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DEGRADAÇÃO SOCIOAMBIENTAL DO RIO BACANGA: UMA REVISÃO BIBLIOGRÁFICA CRÍTICA SOBRE DESAFIOS E PERSPECTIVAS PARA A NAVEGABILIDADE E GESTÃO HÍDRICA

SOCIO-ENVIRONMENTAL DEGRADATION OF THE BACANGA RIVER: A CRITICAL LITERATURE REVIEW ON CHALLENGES AND PERSPECTIVES FOR NAVIGABILITY AND WATER MANAGEMENT

DEGRADACIÓN SOCIOAMBIENTAL DEL RÍO BACANGA: UNA REVISIÓN BIBLIOGRÁFICA CRÍTICA SOBRE DESAFÍOS Y PERSPECTIVAS PARA LA NAVEGABILIDAD Y GESTIÓN HÍDRICA

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Resumo

A navegabilidade de corpos hídricos urbanos está intrinsecamente relacionada à sua condição ambiental, ao uso antrópico das margens e à infraestrutura para circulação aquaviária. No contexto de São Luís (MA), o Rio Bacanga destaca-se por seu potencial histórico, ecológico e funcional para navegação, especialmente para pequenas embarcações e atividades ribeirinhas tradicionais, contudo, o cenário atual revela uma profunda degradação e assoreamento do rio. Dessa forma, o presente trabalho realizou uma revisão de literatura para analisar, por meio de revisão bibliográfica, como as pressões antrópicas, poluição ambiental e as falhas de governança hídrica contribuem para a degradação do Rio Bacanga e limitam sua navegabilidade nas dimensões física, operacional e ambiental/sanitária. Percebeu-se, que a reabilitação da navegabilidade requer uma perspectiva

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alinhada com as necessidades existentes, que contemple o saneamento básico, uma gestão ambiental eficiente e sustentável e o fomento ao desenvolvimento socioeconômico das comunidades ribeirinhas. Assim, busca-se assegurar a saúde da população e a preservação dos recursos hídricos, apesar das iniciativas de passeios turísticos que visam sua valorização.

Palavras-chave: Degradação socioambiental; Rio Bacanga, navegabilidade; gestão hídrica; Revisão Bibliográfica.

Abstract

The navigability of urban water bodies is intrinsically related to their environmental condition, the anthropic use of the banks and the infrastructure for aquaviary circulation. In the context of São Luís (MA), the Bacanga River stands out for its historical, ecological and functional potential for navigation, especially for small vessels and traditional riverine activities. However, the current scenario reveals a deep degradation and siltation of the river. Thus, the present work carried out a literature review to analyze, through a bibliographic review, how human pressures, environmental pollution and water governance failures contribute to the degradation of the Bacanga River and limit its navigability in physical dimensions, operational and environmental/sanitary. It was realized that the rehabilitation of navigability requires a perspective aligned with existing needs, which includes basic sanitation, efficient and sustainable environmental management and the promotion of socioeconomic development of riverine communities. Thus, it seeks to ensure the health of the population and the preservation of water resources, despite the initiatives of tourist tours that aim to enhance their value.

Keywords: socio-environmental degradation; Bacanga river; navigability; water management; literature review.

Resumen

La navegabilidad de los cuerpos de agua urbanos está directamente relacionada con su condición ambiental, el uso antropogénico de sus riberas y la presencia de infraestructura adecuada para la circulación fluvial. En la ciudad de São Luís, Maranhão, el río Bacanga se destaca como una de las principales vías fluviales con potencial histórico, ecológico y funcional para la navegación, especialmente para pequeñas embarcaciones y actividades ribereñas tradicionales. Sin embargo, en el contexto actual, el río experimenta una profunda degradación y sedimentación. De esta manera, el presente trabajo realizó una revisión de la literatura para analizar, por medio de una revisión bibliográfica, cómo las presiones antrópicas, la contaminación ambiental y las fallas en la gobernanza hídrica contribuyen a la degradación del río Bacanga y limitan su navegabilidad en las dimensiones física, operativa y ambiental/sanitaria. Se encontró que restaurar la navegabilidad del río Bacanga requiere una perspectiva alineada con las necesidades existentes, que abarca el desarrollo del saneamiento básico, la gestión ambiental eficiente y sostenible, y la promoción del desarrollo socioeconómico de las comunidades ribereñas. Esto garantiza la salud de la población y la preservación de los recursos hídricos, a pesar de las iniciativas turísticas que buscan mejorar su valor.

Palabras clave: Degradación Socioambiental; Río Bacanga; navegabilidade; Gestión Hídrica; revisión bibliográfica.

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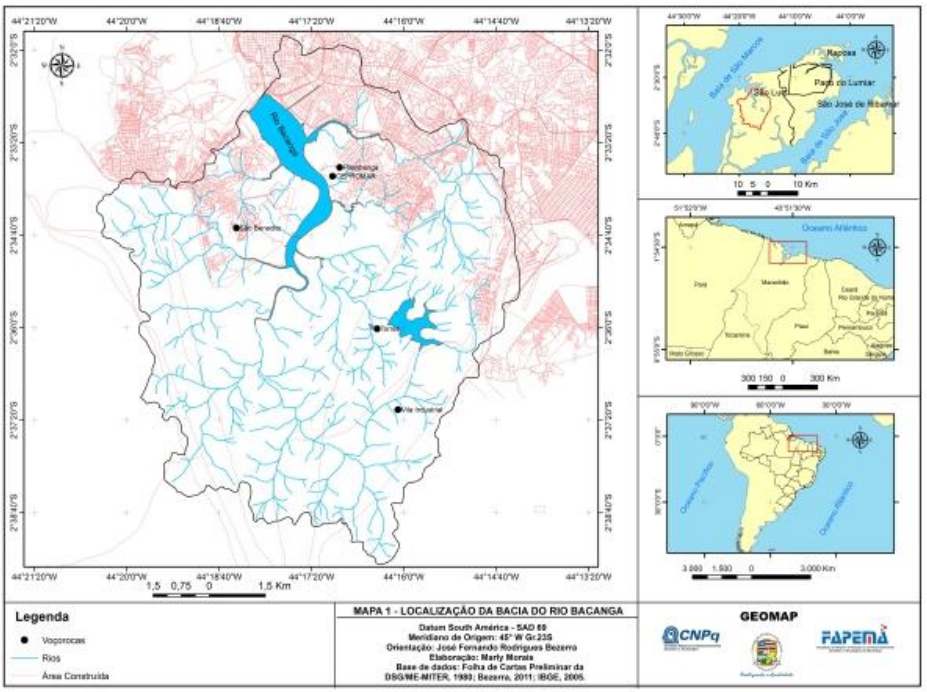
1. Introduction

The navigability of urban water bodies is a direct indicator of their environmental health, reflecting the anthropic use of their banks and the existence of infrastructure for aquaviary circulation. In the city of São Luís (MA), the Bacanga River has a remarkable historical, ecological and functional potential for navigation, especially by small vessels and for traditional riverine activities. However, this valuable watercourse faces significant degradation and silting processes that compromise its functionality and sustainability. The Bacanga River is the main watercourse of the homonymous basin, whose source is located in the neighborhood Anjo da Guarda (Map 1).

Map 1. Location of the Bacanga river basin.



Source: Morais, 2014.

With an extension of 23.84 km and a total area of 105.9 km 2, the basin includes important tributaries such as the rivers Maracanã, Bicas, Coelho, Mamão, Gapara and Sacavém (Soares *et al.,* 2021). Along its course, the river crosses the Bacanga State Park, which is a conservation unit of approximately

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3,075 hectares, and drains into São Marcos Bay, bathing several neighborhoods in the northwest area of São Luís, including Sá Viana, Jambeiro, Vila Embratel, Gapara, Areinha, Parque dos Nobres, Pindorama, Sacavém, Coroadinho and Vila dos Frades. Hydrological dynamics was profoundly altered by the construction of the Bacanga Dam between the 1960s and 1970s (Silva *et al.,* 2014).

Lacroix (2019) emphasizes the importance of the Bacanga State Park for the preservation of the springs and surrounding biodiversity, with remnants of coconut forest and its hydrogeological function. Nevertheless, the disorderly progress of urbanization, associated with the growing demand for housing and the occupation of permanent preservation areas (APP) has intensified environmental degradation, severely compromising the quality of water and, consequently, the navigability of the river.

Silva *et al.* (2024) deepen this problem, identifying the progressive degradation of plant cover and loss of water connectivity in the basin. The research warns that the discharge of domestic sewage without treatment and the silting of the river bed are limiting factors for the fluidity and stability of the watercourse. In view of this, such impacts make it difficult for small vessels to move around, especially in shallow areas and unstable banks, compromising not only navigability but also safety and public health of riverine populations.

Seaworthiness, in this study, is understood in three complementary dimensions and technical definitions of degree of seaworthiness: physical, evaluating depth, width, tide/flow regime, siltation, barriers and continuity of the canal, operational, in the sense of verifying the existence of routes, minimum infrastructure, use conflicts and traffic and environmental/sanitary safety, assessing the conditions of water quality that, although not physically preventing navigation, condition its social and occupational acceptability, according to PIANC WG 236 guidelines (CREECH *et al.,* 2023).

A planning process is developed, initially, as a structure for the improvement of navigability associated with a natural river system. This action begins with the development of an understanding of natural processes and human interventions around the river, as well as a management strategy at systemic scale within the

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context of the system's dynamic morphology (CREECH *et al*., 2023).

The historical relevance of the Bacanga River as a circulation and territorial reference route dates from the 19th century, according to documents such as the Almanak do Maranhão (1849) and A Revista, Folha Política e Literária (1843-1850), which already recorded it as a strategic geographical point, evidencing the importance of the river as a circulation route, reinforcing the role of the river in everyday life and its cultural relevance and urban planning of the city.

Despite its strategic function, the navigability of the Bacanga River was drastically reduced by the absence of effective public policies for sanitation, dredging and control of irregular occupations. Data from the National Water Agency (ANA) and the State Water Resources Plan of Maranhão confirm that, currently, the Bacanga is fundamental for water supply in neighborhoods in the northern area of São Luís, through the dam installed, but is limited in its multiple uses such as leisure, fishing, transport and navigation, due to accumulated degradation (Soares *et al.,* 2021).

As discussed by Rodriguez, Silva and Cavalcanti (2017), the geoecological approach allows to understand the Bacanga River as an integrated landscape unit, in which factors such as land use, public policies and urban dynamics shape its functionality, including navigability. In this sense, the navigability of Bacanga is an indicator of environmental health and quality of territorial management in São Luís. The restoration of this seaworthiness requires coordinated actions to recover the riparian forest, control the discharge of effluents, environmentally safe dredging and promotion of environmental education with the surrounding communities.

The historical, ecological and social relevance of the Bacanga River, combined with the need to subsidize public policies aimed at restoring its navigability and promoting urban sustainability, reinforces its importance as an object of study. Thus, given the above, this study aims to analyze, through a literature review, how human pressures, environmental pollution and water governance failures contribute to the degradation of the Bacanga River and limit its navigability in physical dimensions, operational and environmental/sanitary.

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2. Methodology

The present study is characterized as a review of critical literature, with a qualitative approach, whose objective was to analyze the scientific production about the socio-environmental degradation of the Bacanga River and its implications for seaworthiness, considering the physical dimensions, operational and environmental/sanitary.

The choice for this type of revision is justified by the need to integrate different theoretical and empirical approaches, allowing a broader understanding and interpretative of the degradation processes associated with urban rivers, especially in the context of anthropogenic pressures and the limitations of water governance. Although this is not a strict systematic review, structured methodological procedures were adopted, inspired by the guidelines of PRISMA and the assumptions of Gil (2010), Marconi and Lakatos (2017), aiming to ensure greater rigor, transparency and reproducibility in the conduct of research.

The data collection was carried out through searches in recognized academic and institutional databases, including Google Scholar, CAPES Journal Portal, Brazilian Digital Library of Theses and Dissertations (BDTD), institutional repositories of universities and government bases, as the Brazilian Institute of Geography and Statistics. We used descriptors in Portuguese language and, where applicable, their corresponding in English, combined by Boolean operators (AND, OR), applied in the title, summary and keyword fields.

The search strategy was structured from the combination of two groups of terms: (i) variations of the object of study - ("Bacanga River" OR "Estuary of the Bacanga River" OR "Bacanga River Basin") - and (ii) terms related to degradation, anthropic and management processes - ("environmental" OR "quality" OR "pollution" OR "sedimentation" OR "water management" OR "effluents" OR "social").

The strategy was adapted according to the specificities of each database, maintaining the logic of combination between descriptors. The searches included publications between the years 1970 and 2025, cut that is justified by coinciding

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with the period of intensification of the urbanization process in the Bacanga river basin and the consolidation of Brazilian environmental legislation after the Water Law (Law no. 9.433/1997), allowing to cover both recent studies and relevant productions for the historical contextualization of the object of analysis.

For the selection of studies, pre-established inclusion and exclusion criteria were defined. Scientific articles, dissertations, theses, final course papers that presented academic relevance and directly addressed the Bacanga River were included, especially regarding environmental degradation, water quality, land use and occupation, sanitation and water management. Included publications in Portuguese and English with access to the full text. On the other hand, duplicate studies, publications without access to the full text, papers with low thematic adherence and opinion materials without technical or scientific substantiation were excluded.

The process of selection of studies occurred in sequential stages. Initially, the identification of records in the selected databases was carried out, totaling 110 studies, with 96 coming from the consulted databases and 14 obtained through cross-references and gray literature - understood in this study as dissertations, academic papers and technical reports not indexed in the main databases. Duplicates were then removed, resulting in 92 records. Subsequently, the screening was carried out by reading titles and summaries, excluding 48 studies that did not meet the established criteria. Finally, the 44 remaining studies were submitted to full reading, with 12 excluded because they presented low thematic adherence or limited analytical contribution, resulting in a final sample of 32 studies, as illustrated in Figure 1.

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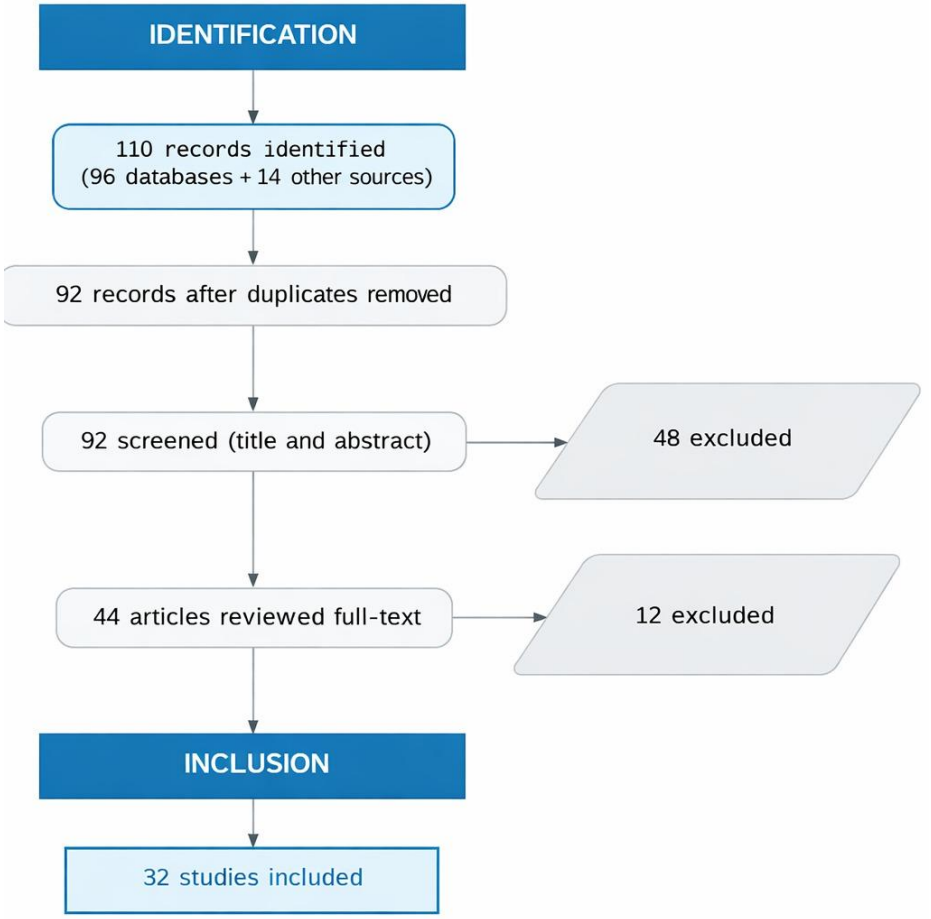
Figure 1. Study selection flow chart (PRISMA model).



Source: Prepared by the authors.

For the purposes of this study, "low thematic adherence" means the absence of a substantive relationship with socio-environmental degradation processes or with the navigability dimensions of the Bacanga River. Already, "limited analytical contribution" refers to the absence of interpretative deepening, the restriction to superficial descriptions or the inability to establish relationships between the analyzed processes and the central problematic of the research. Both criteria were defined prior to the full reading stage and applied consistently throughout the analysis, aiming to minimize selection bias.

The qualitative evaluation of the sources included was carried out based on criteria previously defined by the researcher, considering: *(i)* coherence between objectives, methodology and results; *(ii)* presence of empirical basis or consistent theoretical substantiation; *(iii)* timeliness and relevance of the data; and *(iv)*

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institutional provenance or peer-reviewed nature. In the case of gray literature, additional criteria for reliability were adopted, such as linking to recognized institutions, methodological clarity and consistency of data presented. It should be noted that these criteria constitute an evaluation instrument developed by the researcher himself, not corresponding to external validated checklists, which is recognized as one of the limitations of the study.

Data analysis was conducted through critical and comparative reading of the selected studies, guided by a priori defined analytical categories, corresponding to the three dimensions of seaworthiness adopted in the study: physical, operational and environmental/sanitary. These dimensions have been used as interpretive lenses since the reading stage of sources, guiding data extraction, organization and comparison - not just as a later descriptive structure. The critical dimension of the review was operationalized through systematic comparison between studies, identification of convergences and divergences, analysis of the consistency of findings and recognition of gaps in the literature. In cases of conflicting results between sources, greater reliability was attributed to studies with greater methodological rigor, more robust empirical basis and greater adherence to the local context of the Bacanga River. Additionally, we sought to identify recurring limitations in the analyzed studies, such as lack of updated data, fragmentation of approaches and gaps in the integration between environmental aspects and water governance.

Methodological limitations inherent to the study are acknowledged. The qualitative and interpretive character of the review implies greater subjectivity in the analysis of sources, especially since it was conducted without a protocol of agreement among independent reviewers. In addition, the absence of external validated quality assessment checklists may limit the comparability of the adopted criteria with other reviews of the area. However, these limitations were mitigated by the adoption of explicit and predefined criteria for selection and evaluation, by the use of multiple databases and by conducting a critical analysis structured in analytical categories a priori, contributing to the consistency and reliability of the findings presented.

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Finally, in order to systematize the main scientific productions used, Table 1 presents a summary of the selected studies, including their respective authors, publication types, and main contributions to the analysis of socio-environmental degradation and the navigability of the Bacanga River. The titles originally published in Portuguese have been retained.

Table 1. Works about the environmental problems of the Bacanga River present in the literature.

STUDIES	TITLES	REFERENCES
Book	1. São Luís do Maranhão, Corpo e Alma	Lacroix, 2020
Master's Thesis	1. Efeitos da emissão dos efluentes domésticos na proliferação de *Aeromonas sp.* em águas de superfície e pescado do estuário do rio Bacanga, São Luís/MA.	Martins, 2025.
	2. Avaliação da qualidade ambiental da bacia hidrográfica do Bacanga (São Luís – MA) com base em variáveis físico-químicas, biológicas e populacionais: subsídios para um manejo sustentável.	Martins, 2000.
	3. O índice de sustentabilidade ambiental do uso da água (ISA) como ferramenta de contribuição às políticas públicas de desenvolvimento e conservação na bacia do Rio Bacanga, São Luís/MA.	Nascimento, 2010.
	4. Qualidade socioambiental na bacia do Rio Bacanga: implicações sobre o turismo e saúde das comunidades locais	Costa, 2023.
	5. Distribuição do ictioplâncton na bacia do Rio Bacanga e sua relação com as alterações da paisagem: subsídios para a conservação da pesca na Amazônia Costeira.	Silva, 2025.
	6. Dinâmica espacial da paisagem na bacia hidrográfica do Rio Bacanga: Um estudo integrado sobre degradação ambiental, justiça socioambiental e estratégias de conservação.	Sousa, 2025.
Undergraduate Thesis	1. Circuito flúvio marítimo na Baía de São Marcos.	Cantanhede, 2011.
	2. Análise dos impactos sociais e ambientais no caso do rompimento da barragem do Bacanga.	Sousa, 2019.
	3. Requalificação do passeio eco histórico pelo rio Bacanga com visitação aos Sítios do físico e Piranhenga.	Guia; Almeida; Santos, 2023.
	4. Variação sazonal sobre a comunidade de larvas de peixes no estuário do rio Bacanga, Maranhão, Brasil.	Silva, 2025.

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STUDIES	TITLES	REFERENCES
Journal Articles	1. Comportamento hidrodinâmico e sedimentológico do estuário do Rio Bacanga (São Luís, Estado do Maranhão).	Pitombeira e Morais, 1977.
	2. Análise dos indicadores bacterianos de poluição dos rios Anil e Bacanga, na ilha de São Luís, Estado do Maranhão, Brasil.	Lee Liao *et al.*, 1984.
	3. Aspectos da disponibilidade e dos usos da água na bacia do rio Bacanga/ ilha do Maranhão (i. de São Luís) - MA.	Coelho e Damázio, 2006.
	4. Mapa Geológico – Geotécnico da bacia do Rio Bacanga – São Luís (MA).	Pereira e Zaine, 2007.
	5. Complexação de íons de metais por matéria orgânica dissolvida: modelagem e aplicação em sistemas reais.	Bezerra; Takiyama; Bezerra, 2009.
	6. Quantificação e identificação de *aeromonas* spp. em águas de superfície do estuário do rio Bacanga em São Luís / MA (Brasil)	Martins *et al.*, 2009.
	7. Aspectos epidemiológicos e prevalência de enteroparasitoses em crianças do bairro Jambeiro.	Silva *et al.*, 2011
	8. Comunidade ictioplanctônica da bacia hidrográfica do rio Bacanga na cidade de São Luís, Maranhão, Brasil.	Soares, Cutrim e Silveira, 2014.
	9. Diversidade de larvas de peixes da bacia hidrográfica do rio Bacanga (Maranhão – Brasil).	Soares, Cutrim e Silveira, 2014.
	10. Análise morfológica das áreas degradadas por voçorocamento na bacia do rio Bacanga – São Luís/MA.	Lisboa, *et al.,* 2014.
	11. Mapeamento da fragilidade ambiental na bacia do rio Bacanga, Município de São Luís – MA.	Morais, *et al.*, 2014.
	12. Avaliação integrada da qualidade de águas superficiais: grau de trofia e proteção da vida aquática nos rios Anil e Bacanga, São Luís (MA)	Silva, *et al.,* 2014.
	13. Mudanças do uso e ocupação do solo e degradação eco ambiental usando imagens orbitais: o estudo de caso da bacia do rio Bacanga, São Luís (MA).	Serra; Silva, Silva, 2016.
	14. Aquatic life protection index of an urban river Bacanga basin in northern Brazil, São Luís – MA.	Duarte dos Santos, *et al.*, 2017.
	15. Análise espacial das formas de ocupação da bacia hidrográfica do rio Bacanga.	Pereira, *et al.*, 2018.
	16. Análise integrada e problemas socioambientais da Bacia Hidrográfica do Bacanga, São Luís – MA.	Soares *et al.*, 2021.

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Pages: 1-31

STUDIES	TITLES	REFERENCES
	17. Análise das propriedades física do solo dos processos erosivos acelerados na bacia do rio Bacanga: o caso das voçorocas torres e cepromar.	Lisboa e Bezerra, 2023.
	18. Riscos ambientais das ocupações irregulares nas planícies alagáveis da Bacia Hidrográfica do Bacanga, Ilha de São Luís, Maranhão.	Castro *et al.,* 2024.
	19. Planejamento urbano e gestão de risco de inundação na bacia hidrográfica do rio Bacanga – São Luís, MA.	Pereira, 2024.
	20. Riscos ambientais das ocupações irregulares nas planícies alagáveis da bacia hidrográfica do Bacanga, Ilha de São Luís, Maranhão.	Castro, *et al.*, 2024.
	21. Padrões sazonais e espaciais do ictioplâncton no estuário do rio Bacanga, Brasil: controles ambientais e desafios de conservação.	Silva, Azevedo e Silveira, 2025.

Source: Prepared by the authors.

3. Results and Discussion

Figure 2 presents a panoramic aerial view of the Bacanga River, allowing us to understand its extent and the direct relationship with neighborhoods in the northwest area, reinforcing its geographical and territorial relevance.

Figure 2. Panoramic aerial view of the Bacanga River, highlighting its integration with the urban and natural environment of São Luís.

Source: Prepared by the authors.

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The navigability of the Bacanga River, when observed by the physical, operational and environmental/sanitary dimensions, reveals a framework of progressive and multifactorial degradation. From a physical point of view, there is a consensus in the literature about the impacts of dam construction in the 1960s, which altered the hydrodynamics of the estuary, causing siltation and loss of vegetation. Studies, such as that of Castro *et al.* (2024), confirm that the water volume has decreased over the decades (between 1960 and 2020), showing that the intervention, although favoring the population fixation in nearby areas, compromised the depth and connectivity of the river, restricting its navigability. However, some authors highlight the dam as a solution for tide control, while others point to it as responsible for the loss of navigability.

The analysis of the literature, which included a book, six dissertations, four TCCs and twenty-one scientific articles, highlights a complex and progressive scenario of environmental degradation in the Bacanga River Basin, driven mainly by anthropogenic pressures. The degradation of the Bacanga River is a complex and multifaceted phenomenon, driven in large part by the disorderly occupation of lowland areas and riverbanks without proper planning (Soares *et al.,* 2021; Castro *et al.,* 2024). This uncontrolled urban expansion is visibly marked by intense erosive processes, the drastic reduction of native vegetation and a noticeable decrease in water supply quality.

Morais *et al*. (2014) shows that the acceleration of morphogenetic processes in the basin area under study is related to urban and industrial expansion, without planning and with speculative character, because the small altimetric amplitude and low declivity of geomorphological units do not offer limitations for land use and occupation, causing the emergence of several environmental problems, among them, the emergence and evolution of accelerated erosive processes. Additionally, one of the main factors that aggravate this scenario is the deficit in sewage treatment, with waste being continuously dumped in nature in the Bacanga Basin (Soares *et al*., 2021).

The anthropogenic pressure on the Bacanga River is not limited to the lack of sanitation and the irregular occupation of the banks. The problem of solid waste

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Pages: 1-31

also stands out as an aggravating factor of socio-environmental degradation. Pereira (2024) points out that the absence of effective waste management policies and the precariousness of regular collection favor inadequate disposal on the banks of the river, compromising not only water quality but also social and cultural use of the space. These impacts reinforce the need to integrate basic sanitation and environmental education actions to strategies for restoration of navigability and preservation of the river basin. Figure 3 shows the banks of the Bacanga River, with accumulation of waste and signs of pollution, illustrating the impacts of lack of adequate sanitation.

Figure 3. Banks of the Bacanga River with accumulation of waste and signs of pollution, illustrating the impacts of lack of adequate sanitation.

Source: Prepared by the authors.

The various anthropic actions, added to the inefficiency of the sanitation service in the city of São Luís - MA, contribute to the Bacanga River experiencing a progressive socio-environmental degradation, with direct repercussions on the quality of life of the riverine communities and the health of the ecosystem.

With regard to the operational and water management dimension, the analyzed studies converge in identifying structural deficiencies in the sewage system and solid waste collection. According to Anjos Neto (2006), the sewage system of the Bacanga Basin exhibited a critical flow failure. Although the five existing Raw Sewage Pumping Stations (SPSs)—Parque Timbiras, Areinha, Beco da Prensa, Estrela, and Portinho—were intended to convey wastewater to the

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Pages: 1-31

region's only treatment facility, the Bacanga Wastewater Treatment Plant (WWTP), in practice, most raw sewage was discharged directly into water bodies before reaching the treatment unit. Figure 4A shows an aerial view of the Bacanga Wastewater Treatment Plant (WWTP), while Figure 4B shows a Sewage Pumping Station (SPS) located on Avenida dos Africanos.

Figure 4. (A) Aerial view of the Bacanga Wastewater Treatment Plant (WWTP); (B) Sewage Pumping Station (SPS) located on Avenida dos Africanos, both components of the Bacanga Basin wastewater system.

Source: Prepared by the authors.

This scenario contributes to the contamination of water resources by domestic sewage and other pollutants, including pathogenic organisms, organic substances, heavy metals and trace elements, thus possessing, direct or indirect effects on ecosystems and aquatic organisms, in addition to spreading diseases through contaminated water and food (Torres, 2004).

In 2015, within the framework of the PAC Sanitation, the State Government announced the intensification of works to eliminate direct discharges on the rivers Anil and Bacanga. The central plan for the region involved the deployment of three new EEs and an interceptor on Avenida dos Africanos, which borders the river. The goal was to intercept the right bank sewer and transport it to ETE Bacanga, with the expectation of increasing the city's sewage treatment rate (CAEMA, 2015). Figure 5 shows a canal located near an EEE in the implementation phase, on Avenida dos Africanos, highlighting the precariousness of the infrastructure and the visible impacts of liquid and solid waste discharge into the urban environment.

REMUNOM
ISSN 2178-6925

Received: 13/01/2026 - **Accepted:** 10/04/2026
Vol: 13.06
DOI: 10.66104/h3refn96
Pages: 1-31

Figure 5. Drainage channel located near a Sewage Pumping Station (SPS) under construction on Avenida dos Africanos, highlighting inadequate infrastructure and visible impacts of liquid and solid waste discharge.

Source: Prepared by the authors.

Despite strategic planning, the current reality indicates that these works, initiated nearly a decade ago, have not yet been fully completed or are not operating at full capacity. The delay in the completion of pumping stations and interceptors along Avenida dos Africanos perpetuates the socio-environmental degradation described by Freitas *et al*. (2010), maintaining issues such as unpleasant odors, water pollution, and inadequate waste disposal.

The pollution observed along the banks of the Bacanga River, characterized by the accumulation of solid waste and turbid water, reflects persistent sanitation deficiencies and irregular land occupation. Studies have reported elevated levels of coliforms and electrical conductivity exceeding legal limits (Silva *et al.,* 2011; Bezerra *et al.,* 2009), reinforcing the urgency of environmental restoration measures and stricter effluent control. Figure 6 illustrates a critical section of the river, where improper waste disposal compromises water quality and exacerbates environmental degradation processes.

REMUNOM
ISSN 2178-6925

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Vol: 13.06
DOI: 10.66104/h3refn96
Pages: 1-31

Figure 6. Banks of the Bacanga River showing the accumulation of solid waste and visible signs of pollution.

Source: Prepared by the authors.

Silva *et al.* (2011) identified high levels of total and thermotolerant coliforms (most probable number per 100 mL) in supply wells, a pond, tap water, and at the source of the Bacanga River in a riverine community in the Jambeiro neighborhood. Although, at the time of the study, only one sampling point met the acceptable standards (<3 MPN/100 mL), current regulations established by Ordinance No. 888/2021 consider all points unfit for consumption, as the complete absence of coliforms in 100 mL of the sample is required.

Regarding physicochemical characteristics, Bezerra et al. (2009) reported that the conductivity of the Bacanga River reached 2800 µS/cm, indicating a high degree of pollution from domestic and industrial sewage. According to Brazilian legislation (Brazil, 2006), natural waters with conductivity above 1000 µS/cm are considered contaminated. Nevertheless, the pH recorded in the same study (8.64) was within the permitted range (6–9) for water bodies (Brazil, 2005).

In addition, the river exhibited a high concentration of dissolved organic carbon (24.09 mg/L), which the authors attributed to the proximity of residential areas and the decomposition of organic waste. The presence of pathogenic parasites, such as *Ascaris lumbricoides, Entamoeba histolytica*, and *Giardia lamblia*, was also identified. Furthermore, the presence of microbiota in the basin's watercourses had already been reported by SEMATUR in 1991 (SEMATUR, 1991, apud Martins, 2000).

REMUNOM
ISSN 2178-6925

Received: 13/01/2026 - **Accepted:** 10/04/2026
Vol: 13.06
DOI: 10.66104/h3refn96
Pages: 1-31

Evidence of this issue was highlighted by Martins (2005), who reported that the Bacanga River estuary is contaminated with *Aeromonas*, as it functions as a receiving basin for urban sewage. In this study, the Most Probable Number (MPN/100 mL) and standard plate count (CFU/mL) using Glutamate Starch Phenol-red (GSP) agar were determined for *Aeromonas* in 90 surface water samples collected from the estuary of the Bacanga River between March and October 2004.

The results indicated that the highest *Aeromonas* counts occurred in April, with values ranging from 9.8×10^4 CFU/mL to 3.0×10^7 CFU/mL and an MPN of 1.6×10^7/100 mL. This scenario poses a significant risk to the health of fishermen working in these waters, as well as to consumers of fish caught in the area and marketed in the city of São Luís.

Figure 7 illustrates small vessels in the estuary used for community activities, highlighting the historical, cultural, touristic, and recreational potential of the river.

Figure 7. Vessels in the Bacanga River.

Source: Prepared by the authors.

Fishing activities in the Bacanga River represent not only an economic practice but also a cultural and subsistence activity for riverine communities. Despite contamination by sewage and pathogenic organisms, such as *Aeromonas spp.,* due to its role as a receiving basin for urban sewage, fishing remains a source of income and food, highlighting the socio-environmental vulnerability of these populations (Martins, 2005). Figure 8 illustrates artisanal fishermen in action,

REMUNOM
ISSN 2178-6925

Received: 13/01/2026 - **Accepted:** 10/04/2026
Vol: 13.06
DOI: 10.66104/h3refn96
Pages: 1-31

highlighting the socioeconomic importance of the river and the risks faced by those who directly depend on its resources.

Figure 8. Artisanal fishermen in activity on the Bacanga River

Source: Prepared by the authors.

In the environmental and health dimension, the literature converges to demonstrate high levels of water pollution. These data support the association between environmental degradation and direct health risks of riverine communities, which continue to depend on artisanal fishing and local water consumption.

The construction of the Bacanga Dam in the 1960s is a relevant point in the history of degradation. In fact, the dam has drastically altered the hydrological dynamics of the estuary, restricting the natural flow of tides and provoking silting, loss of vegetation and changes in water quality (Castro *et al.*, 2024). This intervention, carried out without well-documented technical criteria, opened space for urban and industrial expansion in São Luís, as highlighted by Lacroix (2020).

Figure 9 illustrates this human intervention, highlighting the dam structure and its impacts on navigability and water quality.

Between 1960 and 2020, Castro *et al.* (2024) documented a decrease in the river's water volume from 5.29 km^2 to 4.48 km^2, an effect directly related to the dam and increasing urbanization. Despite the environmental problems that the dam created, some authors suggest that it facilitated the establishment of residents by controlling tidal movement (Sousa, 2019).

REMUNOM
ISSN 2178-6925

Received: 13/01/2026 - **Accepted:** 10/04/2026
Vol: 13.06
DOI: 10.66104/h3refn96
Pages: 1-31

Figure 9. Bacanga River dam illustrating its structural features.

Source: Prepared by the authors.

The navigability of the river, once an essential means of transport for the riverine population, does not have the same expressiveness today, mainly due to dependence on the road system. However, there are efforts to value the natural resource, history and local culture. Guia, Almeida and Santos (2023) highlight the "Historical Eco Tours via Bacanga River" through social networks, which consist of canoe trips from the Cultural Port of the neighborhood of Sá Viana to the Piranhenga and Físico sites. On the other hand, Cantanhede (2011) observed at

REMUNOM
ISSN 2178-6925

Received: 13/01/2026 - **Accepted:** 10/04/2026
Vol: 13.06
DOI: 10.66104/h3refn96
Pages: 1-31

the mouth of the river that most of the trips are made by owners of boats anchored in Ponta d'Areia. In addition to the historical eco tours already mentioned, there are records of canoeing activities and small boats used for leisure and cultural tourism.

In Figure 10, canoes intended for leisure activities can be seen, which highlights the tourist and recreational potential of the river.

Figure 10. Vessels along the banks of the Bacanga River.

Source: Prepared by the authors.

Recreational areas near the Bacanga River, such as community squares, including “Praça dos Gatos,” located on Avenida dos Africanos, play an important role in the social and cultural life of the local population, as they are used for walking, community gatherings, and leisure activities. These practices reinforce the population’s connection to the river and highlight its potential for community-based tourism.

Such spaces and their multiple uses underscore the importance of the river not only as a water resource but also as an element of territorial identity and urban coexistence (Guia, Almeida, and Santos, 2023). Figure 11 illustrates one of these squares, highlighting its function as a space for leisure and community integration.

REMUNOM
ISSN 2178-6925

Received: 13/01/2026 - **Accepted:** 10/04/2026
Vol: 13.06
DOI: 10.66104/h3refn96
Pages: 1-31

Figure 11. "Praça dos Gatos", used for community recreation.

Source: Prepared by the authors.

To illustrate the evolution of the problems, a timeline of environmental degradation of the Bacanga River can be traced from the articles cited in Table 1.

- **1960s:** The construction of the Bacanga Dam modified the hydrodynamics of the estuary, resulting in silting, loss of vegetation and changes in water quality.
- **1970-2000:** There was an expansion of unplanned urbanization and intense anthropogenic pressures. Population growth and irregular occupation of riverbanks aggravated sanitation problems, erosion, and vegetation loss, contributing to the reduction of green areas and increasing flood risks.
- **2006-2010:** Studies already indicated a reduction in water availability in the basin, which supplies 18% of São Luís' water, due to urbanization and industrialization, with warnings of potential supply collapse in the absence of sustainable management (Coelho and Damázio, 2006; Nascimento, 2010).
- **2014:** The deterioration in water quality intensified, with significant pollution from domestic sewage, severe eutrophication, and low protection for aquatic life, according to Silva *et al.* (2014).
- **2018–Present:** Urban occupation has advanced into spring areas, causing significant impacts on riparian vegetation and ecosystems. The dam has been confirmed as a permanent modifier of the estuary's hydrodynamics (Pereira *et al.,* 2018; Castro *et al.,* 2024). Recent studies (Lisbon and

REMUNOM
ISSN 2178-6925

Received: 13/01/2026 - **Accepted:** 10/04/2026
Vol: 13.06
DOI: 10.66104/h3refn96
Pages: 1-31

Bezerra, 2023) also highlight erosion processes, emphasizing soil vulnerability and the risk of landslides for local communities.

Studies such as that of Liao *et al.* (1984), although presenting methodological limitations typical of the time, provided important early diagnoses of bacteriological pollution. These studies revealed higher pollution levels in the headwaters and during the rainy season, associating inadequate sanitation with public health risks. Martins *et al.* (2009) evaluated the occurrence of *Aeromonas spp.,* correlating it with environmental conditions and the presence of domestic sewage, thereby highlighting the vulnerability of riverine populations.

The study by Soares, Cutrim, and Silveira (2014) on ichthyoplankton in the Bacanga River emphasizes its role as a natural nursery for marine species (especially Engraulidae). However, both studies report low larval diversity, influenced by seasonality and salinity. In addition, pollution from domestic effluents and unplanned urbanization are critical factors compromising ecosystem sustainability.

In summary, the studies by Morais *et al.* (2014), Silva *et al*. (2014), and Santos *et al.* (2017) corroborate these findings by highlighting the high environmental fragility and low water quality in the Bacanga basin, resulting from unplanned urbanization, sewage pollution, and inadequate land use. Therefore, the degradation of the estuary, which, even if it is a natural nursery, suffers impacts of pollution, exotic species and loss of vegetation, which directly threatens the aquatic biodiversity and communities dependent on fishing.

The navigability of the Bacanga River, to be understood consistently, needs to be translated into technical indicators that directly relate environmental degradation factors to loss of river transport capacity. The literature converges by pointing out that silting, water pollution and dam are central elements in reducing navigability, but diverges regarding intensity and assigned responsibilities. For example, while some studies emphasize the dam as a solution to tide control and urban stabilization, others consider it the main factor of loss of connectivity with the estuary and reduction of depth. Table 2 presents an analytical matrix that articulates

REMUNOM
ISSN 2178-6925

Received: 13/01/2026 - **Accepted:** 10/04/2026
Vol: 13.06
DOI: 10.66104/h3refn96
Pages: 1-31

the physical, operational and environmental dimensions.

Table 2. Analytical Matrix

FACTOR	TECHNICAL INDICATOR	IMPACT ON NAVIGABILITY	EMPIRICAL EVIDENCE
Siltation	Average depth; sediment load	Reduction of the navigable channel	Castro *et al.* (2024); Morais *et al.* (2014).
Water pollution	Electrical conductivity; coliforms; pathogens	Health risk and impairment of tourist transport	Bezerra *et al.* (2009); Silva *et al.* (2011); Martins (2005).
Dam	Controlled flow; water level variation	Alteration of hydrodynamics; loss of connectivity	Castro *et al.* (2024); Sousa (2019).
Irregular occupation	Floodplain occupation; vegetation suppression	Intensification of erosion and landslides	Soares *et al.* (2021); Lisboa & Bezerra (2023).
Water management	WWTP capacity; waste collection coverage	Persistence of pollution; low reliability	Anjos Neto (2006); CAEMA (2015).

Source: Author's own elaboration, 2026.

The absence of studies that systematise these indicators in an integrated way constitutes a significant methodological gap. International experiences, such as the revitalization of the Seine River, demonstrate that urban navigability is sustained when there is continuous monitoring of technical parameters and integration with sanitation, leisure and transport policies (E+ELeader, 2025).

4. Final Considerations

This literature review analyzed the complex socio-environmental context of the Bacanga River in São Luís, Maranhão, emphasizing its navigability and the impacts of unplanned urban occupation. The studies reviewed reveal a concerning scenario, characterized by irregular land use along riverbanks, lack of basic sanitation, and inadequate solid waste management. The continuous discharge of untreated sewage, combined with the disposal of domestic waste and debris in wetland areas, leads to severe water contamination. This is evidenced by high concentrations of fecal coliforms, the presence of parasites, and the accumulation of chemical pollutants, ultimately compromising public health and environmental

REMUNOM
ISSN 2178-6925

Received: 13/01/2026 - **Accepted:** 10/04/2026
Vol: 13.06
DOI: 10.66104/h3refn96
Pages: 1-31

quality.

Furthermore, the construction of the dam, although it facilitated human settlement and tidal control, has had negative consequences for water quality and river navigability, intensifying the silting process and permanently altering the hydrodynamics of the estuary. The literature indicates a significant reduction in natural vegetation and an increased risk of flooding between 1960 and 2020, with the dam representing a key driver of ecosystem degradation and transformation. This process has also affected aquatic biodiversity, leading to reduced ichthyoplankton diversity and threatening species that rely on the estuary as a natural nursery.

In summary, the navigability of the Bacanga River cannot be understood only as a matter of transport, but as a result of the interaction between physical processes, operational failures and environmental risks. For the rehabilitation of the navigability of the Bacanga River and the recovery of its environmental health, a multifactorial approach is necessary, which should include, as a priority, the implementation of comprehensive basic sanitation, efficient environmental management of solid waste, the control of irregular occupation and the recovery of riparian vegetation. In addition, it is necessary to foster the socioeconomic development of riverine communities by integrating environmental education and cultural appreciation into public policies.

Such measures are relevant to ensure the population’s health and the preservation of water resources, even in the face of leisure and tourism initiatives, such as sightseeing tours and recreational activities in squares, which, although important for cultural and social enhancement, do not replace the urgency of structural interventions and robust water management policies. Thus, operationalizing the navigability of the Bacanga requires not only to recognize the degradation factors but to measure, monitor and injure in a systematic way.

REMUNOM
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