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ASSESSMENT OF NUTRIENT POLLUTION TRENDS AND RECOVERY FEASIBILITY IN THE TUKAD BADUNG RIVER ECOSYSTEM

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ABSTRACT

The study investigates the fluctuating levels of nitrogen and phosphorus pollutants along the Tukad Badung River, a vital water source for neighboring communities challenged by waste influx from various activities within its watershed. Conducting bi-daily sampling at six points spanning upstream and downstream areas revealed discernible patterns in nutrient concentrations, influenced by both anthropogenic and natural factors. High amounts of total suspended solids, ammonia, nitrite, nitrate, total phosphorus, and total nitrogen, especially further downstream and in the evening, show how important it is to manage the watershed as a whole to stop nutrient pollution and protect river ecosystems. Moreover, the study's insights lend support to the development of nutrient recovery initiatives aligned with circular economy principles. These initiatives contribute to resource conservation, environmental protection, and sustainable development within and beyond the Tukad Badung River watershed by extracting valuable nutrients from stream water for use in fertilizers or bioenergy production. This highlights the critical role of adaptive management strategies and circular economy approaches in addressing nutrient pollution and ensuring the resilience of river ecosystems for present and future generations.

Keywords: circular economy, nutrient recovery, nutrient trend, stream water, water quality.

INTRODUCTION

Rivers play a crucial role in supporting several communities globally, serving as vital sources of water for household, agricultural, and industrial needs (Khonok et al., 2022; Wu et al., 2023). Nevertheless, the swift process of urbanisation and industrialization has resulted in concerning levels of pollution in numerous river systems, posing a threat to both the quality of water and the health of ecosystems. The Tukad Badung River, located in the Badung

Regency and Denpasar City on the beautiful island of Bali, is currently facing significant pollution issues (Wijaya et al., 2023).

The Tukad Badung River covers an area of around 30 kilometres and has a watershed of 37.7 square kilometres. It is an important water source for nearby villages (Nyoman Wiarta et al., 2008). Despite its importance, a constant flow of solid and liquid waste from various human activities within its watershed is attacking this crucial resource. The increased flow of pollutants, particularly nitrogen and phosphorus compounds, presents a danger to the natural balance of the river and the welfare of people downstream (Ciawi et al., 2022). To tackle the complex problems caused by river pollution, it is necessary to engage in new and interdisciplinary research efforts (Rey-Martínez et al., 2024a; Romero et al., 2021). The present study aims to examine the complex interactions of nitrogen and phosphorus pollution in the Tukad Badung River, with a particular emphasis on identifying methods for extracting nutrients from the stream water. This research programme is driven by a strong dedication to both environmental stewardship and the ideals of the circular economy.

This study is centred around an innovative method for preserving rivers and managing their resources. This project aims to explore the patterns of nitrogen and phosphorus levels in stream water and develop innovative methods for recovering nutrients. Its goal is to establish a connection between environmental conservation and the sustainable use of resources. The innovative component of this endeavour is its investigation of stream water as a source of nutrients that can be recovered (Betti & Nurhayati, 2022; Katkaew & Chamchoi, 2024; Li et al., 2024). This presents a shift in the traditional view of dirty water as a problem rather than a valuable resource. Moreover, the importance of this work is emphasised by the immediate necessity to tackle the increasing difficulties posed by water contamination and resource depletion. Given the current state of rivers globally, which is characterised by an unparalleled degree of pollution, it is crucial to urgently devise efficient and scalable measures to protect these precious ecosystems (Suwarno et al., 2014; Vigiak et al., 2023; Wijaya et al., 2023). This study aims to provide practical solutions for reducing pollution and utilising dirty water as a resource for sustainable development by combining scientific investigation with effective interventions. The primary goals of this study are to understand how nitrogen and phosphorus concentrations change over space and time in the Tukad Badung River and to investigate new methods for extracting nutrients from the river water. This project seeks to provide a valuable contribution to the growing field of river conservation and sustainable water management, as well as promote the concepts of the circular economy worldwide (Díaz et al., 2024; Piash et al., 2021). This will be achieved by meticulous data collection, analysis, and experimentation.

MATERIALS AND METHODS

The methodology employed in this study encompasses a systematic approach to data collection, analysis, and experimentation aimed at elucidating nitrogen and phosphorus trends in the Tukad Badung River and exploring avenues for nutrient recovery from stream water. The research activities are structured into distinct phases, each designed to achieve specific objectives in a methodologically rigorous manner. Prior to commencing fieldwork and laboratory experiments, meticulous preparations were undertaken to ensure the smooth execution of the research activities. Additionally, a comprehensive inventory of equipment, materials, and personnel was conducted to facilitate seamless data collection and analysis throughout the research period.

Sampling Points

Sampling points were strategically chosen along an 18-kilometer stretch of the Tukad Badung River, segmented into upstream, midstream, and downstream zones (Fig.1). This zoning approach enables the capture of spatial variations in nutrient concentrations along the river's course. Specifically, six sampling points were designated, with two points situated in each zone, ensuring adequate coverage of the river's spatial dynamics. The selection of sampling points adhered to established guidelines outlined in Ministerial Regulation No. 01 of 2007, ensuring consistency and reliability in data collection.

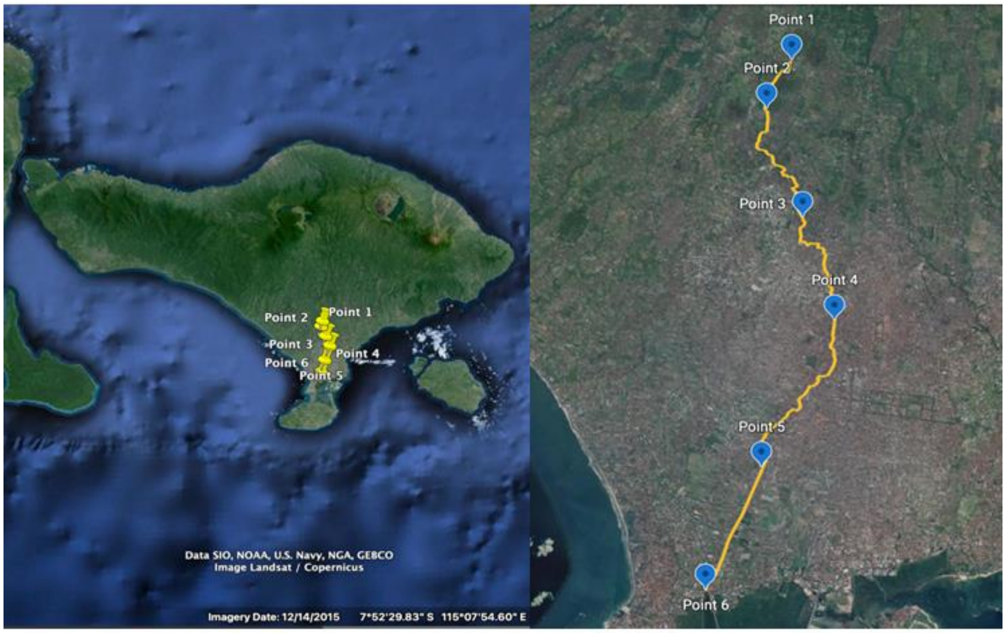

Figure 1. Sampling points in Tukad Badung River.

Sampling Collection

Sampling activities were conducted twice daily, at 08:00 am in the morning and at 07.00 pm in the evening, to capture diurnal variations in nutrient levels and peak domestic wastewater conditions. At each sampling point, water samples were collected using standardized techniques outlined in the SNI 6989.57-2009 standard for surface water sampling methods. A total volume of five litres of water was collected from each sampling point during each sampling event, ensuring an adequate sample size for subsequent laboratory analysis.

Laboratory Analysis

Upon collection, water samples were transported to the laboratory for comprehensive analysis of key water quality parameters, including total suspended solids (TSS), ammonia (NH_3^-), nitrite (NO_2^-), nitrate (NO_3^-), total nitrogen (Total N), total phosphorus (Total P). Spectrophotometric analyses were conducted using state-of-the-art equipment and methodologies, ensuring accuracy and precision in the measurement of nutrient concentrations.

Data Analysis

Data collected from both field sampling and laboratory experiments were subjected to rigorous statistical analysis to identify spatial and temporal trends in nitrogen and phosphorus concentrations along the Tukad Badung River. Additionally, graphical representations such as maps and trend charts were generated to visualize spatial and temporal variations in nutrient concentrations, aiding in the interpretation of research findings. The culmination of data analysis and experimentation enabled the interpretation of research findings and the formulation of evidence-based conclusions. The implications of the observed nutrient trends and the efficacy of nutrient recovery strategies were critically evaluated in the context of river conservation and sustainable water management. Insights derived from this study contribute to the body of knowledge surrounding nutrient dynamics in river ecosystems and provide valuable guidance for policymakers, environmental practitioners, and stakeholders involved in water resource management and conservation efforts.

An examination of nitrogen and phosphorus levels at six specific sampling locations along the Tukad Badung River yields useful information about the spatial and temporal changes in nutrient pollution within the river ecosystem. The morning sample session at 08:00 am and the evening sampling session at 07:00 pm exhibited clear patterns in nutrient levels, indicating fluctuations throughout the day and possible origins of pollution within the watershed. The following analysis provides a comprehensive examination of each metric, followed by a discussion of its impact on water quality and aquatic life.

RESULT AND DISCUSSION

Total Suspended Solids (TSS)

The TSS values exhibited considerable variability across different sampling stations and collection times, indicating geographical and temporal fluctuations in sediment loads and the dynamics of water quality. Geographically, the concentrations of TSS in Fig.2 showed significant variations among the sampling locations. Sample Points 3 and 4, located in the middle of the stream, consistently showed higher concentrations of Total Suspended Solids (TSS) compared to the upstream (Sample Points 1 and 2) and downstream (Sample Points 5 and 6) sites. The observed spatial arrangement indicates that sedimentation and erosion in the middle segment of the river are concentrated in specific areas, likely caused by human activities such as farming, building, and urbanisation (Baiyin et al., 2024; Silva-Gálvez et al., 2024; Yuan et al., 2023). Temporarily, the levels of TSS varied between the morning and evening sample sessions. Typically, the concentrations of total suspended solids (TSS) showed a tendency to rise during the night-time sample sessions. This could be attributed to the disturbance of sediment and the increased flow of water from the nearby land regions that occurred throughout the day (Noor et al., 2023; South & Nazir, 2016; Wang & Liu, 2023). The fact that sediment transport processes within the river ecosystem vary during the day emphasises the dynamic nature of these processes. It also emphasises the need to consider changes over time when assessing water quality.

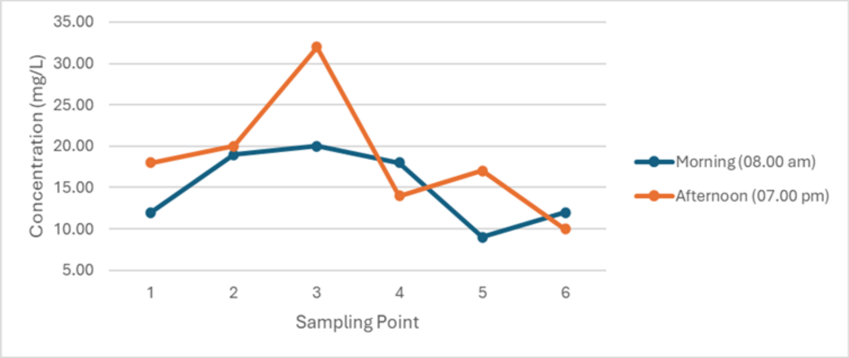

Figure 2. Total suspended solid (TSS) concentration trend.

Elevated TSS (total suspended solids) concentrations can have substantial consequences for the hydrodynamics of water streams and the biodiversity of aquatic ecosystems. Excessive sedimentation can hinder water clarity, leading to a decrease in the amount of light that can penetrate the water and lowering the ability of aquatic plants to carry out photosynthesis (Khonok et al., 2022; Soedjono et al., 2018; Suantara et al., 2020). Consequently, this can disturb the habitats at the bottom of the river and modify the natural equilibrium of the river ecosystem. In addition, water containing silt can suffocate aquatic environments, such as gravel beds and riffles, which are vital for fish reproduction and the habitat of macroinvertebrates. In addition, high levels of total suspended solids (TSS) can lead to greater turbidity, which decreases visibility for aquatic creatures and hinders predator-prey interactions (García-Avila et al., 2023; Rowland et al., 2021; Ural-Janssen et al., 2024). Suspended silt particles can obstruct the respiratory organs of fish, disrupt the feeding process of filter-feeding animals, and inhibit the growth of fish embryos and larvae. As a result, elevated levels of total suspended solids (TSS) can have a negative impact on the diversity of aquatic life, causing a decrease in populations and degradation of the environment over a period (Dory et al., 2024; Qiu et al., 2024; Sumantra et al., 2023).

Multiple reasons can lead to elevated levels of Total Suspended Solids (TSS) in river water, such as soil erosion originating from agricultural fields, construction sites, and deforested areas (Wiegers & Larsen, 2024; Zarei, 2020). Urban runoff, which includes particles from roads, rooftops, and paved surfaces, can increase the concentration of total suspended solids (TSS) in river systems. In addition, natural phenomena such as bank erosion, streambed scouring, and the suspension of sediment during periods of high flow can increase the amount of silt in rivers (Darji et al., 2022; Nugraha et al., 2020). Human activities, such as clearing land, mining, and inappropriate waste disposal, can worsen sedimentation problems by increasing the pace at which soil erodes and silt is carried into bodies of water. Insufficient soil conservation methods, such as inappropriate land management and deforestation, can exacerbate sedimentation issues, resulting in diminished water quality and the loss of habitats in river ecosystems (Kaown et al., 2023).

The examination of TSS concentrations in the Tukad Badung River emphasises the fluctuation in sediment loads across space and time and the possible consequences of elevated TSS levels on the quality of water and aquatic organisms. To tackle sedimentation problems, it is necessary to implement holistic approaches to managing watersheds. These approaches should incorporate steps to conserve soil, plan land use effectively, and implement erosion control procedures (Darji et al., 2022). By doing so, we may reduce the amount of sediment that is transported to water bodies and protect river ecosystems for future generations.

Ammonia

The levels of ammonia showed noticeable variations in both space and time, indicating the impact of specific locations and daily changes in the amount of pollution. Geographically, according to Fig 3, there were significant differences in ammonia concentrations among the sampling stations. Elevated concentrations of ammonia were regularly detected at the downstream sample points (Sample Points 5 and 6) in comparison to the upstream (Sample Points 1 and 2) and midstream (Sample Points 3 and 4) locations. The observed arrangement of locations indicates that there are specific sources of pollution, such as industrial waste or urban runoff, that are causing higher levels of ammonia in the lower parts of the river. Temporarily, the amounts of ammonia showed variations between the morning and evening test sessions. Typically, the levels of ammonia were greater during the evening sampling sessions at all sample locations. The diurnal pattern seen can be explained by the heightened biological activity and decomposition of organic matter during daylight hours, resulting in an enhanced generation of ammonia and its release into the water column (Conley et al., 2009; Ezzati et al., 2023). In addition, lower water flow rates and sluggish circumstances in the evening might lead to an increase in ammonia levels and a decrease in the ability to dilute it.

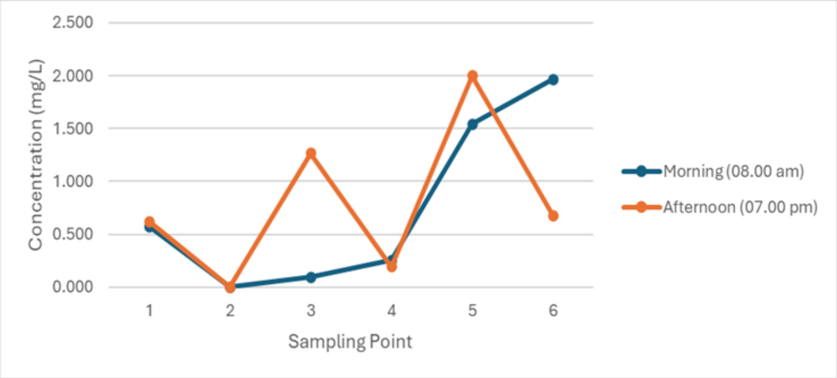

Figure 3. Ammonia concentration trend.

High levels of ammonia can be harmful to the quality of water and the organisms that live in it. High amounts of ammonia are highly hazardous to aquatic organisms, especially fish and invertebrates (Bartelme et al., 2017; Kim et al., 2010; Pejman Sereshkeh et al., 2024). It disrupts respiratory activities and can cause harm to the gills, hinder growth, and make the organism more susceptible to illnesses. In addition, the presence of high levels of ammonia can interfere with the normal functioning of physiological systems in aquatic animals, including osmoregulation and metabolic functions (Chen et al., 2024; Gu et al., 2024). This disruption can result in decreased rates of survival and reproductive success. In addition, elevated ammonia concentrations can modify the chemical composition of water, resulting in changes in pH levels and impacting the cycling of nutrients in aquatic environments. Ammonia poisoning can also have an indirect effect on other aquatic creatures by causing disturbances in food webs and community dynamics (Astals et al., 2018; Ha et al., 2023; Muscarella et al., 2021). Therefore, increased levels of ammonia can have substantial negative impacts on the diversity of aquatic life and the overall health of ecosystems, especially in vulnerable regions like spawning grounds and nursery areas. Multiple variables can contribute to elevated ammonia concentrations in river water. Industrial discharges, sewage effluents, and agricultural runoff are examples of point sources of pollution that can introduce high levels of ammonia into the water stream (Trap et al., 2024; Vystavna et al., 2023). Ammonia pollution issues can be worsened by inefficient wastewater treatment procedures and incorrect disposal of organic wastes, resulting in concentrated areas of contamination. In addition, natural processes such as the decomposition of organic waste and the cycling of nutrients in aquatic settings can contribute to the creation of ammonia (Patterson, 2003; Serra et al., 2023; Yates et al., 2022). An overabundance of organic materials, such as decomposing plants or animal excrement, can trigger the growth of microorganisms and the process of ammonification, resulting in a higher release of ammonia into the water. In addition, the presence of still water, decreased water movement, and insufficient amounts of dissolved oxygen can worsen the buildup of ammonia and hinder the natural processes that help reduce pollution, thereby aggravating the pollution problem even more (Ural-Janssen et al., 2024). It is necessary to implement comprehensive strategies that address both specific and diffuse causes of contamination. This includes improving wastewater treatment methods and promoting sustainable land use practices to reduce fertiliser inputs and protect river ecosystems for future generations.

Nitrite and Nitrate

The research uncovers clear regional and temporal patterns in the levels of nitrite and nitrate, which indicate specific localised influences and daily variations in nutrient loads. Geographically, the levels of nitrite and nitrate showed significant differences among the locations where samples were taken (Fig 4 and Fig 5). Elevated concentrations of nitrite and nitrate were regularly detected at the sampling points downstream (Sample Points 5 and 6) in comparison to the upstream (Sample Points 1 and 2) and midstream (Sample Points 3 and 4) regions. Specific pollution sources, such as agricultural runoff or industrial discharges, have an impact on the lower parts of the river, as indicated by the observed spatial gradient. This contributes to higher nutrient levels. Temporally, the levels of nitrite and nitrate exhibited variations between the morning and evening sampling sessions. In general, the amounts of both nitrite and nitrate were greater during the night-time sampling sessions at all sample stations. Human activities, such as farming or urban runoff, introduce additional nutrients into the water during daylight hours, explaining the observed daily fluctuation in nutrient levels. This results in an increased concentration of nutrients in the water column. In addition, lower water flow rates and stagnant circumstances in the evening can lead to the build-up of nutrients and a decrease in the ability to dilute them (Busico et al., 2024; Flynn et al., 2023).

High levels of nitrite and nitrate in water can have serious consequences for the water's quality and the organisms that live in it. Nitrite and nitrate are vital nutrients for plant development (Begam et al., 2024; Sorokin et al., 2012). However, when present in excessive amounts, they can lead to eutrophication, algal blooms, and oxygen depletion in aquatic habitats. Excessive nitrogen inputs can trigger the growth of algae, resulting in the production of thick mats of algae and the eventual depletion of oxygen due to microbial breakdown processes (van Wijk et al., 2024; Yu et al., 2014). In addition, elevated levels of nitrites can have a detrimental effect on aquatic creatures, including fish and invertebrates, by interfering with their ability to breathe properly and producing a condition called methemoglobinemia, which lowers the capacity of their blood to carry oxygen (Carneiro Marques et al., 2023; Ma et al., 2016; Silvestrini et al., 2024). Nitrate can have indirect effects on aquatic ecosystems by stimulating algal proliferation and modifying water chemistry, resulting in shifts in pH levels and nutrient cycle mechanisms. Moreover, increased concentrations of nitrates might pose hazards to human well-being by polluting supplies of potable water, especially in regions that depend on underground water reserves. Multiple factors can contribute to elevated levels of nitrite and nitrate in river water. Agricultural operations, such as the use of fertilisers and the rearing of livestock, can bring increased concentrations of nitrogen compounds into the water stream through surface runoff and leaching processes (Arcas-Pilz et al., 2023). Furthermore, the process of urbanisation and industrialization can lead to the contamination of nitrite and nitrate due to the release of nitrogen-rich pollutants in sewage effluents, industrial discharges, and stormwater runoff.

Atmospheric deposition and biological nitrogen fixing are natural processes that can also add nitrite and nitrate to aquatic habitats. Nevertheless, human activities have greatly increased nitrogen pollution problems, resulting in extensive deterioration of water quality and disturbances to ecosystems (Panjwani et al., 2021; Stein & Klotz, 2016; Zhou et al., 2024). The combination of ineffective nutrient management strategies, poor waste disposal, and insufficient wastewater treatment facilities worsens the problem of nitrite and nitrate pollution. This presents significant challenges for river protection and water resource management. Finally, the examination of nitrite and nitrate levels in the Tukad Badung River highlights the intricate nature of nitrogen pollution processes and their effects on water quality and ecosystems it supports. Well-coordinated approach is needed to address the sources of nutrients from both specific locations and diffuse sources (Lavallais & Dunn, 2023). This can be achieved by implementing effective nutrient management practices and promoting sustainable land use practices. By doing so, we can protect river ecosystems and ensure the availability of clean and healthy water resources for current and future generations.

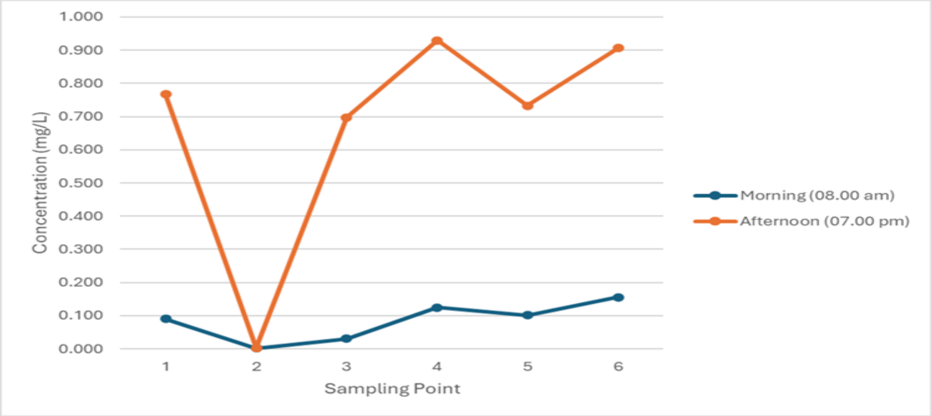

Figure 4. Nitrite concentration trend.

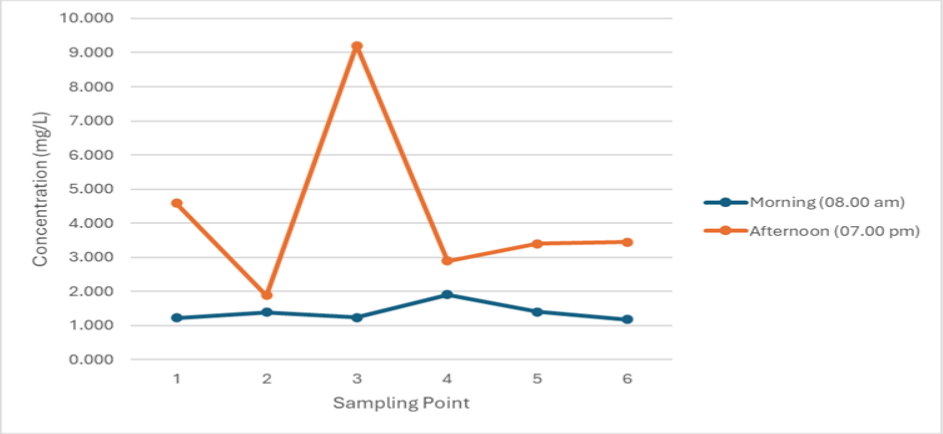

Figure 5. Nitrate concentration trend.

Total Phosphate

The research uncovers noticeable regional and temporal patterns in the levels of total phosphorus, which indicate the presence of localised impacts and daily variations in nutrient loads. Geographically, there was substantial variability in the levels of total phosphorus among the several locations where we took samples (Fig 6). Downstream sampling stations (Sample Stations 5 and 6) consistently exhibited elevated total phosphorus levels relative to upstream (Sample Points 1 and 2) and midstream (Sample Points 3 and 4) locations. Specific locations along the river, such as agricultural runoff or urban discharges, introduce pollution, as indicated by the observed spatial gradient. This pollution causes higher levels of nutrients in the downstream areas of the river.

Temporarily, the levels of total phosphorus exhibited variations between the morning and evening sample sessions. In general, the amounts of total phosphorus were greater during the evening sampling sessions at all sample stations. Human activities such as farming or urban runoff introduce additional nutrients into the water during daylight hours, explaining the observed daily fluctuation in nutrient levels. This results in an increased concentration of nutrients in the water column (Ezzati et al., 2023; Lu et al., 2024; Xu et al., 2018). In addition, lower water flow rates and sluggish circumstances in the evening can lead to the accumulation of nutrients and a decrease in the ability to dilute them.

High levels of total phosphorus can have a significant impact on the quality of water and the organisms that live in it (Conley et al., 2009; Smith & Myers, 2024). Excessive amounts of total phosphorus, an essential nutrient for the growth of algae, can cause eutrophication, algal blooms, and oxygen depletion in aquatic habitats. Elevated phosphorus concentrations can trigger the rapid growth of algae, leading to the development of thick mats of algae that block sunlight from reaching native plants and decrease the variety of species present (Correll, 1998; Suryawan et al., 2024; Zhang et al., 2023). Furthermore, the proliferation of algal blooms can result in a reduction in oxygen levels due to the breakdown of organic matter by microorganisms. This can create hypoxic conditions that are detrimental to aquatic animals (Hu et al., 2023).

In addition, elevated quantities of total phosphorus can disrupt the chemical composition of water, resulting in fluctuations in pH levels and the functioning of nutrient cycle systems. The acidification of water bodies can have detrimental effects on aquatic creatures, compromising their metabolic functions and reproductive success (Liu et al., 2024; Rey-Martínez et al., 2024b). Additionally, phosphorus pollution can have an indirect effect on human health by contaminating sources of drinking water, especially in regions that depend on surface water for their supply of safe drinking water (Panasiuk, 2012; Proskynitopoulou et al., 2024; Silva et al., 2023). Multiple variables can contribute to elevated levels of total phosphorus in river water. Agricultural practices, such as the application of fertilisers and the rearing of livestock, can lead to increased levels of phosphorus in water bodies due to surface runoff and leaching (Koulouri et al., 2024; Zhu et al., 2023). In addition, the process of urbanisation and industrialization can lead to the contamination of phosphorus due to the release of phosphorus-rich pollutants in sewage effluents, industrial discharges, and stormwater runoff.

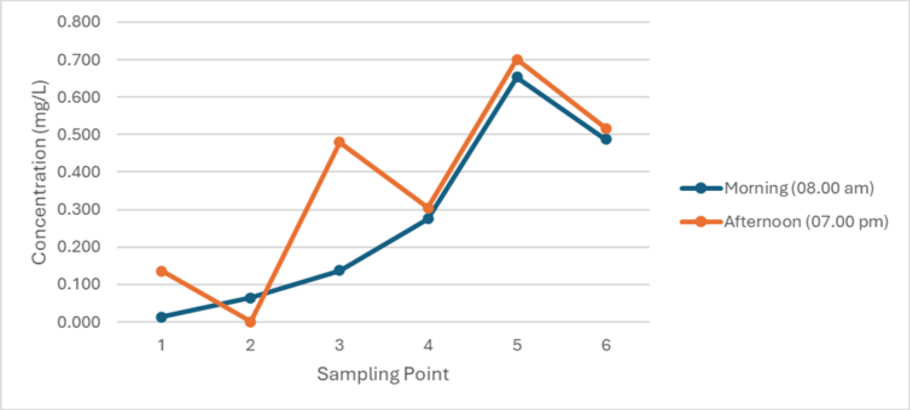

Figure 6. Total Phosphate concentration trend.

Natural processes, such as the weathering of phosphorus-containing rocks and the resuspension of silt, can also influence phosphorus inputs in aquatic ecosystems. Nevertheless, human activities have greatly increased the problem of phosphorus pollution, resulting in extensive deterioration of water quality and disturbances to ecosystems. Inefficient nutrient management practices, inappropriate waste disposal, and inadequate wastewater treatment facilities exacerbate phosphorus contamination difficulties (Galeano et al., 2023; Galligan & McClanahan, 2024; Ruijter et al., 2016). These factors provide considerable challenges for river conservation and water resource management. The examination of overall phosphorus levels in the Tukad Badung River highlights the intricate nature of nutrient contamination patterns and their effects on the quality of water and aquatic ecosystems. It is necessary to implement comprehensive management strategies that address both specific and diffuse sources of contamination. This includes improving nutrient management and promoting sustainable land use practices to protect river ecosystems and ensure the availability of clean and healthy water resources for current and future generations.

Potential of Nutrient Recovery from Streamwater

This study provides valuable insights that can support the initiative of nutrient recovery from stream water as part of a circular economy model for wastewater treatment. By analysing the spatial and temporal variations of nutrient pollutants along the Tukad Badung River, the study identifies opportunities for the sustainable management and utilisation of these nutrients to minimise environmental impact and promote resource efficiency. Firstly, the study highlights the significant concentrations of nutrients, including nitrogen and phosphorus, in the river water. These nutrients, if properly recovered, can serve as valuable resources for various applications, such as agricultural fertilisers, bioenergy production, and aquaculture feed (Hofmann et al., 2024; Winkler & Straka, 2019; Xiao et al., 2016). By implementing technologies for nutrient recovery, such as nutrient adsorption, precipitation, and biological processes, wastewater treatment facilities can extract these nutrients from stream water and convert them into valuable products, thereby closing the nutrient loop and reducing dependency on synthetic fertilizers and other external inputs (Lin et al., 2016; Marcińczyk et al., 2022; Rey-Martínez et al., 2024b; Sari et al., 2023; Xiao et al., 2016). Moreover, the study identifies the spatial distribution of nutrient hotspots along the river course, indicating potential locations for nutrient recovery facilities. By strategically locating nutrient recovery plants near areas with high nutrient concentrations, such as urban centres or industrial zones, wastewater treatment operators can optimise resource recovery and minimise transportation costs associated with nutrient extraction and distribution (Soedjono et al., 2017; Sumantra et al., 2022; Wijaya et al., 2017). Furthermore, the temporal variations in nutrient concentrations revealed by the study underscore the dynamic nature of nutrient pollution in river ecosystems. By implementing real-time monitoring systems and adaptive management strategies, wastewater treatment facilities can adjust nutrient recovery processes in response to fluctuations in nutrient loads, maximising resource recovery efficiency and minimising environmental impact. Overall, this study provides essential data and insights that can inform the development and implementation of nutrient recovery initiatives as part of a circular economy model for wastewater treatment (Antunes et al., 2022; Sauvé et al., 2021; Slootweg, 2020; Zvimba et al., 2021). These initiatives, which recover valuable nutrients from stream water and convert them into reusable products such as fertilizers or bioenergy, can contribute to resource conservation, environmental protection, and sustainable development in the Tukad Badung River watershed and beyond.

CONCLUSION

The findings of this study underscore the urgent need for effective management strategies to address nutrient pollution in the Tukad Badung River. Elevated levels of total suspended solids, ammonia, nitrite, nitrate, total phosphorus, and total nitrogen indicate significant degradation of water quality, posing threats to aquatic ecosystems and human health. Anthropogenic activities, including agriculture, urbanisation, and industrialization, are major contributors to nutrient pollution, exacerbating environmental degradation and ecosystem disruptions. To mitigate these challenges, comprehensive watershed management approaches are essential, incorporating measures to reduce nutrient inputs from point and non-point sources, improve wastewater treatment practices, and promote sustainable land use practices. Additionally, increased monitoring and enforcement of water quality regulations are necessary to ensure the protection and restoration of the Tukad Badung River ecosystem for present and future generations.

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