces infiltration and increases surface runoff. In Manggala District, Makassar City, changes in land use have been associated with increasing flood susceptibility and changes in surface-water response

(Rachmat et al., 2015; Rumata et al., 2023). Previous assessments of Makassar have also identified inadequate drainage capacity, drainage obstruction, topographic conditions, and insufficient runoff conveyance as important contributors to inundation (Subhan et al., 2019; Karamma et al., 2021; Arief & Nilawati, 2024). Recent flood mapping in Makassar further demonstrates the continuing significance of flood exposure at the sub-district level, particularly during extreme rainfall events (Dewantara et al., 2026).

Several approaches have been proposed to address urban flooding in Indonesia, including retention ponds, infiltration wells, ecodrainage, permeable surfaces, and community-based mitigation. In Makassar, retention-based drainage has been investigated as an alternative for reducing flood impacts, while studies in other Indonesian cities have examined infiltration wells and ecodrainage based on groundwater depth and soil permeability (Karamma et al., 2021; Joleha et al., 2024). Similar approaches have emphasized the importance of combining structural drainage improvements with spatial planning and community-based flood mitigation (Indrayani et al., 2025; Febriani et al., 2025). International research has likewise demonstrated that green

infrastructure and low-impact development can reduce runoff and complement conventional drainage infrastructure (Nazarpour et al., 2023; Huang, 2024; Lu et al., 2024; Sobhaninia et al., 2025).

However, most previous studies in Makassar have focused on open drainage improvement, retention ponds, infiltration wells, or general flood-risk assessment Makhbul, R. (2023). Comparatively fewer studies have presented a reproducible, discharge-based design framework for fully closed urban drainage systems using explicit rainfall return periods and zone-specific hydraulic capacity evaluation. Underground drainage networks are increasingly recognized as important components of urban flood management because their hydraulic performance depends on pipe capacity, flow velocity, network connectivity, and rainfall characteristics (Chen & Huang, 2024; Getirana et al., 2023). Recent Indonesian studies have similarly demonstrated the importance of combining rainfall-frequency analysis, runoff estimation, hydraulic capacity assessment, and drainage redesign to improve infrastructure performance (Farida et al., 2025; Panguriseng et al., 2026).

Therefore, this study develops a sustainable design framework for closed circular drainage infrastructure in Manggala District, Makassar City. The analysis integrates rainfall-frequency analysis, design rainfall estimation, land-use-weighted runoff coefficients, rational-method discharge estimation, and Manning-based hydraulic evaluation. The proposed design is intended to improve drainage reliability, accommodate design discharge, reduce exposure of drainage infrastructure to sediment and solid waste, and utilize road corridors more efficiently while maintaining hydraulic performance.

2. Study Area and Existing Drainage Identification

The study was conducted in Zone 1 of the Manggala urban drainage system, Makassar City, South Sulawesi, Indonesia. The study area was divided into two principal drainage zones based on drainage connectivity, catchment characteristics, and existing flow pathways. Field observations were undertaken to identify existing drainage conditions, inundation locations, sediment accumulation, drainage obstruction, and connectivity between drainage segments.

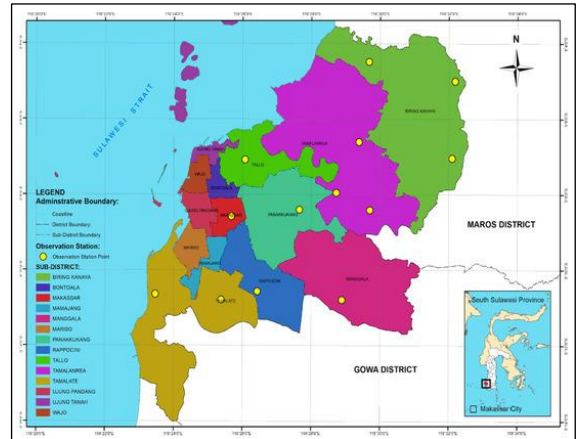


Fig. 1. Administrative location of Manggala District within Makassar City and observation stations.

The use of field observations combined with hydrological and hydraulic assessment is consistent with recent urban drainage studies in Indonesia, which demonstrate that drainage performance can be affected

by obstruction, inadequate capacity, sedimentation, and discontinuity between drainage segments (Indrayani et al., 2025; Farida et al., 2025). Previous studies in Makassar have also identified land-use change and inadequate drainage infrastructure as important factors associated with flood occurrence (Rachmat et al., 2015; Subhan et al., 2019).

The land use of the Zone 1 catchment, including its drainage alignment, contour pattern, and existing canals, is presented in Fig. 2. The map confirms that residential cover dominates the catchment and that the existing channel hierarchy—tertiary to secondary to primary—does not function optimally: several reaches are discontinuous, and roadside channels along Batua Raya, Borong Raya, Pampang Raya, and Toddopuli streets are frequently obstructed.

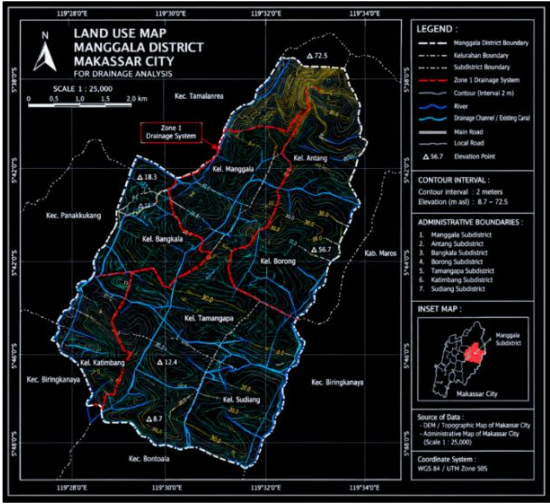


Fig. 2. Land-use map of the Zone 1 drainage catchment, Manggala District, Makassar City (scale 1:25,000).

Field inventory of the existing network indicates that the current channels require both enlargement and desilting. Inundation typically develops when rainfall persists for more than one hour, with recorded ponding depths of roughly 20–50 cm above the road surface. The recurrent causes are consistent across the catchment: very gentle channel-bed slopes that slow conveyance toward the river; settlements sited in low-lying basins below the flood level; undersized channel dimensions relative to incoming runoff; blockage by solid waste and sediment; and discontinuity of the network where culverts are absent. These observations align with resident-perception studies elsewhere in Indonesia that attribute drainage under-performance primarily to poor maintenance and sediment clogging (Suwindu, 2025).

The Antang retention pond, with a holding capacity of approximately 80,000 m³ over a 6.5 ha surface, forms part of the broader strategy by temporarily storing runoff before controlled release into the Pampang River. During the 2021–2022 wet season, field observation in this study recorded a reduction in average flood depth from about 50 cm to 15–20 cm in adjacent areas. Nevertheless, urban expansion and inadequate maintenance continue to impair channel capacity, so residual flood risk remains high between December and February. This condition motivates the transition from the existing trapezoidal open channels to a closed circular conduit network designed explicitly against a defined design discharge, as developed in the following sections.

3. Method

The study was conducted in the Zone 1 drainage catchment of Manggala District and follows a sequential hydrological–hydraulic design procedure. The overall workflow—from data collection through hydrological analysis, hydraulic checking, drainage design, and evaluation—is summarised in Fig. 3, which provides an auditable path from input data to final design.

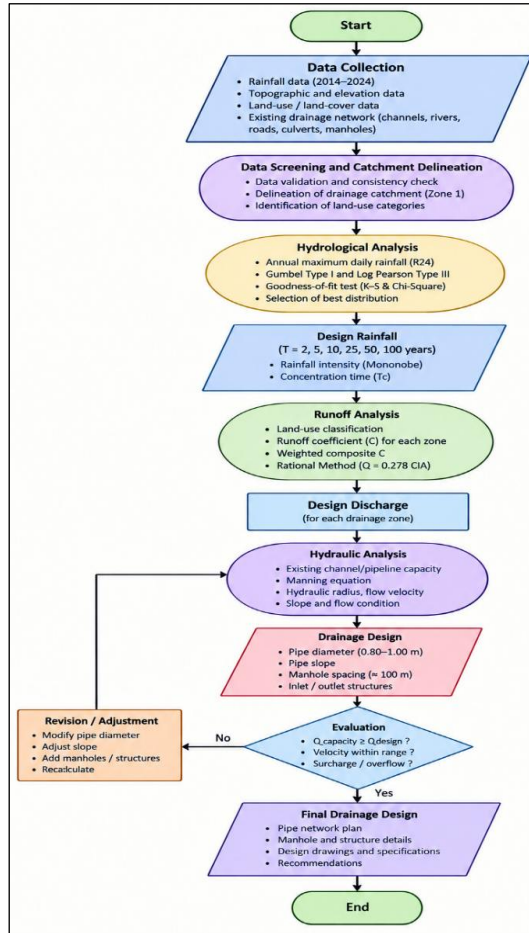


Fig. 3. Research methodology flowchart for the discharge-based closed drainage design.

3.1 Data collection

Primary data were obtained through field observation, including a direct survey of the catchment, interviews with residents at the planned disposal points, and photographic documentation. Secondary data comprised annual maximum daily rainfall for 2014–2024 from the Makassar station, together with the contour map, the Makassar City spatial plan (RTRW), the Manggala detailed spatial plan (RDTR), and the road-network map. Because no gauged discharge record exists for the catchment, design discharge was derived from rainfall using a rainfall–runoff model, an approach also adopted where gauged basins are unavailable in comparable Riau catchments (Harmiyati and Fuaji, 2023).

3.2 Rainfall frequency analysis and design storm

Annual maximum daily rainfall data for 2014–2024 were analyzed to estimate design rainfall for selected return periods. Gumbel and Log-Pearson Type III distributions were applied and evaluated using goodness-of-fit procedures. Frequency analysis is a fundamental

component of urban drainage design because design rainfall directly controls the estimated peak runoff and consequently the required conveyance capacity (Schlef et al., 2023; Qalbi et al., 2024).

The use of rainfall-frequency analysis for drainage and flood-control design has also been demonstrated in recent engineering studies using return-period-based hydrological design (Ananda et al., 2026; Farida et al., 2025). In the present study, the 10-year return period was selected as the principal design condition for the closed drainage system.

3.3 Design Flood Discharge

The design flood discharge was estimated using the Rational Method:

$$Q = 0.278 \cdot C \cdot I \cdot A \dots \dots \dots (1)$$

Where Q is peak discharge (m^3/s), C is the dimensionless runoff coefficient, I is rainfall intensity for the design return period (mm/h), and A is the catchment area (km^2). For sub-catchments of non-uniform land use, a composite runoff coefficient was computed as the area-weighted mean:

$$C = (C_1 A_1 + C_2 A_2 + \dots + C_n A_n) / (A_1 + A_2 + \dots + A_n) \dots \dots (2)$$

With C_i and A_i representing the runoff coefficient and area of each land-use class. Coefficient values by land use were adopted from the standard classification (Suripin) reproduced in Table 1. The residential class, which dominates the catchment, carries the highest weighting and therefore governs the composite value. The time of concentration was estimated with the Kirpich equation:

$$tc = 0.0195 (L^3 / H)^{0.385} \dots \dots \dots (3)$$

Where tc is the time of concentration, L is the channel length from the upstream boundary to the control point, and H is the elevation difference along that path. The rainfall duration was set equal to the time of concentration so that the whole sub-catchment contributes simultaneously to the peak at the control point.

Table 1. Runoff coefficient (C) by land-use class (after Suripin).

Land-use class	C
Secondary dryland forest	0.03
Shrub / bush	0.07
Industrial plantation forest	0.05
Secondary swamp forest	0.15
Plantation	0.40
Dryland farming	0.10
Mixed dryland agriculture	0.10
Settlement / residential	0.60
Rice field	0.15
Pond	0.05
Open land	0.20
Water body	0.05

Source: adapted from Suripin.

The Rational Method remains widely used for relatively small urban catchments because it provides a direct relationship between rainfall intensity, catchment characteristics, and peak runoff. Recent studies have applied rational or modified rational approaches to urban drainage capacity assessment and infrastructure design (Simpson et al., 2023; Ibrahim & Ahmad, 2023; Pamuttu et al., 2023).

The runoff coefficient was determined based on the dominant land-use characteristics within each drainage

zone. This approach accounts for the effect of increasing impervious surfaces on runoff generation, which has been identified as an important factor in urban drainage response (Oswald et al., 2023; Simpson et al., 2023).

3.4 Hydraulic Design of Closed Circular Drainage

The required conduit dimensions were checked with the Manning equation, combining the rational-method design discharge with the circular section's uniform-flow capacity:

$$V = (1/n) \cdot R^{2/3} \cdot S^{1/2} \quad (4)$$

$$Q = V \cdot A \quad (5)$$

Where V is flow velocity (m/s), n is the Manning roughness coefficient dependent on conduit material, R is the hydraulic radius (m), equal to the wet cross-sectional area A divided by the wetted perimeter P , and S is the channel-bed slope. A Manning coefficient of $n = 0.013$ was adopted for precast reinforced concrete, consistent with the material-specific values in Table 2 and with reported field ranges for concrete conduits (Abd Elmoaty and El-Samman, 2020). Conduits were sized so that the full-flow capacity equals or exceeds the design discharge while the mean velocity remains within the self-cleansing to non-scouring range of about 0.6–3.0 m/s.

Table 2. Manning roughness coefficient (n) by conduit material (after Triatmodjo).

Material	Min.	Normal	Max.
Cement	0.010	0.012	0.015
Concrete	0.010	0.013	0.017
Wood	0.015	0.017	0.020
Tiles	0.011	0.013	0.017
Stone masonry	0.017	0.025	0.030
Brick	0.012	0.013	0.015
Short-grass land	0.025	0.030	0.035
Bush	0.035	0.050	0.070

Source: adapted from Triatmodjo.

Hydraulic evaluation of urban drainage infrastructure should consider both conveyance capacity and flow conditions to ensure that the proposed system can accommodate the design discharge without excessive surcharge or undesirable flow velocities. Recent research has demonstrated the importance of hydraulic-capacity assessment in drainage redesign and road infrastructure protection (Farida et al., 2025; Chen & Huang, 2024).

3.5 Closed drainage design criteria and standards

The closed drainage model routes circular reinforced-concrete pipes beneath the road corridor. Design criteria followed applicable national drainage practice for urban stormwater conduits: precast circular reinforced-concrete pipe as the conveyance element; a maximum manhole (control-basin) spacing of 100 m to permit inspection and cleaning; conduit cover depth referenced to traffic-loading requirements; and a longitudinal gradient set to keep velocity within the self-cleansing to non-scouring range. Manholes provide access for maintenance and flow monitoring at junctions and at the prescribed spacing, and inlet chambers with sediment traps intercept street runoff before it enters the mainline. Where terrain prevents gravity flow in low-lying reaches, gravity-fed detention or pumped assistance is provided at outfalls. Pipe diameters were selected from the standard

precast range (600–1200 mm) according to the design discharge of each zone.

The proposed pipe diameter was selected by comparing the calculated design discharge with the full-flow capacity of available circular conduits. The design was considered hydraulically adequate when the pipe capacity exceeded the design discharge while maintaining acceptable flow velocity and ensuring continuity between upstream and downstream drainage segments.

This approach is consistent with recent urban drainage studies emphasizing the importance of capacity ratios, hydraulic continuity, and system-level evaluation rather than assessing individual drainage segments independently (Getirana et al., 2023; Rohith & Sudheer, 2023; Farida et al., 2025).

4. Result And Discussion

4.1 Physical and hydrological setting of the catchment

The topographic and soil setting of Manggala strongly conditions its runoff behavior. The undulating terrain, with elevations from –5 to 42 m above sea level, generates rapid downslope flow that concentrates in low-lying neighborhoods during intense or prolonged rainfall. The catchment is underlain by two soil orders whose proportions are summarized in Fig. 4: Inceptisols cover 56.8% and Ultisols 43.2%. This balance is hydrologically significant—Inceptisols offer moderate permeability on gentle slopes but perform poorly on steeper gradients, whereas the high clay content and compacted subsurface horizons of Ultisols retain water poorly and promote overland flow. The net effect is a catchment with limited vertical infiltration and elevated surface-runoff velocity, which raises the effective runoff coefficient used in Eqn. (1) and reinforces the need for engineered conveyance. Similar interactions between soil erodibility, slope, and runoff have been documented in nearby Sumatran sub-watersheds, where conservation strategies are recommended alongside engineered measures (Ramsos et al., 2025).

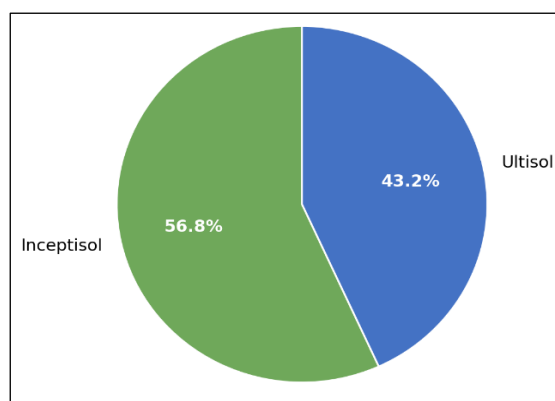


Fig. 4. Soil-type composition of Manggala District, Makassar City.

Catchment delineation for Zone 1, including the contour pattern and the drainage outlet, is shown in Fig. 5. The delineation fixes the contributing area and the longitudinal flow path used to estimate the time of concentration in Eqn. (3), and confirms that runoff converges on the Pampang River through the Antang and Gowa sub-systems. This delineation provides the area terms A required by the rational method and isolates the two design zones treated below.

Field observations identified several drainage sections with inadequate conveyance, sediment accumulation, obstruction by solid waste, and discontinuity between drainage segments. These conditions contribute to localized inundation following prolonged or high-intensity rainfall. Similar drainage-related flood mechanisms have been documented in Indonesian urban areas, where drainage obstruction, sedimentation, insufficient capacity, and poor network connectivity can increase inundation frequency and duration (Indrayani et al., 2025; Marzuki & Pratama, 2025).

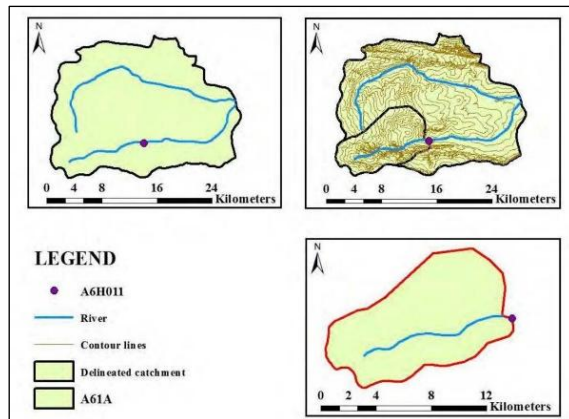


Fig. 5. Delineated Zone 1 catchment showing river alignment, contour lines, and drainage outlet.

In Manggala District, the observed drainage problems are consistent with previous research linking land-use conversion and urban development with increasing flood susceptibility (Rachmat et al., 2015; Rumata et al., 2023). Previous assessments have also identified Manggala as an area with substantial flood vulnerability, particularly in the Perumnas Antang area (Arief & Nilawati, 2024; Febriani et al., 2025).

The results indicate that the existing drainage problem cannot be addressed solely by increasing channel dimensions. The system requires improvement in hydraulic capacity, network continuity, and protection from sediment and solid-waste accumulation. Recent flood-mapping research in Makassar similarly emphasizes the importance of spatially identifying flood exposure to support more targeted mitigation and infrastructure planning (Dewantara et al., 2026).

4.2 Design discharge and closed circular conduit capacity

Applying the rational method (Eqn. 1) with the land-use-weighted runoff coefficient (Eqn. 2) and the 10-year design storm, and checking conduit capacity with the Manning equation (Eqns. 4–5), yields the zone-specific design summarized in Table 3. The catchment was divided into two zones by topography and runoff-concentration pattern. Zone I, the larger catchment at 857.1 ha, carries a design discharge of 0.63–1.57 m³/s and requires 1.86 km of closed channel. Zone II, at 272.4 ha, carries 0.35–0.80 m³/s over a longer network of 14.39 km. Circular conduits of 800–1200 mm in Zone I and 600–900 mm in Zone II provide full-flow capacities of 0.94–2.76 m³/s and 0.43–1.28 m³/s respectively, so capacity meets or exceeds the design discharge in both zones.

Table 3. Design discharge and closed circular conduit capacity by drainage zone.

Zone	Area (ha)	Design Q (m ³ /s)	Pipe Ø (mm)	Full-flow capacity (m ³ /s)	Velocity (m/s)	Length (km)
I	857.1	0.63–1.57	800–1200	0.94–2.76	1.9–2.4	1.86
II	272.4	0.35–0.80	600–900	0.43–1.28	1.5–2.0	14.39

Source: data processing, 2024.

As reported in Table 3, the capacity margin is deliberate rather than incidental: sizing the conduit so that full-flow capacity exceeds the 10-year peak provides freeboard for uncertainty in the runoff coefficient and for progressive densification of the catchment. The computed velocities, from about 1.5 m/s in the smaller Zone II conduits to about 2.4 m/s in the largest Zone I pipes, sit comfortably inside the accepted band: high enough to entrain sediment and prevent deposition, yet below the threshold at which abrasion of the concrete invert becomes a concern (Rohith & Sudheer, 2023; Schlef et al., 2023). This velocity control is the principal hydraulic advantage of the closed circular section over the existing trapezoidal open channels, in which low velocities and exposure to debris promote the sedimentation and blockage documented during the field inventory (Tamm et al., 2023; Bagrecha et al., 2024).

The choice of a circular cross-section is justified on hydraulic grounds. For a given flow area, the circle minimises the wetted perimeter, maximising the hydraulic radius and hence, through Eqn. (4), the conveyance for a given slope and roughness; the curved invert also concentrates low flows and sustains self-cleansing velocities that a wide trapezoidal or box section cannot maintain at partial depth. Comparative culvert-hydraulics studies similarly report that section geometry and inlet condition govern conveyance efficiency and blockage susceptibility (Simpson et al., 2023; Oswald et al., 2023). The typical conduit cross-section adopted here—internal diameter, bedding, and cover arrangement beneath the carriageway—is shown in Fig. 6.

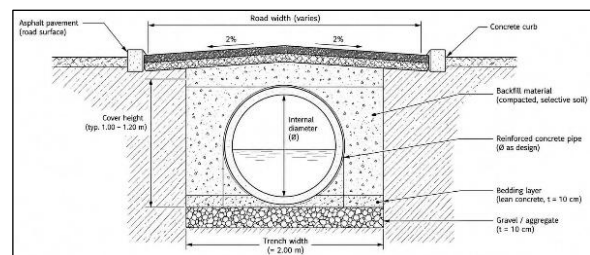


Fig. 6. Typical cross-section of the proposed closed circular drainage channel beneath the road corridor.

4.3 Network configuration and structural detailing

The plan configuration of the closed system places precast circular pipes between control basins at a maximum spacing of 100 m, as illustrated in Fig. 7. This spacing is the single governing maintenance interval adopted throughout the design; it supersedes the shorter intervals sometimes cited for utility access and was fixed at 100 m to match the inspection and cleaning practice for stormwater conduits of this diameter. Each manhole is offset from the main alignment to provide working clearance, and the pipe segment between successive manholes does not exceed 100 m so that cleaning and inspection remain practicable over the entire network.

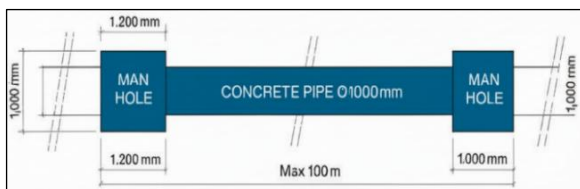


Fig. 7. Plan layout of the precast concrete pipe network with manholes at 100 m maximum spacing.

The manhole detail is shown in Fig. 8. The chamber houses the concrete conduit within reinforced walls, is capped by a precast cover set flush with the pavement to distribute vehicle loads, and is fitted with step irons for safe access (Chen & Huang, 2024). A cast-in-place base slab stabilises the structure against settlement, while inlet chambers with sediment traps intercept street runoff and prevent coarse material from entering the main line. This detailing operationalises the maintenance strategy: sediment is captured at defined, accessible points rather than distributed along an exposed open channel, which is the recurring failure mode of the existing network (Getirana et al., 2023).

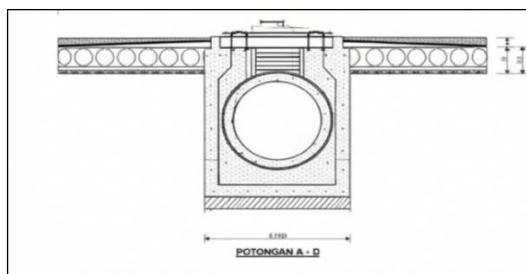


Fig. 8. Cross-section of a reinforced-concrete manhole integrated with the road-drainage conduit (Section A-A).

4.4 Effectiveness, comparison with previous studies, and limitations

Placing the design in the context of previous work clarifies both its contribution and its boundaries. The eco-drainage evaluation of Makassar reported peak-discharge reductions approaching 2.0 m³/s from infiltration wells and revitalised secondary channels (Farida et al., 2025; Indrayani et al., 2025). The present closed system operates in a comparable discharge range but shifts the mechanism from surface infiltration to reliable subsurface conveyance, which is less sensitive to the low soil permeability established in Section 4.1. Relative to LID modelling that attributes roughly 30% peak-flow reduction to combined infiltration-storage measures and to nature-based reviews that report meaningful but partial mitigation, the closed conduit is best understood not as a substitute for such measures but as the grey-infrastructure backbone repeatedly found to be required under intense tropical rainfall (Joleha et al., 2024; Huang, 2024; Lu et al., 2024; Nazarpour et al., 2023).

A trend consistent with improved conveyance is visible in the observed flood-duration record for the Antang and Bangkala areas, shown in Fig. 9. Average flood duration declined from about 18 hours in Antang and 20 hours in Bangkala in 2017 to roughly 3 and 4 hours in 2023, corresponding to reductions of approximately 78–83% over the period. These figures are field observations spanning a period in which several drainage and retention interventions were implemented, so the reduction reflects the combined effect of those works rather than the closed conduit alone. The record should

therefore be read as corroborating the direction and plausible magnitude of the expected benefit, not as an isolated measurement of the proposed system. Presenting the trend in this qualified way avoids overstating causal attribution while still grounding the expected improvement in measured data.

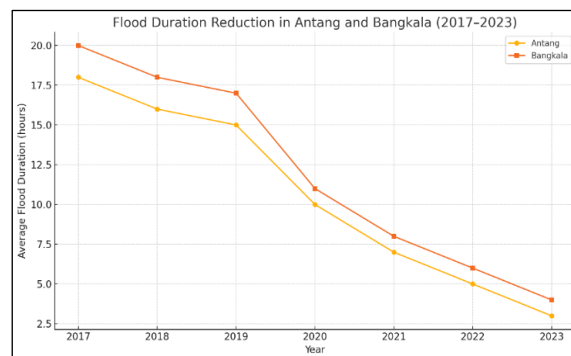


Fig. 9. Observed reduction in average flood duration in the Antang and Bangkala areas, 2017–2023.

Several limitations qualify the design. First, the absence of gauged discharge meant the peak flow had to be inferred from rainfall using the rational method. Its assumptions of uniform intensity and a single runoff coefficient are approximations for a catchment as heterogeneous as Manggala; hydrodynamic simulation with observed hydrographs would refine these estimates. Second, the closed circular network carries a higher capital cost than open channels and imposes strict maintenance obligations—manholes and sediment traps must be cleared on schedule, since a blocked closed conduit is harder to rehabilitate than an open drain. Third, sediment management depends on sustaining the self-cleansing velocity across the full range of operating flows, which the partial-depth hydraulics of small storms may not always guarantee. Fourth, construction beneath congested road corridors entails traffic disruption and careful coordination with buried utilities. These constraints do not negate the approach but define the operational and financial commitments required for it to deliver the modeled performance, and they frame the monitoring that should accompany implementation.

Beyond hydraulic performance, routing the network beneath the carriageway releases surface land for road and pedestrian use and removes the open channels that currently accumulate waste, representing a tangible urban-functionality gain in a densely built district. Integration with real-time water-level telemetry of the kind now deployed on Indonesian urban drainage (Joleha et al., 2024; Huang, 2024; Sobhaninia et al., 2025), and with the flood-prediction and vulnerability-mapping tools developed for Makassar and comparable Indonesian cities (Rachmat et al., 2015; Rumata et al., 2023; Arief & Nilawati, 2024), would allow the closed system to be operated adaptively rather than passively. Coupling the structural network with non-structural preparedness—such as the evacuation-route planning developed for flood-prone Indonesian districts would further strengthen its contribution to urban flood resilience.

5. Conclusion

This study concludes that a closed drainage system with a circular cross-section is a strategic solution to reduce flood risk in Manggala District. Based on topographical analysis and runoff patterns, the area is

divided into two zones. Zone I, covering 857.1 hectares, requires a flow capacity ranging from 0.63 to 1.57 m³/s with a closed channel length of 1.86 km. Meanwhile, Zone II, with an area of 272.4 hectares, requires a capacity of 0.35 to 0.80 m³/s and a channel length of 14.39 km. The implementation of this system not only improves hydrological efficiency and infrastructure resilience but also supports urban spatial functions by placing the drainage network beneath roadways. With adaptive and integrated design, this model is expected to significantly reduce the duration and intensity of flooding, while contributing to the achievement of sustainable urban development goals in flood-prone areas such as Manggala.

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