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*Nota técnica*

# How have bridges and culverts changed rivers? A scientometric investigation

## *Como pontes e bueiros podem mudar os rios? Uma investigação cienciométrica*

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**Abstract:** Bridges and culverts play a crucial role as connectors between river banks. However, these crossing structures alter sediment transport, flow regime, and river morphology. In this study, the aim was the scientometric analyses of studies on the morphological changes in fluvial landscapes caused by bridges and culverts with an analysis of the quantity and global distribution of scientific production. These analyses demonstrate that there is a geographical gap in characterising and quantifying geomorphological alterations. It is necessary to focus the need for additional research in diverse regions worldwide that quantify and characterises geomorphological changes according to the type of structures and their spatial distribution in the river, i.e., understanding how alterations occur upstream and downstream of the structures. Furthermore, it emphasises the importance of interdisciplinary collaboration between fluvial geomorphology and river engineering, which can enhance the development of new structural projects.

**Keywords:** Crossing structures; Fluvial geomorphology; Channel change; Fluvial engineering.

**Resumo:** Pontes e bueiros desempenham um papel crucial como conectores entre as margens dos rios. No entanto, essas estruturas de travessias alteram o transporte de sedimentos, o regime de fluxo e a morfologia do rio. Neste estudo, o objetivo foi realizar uma análise cienciométrica sobre as mudanças morfológicas em paisagens fluviais causadas por pontes e bueiros, como também a análise da quantidade e distribuição global da produção científica. Os resultados indicaram uma lacuna geográfica na caracterização e quantificação das alterações geomorfológicas, evidenciando a necessidade de pesquisas que quantifiquem e caracterizem as mudanças geomorfológicas de acordo com o tipo de estruturas e sua distribuição espacial no rio, ou seja, entender como as alterações ocorrem a montante e a jusante das estruturas. Além disso, o estudo enfatiza a importância da colaboração interdisciplinar entre geomorfologia fluvial e engenharia fluvial, o que pode aprimorar o desenvolvimento de novos projetos de estruturas.

**Palavras-chave:** Estruturas de travessia; Geomorfologia fluvial; Mudança no canal; Engenharia fluvial.

## 1. Introduction

The alterations in fluvial morphology are related to deposition and erosion processes, which vary according to multiple factors. In the context of fluvial geomorphology, rivers are understood as dynamic systems that respond to various environmental and anthropogenic factors present in the watershed (WOHL, 2014). These factors include, for instance, climate, agriculture, and urbanisation (MORAIS; MONTANHER, 2022). Beyond, anthropogenic structures such as river-crossing structures, including bridges and culverts, partially disconnect sediment transport in the channel, primarily affecting longitudinal connectivity and altering channel adjustments (FITZPATRICK; NEESON, 2018).

River-crossing structures, including bridges and culverts, are essential for ensuring road continuity over rivers and playing a crucial role in regional mobility (EL DEBS, 2021). Aside from structural differences between bridges and culverts, the design and studies required for construction vary according to the type and scale of the structure. Bridges require complex studies that consider engineering requirements, design objectives, site conditions, and the materials used for their construction (PFEIL, 1979). Culverts, on the other hand, can be classified into box culverts (rectangular-shaped) and pipe culverts (cylindrical-shaped) (ROCHA, 2022), and they are integral to the roadway drainage system. These structures can be either permanent or temporary (EL DEBS, 2021).

Despite their vital role in societal development, river-crossing structures often lead to significant changes in the fluvial landscape, such as the retention of woody debris (DE CICCO et al., 2018) and disruptions in fish migration (HARPER; QUIGLEY, 2005; FITZPATRICK; NEESON, 2018). The challenge of balancing the presence of these structures with ecological concerns, as well as with the functional interests of engineering, can benefit from advancements in fluvial geomorphology. Fluvial geomorphology is a science marked by the multidisciplinary nature of its studies, which encompass different dimensions related to the spatiotemporal and historical dynamics of river landscapes. It analyzes various physical and anthropogenic variables that modify river systems (STEVAUX; LATRUBESSE, 2017). This scientific field also focuses on understanding how bridges and culverts influence river dynamics and morphology (BORTOLUZZI; FERNANDEZ, 2017; DHALI et al., 2020; UDDIN et al., 2022). It is a strategic approach for comprehending the anthropogenic impacts on fluvial systems and fostering interdisciplinary connections, such as fluvial engineering (WOHL, 2014).

The modifications caused by these structures include changes in depositional processes due to obstructions, as well as intensified erosion along channel banks and beds, resulting from increased flow velocity (DHALI et al., 2020; BISWAS; PANI, 2021; MCDOWELL; HASSAN, 2024). Additionally, in some scenarios, these alterations can exacerbate the magnitude of flooding, especially in culvert areas (JONES et al., 2000; BORTOLUZZI; FERNANDEZ, 2017; GHOSH, 2024). Therefore, these fluvial reaches represent environmentally fragile areas where impacts can be further intensified by factors such as increased sediment supply in rural areas due to agricultural activities or soil sealing in urban areas.

Despite the potential geomorphological changes caused by these structures, a comprehensive understanding of the adverse physical effects of river-crossing structures remains limited. The global overview of the adverse physical effects that crossing structures can cause to rivers is still not well understood. Thus, this study aims to analyze the effects of bridges and culverts on river morphology and dynamics through a scientometric approach. The study contributes by summarizing the alterations that bridges and culverts can cause in river forms and processes, as well as by indicating promising directions for future research.

## 2. Changes in the sediment and hydrological regime

The influence of crossing structures on rivers often focuses on hydrological and sedimentological metrics in an integrated approach. This integration can be evidenced by increase deposition associated with the higher probability of upstream flooding, and the relationship of increase flow velocity with a higher likelihood of bank erosion and an increased width-depth ratio downstream, as in the Chel River in India and streams in the New Forest in England (GREGORY; BROOKES, 1983; BISWAS; BANERJEE, 2018). This scenario may vary in some rivers, as is the case of the Barakar River in India, where the flow is high at upstream causing rapids (BISWAS; PANI, 2021).

The grain size of sediments that are deposited upstream and downstream of bridges and culverts may changes. The upstream bed load can be characterized by coarse-grained throw debris, while the bed load at downstream is finer (GHOSH, 2024). Consequently, there is variability in turbidity parameters and sediment transport near bridges (SZATTEN et al., 2019), and at upstream reaches may be more susceptible to flooding (GHOSH, 2024).

It is necessity to differentiate between structures types-bridges, box culverts, and pipe culverts-as they influence river behavior different (ROY; SAHU, 2018). There re indications that they have a greater potential to cause changes in sediment transport and hydrological regime of culverts, as observed in rivers in India (ROY; SAHU, 2018) and Brazil (BORTOLUZZI; FERNANDEZ, 2017). Culverts can increase the magnitude of flooding in the area during significant precipitation events (JONES et al., 2000), due to blockages caused by the reduction in the channel's cross-sectional area and increased accumulation of woody debris (BORTOLUZZI; FERNANDEZ, 2017). In addition to increasing upstream aggradation, culverts enhance bed and bank erosion processes downstream (KELLER; CLARKIN, 2007; BORTOLUZZI; FERNANDEZ, 2017).

A different scenario that can influence geomorphological changes is the replacement of these structures, with culverts being replaced by bridges. Culverts caused sediment retention upstream of the structure, and when they were removed, there was an increase in sediment downstream of the structure in East Creek River, Canada (MCDOWELL; HASSAN, 2024). In this scenario, the culverts released the retained sediment and deposited it in other areas downstream of the bridge.

## 3. Channel Change

Changes in river morphology can manifest through alterations in width, thalweg position, bed elevation, and channel incision. Width change patterns are not homogeneous across all rivers; upstream of the Dharla River bridge in Bangladesh, a decrease in width was observed (UDDIN et al., 2022), while upstream of the Ngawun Bridge in Myanmar, the channel widened, making the upstream width greater than the downstream width (THU; SHWE; KYI, 2018). Regarding thalweg position variation, an alteration was found upstream of the Surma River in India (BISWAS, 2010).

As mentioned earlier, in most rivers, upstream reaches exhibit higher sediment deposition rates. In the Ajay River, India, a progressive development of bars associated with increased sediment deposition was observed, which interferes with the channel migration upstream, while downstream there is bed channel incision, a change also noted in the Barakar River, in India (ROY; SAHU, 2016; BISWAS; PANI, 2021). The incision processes of the downstream channel may result from increased erosion and a decrease in the width-to-depth ratio (BOUSKA; KEANE; PAUKERT, 2010; ROY; SAHU, 2017).

Other changes that can occur due to structures are the floodplain narrowing and the elevation of some areas downstream of the bridge. These changes were observed in the Chel River, India (BISWAS; BANERJEE, 2018), as well as an increase in channel excavation (DHALI et al., 2020). An interesting point is the sinuosity change upstream and downstream of the bridge. For example, increased sinuosity was noted downstream of the bridge in the Barakar River, India, while studies carried out on the Kunur River showed a sinuosity decrease downstream (ROY; SAHU, 2016; ROY; SAHU, 2018; BISWAS; PANI, 2021). The reduction in the overall sinuosity index was approximately 22% downstream of the channel when compared to upstream, indicating that this type of change does not occur uniformly across all channels. The decrease in the sinuosity index downstream of crossings indicates the formation of an incised valley and the disconnection of the floodplain from the river (ROY; SAHU, 2017).

Culverts have previously been discussed as structures that alter river dynamics, particularly by increasing sediment deposition upstream (WILHERE et al., 2017) and reducing the average water depth. These impacts, however, extend further: bed erosion and flow velocity increase as culvert depth increases (HINTZ et al., 2022), intensifying incision processes (GALIA; ŠILHÁN; ŠKARPICH, 2017). Such processes result in the formation of riffles and deep pools downstream of culverts, as observed in first-order streams in Ohio, United States (HINTZ et al., 2022), and East Creek, Canada (WLODARCZYK; HASSAN; CHURCH, 2023). These geomorphological changes have cascading effects on the biotic communities, influencing fish migration patterns (FITZPATRICK; NEESON, 2018) and aquatic habitat connectivity. Therefore, analyzing these impacts from a geomorphological perspective is essential to understanding alterations in other ecological and social systems associated with rivers.

## 4. Methodological Procedures

A systematic review of the impacts caused by bridges and culverts on rivers was carried out. The databases used for the literature search were the scientific research platforms, Scopus®, ScienceDirect®, Wiley®, and Google Scholar, which were defined according to the precepts defined by Öztürk et al., (2021). For the search on these platforms, the 'AND' operator was used in advanced searches, combining in the fields: title-abstract-keywords (Scopus® and ScienceDirect®) and anywhere (Wiley®). The terms used were related to the study topic, ranging from more general combined terms for contextualisation of the theme, such as 'impact AND urban AND river' and 'infrastructure AND urban AND geomorphology', to more specific search queries, such as 'bridge AND geomorphology' and 'impacts AND geomorphological AND bridges AND river'. Other terms were added to enhance the search, such as 'stream' and 'culvert'.

Research Rabbit, an artificial intelligence tool that provides literature mapping based on citations and similar keywords, was also used. In other words, the tool shows which works are similar, who cited the article, and previously published works through a data network. The tool is synchronised with other databases, such as ScienceDirect® and Google Scholar®, allowing for enhanced visualisation of articles and documents, such as dissertations and theses, related to the research topic. Thus, the platform was used to refine the database of articles found on the other platforms, such as Scopus®. The main articles directly addressing the impact of bridges and culverts on rivers were uploaded to the platform. Once the database was uploaded and a specific collection was created, all articles were selected, and the similarity search tool was used-that is, all articles and published works similar to the initial database were displayed in the form of a network. Next, the articles suggested through network connections were analyzed, and those that fit the research objective were identified.

The articles were selected based on discussions related to geomorphological changes in rivers caused by bridge and culvert crossing structures, from the earliest to the most recent publication on the subject. A filtering process of these results was carried out, first considering the title, i.e. articles that exclusively dealt with biotic changes and alterations or crossing structures were not considered. The abstracts of the selected articles were reviewed, and those that were relevant to the topic were systematically analyzed. After this step, a categorised database was developed with: the year of publication, author(s), study location, objective, methodological procedures, geomorphological changes caused by the structures and the assessed location of the river (upstream and/or downstream of the structures).

## 5. Results and discussion

### *5.1. Database*

The searches for broader terms resulted in a high number of published articles, with over 9,000 results, mainly in the Scopus® and ScienceDirect® databases. However, in more specific searches related to the topic, the Wiley® platform yielded more results, ranging from 700 to almost 5,000 results in some searches. The Research Rabbitapp tool generated 4,754 works similar to the database; however, only 50 articles established a direct connection with the database (Figure 1). Thus, the filtering process resulted in 27 articles that directly addressed river changes and alterations caused by crossing structures, covering the period from 1983 to 2024. The Research Rabbitapp tool proved useful for bibliographic searches, as the cluster tool enabled the identification of some articles not found organically on the mentioned platforms.

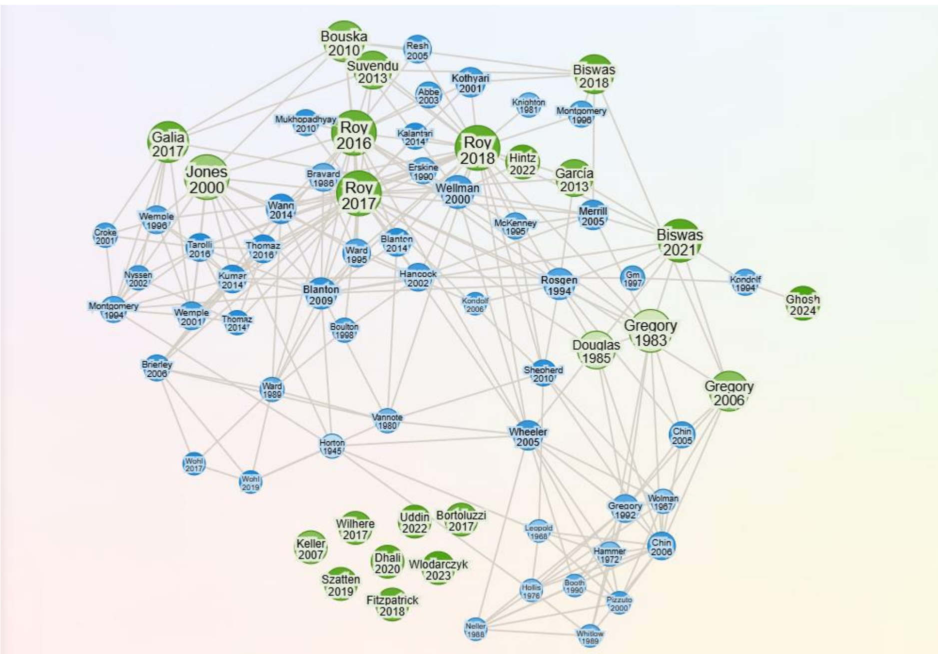

**Figure 1.** Result of the database network on the Research Rabbit platform. The green circles correspond to the articles analyzed in this study. The blue circles correspond to similar articles, but they do not primarily address the topic of the analysis.

*5.2. Scientometric Analysis*

The analysis of the spatial distribution of publications reveals how research on the topic has been developing internationally. The Asian region stood out as the main producer of articles on the subject in recent years, where India accounted for seven articles published from 1983 to 2024 (28%), followed by the United States with six articles (20%) (Figure 2). However, this scenario diverges when compared to the international panorama of publications in the field of fluvial geomorphology, where the United States stands out as the main country in publications in fluvial geomorphology, while Asian countries have a lower production (PIÉGAY et al., 2015).

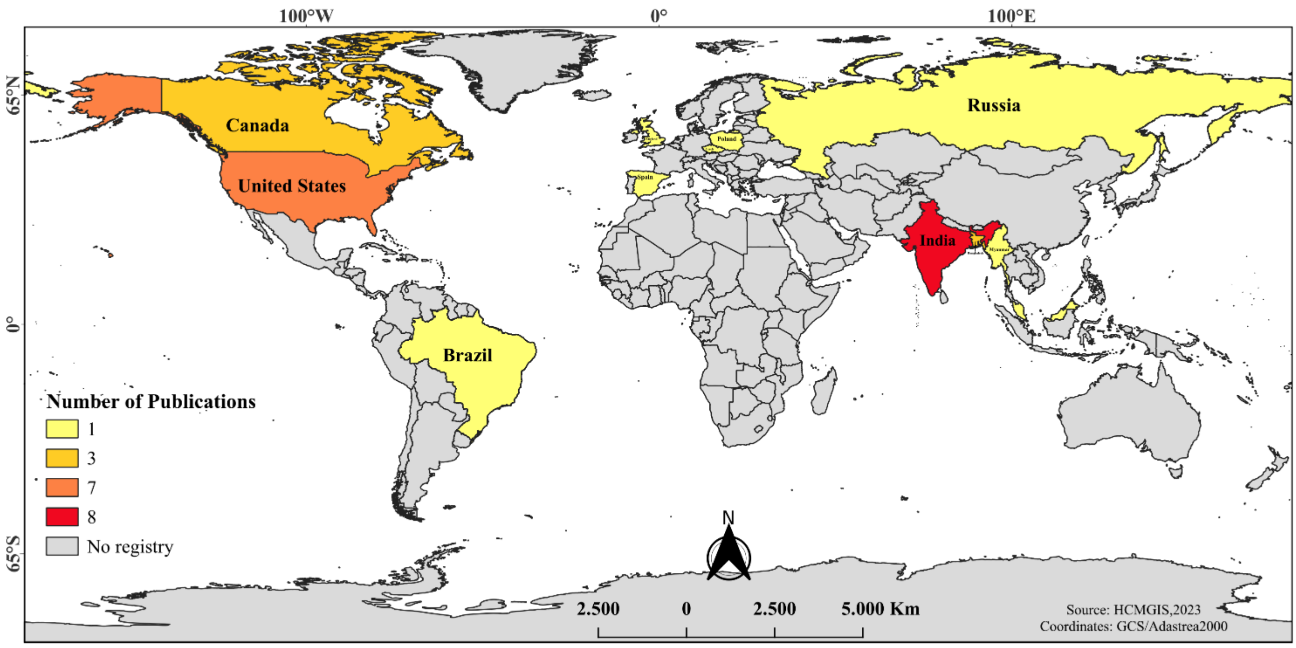


**Figure 2.** Spatial Distribution of Publications Worldwide (1983-2024).

The years 2017 and 2018 recorded the highest number of publications (Figure 3). This result can be explained according to the trends in fluvial geomorphology worldwide, with more attention to the geomorphological changes caused by human actions since the beginning of twenty-first century (WOHL, 2014).

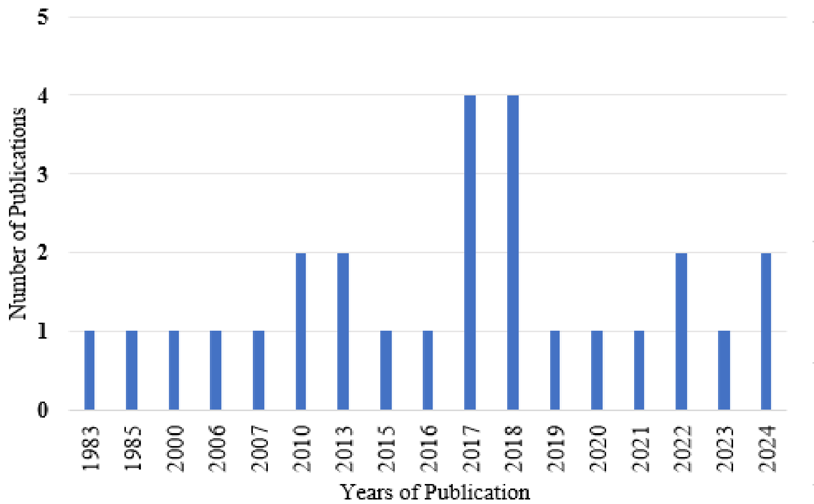


**Figure 3.** Number of scientific articles on river crossing structures in geomorphology (1983-2024).

Bridges stand out as the most studied structure type (45%) (Figure 4). However, culverts cause more changes when compared to bridges (BORTOLUZZI; FERNANDEZ, 2017). This scenario demonstrates the need for an increase in studies specifically involving culvert structures. Additionally, more detailed evaluations of the type of structure enable us to understand the greatest threats to fluvial dynamics, individualize change models, and verify if channel patterns show the distinction of change according to the type of structure. When distinguishing between different types of structures, culverts can tend to cause damming upstream and channelization downstream. Undersizing or inadequate planning of culverts should also be investigated and taken into consideration when evaluating the problems caused by these structures (ROY; SAHU, 2018). Studies of these structures within engineering should provide an analysis of how these structures are being projected, as well as the variables that are taken into consideration for calculations, particularly in a global warming scenario.

The intensification of extreme weather events due to climate change, particularly significant precipitation and flooding, exacerbates the impacts of culverts. Obstructions caused by these structures can amplify the magnitude and frequency of floods in both rural and urban areas (JONES et al., 2000; BORTOLUZZI; FERNANDEZ, 2017; GHOSH, 2024). Consequently, these areas become critical points of environmental and urban risk, leading to infrastructure damage, such as on highways, and increased concerns regarding the safety of local populations (CONESA-GARCÍA; GARCÍA-LORENZO, 2013). Therefore, this highlights the need for a better understanding of how climate change, combined with the geomorphological changes caused by these structures in rivers, can impact both environmental and social contexts.

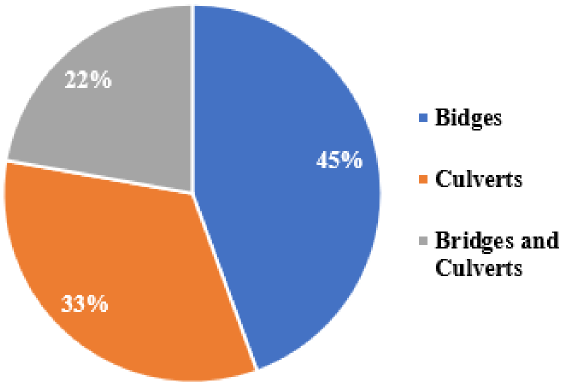


**Figure 4.** Concentration of studies by type of structures.

The methodological procedures for studying river changes caused by bridges and culverts are based on remote sensing and GIS techniques, geomorphological analysis (stream power, statistical analysis of sediments, variations in the cross-sectional profile), and the use of hydraulic formulas (Table 1). As researchers increasingly use these techniques in fluvial geomorphology (WOHL, 2014; PIÉGAY et al., 2015), they explain these methodological procedures. Thus, researches also apply the tools commonly used in fluvial geomorphology to studies on the influence of bridges and culverts on geomorphology. However, the analyzed studies do not detail geomorphological mapping, a methodology that should be highlighted. Currently, geomorphological mapping has sought to incorporate elements of the urban landscape (PELECH; PEIXOTO, 2020). An example is the understanding of fluvial structural elements, understood as discrete elements that directly influence the river's hydraulic process. These structural elements can be anthropogenic; therefore, bridges and culverts become targets for geomorphological mapping, as modifiers of the fluvial landscape (BRIERLEY; FRYIRS, 2005; WHEATON et al., 2015).

Few studies have employed statistical analyses to characterise and describe these bridge and culverts impacts on river morphology. The inclusion of statistical analyses can help better understand patterns of occurrence of changes, as well as verify the significance of these alterations in the river. Thus, the study demonstrates a need for the use of statistics for data analysis, as well as the characterization and analysis at the watershed level (MORAIS;

MONTANHER, 2022). Also, we identified how damming structures affect the river and how these structures can interfere with the functioning of the river through the characterization of the river basin level.

**Table 1.** Methodological procedures adopted in studies on the influence of bridges and culverts on fluvial geomorphology.

| Methodological procedures | Authors |
|---|---|
| Remote Sensing, GIS | (KAUSER; ALAM; ISLAM, 2015; ROY; SAHU, 2016; ROY; SAHU, 2017; THU; SHWE; KYI, 2018, BISWAS; BANERJEE, 2018, BISWAS; PANI, 2021, UDDIN et al., 2022; GHOSH, 2024). |
| Hydraulic characterization of structures | (ROY; SAHU, 2018). |
| Characterization of watershed | (BORTOLUZZI; FERNANDEZ, 2017; HINTZ et al., 2022;). |
| Field data collection through cross-sectional surveys | (GREGORY; BROOKES, 1983, JONES et al., 2000; GALIA; ŠILHÁN; ŠKARPICH, 2017; ROY; SAHU, 2017; ROY; SAHU, 2018; DHALI et al., 2020; BISWAS; PANI, 2021, GHOSH, 2024). |
| Modeling in general | (BISWAS, 2010; WILHERE et al., 2017; FITZPATRICK; NEESON, 2018; ROY; SAHU, 2018). |
| Granulometric analysis of sediments | (BISWAS; BANERJEE, 2018, BISWAS; PANI, 2021, GHOSH, 2024). |
| Analysis of water turbidity | (SZATTEN et al., 2019). |
| Application of indices and forms for structure evaluation | (KELLER; CLARKIN, 2007; BORTOLUZZI; FERNANDEZ, 2017). |
| Analysis of geomorphological data (stream power; longitudinal profile; width-depth ratio) | (GREGORY; BROOKES, 1983; DOUGLAS, 1985; BOUSKA; KEANE; PAUKERT, 2010; CONESA-GARCÍA; GARCÍA-LORENZO, 2013; SUVENDU, 2013; GALIA; ŠILHÁN; ŠKARPICH, 2017; DHALI et al., 2020; BISWAS; PANI, 2021, HINTZ et al., 2022; GHOSH, 2024). |
| Analysis of hydrological data (Floods, discharge, hydraulic force, among others) | (DOUGLAS, 1985; CONESA-GARCÍA; GARCÍA-LORENZO, 2013; GALIA; ŠILHÁN; ŠKARPICH, 2017; ROY; SAHU, 2018; SZATTEN et al., 2019, WLODARCZYK; HASSAN; CHURCH, 2023; MCDOWELL; HASSAN, 2024). |
| Statistical analysis (ANOVA, Multivariate Correlations) | (CONESA-GARCÍA; GARCÍA-LORENZO, 2013; FITZPATRICK; NEESON, 2018; ROY; SAHU, 2018). |

Our analysis demonstrates a predominance of higher sediment deposition rates and reduced flow upstream of the crossing structures, while erosive processes on the banks, increased flow, and channel bed incision downstream (Table 2). However, there are exceptions, such as the studies by Dhalia et al., (2020), where there is an increase in channel bed elevation downstream and channel incision upstream, as well as the studies by Biswas and

Banerjee (2018) showing changes in the thalweg and erosive processes upstream and downstream. In these cases, these discrepancies may be occurring due to the watershed geomorphology.

The channel width changes vary according to the location and characteristics in the river. The channel width at upstream may be smaller than downstream, with an increase in the width-depth ratio (GALIA; ŠILHÁN; ŠKARPICH, 2017; GHOSH, 2024), while there is a predominance of channel incision and bank erosion, increasing the width of the channel at downstream (GALIA; ŠILHÁN; ŠKARPICH, 2017). The grain size distribution may vary depending on the location of the analysis with. Roy and Sahu (2018) found fine sediment deposition at upstream, while in Ghosh's (2024) study, upstream showed a predominance of coarse sediments mixed debris and downstream, an increase in fine sediment deposition.

**Table 2.** Changes in river forms and processes, upstream and downstream of the structures.

| Types of alterations | Upstream | Downstream | Articles |
|---|---|---|---|
| High sediment deposition | X | | (GREGORY; BROOKES, 1983, BISWAS, 2010; KAUSER; ALAM; ISLAM, 2015; ROY; SAHU, 2016; BISWAS; BANERJEE, 2018, BISWAS; PANI, 2021, MCDOWELL; HASSAN, 2024). |
| Increased bank erosion | X | X | (GREGORY; BROOKES, 1983, BISWAS, 2010; BOUSKA; KEANE; PAUKERT, 2010; BISWAS; BANERJEE, 2018, BISWAS; PANI, 2021, MCDOWELL; HASSAN, 2024). |
| Higher probability of floods | X | | (BISWAS; BANERJEE, 2018, GHOSH, 2024). |
| Increased water velocity | | X | (ROY; SAHU, 2016; BISWAS; BANERJEE, 2018, BISWAS; PANI, 2021). |
| Reduction of floodplain | | X | (BISWAS; BANERJEE, 2018). |
| Reduction of elevated areas | | X | (BISWAS; BANERJEE, 2018). |
| Sudden increase in bed profile | X | | (ROY; SAHU, 2018). |
| Higher rate of fine sediments | X | X | (BOUSKA; KEANE; PAUKERT, 2010; ROY; SAHU, 2018; GHOSH, 2024). |
| Reduction in sinuosity | | X | (ROY; SAHU, 2018). |
| Increase in sinuosity | | X | (BISWAS; PANI, 2021). |
| Bed excavation | | X | (GREGORY; BROOKES, 1983, ROY; SAHU, 2016; GALIA; ROY; SAHU, 2017; ŠILHÁN; ŠKARPICH, 2017; |

| | | | |
|---|---|---|---|
| | | | DHALI et al., 2020; BISWAS; PANI, 2021, MCDOWELL; HASSAN, 2024). |
| Change in river width | X | X | (GREGORY; BROOKES, 1983, GALIA; ŠILHÁN; ŠKARPICH, 2017; DHALI et al., 2020; UDDIN et al., 2022; GHOSH, 2024). |
| Increase in bed elevation | | X | (DHALI et al., 2020;). |
| Shift in thalweg | X | X | (ROY; SAHU, 2016; BISWAS; BANERJEE, 2018, UDDIN et al., 2022). |
| Formation of Pools | | X | (HINTZ et al., 2022; WLODARCZYK; HASSAN; CHURCH, 2023). |

**6. Conclusions**

We conducted a scientometric analysis of geomorphological research that characterised and quantified changes in fluvial forms and processes caused by bridges and culverts. These changes include high deposition rates and reduced flow power upstream, and more intense erosive processes and increased flow power downstream, despite some divergences. The quantification of research and global distribution highlight the need to expand geographical studies on river alterations caused by these structures. In this way, this study allowed us to identify river responses with different channel patterns, as well as understanding how these changes occur in increasingly urbanized areas. Rivers under the influence of bridges receive more studies, while culverts have a greater capacity to alter rivers, indicating the need for more research on culverts. This theme of research on how these structures interfere with fluvial dynamics is, therefore, promising for an integration of ecological and engineering interests to the effective maintenance of river integrity.

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