Vol. 7, No. 8, August 2026
E-ISSN:2723 – 6692 P-ISSN:2723– 6595
http://jiss.publikasiindonesia.id/

Rapid Flood Assessment, September 10, 2025, to Support Climate-Resilient Development Planning: A Case Studies of the *Tukad Mati* and *Tukad Badung* River Basins, Bali

Anak Agung Ngurah Ardhyana
Badan Perencanaan Pembangunan Daerah (Bappeda) Kabupaten Badung, Indonesia
Email: gungardy@gmail.com

Keywords:
Flood;
Rapid Assessment;
Zero Delta Q;
Watershed;
Surface Runoff.

Abstract

On 10 September 2025, severe flooding affected Badung Regency and Denpasar City, disrupting economic activities, tourism, and infrastructure, highlighting the urgent need for climate-resilient development planning. While previous studies have focused on structural flood control, limited attention has been given to rapid post-disaster assessments integrating infrastructure evaluation, policy analysis, and community-level runoff control in Balinese traditional settlements. This research conducted a rapid assessment of flood control operations and formulates climate-resilient planning recommendations, focusing on infrastructure performance in the *Tukad Badung* and *Tukad Mati* watersheds, Zero Delta Q runoff control policies, and their implementation in traditional Balinese settlements. A descriptive qualitative rapid assessment was employed through field surveys across three watershed segments, infrastructure observations, documentation, regulatory reviews, and expert discussions. The findings indicate that flooding resulted from extreme rainfall, declining infiltration areas, increasing runoff from built-up expansion, and limited infrastructure capacity. The Zero Delta Q principle has been incorporated into national and regional regulations through spatial-use intensity controls including Building Coverage Ratio (KDB), Built-up Area Coefficient (KWT), and Green Coverage Ratio (KDH), though effectiveness depends on consistent community-level implementation. In traditional Balinese settlements, increasing concrete and paving in residential yards has reduced infiltration and accelerated runoff. This study concludes that flood management should integrate infrastructure improvement with source-based runoff control by implementing Zero Delta Q in individual residential yards as the smallest hydrological units within a watershed. The findings contribute to climate-resilient planning by providing empirical evidence on integrating infrastructure, policy, and community interventions, offering actionable recommendations for policymakers and planners.

INTRODUCTION

Climate change has increased the risk of extreme weather events in various regions, including the island of Bali (Ayu Puspitasari & Wu, 2025; Bharata et al., 2024; Fidinina et al., 2026; Hariadi et al., 2024; Rahmah & Sulistyono, 2024; Sudarma et al., 2024). Rising rainfall intensity has become one of the threats to urban areas because it can increase surface runoff volume and flood risk. Badung Regency and Denpasar City, as centres of economic growth and tourism in Bali, face increasing pressure from the interaction between extreme rainfall and the rapid development of built-up areas. Urbanization and land-use change have converted part of the natural surface into impervious surfaces, reducing the soil's capacity to infiltrate rainwater and accelerating flow toward the drainage system and rivers. This condition causes the hydrological response of the area to become faster and increases the load on flood control infrastructure (Abdullah et al., 2025; Fan et al., 2024; Papaioannou et al., 2023; Ridwansyah et al., 2026; Wang et al., 2022).

On 10 September 2025, a flood occurred that affected several areas in Badung Regency and Denpasar City. The event caused inundation in a number of residential areas, economic centers, and other public infrastructure. The impact was not only material loss, but also disruption to social and economic activity, compounded by a decline in tourism visits, which ultimately affected the achievement of Regional Original Revenue (PAD) targets. In the context of regional development planning, disaster events such as flooding should become an important source of learning to improve planning quality.

Rapid assessment is one approach that can be used to quickly identify the impact, causes, and level of regional vulnerability after a disaster occurs (Abbasi et al., 2024; Bosmans et al., 2022; Legge et al., 2022; Liang et al., 2023). This approach allows planners to obtain an early, comprehensive picture of field conditions, so that it can serve as a basis for formulating policy that is more responsive and adaptive to disaster risk, particularly risk triggered by climate change.

Several studies have examined flood events in Bali and their contributing factors. Kompas.com (2025) and detikBali (2025) reported on the widespread impacts of the September 2025 floods across the island, while Mongabay Indonesia (2025) highlighted the role of environmental degradation and land-use change in exacerbating flood impacts. Tunas Hijau (2025) further emphasized the lessons from the 2025 Bali floods for climate change adaptation and spatial planning. However, these studies have primarily focused on reporting the event and its immediate impacts, without conducting systematic infrastructure evaluation, policy analysis, or community-level assessment. Academic research has also examined flood management in Bali, but most studies have focused on structural measures such as drainage system improvement and river normalization (Suripin, 2004; Asdak, 2023), with limited attention to integrated assessments that combine infrastructure performance evaluation, policy implementation analysis, and community-level runoff control, particularly in the context of traditional Balinese settlements and the application of the Zero Delta Q concept.

Based on this background, the research problems are formulated as follows: (1) how is the condition and performance of flood control infrastructure operation in the *Tukad Badung* and *Tukad Mati* watersheds in facing the flood event of 10 September 2025; (2) how is the Badung Regency Government's policy in controlling impervious surface area to control surface runoff as an instrument of flood risk reduction (Zero Delta Q); and (3) how is the Zero Delta Q policy implemented at the community level, particularly based on a rapid assessment sampling of traditional Balinese settlements in Badung Regency.

Accordingly, this study aims to conduct a rapid assessment of the operation of flood control infrastructure, the rainwater runoff control policy (Zero Delta Q), and the implementation of this concept, as a basis for formulating recommendations for climate-resilient development planning. Specifically, this study aims to: (a) conduct a rapid assessment of the condition and performance of flood control infrastructure operation in the *Tukad Badung* and *Tukad Mati* watersheds in facing the flood event of 10 September 2025; (b) conduct a rapid assessment of the Badung Regency Government's regulation/policy in controlling impervious surface area as an instrument of flood risk reduction (Zero Delta Q); (c) conduct a rapid assessment of the implementation of the Zero Delta Q policy at the community level, particularly through a rapid assessment sampling of traditional Balinese settlements in Badung Regency; and (d) formulate recommendations for strengthening flood control operation in Badung Regency, as an effort to realize regional development planning that is adaptive to climate change.

This research is expected to contribute theoretically to the development of knowledge in the field of flood control for disaster risk reduction, in order to improve the effectiveness of regional development planning. Practically, the findings are expected to serve as evaluation material for the regional government regarding the operation of flood control infrastructure and the implementation of impervious-surface control policy; as a reference in the preparation of regional development planning documents, such as the RPJPD, RPJMD, RTRW, and RDTR; as a basis for technical agencies responsible for public works and spatial planning, housing and settlement areas, the environment, community and village empowerment, and investment affairs in improving the effectiveness of drainage infrastructure, flood control systems, and the application of the Zero Delta Q concept; and to improve public understanding of the importance of controlling rainwater runoff through the provision of infiltration areas, infiltration wells, and other green infrastructure. At the policy level, the results of this post-disaster rapid assessment can be used as a basis for refining policy, control, and the preparation of development programs that are more resilient to climate change.

METHOD

Research Approach

This study used a descriptive qualitative approach. This approach aims to gain an in-depth understanding of the characteristics of the flood event that occurred on 10 September 2025 through direct field observation and interpretation of the physical condition of the area and existing infrastructure. The descriptive qualitative approach was chosen because this study not only identifies the causes of the flood, but also examines the process and the interrelationship among the factors influencing the flood within a single watershed (DAS) system.

Research Location and Time

The research was conducted in the *Tukad Mati* watershed area of Badung Regency and the *Tukad Badung* watershed area of Denpasar City. Observation locations were focused on three main segments of the river flow system, as summarized in Table 1.

Table 1. Research Location and Observed Watershed Segments

Segment	Location	Description
Upstream	Tanah Putih Dam, Belumbungan Village, Abiansemal Subdistrict, Badung Regency	The initial point of the flood control system leading toward Badung City and Denpasar City, located at the head of the *Tukad Mati* and *Tukad Badung* watershed system
Midstream	Aungan (traditional Balinese channel), Penarungan Village, Abiansemal Subdistrict, Badung Regency	A location of quite severe flooding, where water level rose more than 10 meters above the normal river flow,

Segment	Location	Description
		causing water to spill onto the road and submerging several public facilities
Downstream	Long Storage *Tukad Mati* and Muara Nusa Dua Reservoir, Kuta Subdistrict, Badung Regency – border of Badung and Denpasar	The final segment of the flood control system, bordering directly on the sea; system failure at these two locations is estimated to be one of the causes of the 10 September 2025 flood

Source: Authors' field survey (2025)

Field observation was carried out on 28–31 October 2025, followed by discussion and further review until this report was completed.

Types and Sources of Data

This study uses primary and secondary data. Primary data consist of rapid assessment field survey results; observation of the condition of the *Tukad Badung* and *Tukad Mati* watersheds; field photo documentation; and interviews and discussions with dam operators, relevant agencies, and technical experts with backgrounds in spatial planning, environmental science, and water resources from Indonesia, Japan, and the Netherlands. Secondary data consist of laws (UU), government regulations (PP), ministerial regulations (Permen), regional regulations and regent regulations, RTRW, RDTR, RPJMD, and RKPD documents, BMKG rainfall data, satellite imagery, national media information, regional media information, social media information, and books, journals, and prior research results.

Data Collection Technique

This study uses a data collection technique that combines primary and secondary data to obtain a comprehensive picture of the flood event, the performance of flood control infrastructure, and the implementation of rainwater runoff control policy, particularly in Badung Regency. A field survey (rapid assessment) was conducted directly in the upstream, midstream, and downstream areas of the watershed to observe existing conditions related to the flood event. Observation covered the condition of flood control infrastructure such as diversion weirs, rivers, subak/aungan channels (traditional tunnel-type irrigation), estuary reservoirs, and long storage. Documentation was carried out by collecting field photographs and satellite imagery related to the research locations, used to support the observation results and strengthen the analysis of field conditions. Interviews and discussions with experts (expert judgment) were conducted with the assistance of dam operators, relevant agencies, and technical experts to obtain a technical assessment of flood causes and infrastructure performance, used to verify the field survey results. A document study was conducted on various relevant documents to obtain a theoretical foundation, regulatory framework, and supporting data for the analysis.

Data Analysis Method

Data analysis in this study uses the descriptive qualitative method with a rapid assessment approach, namely rapidly analyzing existing conditions after the flood event through the integration of field survey, observation, documentation, interview, and document study results. The analysis was carried out to identify the factors causing the flood, evaluate the performance of flood control infrastructure, and analyze the implementation of rainwater runoff control policy in Badung Regency. Data reduction involved collecting, selecting, and grouping primary and secondary data according to the research focus, namely watershed condition, flood control infrastructure performance, and the direction and implementation of regional government policy, to simplify the data so that the information conveyed is relevant to the research objective. Analysis of the condition and performance of flood control infrastructure was carried out by evaluating existing conditions covering upstream, midstream, and downstream watershed infrastructure. Policy analysis was carried out to determine the extent to which existing regulation has supported flood prevention and control efforts. Policy implementation analysis was carried out by comparing existing field conditions against applicable regulation, particularly the application of the Zero Delta Q concept as an instrument of flood risk reduction and sustainable development. The final stage, drawing conclusions, was carried out by integrating the analysis results to formulate the research conclusions.

Conceptual Framework

The flood event of 10 September 2025 forms the starting point of this research. The flood was triggered by climate change, which produced extreme rainfall, but is presumed to have been aggravated by the not-yet-optimal operation of flood control infrastructure and the implementation of rainwater runoff control policy. Through the rapid assessment approach, these conditions were analyzed to identify the flood event. The analysis results were then used to formulate an integrated regional development strategy that is more adaptive to climate change.

Accordingly, this study positions rapid assessment as a bridge between the disaster event and the regional development planning process. The analysis results form the basis for formulating recommendations on policy strengthening, flood control infrastructure optimization, and development planning strategies that are adaptive to climate change and oriented toward flood risk reduction, as illustrated in Figure 1.

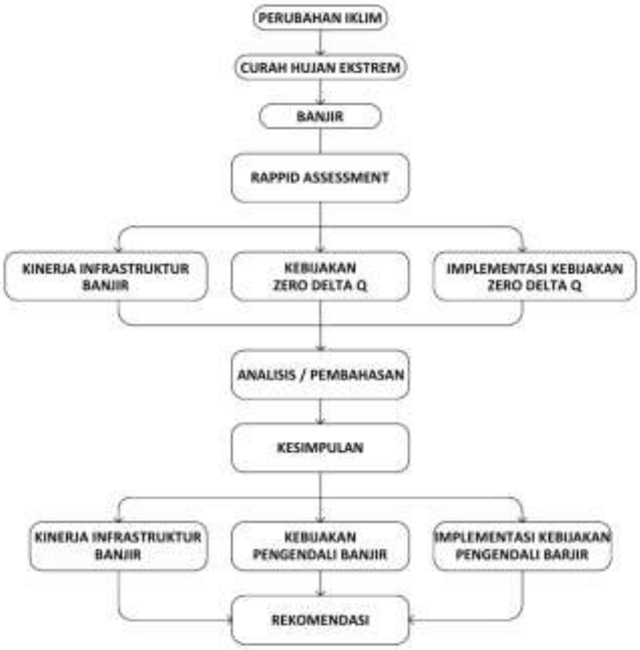

Figure 1. Conceptual Framework

Source: Authors' research design (2026)

RESULTS AND DISCUSSIONS

The flood event that occurred on 10 September 2025 in Badung Regency and Denpasar City was a hydrometeorological event triggered by various factors, primarily high-intensity rainfall over a relatively long duration as a result of climate change. Based on data from the Meteorology, Climatology, and Geophysics Agency (September 2025), rainfall during that period was classified as heavy to very heavy and lasted for two consecutive days. This condition caused a significant increase in surface flow discharge, exceeding the capacity of the drainage system and rivers.

The impact of this increased rainfall intensity was felt widely across Bali Province, with seven of the eight regencies/cities affected, namely Jembrana, Tabanan, Badung, Gianyar, Klungkung, and Karangasem Regencies, as well as Denpasar City. The most significant flood impact occurred in the *Tukad Mati* and *Tukad Badung* watersheds, influenced by area characteristics dominated by urban zones with high settlement density, which increased surface runoff and reduced infiltration capacity.

Both watersheds pass through the Sarbagita Metropolitan National Activity Center (PKN), specifically PKN Kuta and PKN Denpasar. The flood also disrupted activity in the Kuta, Sanur, Nusa Dua, and surrounding National Strategic Tourism Areas (KSPN). This shows that the flood affected not only environmental and residential aspects, but also had significant implications for the tourism sector and the regional economy.

Field observation results show that the midstream and downstream areas were the most affected, with greater inundation height and duration compared with the upstream area, caused by the accumulation of flow from the upstream area and the limited capacity of the drainage system to accommodate the increased water discharge. Besides the rainfall factor, the flood event was also influenced by land-use change and urban area development. Land conversion in the midstream and upstream areas reduced infiltration areas, thereby increasing surface runoff flowing to the downstream area. On the other hand, suboptimal drainage infrastructure conditions, such as channels blocked by waste and sedimentation, further worsened the inundation.

Rapid Assessment of Flood Control Infrastructure Operation

The operation of the flood control system in the *Tukad Badung* and *Tukad Mati* watersheds is an important part of hydrometeorological disaster risk mitigation efforts in the Sarbagita Metropolitan Area, particularly Badung Regency and Denpasar City. Evaluation of this system was conducted to assess infrastructure performance, management effectiveness, and suitability to the dynamics of environmental change and area development.

In general, the flood control system in both watersheds includes diversion weirs, rivers, subak irrigation networks, urban drainage, and the management of trash rakes, water gates, and floating weirs. However, based on field observation results, the existing system has not been fully able to anticipate extreme rainfall events such as the one that occurred on 10 September 2025. In terms of water volume capacity, some drainage channels and rivers in the *Tukad Badung* and *Tukad Mati* watersheds experience limited carrying capacity, caused by an increase in flow discharge not matched by the infrastructure's original design capacity. In addition, there are indications of disrupted water flow due to waste, sedimentation, and space-use activity along river borders, which further reduces flow capacity.

From the operation and maintenance aspect, problems remain in the form of suboptimal normalization and channel-cleaning activity. The buildup of sediment and domestic waste at several points obstructs water flow, accelerating inundation during high-intensity rainfall, indicating that routine maintenance has not been carried out consistently and in an integrated manner. Furthermore, from the spatial planning and land-use control aspect, rapid urban development in the upstream and midstream watershed areas has contributed to increased surface runoff. Conversion of infiltration areas into built-up zones reduces the soil's capacity to absorb rainwater, increasing the load on the downstream drainage system and ultimately raising flood potential.

From the institutional side, the operation of the flood control system still faces challenges in inter-agency coordination. Watershed management involves various parties, from the central government, regional government, to the community; however, effective synergy in planning, implementation, and oversight has not been fully realized, so flood handling tends to be partial. In addition, the existing flood control system is still dominated by structural measures, such as physical infrastructure construction, while non-structural approaches, such as increasing public awareness, spatial-use control, and early warning systems, have not been fully optimized.

Upstream Flood Control Operation

Tanah Putih Dam is a water structure located in Darmasaba Village, Abiansemal Subdistrict, Badung Regency, Bali, situated on the Tukad Pangi Darmasaba River and functioning as part of the irrigation system of the Mambal Irrigation Area (DI). Hydrologically, this location has a strategic role because it is presumed to be one of the initial points of flow distribution (supply) from the Ayung watershed toward the *Tukad Badung* and *Tukad Mati* watersheds.

The Tanah Putih spillway structure functions to regulate the division of water flow between irrigation needs and flow toward the river system. Under certain conditions, particularly during high discharge, water from the irrigation channel may overflow through the spillway structure and potentially cause inundation in the downstream area, as identified in the area of the Dalem Temple/Setra of Anggungan Village.

Analysis shows that the main contribution to increased flow discharge originates not only from the river system at Tanah Putih Dam, but also from land-use characteristics in the upstream area. Paddy fields have different hydrological characteristics compared with dryland or plantation areas; under saturated or inundated conditions, paddy fields tend to have low infiltration capacity, so most rainwater becomes surface runoff channeled into irrigation canals. This runoff subsequently accumulates and enters the river system, significantly increasing flow discharge downstream. This condition indicates that although weir operation was carried out in accordance with procedure, runoff contribution from paddy field areas remains an important factor in increasing flood risk in the *Tukad Badung* watershed.

Based on the field survey results at Tanah Putih Dam (upstream) related to the flood event of 9–10 September 2025, several conditions were identified: in general, the dam condition functioned well and showed no indication of structural damage; at the time of the flood event, weir operators were on-site, working according to standard operating procedure (SOP), and opened the outlet channel to reduce the volume of water entering the direction of Badung City (*Tukad Mati* watershed); water-gate operation was carried out manually by operators residing near the dam location, coordinating via a WhatsApp communication group; and nevertheless, a significant volume of water still entered the river system, originating from rainwater runoff in the paddy field areas surrounding the watershed.

Midstream Flood Control Operation

The Setra Anggungan location is situated in the midstream section of the *Tukad Mati* watershed system and was one of the areas quite significantly affected during the flood event of 9–10 September 2025. Based on field observation results, inundation in this area reached the Temple and Setra of Anggungan Village (located 15 meters above the water surface) and overflowed onto the surrounding road network.

Rapid assessment results indicate that the increase in discharge at this location originated from the accumulation of flow in irrigation channels connected to the water supply system from the direction of Tanah Putih Dam, in addition to rainwater runoff from the surrounding catchment area. As discharge increased, flow toward the downstream section was presumed to experience flow restriction at several points, particularly at culverts and traditional tunnel-type irrigation channels (aungan) with relatively narrow dimensions. This condition caused the channel capacity to be unable to accommodate the entire incoming discharge, so the water level rose and overflowed onto the road and the Temple/Setra Anggungan area.

Based on field observation results, several conditions with the potential to affect the capacity and smoothness of flow in the channel system in the Setra Anggungan area include the following: in several segments, the boundary between the channel and residential areas is not clearly defined, with the potential to affect the channel's function and flow space; vegetation such as bamboo and other plants grows along the channel banks, with some stems and branches extending or leaning into the channel body, with the potential to trap material and waste carried by the flow, thereby narrowing the channel's effective cross-section and increasing blockage risk; there is a traditional irrigation channel in the form of a tunnel penetrating a rock formation, locally known as aungan, with relatively narrow dimensions, a characteristic with the potential to become a bottleneck point when receiving high discharge, particularly when waste, sediment, or vegetation material is carried by the flow; and management of the river system and water resource infrastructure at this location involves central government authority through the River Basin Organization (Balai Wilayah Sungai), while the affected location is administratively within Badung Regency, so that the division of authority for water resource infrastructure management becomes an important aspect in flood handling, requiring effective coordination, particularly in maintenance activity, flow-obstruction handling, and emergency response.

Downstream Flood Control Operation (Muara Nusa Dua Reservoir and Long Storage *Tukad Mati*)

In the downstream area, the team monitored and evaluated flood control infrastructure at two locations, namely the Muara Nusa Dua Reservoir and the Long Storage *Tukad Mati*. Both infrastructures have different flood control system characteristics, resulting in different responses to the extreme rainfall event of 9–10 September 2025.

The Muara Nusa Dua Reservoir has a flow system from the upstream direction toward the reservoir with elevation differences divided into several segments utilizing drop structures. At the downstream section, there is an elevation difference between the reservoir water surface and the sea water surface, providing space for regulating river-water release toward the sea.

This condition allows the reservoir to function as a storage and flow-control facility before water is released to the sea.

Meanwhile, the Long Storage *Tukad Mati* has relatively gentle river-channel characteristics. At several locations, the water surface elevation or river embankment is relatively higher than the surrounding residential area. At the downstream section, the elevation difference between the long-storage system and the sea water surface is relatively small, so drainage to the sea is strongly influenced by tidal conditions; the *Tukad Mati* flood control system therefore cannot rely solely on gravity.

Interestingly, during the flood event of 9–10 September 2025, a condition different from previous flood patterns was found. The area around the Muara Nusa Dua Reservoir system experienced quite significant flooding, whereas the Long Storage *Tukad Mati* area, which historically has flood vulnerability, did not show a significant increase in flooding. This condition is an important finding in the rapid assessment, as it shows that the level of flood impact is determined not only by the magnitude of rainfall, but also by the performance of the flood control system and the operational condition of infrastructure at the time of the event.

Figure 2. Muara Nusa Dua Reservoir Infrastructure Layout

Source: Authors' documentation (2025)

Based on field tracing and operator information, rainfall began on 9 September 2025 at approximately 19:00 local time (WITA) with light intensity, then increased to heavy rain around 22:00 WITA. Entering 10 September 2025, inundation began to occur in the Badung Market area at approximately 02:00 WITA. Around 03:00 WITA, flow in the Taman Pancing area, located to the north of the Muara Nusa Dua Reservoir, began to overflow. The high inundation prevented operator vehicles from crossing the access route from Taman Pancing to the Muara Reservoir.

Rapid assessment results indicate that one of the main factors causing the overflow of flow to the north of the reservoir was the obstruction of inflow toward the Muara Reservoir due to waste buildup in the trash rake system at the reservoir inlet. Waste carried along with increased river discharge accumulated on the trash rake, reducing the effective flow cross-section and obstructing water entry into the reservoir. This condition caused a rise in water level on the upstream side and subsequently triggered overflow into the surrounding area. Another important finding is that, at the time of the event, the water surface elevation inside the Muara Reservoir remained within technical capacity and relatively controlled. Thus, observation results indicate that the problem was not solely caused by reservoir storage capacity, but rather by obstruction in the process of flow entering the reservoir from the river.

This condition demonstrates the importance of the operation and maintenance aspect as an integral part of the flood control system. Infrastructure with adequate storage capacity can still lose effectiveness if the water-entry path becomes blocked at peak discharge. Evaluation results indicate the need for a more specific Standard Operating Procedure (SOP) regarding the operation of the trash rake, water gate, and rubber weir of the Muara Reservoir, particularly in facing extreme conditions involving a combination of high rainfall, increased discharge, and large waste volume. In addition, the opening of the rubber weir during flooding cannot be carried out fully without considering tidal conditions; based on discussion with technical experts, sea water surface elevation needs to become one of the main parameters in gate operation, since if sea water level is higher than reservoir water level, gate opening has the potential to cause seawater backflow into the reservoir system. Reservoir operation during flooding must therefore simultaneously consider discharge from upstream, reservoir water surface elevation, trash rack/rake condition, and tidal elevation.

The downstream flood control system of *Tukad Mati* was developed through construction of the Long Storage *Tukad Mati*, consisting of a river embankment and a movable weir. This infrastructure utilizes a normalized river body as temporary storage space to control increased discharge before it is channeled to the sea. The river body is reinforced using a Corrugated Concrete Sheet Pile (CCSP) system, corrugated precast concrete elements functioning as soil- and water-retaining structures. At the downstream section, a movable weir functions to control the hydraulic connection between the river and the sea, particularly to prevent seawater intrusion into the river channel during high tide.

Figure 3. Long Storage *Tukad Mati* Infrastructure – River Embankment (left) and Movable Weir (right)

Source: Authors' field observation (2025)

Historically, *Tukad Mati* was part of the irrigation system, so in some sections the position of the river channel is relatively higher than the surrounding agricultural land and residential areas. This characteristic causes areas along the *Tukad Mati* watershed to be vulnerable to inundation if overflow occurs from the river body. To reduce this risk, the Badung Regency Government, together with the River Basin Organization, has developed an active flood control system in the *Tukad Mati* watershed. This system does not rely solely on river capacity, but is also supported by flood control pumps at several vulnerable points; the Badung Regency Government has operated three flood pump systems equipped with generator sets as backup power sources, including the construction of a flood pump system in the Jalan Arjuna area. At the downstream section, construction of the Long Storage *Tukad Mati* strengthens this system by providing temporary storage capacity while controlling the interaction between river flow and sea tide.

Rapid Assessment of Zero Delta Q Policy in Badung Regency

One strategic effort to reduce urban flood risk is the application of the Zero Delta Q concept, the principle of rainwater runoff management requiring that every development not increase the discharge of runoff leaving an area compared with conditions prior to development. Through the provision of infiltration and storage infrastructure, such as infiltration wells, retention ponds, detention ponds, rain gardens, and porous pavement, rainwater runoff can be held, infiltrated, or released gradually so as not to burden the drainage system and rivers in the downstream area.

At the national level, Government Regulation (PP) No. 13 of 2017 concerning Amendment to Government Regulation Number 26 of 2008 concerning the National Spatial Plan, Article 99 Paragraph 3, mandates the application of the Zero Delta Q Policy principle to every proposed built-up cultivation activity, defined as the requirement that no building may result in increased water discharge into the drainage channel system or river flow system.

At the provincial level, Bali Provincial Regulation Number 2 of 2023 concerning the Bali Provincial Spatial Plan 2023–2043 has adopted the Zero Delta Q principle in spatial policy. Article 58 regulates development policy for the Bedugul-Pancasari and Kintamani Special Regional Strategic Tourism Areas (KSPD), directing that these areas be maintained as upstream regions and water catchment conservation areas, with settlement and tourism-facility spatial patterns developed sustainably and integrated with agricultural areas at a maximum built-up area coefficient (KWT) of 5% of the KSPD area. Article 95 regulates zoning direction for tourism areas, including a limitation on the Building Coverage Ratio (KDB) for every tourism accommodation and facility business at a maximum of 50% of the controlled parcel. Article 107 Paragraph 2 stipulates special provisions for water catchment areas, requiring the application of a high capacity to retain rainwater runoff (Zero Delta Q policy) for every proposed built-up cultivation activity.

At the regency level, Badung Regency has regulated the Building Coverage Ratio (KDB) and Green Coverage Ratio (KDH) in detail for each zoning category based on area characteristics, as summarized in Table 2.

Table 2. Building Coverage Ratio (KDB) and Green Coverage Ratio (KDH) by Zoning Category in Badung Regency

Zoning Category	Maximum KDB	Minimum KDH
Food crop area (Art. 92)	10%	75%

Zoning Category	Maximum KDB	Minimum KDH
Horticulture area (Art. 92)	30%	55%
Plantation area (Art. 92)	30%	55%
Tourism area (Art. 96)	50%	15%
Urban residential area (Art. 97)	75%	10%
Rural residential area (Art. 97)	70%	15%

Source: Badung Regency Spatial Plan Regulation, Articles 92, 96, and 97. Article 101 Paragraph 13 additionally stipulates special provisions for water catchment areas, requiring the application of a high capacity to retain rainwater runoff (Zero Delta Q policy), construction of infiltration wells and biopore infiltration holes, development of two groundwater recharge wells for every one groundwater production well, and conversion of groundwater production wells into Aquifer Storage and Recovery (ASR) wells with dual production and recharge function.

Hydrologically, the limitation of KDB and KDH is a form of application of the Zero Delta Q principle, namely maintaining that development does not increase surface runoff discharge compared with conditions prior to development. By maintaining the proportion of open space and infiltration areas, rainwater has a greater opportunity to infiltrate into the soil, thereby reducing the load on the drainage system and rivers and lowering flood potential in the downstream area. Although the Zero Delta Q principle has been accommodated in spatial policy from the national to the regional level through the control of KWT, KDB, and KDH, the effectiveness of its implementation still depends on consistency of application at the community level; without adequate technical implementation, building-intensity limitation does not necessarily maintain the hydrological balance of the watershed optimally.

Rapid Assessment of Zero Delta Q Implementation in Traditional Balinese Settlements

One factor contributing to increased flood risk in urban areas is the increasingly rapid channeling of rainwater toward drainage systems and rivers due to reduced land infiltration capacity. Land-use change at the household scale is one cause of increased surface runoff, particularly in residential areas experiencing intensified development.

In the traditional Balinese house concept, the yard's spatial layout (natah) is designed not only as a space for social and cultural activity, but also functions as green open space allowing rainwater to infiltrate into the soil. A traditional house complex consists of several building masses separated by open courtyards, so that most rainwater falling on the yard can still undergo infiltration before flowing to the drainage channel.

However, along with economic development, population growth, and changing community needs, the ecological function of the yard has begun to change. Open yards previously consisting of soil and vegetation have increasingly undergone concreting or paving using paving blocks, natural stone, ceramic, or concrete. This change is generally carried out to improve comfort, cleanliness, vehicle parking capacity, and ease of household environment maintenance.

Figure 4. Paved Traditional Balinese House Yard (Natah)
Source: Authors' field documentation (2025)

From a hydrological perspective, an increase in impervious surface area causes the runoff coefficient to increase while soil infiltration capacity decreases. As a result, most rainwater is no longer absorbed into the soil, but is instead channeled directly to the drainage system and rivers within a relatively short time. If this condition occurs massively across an area, the peak flow discharge in the drainage system and rivers will increase, thereby enlarging flood potential, particularly during high-intensity rainfall.

This condition shows that changing settlement patterns affect not only the physical aspect of an area, but also alter the hydrological cycle balance at the micro scale, which cumulatively affects watershed conditions. The application of the Zero Delta Q principle in residential areas is therefore important to maintain water infiltration function through the provision of green open space, infiltration wells, biopore holes, household-scale retention ponds, and the use of pavement materials with infiltration capacity. Accordingly, flood control efforts should be carried out not only through increasing drainage channel capacity, but also through runoff control at the source (source control), namely at every house yard as the smallest unit within a watershed.

CONCLUSION

This rapid assessment concluded that the 10 September 2025 flood resulted from extreme rainfall that existing flood control infrastructure failed to anticipate, aggravated by increased post-development runoff from the conversion of infiltration areas into impervious surfaces. At Tanah Putih Dam upstream, the structure and operation functioned properly with no structural failure, yet the flood was still driven by runoff from surrounding paddy fields, indicating that upstream control must extend beyond weir operation to source control and integrated irrigation-drainage management. At Setra Anggungan midstream, flooding was driven not by upstream discharge alone but by limited channel capacity at bottleneck points such as narrow traditional aungan tunnels, underscoring the need for integrated *hulu ke hilir* management and cross-authority coordination. Downstream, the Muara Nusa Dua Reservoir flooded significantly despite adequate storage capacity, caused by trash-rake blockage at the inlet, whereas the historically flood-prone Long Storage *Tukad Mati* remained relatively controlled through its integrated system of normalization, embankment, movable weir, and flood pumps, showing that flood impact depends as much on operation and maintenance as on infrastructure capacity. The Zero Delta Q principle has been accommodated in spatial regulation from the national to the regency level through KWT, KDB, and KDH controls, but its effectiveness still depends on consistent community-level implementation; in traditional Balinese settlements, the conversion of yards (natah) into paved surfaces has cumulatively increased runoff despite each individual change appearing minor. It is recommended that flood control be strengthened as an integrated upstream-to-downstream system with reinforced SOPs and early-warning systems, that cross-authority coordination be strengthened, that Zero Delta Q be reinforced through technical infiltration instruments at both the parcel and household scale, that rapid assessment findings be integrated into regional development plans, and that incentive and disincentive instruments be applied, so that Badung Regency's development planning becomes more resilient to climate change.

REFERENCES

Abbasi, S., Modibbo, U. M., Jafari Kolashlou, H., Ali, I., & Kavousi, N. (2024). Environmental impact assessment with rapid impact assessment matrix method: During disaster conditions. *Frontiers in Applied Mathematics and Statistics, 10*, 1344158.

Abdullah, F., Mamoon, W. Bin, Islam, A. K. M. S., Islam, G. M. T., Bala, S. K., Kaiser, S., Mohammed, K., Billah, M., & Das, M. K. (2025). Hydrological responses of the Brahmaputra river basin using CMIP6 GCM projections for supporting climate resilient infrastructure design. *Sustainable and Resilient Infrastructure, 10*(1), 75–101.

Asdak, C. (2023). *Hidrologi dan pengelolaan daerah aliran sungai* (Rev. ed.). Gadjah Mada University Press.

Ayu Puspitasari, S., & Wu, C.-F. (2025). Assessing future climate change with a weather generator: A case study in Bali, Indonesia. *BIO Web of Conferences, 155*, 3003.

Bharata, I. B. A. Y., Suryana, I. G. P. E., & Atmaja, D. M. (2024). The change of coastal typology in Bali Island Karst Region at southern formation. *Eighth Geoinformation Science Symposium 2023: Geoinformation Science for Sustainable Planet, 12977*, 343–351.

Bosmans, M. W. G., Baliatsas, C., Yzermans, C. J., & Dückers, M. L. A. (2022). A systematic review of rapid needs assessments and their usefulness for disaster decision making: Methods, strengths and weaknesses and value for disaster relief policy. *International Journal of Disaster Risk Reduction, 71*, 102807.

detikBali. (2025). *Underpass Dewa Ruci Kuta terendam banjir, turis-turis dievakuasi.*

Fan, C., Hou, J., Li, D., Chen, G., Guan, B., Wang, T., Pinpin, L., & Gao, X. (2024). Characteristics and drivers of flooding in recently built urban infrastructure during extreme rainfall. *Urban Climate, 56*, 102018.

Fidinina, A. S., Pratama, A., & Nurlatifah, A. (2026). Impact of climate change on the potential for extreme rainfall events in the Lesser Sunda Islands-Indonesia. *International Journal of Global Warming, 39*(3), 298–328.

Hariadi, M. H., Van Der Schrier, G., Steeneveld, G.-J., Sutanto, S. J., Sutanudjaja, E., Ratri, D. N., Sopaheluwakan, A., & Klein Tank, A. (2024). A high-resolution perspective of extreme rainfall and river flow under extreme climate change in Southeast Asia. *Hydrology and Earth System Sciences, 28*(9), 1935–1956.

Kompas.com. (2025, September 10). *Bali dikepung banjir, apa penyebabnya?*

Legge, S., Woinarski, J. C. Z., Scheele, B. C., Garnett, S. T., Lintermans, M., Nimmo, D. G., Whiterod, N. S., Southwell, D. M., Ehmke, G., & Buchan, A. (2022). Rapid assessment of the biodiversity impacts of the 2019–2020 Australian megafires to guide urgent management intervention and recovery and lessons for other regions. *Diversity and Distributions, 28*(3), 571–591.

Liang, B., Hou, J., & He, Z. (2023). Rapid assessment method to assess vulnerability of structures using vulnerability index and disaster matrix. *Bulletin of Earthquake Engineering, 21*(5), 2691–2722.

Mongabay Indonesia. (2025, September 16). *Lingkungan rusak dan alih fungsi lahan perparah dampak banjir Bali.*

Papaioannou, G., Alamanos, A., & Maris, F. (2023). Evaluating post-fire erosion and flood protection techniques: A narrative review of applications. *GeoHazards, 4*(4), 380–405.

Rahmah, M., & Sulistyono, A. (2024). The integration of traditional knowledge and local wisdom in mitigating and adapting climate change: Different perspectives of indigenous peoples from Java and Bali Island. In *Traditional knowledge and climate change: An environmental impact on landscape and communities* (pp. 61–80). Springer.

Ridwansyah, I., Pawitan, H., Hidayat, Y., Yulianti, M., & Hakim, A. M. Y. (2026). Analysis of the impact of land use changes on hydrological responses in the Cisadane watershed, Indonesia. *International Journal of Environmental Studies, 83*(1), 82–100.

Sudarma, I. M., Wiguna, P. P. K., Djelantik, A., & Wijana, I. M. S. (2024). Mitigation and adaptation of chili farmers to climate change in Baturiti District, Bali Province, Indonesia. *International Journal of Design & Nature and Ecodynamics, 19*(4), 1391–1403.

Suripin. (2004). *Sistem drainase perkotaan yang berkelanjutan*. Andi.

Tunas Hijau. (2025). *Banjir Bali 2025: Pelajaran pahit dari perubahan iklim dan tata ruang.*

Wang, L., Cui, S., Li, Y., Huang, H., Manandhar, B., Nitivattananon, V., Fang, X., & Huang, W. (2022). A review of the flood management: From flood control to flood resilience. *Heliyon, 8*(11).