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Water Science & Technology

Water Science & Technology Vol 88 No 8, 2068 doi: 10.2166/wst.2023.318

Procedure for emergetic assessment in urban river de-pollution

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ABSTRACT

Using emergetic indicators to evaluate complex processes such as the de-pollution of urban rivers aims to contribute to better use and preservation of the resources, besides the valuation of ecosystem services provided by the water body. Within this context, we conducted a bibliometric and systematic review that shows the lack of emergetic indicators in urban river de-pollution. Thus, this work aims to propose an emergetic assessment procedure to evaluate the de-pollution process of urban rivers that allows technicians, academics, and revitalization process managers of urban rivers to improve the monitoring and decision-making directly related to the process, concluding that an emergetic assessment procedure contributes to theory to create new scientific analyses applied to urban revitalization and nature preservation processes. The emergetic assessment procedure contributes to society by improving the disposal of public resources and the effective maintenance of urban rivers that provide ecosystem services to all stakeholders (residents, grantors, and sanitation companies). In practice, the use of the emergetic assessment contributes to the monitoring from the first stages of the clean-up process, demonstrating the sustainability of the process for the adequacy of resources and maintenance of the water body that shall be cleaned.

Key words: ecosystem services, emergy, urban rivers

HIGHLIGHTS

- Emergetic assessment in urban river de-pollution.
- Emergetic assessment to reduce environmental impact in the water.
- Emergetic assessment and indicators to improve sustainability.
- Indicators to improve the sustainability of the urban streams and rivers.

1. INTRODUCTION

The advance of large metropolises on nature without proper social and urbanistic care causes the degradation of natural resources that seriously affect the value of ecosystem services (ES) in rivers and streams. We can observe these changes in the frequency and pollution intensity increase in urban water bodies (Surya *et al.* 2020).

Aware of this, it is increasingly important to identify and evaluate the determinants that lead to the causes of these changes in water bodies. The indicators can present the effects and results of actions to improve the sustainability of recovery processes (Lv *et al.* 2018; Liu *et al.* 2019).

Applications to river-related issues identified the following sustainability indicators: input–output analysis (IOA) (Chen *et al.* 2017; Incera *et al.* 2017; Zhao *et al.* 2019); life cycle assessment (LCA) (Phillips *et al.* 2018; Chen *et al.* 2019; Zhang *et al.* 2019); ecological footprint (EF) (Dai *et al.* 2019; Fan & Fang 2020; Taffarello *et al.* 2020); carbon footprint (CF) (Anenberg *et al.* 2019; Xu *et al.* 2019); and cost–benefit analysis (CBA) (Becker *et al.* 2018; Li *et al.* 2019; Yaacovi *et al.* 2021).

In the context of the de-pollution of Brazilian urban rivers, the use of parameters for qualitative control of water was identified, such as the BOD (biochemical oxygen demand) which is monitored monthly to determine the situation of the river water (Flausino Gallardo 2019). The qualitative analysis of water does not allow the evaluation of the process as a whole, and the application of emergy analysis is an innovation for improving the process, integrating several aspects inserted in a revitalization process (Zhan *et al.* 2018).

In this context, the diversity of parameters incorporated into the urban river clean-up process (economics, technical, and social) requires greater complexity for developing sustainability indicators, with the emergetic analysis reflecting both the contribution of the energy system and that of the environment (Brown & Ulgiati 2002).

Emergy can be defined as the energy previously used, directly or indirectly, to produce a product or service (Odum 1996). The emergetic theory allows a better comprehensive evaluation by converting the different forces acting into a common unit, which can be expressed in solar equivalent joules (sej) (Liu *et al.* 2019; Song *et al.* 2019).

Using emergy is suitable for evaluating hybrid, natural, and economic systems to assess sustainability in anthropogenic systems, such as watersheds (Zhan *et al.* 2018). In this context, previous studies have presented the use of emergetic indicators in environmental assessments related to water issues, looking at aspects such as the restoration of wetlands and waterways from emergetic indices before and after restoration (Di *et al.* 2019; Sun *et al.* 2019).

Other studies show the evolution of the ecosystem and the investment made by nature, calculating the costs of restoring ecology in watersheds (Zhong *et al.* 2018; Sun *et al.* 2021). Emergetic assessment and water quality were used as a reference to measure economic development and the emergy contribution embedded in the watershed restoration process in the studies by Zhang *et al.* (2017) and Lv *et al.* (2018).

Other research relates the emergetic indicators to the level of regional economic development, the rate of urbanization, and the rational use of resources in wetlands and urban areas (Zeng *et al.* 2010; Su *et al.* 2013). Analysis of the relationships and influences between water resources, social economy, and ecological environment for promoting sustainability and maintaining ecosystem integrity and health were identified in the studies by Di *et al.* (2019) and Song *et al.* (2021).

Studies have shown that the use of emergetic indicators is an effective tool to assess the natural value of resources in rivers and sustainable urban development from a rational management of resources (Chen *et al.* 2009; Pulselli *et al.* 2011). The reduction in the inflow of gained resources and increase in the availability of natural resources, which directly affect ecosystem services in water bodies, was shown in the studies by Zhan *et al.* (2018) and Song *et al.* (2019).

Additionally, other aspects verified in previous studies showed indicators of emergy in water bodies, wetlands, and forests, contributing to the improvement of ecosystem services. The concept of ecosystem services has been useful in facilitating communication between stakeholders and policymakers (Liu *et al.* 2019; Lv *et al.* 2020).

Improving ecosystem services in forests, wetlands, watersheds, groundwater, and agricultural areas from the emergy-based economic valuation and understanding the true value of ecosystem services can promote regional ecosystem service maintenance and conservation, provide a scientific basis for formulating regional ecological civilization-building plans, sustainable development plans, and ecological compensation policies (Wang *et al.* 2019; Li *et al.* 2021).

In view of this, and after developing the basis of the bibliometric and systematic review of works that used the emergetic method in water systems, no tasks were identified that used the emergetic assessment and its indicators to improve the sustainability of the recovery process of urban streams and rivers. Given this finding, this study presents emergy indicators used in similar actions: interventions in wetlands (Liu *et al.* 2019), watersheds, and forests (Zhan *et al.* 2018; Liu *et al.* 2019), which supports the application of emergy in urban river revitalization processes (Lv *et al.* 2018).

Based on this research gap, this work aims to propose an emergy evaluation procedure for the evaluation of the depollution process of urban rivers, identifying the main aspects inserted in the revitalization process and improving the control mechanism for sustainable development, using the emergies that are incorporated into the entire system of the stream.

The emergy theory proposed by Odum has been used in several complex systems (agriculture, watersheds for supply, swamps); however, in revitalization processes, the use of emergy is incipient and can contribute to several aspects that encompass an urban water revitalization.

The theoretical contribution of this study is the development of new scientific analyses applied to urban revitalization and nature preservation processes, presenting new sustainable indicators. Using emergetic indicators by sanitation service providers and/or the granting authority proposes the sustainability of re-urbanization processes, besides the optimization in the allocation of resources. Among the perspectives of the effective application of the emergetic indicators is the improvement of aspects related to the control of urban revitalization and the distribution of resources, allowing society to increase its integration with urban areas and the perception of the ecosystem services observed.

The conception of this study through bibliographic, bibliometric, and systematic analysis related to emergetic indicators supports the assertion that emergy can improve sustainability in an urban river or stream de-pollution process (Liu *et al.* 2019).

2. METHODS

The bibliometric and systematic review carried out in this study analyzed the scientific research on the use of emergetic assessment for the adoption of indicators in the urban river or stream de-pollution processes, to contribute to the improvement of these processes.

The search was designed to identify studies related to emergy, ecosystem services, sustainability indicators, watershed revitalization/restoration, and urban rivers, the following terms were used: (i) 'emergy' and 'ecosystem services'; (ii) 'emergy' and 'sustainability indicators'; (iii) 'emergy' and 'urban river revitalization'; (iv) 'emergy' and 'watershed restoration'; and (v) 'emergy' and 'urban rivers'. The following databases were searched: Scopus, Elsevier, Google Scholar, Web of Sciences, Springer, and Proquest.

The search returned 726 articles, which were filtered based on the PRISMA method (Moher *et al.* 2009), as shown in Figure 1. The bibliometric and systematic review used as its initial date criteria the previous research conducted by He *et al.* (2020) on studies that applied the emergetic theory and observed that, although research on the subject has significantly increased since its inception by Odum in 1996, regarding studies conducted on urban rivers and their de-pollution, the subject is still incipient.

The bibliometric survey carried out identified that most articles found used emergy and ecosystem services, but without directly citing intervention in urban rivers or measuring indicators in the de-pollution or revitalization of urban rivers. We identified 40 articles in which the emergetic assessment was used to develop indicators in processes of environmental intervention, of which 19 articles presented direct correlation with the proposed theme, as they used the emergy assessment in watershed revitalization issues, wetlands are embedded in water issues.

Finally, the research methodologies used in the studies selected during the systematic review were analyzed to verify the application of the emergetic assessment as well as suggest the use of this method in future research because of the little use in current studies on urban rivers and related subjects (Oliveira Neto *et al.* 2018).

In this context, this research proposes the use of emergetic appraisal in urban river de-pollution processes, starting with the development of a theoretical model to assess the feasibility of introducing the concepts of emergy, adopting the indicators proposed by Odum & Odum (2001).

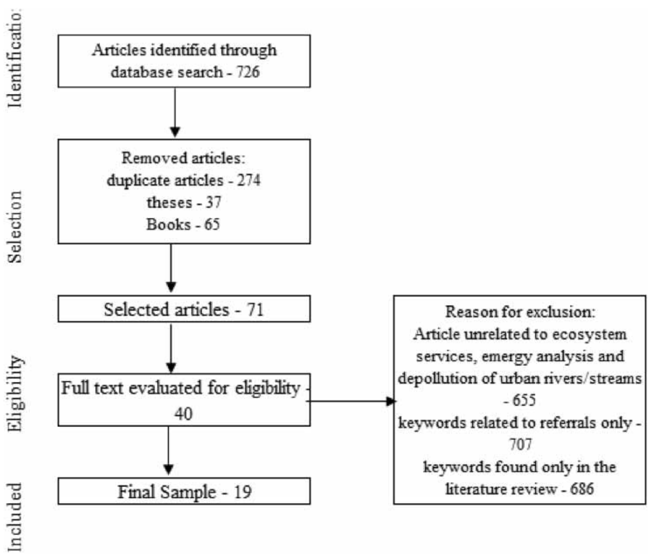

Figure 1 | Selection process.

As presented in Figure 1, 19 articles that addressed the emergetic assessment in water bodies were identified. The publications related to the subject began in 1988, but we did not identify the use of emergy in works on revitalization and/or restoration of water bodies prior to 2010 (He *et al.* 2020).

3. BIBLIOMETRIC REVIEW ON EMERGETIC ASSESSMENT IN URBAN RIVER DE-POLLUTION

Figure 2 presents the number of publications from 2010 onwards in this article, showing a year-on-year increase, with a slight drop between 2015 and 2016 and a subsequent increase in publications since then.

The recent increase in publications in this area reinforces the demonstration of interest in the revitalization of water bodies, as well as the search for sustainability in hydrological issues, with the necessary application of indicators that evaluate complex processes (e.g., de-pollution of rivers in urban areas) that directly impact the restoration of water resources.

Figure 3 shows that the journal *Water Science and Technology* has published the largest number of research related to watershed analysis (27 articles identified in the bibliometric survey) because of its scope directly connected to key sustainability issues in watersheds. Twenty-five publications and 22 articles also collaborated, respectively, from the *Journal of Cleaner Production and Ecological Indicators*. The articles studied from these publications focus on the use of emergetic

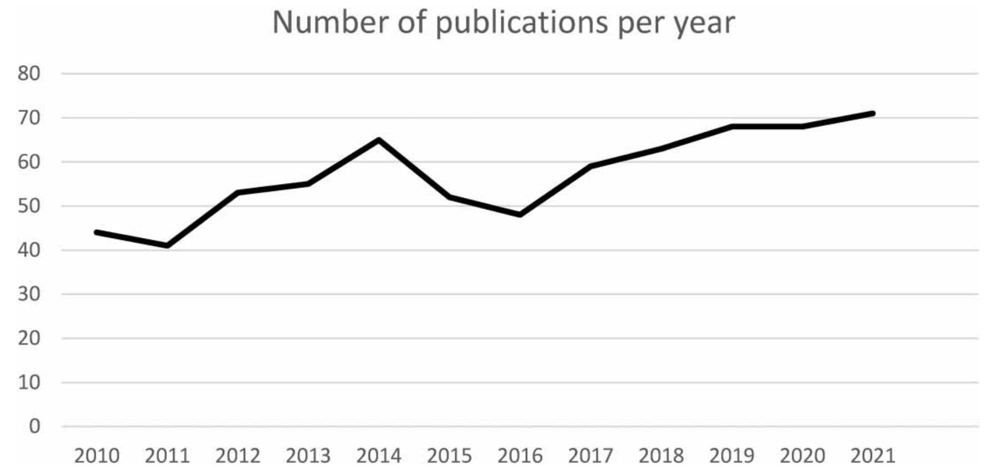

Figure 2 | Number of publications per year.

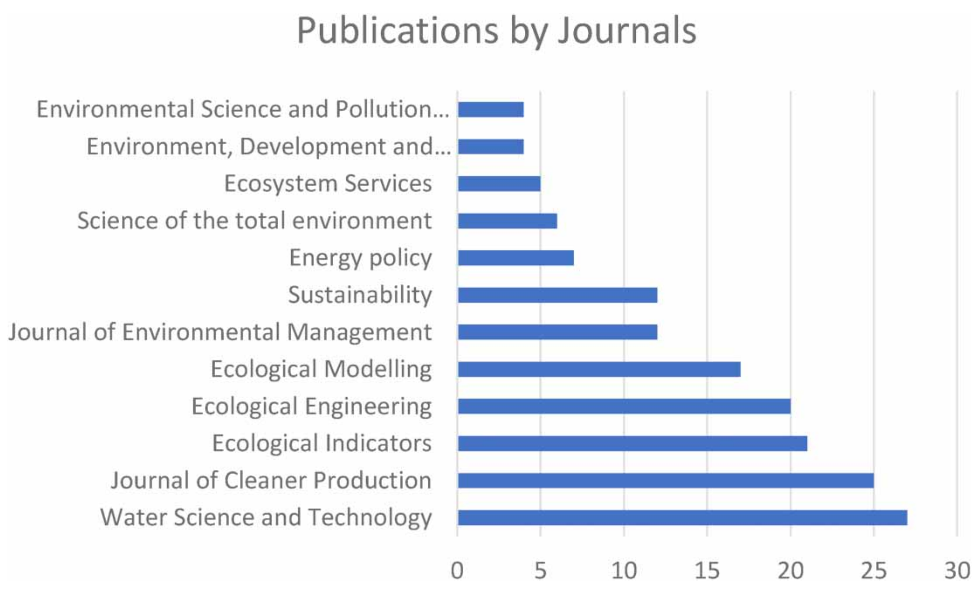

Figure 3 | Number of articles published by journals.

indicators in revitalization actions and sustainable development capacity in watersheds in places where there was industrial growth.

Figure 4 shows the methodologies used in the articles that were entered into this systematic review. The design of the theoretical model presented in this report used studies that applied the case study method (50%) and the experimental model (38%) in complex situations (hydrological and urban systems) allowing for a meaningful investigation of actual events involving emergetic assessment.

The use of these methodologies in 88% of the studies shows that the application of emergy assessment has been applied to validate the theory in practical issues, but without measuring results in urban processes of the streams de-pollution, and that emergetic sustainability indicators are used for improvement and development of regions where availability or restoration of ecosystem services are needed.

The largest number of studies of emergetic valuation identified in the bibliometric and systematic review associated emergy directly with a valuation of ecosystem services (20%). The systematic review identified that most studies are directly connected to topics linked to sustainability analysis on water issues (Figure 5).

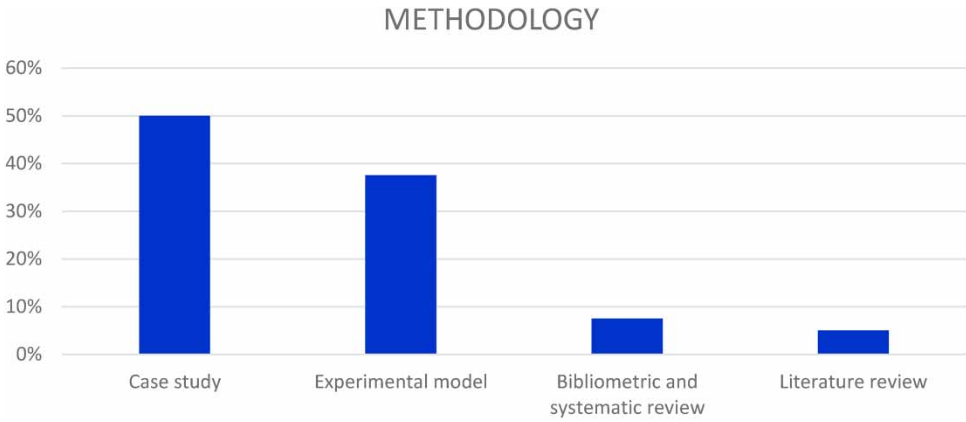

Figure 4 | Publications by the methodology used.

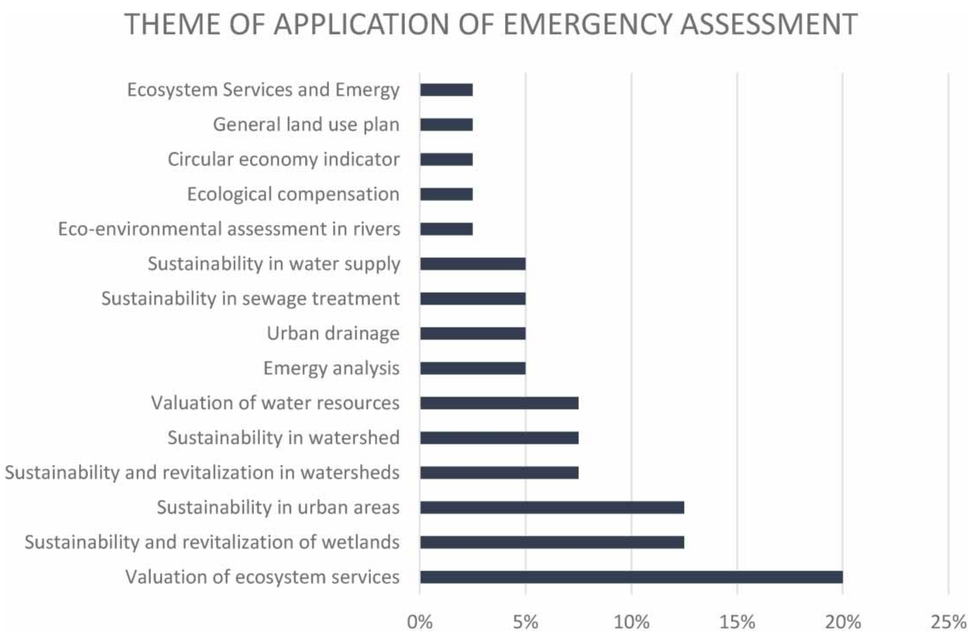

Figure 5 | Relationship between studies and knowledge theme.

The studies that used the emergetic valuation are related to aspects directly connected to sustainability (in wetlands (13%), urban areas (13%), water supply (8%), and sewage treatment (5%)) as well as the need for valuation of water resources (8%), mentioning only one of the questions that this article aims to answer, without effectively observing the revitalization of urban rivers.

This finding is important to present to managers and society that the use of emergetic indicators can contribute to the reduction of costs and environmental effects, presenting the potential of using this evaluation in the development of public policies in actions such as the de-pollution of urban rivers.

The bibliometric and systematic review presents relevant aspects inserted in water revitalization based on emergy analysis but does not directly identify procedures for applying emergetic indicators in urban river de-pollution processes. Therefore, this study presents a model for the application of the theory in the de-pollution of urban rivers or streams.

4. SYSTEMATIC REVIEW FOR PROPOSING A CONCEPTUAL MODEL TO EVALUATE THE DE-POLLUTION OF URBAN RIVERS

The analyses proposed by the emergetic theory identified by the systematic review show that social and environmental development must go hand in hand with entrepreneurship to build a prosperous and sustainable future, allowing basic conditions for future generations (Odum & Odum 2001).

Since emergetic assessment allows for the analysis of the quality of energy flow and enables comparisons to be made between distinct forms of energy (sun, water) with other systems (financial and human resources) (Song *et al.* 2021), the adoption of indicators that relate all used emergy to natural resources contributes to the greater sustainability of complex systems and their survival (Sun *et al.* 2019).

The calculation of the yield of the emergy incorporated by the system provides a gain in primary energy made available to the economy that will consume the product, so it allows observing the economic gains acquired during and after the process (Song *et al.* 2021).

Implementation of emergetic indicators besides economic analyses allows to evaluate the effects that the production system has on the ecosystem, showing whether there is greater pressure from the economic system on the ecosystem, as well as, verifying if the environmental effects caused can be absorbed by the system (Lv *et al.* 2020; Li *et al.* 2021).

The studies verified in this review applied the emergy evaluation and showed results that are directly connected to the proposal of a model for emergetic evaluation in the de-pollution of urban rivers using the procedures elaborated by Odum & Odum (2001). The model presented in this study observed the use of emergetic evaluation in cases similar to the proposal shown, aiming to adapt the methodological procedures of emergy for effective implementation in de-pollution processes.

4.1. Theoretical model proposal for the application of emergetic evaluation in urban rivers de-pollution

The construction of the theoretical model of this work proposes the introduction of the emergetic method elaborated by Odum & Odum (2001) proposing the creation of new indicators that can foster the de-pollution of urban rivers, optimizing the use of resources and improving the implicit processes (basic sanitation, urbanization, public resources, environment).

The framework for emergetic evaluation presents the existing problems (river pollution) and indicators, observing that the production of knowledge and practical use for improvement in the process of de-pollution of urban rivers and evaluation of ecosystem services is directly correlated to the aspects to be developed by this research.

In wetland revitalization, emergetic indicators demonstrate ecological improvements and their use in urban river revitalization processes contributes to the availability of SE, improvement of actions, and development of a more sustainable process (Sun *et al.* 2021).

The construction of the theoretical model (Figure 6) for the emergetic analysis of the de-pollution of urban rivers and streams was developed from the systematic review and is divided into four stages (natural resources, revitalization, data collected, and emergetic indicators), in line with research that has adopted that assessment in similar situations directly related to water resources.

The construction of the theoretical model is divided into four stages (natural resources, revitalization, data collection, and emergy indicators), directly related to water resources. The phases that form the theoretical model adopted in this study were adapted from the emergetic evaluation model of the components that make up the diagram of the energy system inserted in the system to be studied (Chen *et al.* 2009). Table 1 presents the phases that make up the model based on the concepts of emergy evaluation used in studies that applied the theory with indicators in the analysis of hydrographic systems.

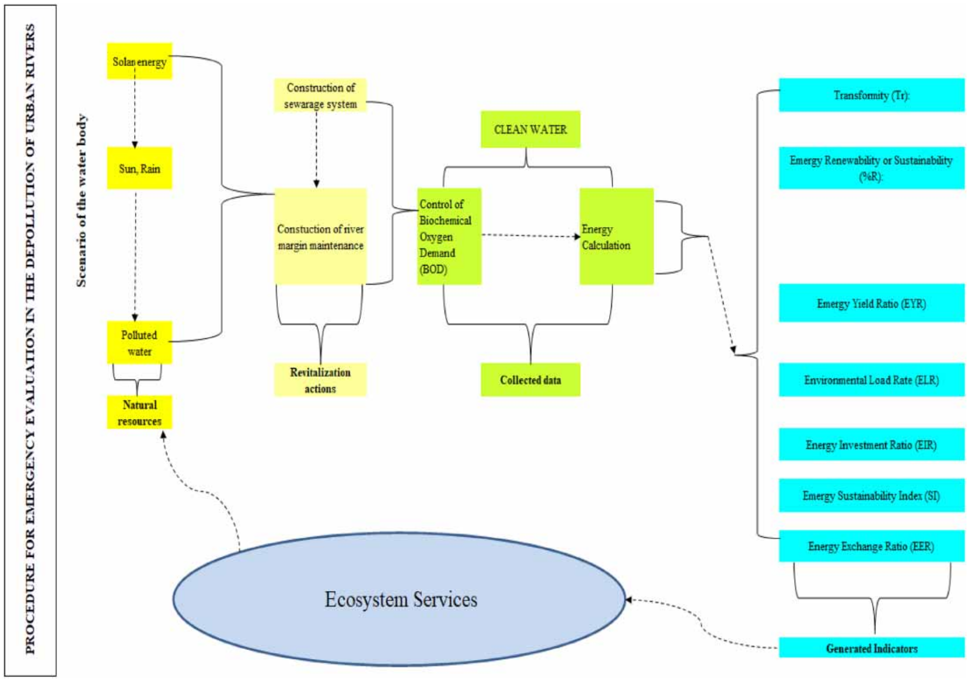

Figure 6 | Theoretical model for the emergetic evaluation of urban rivers.

Table 1 | Phases of the emergetic analysis

Steps	Emergetic indicators	Concept	Reference
Natural resources	Tr; %R; EYR; ELR EIR; SI; EER	Measure the water contribution rate in emergy, as well as the contribution to the economy from the verification of the natural resources inserted in the water system	Chen *et al.* (2009), Zeng *et al.* (2010), Lv *et al.* (2018)
Actions for revitalization	Tr; %R; EYR; ELR EIR; SI; EER	Analysis of works carried out to revitalize water bodies, based on the introduction in the equations of activities and inputs used	Pulselli *et al.* (2011), Lv *et al.* (2018)
Collected data	Tr; %R; EYR; ELR EIR; SI; EER	Collecting water quality analysis data was introduced into the emergy indicator equations for evaluating regions affected by economic growth	Sun *et al.* (2019), Di *et al.* (2019)
Indicators generated	Tr; %R; EYR; ELR EIR; SI; EER	The generated indicators make it possible to analyze the processes of deterioration and restoration in revitalization actions, allowing interested parties to develop policies for sustainable development	Chen *et al.* (2009), Lv *et al.* (2018), Zeng *et al.* (2010), Sun *et al.* (2019), Di *et al.* (2019)

The parameters that make up the analysis phases and subsequently the emergetic indicators are directly related to the design of the emergy diagram according to the flow of natural energy (renewable and non-renewable), material and services that occur within the system studied (Lv *et al.* 2018).

4.1.1. Procedure for calculating the emergetic indicators in the de-pollution of urban rivers

The development of the emergetic evaluation is carried out from the design of the emergy flowchart (Figure 7) and the verification of the inputs and outputs of energy in the system to be studied, converting all parameters into joules of solar energy (seJ). The determination of the emergy indices to be adopted for calculating the indicators is designed according to the characteristics of the system to be studied (Zhang *et al.* 2017; Sun *et al.* 2021).

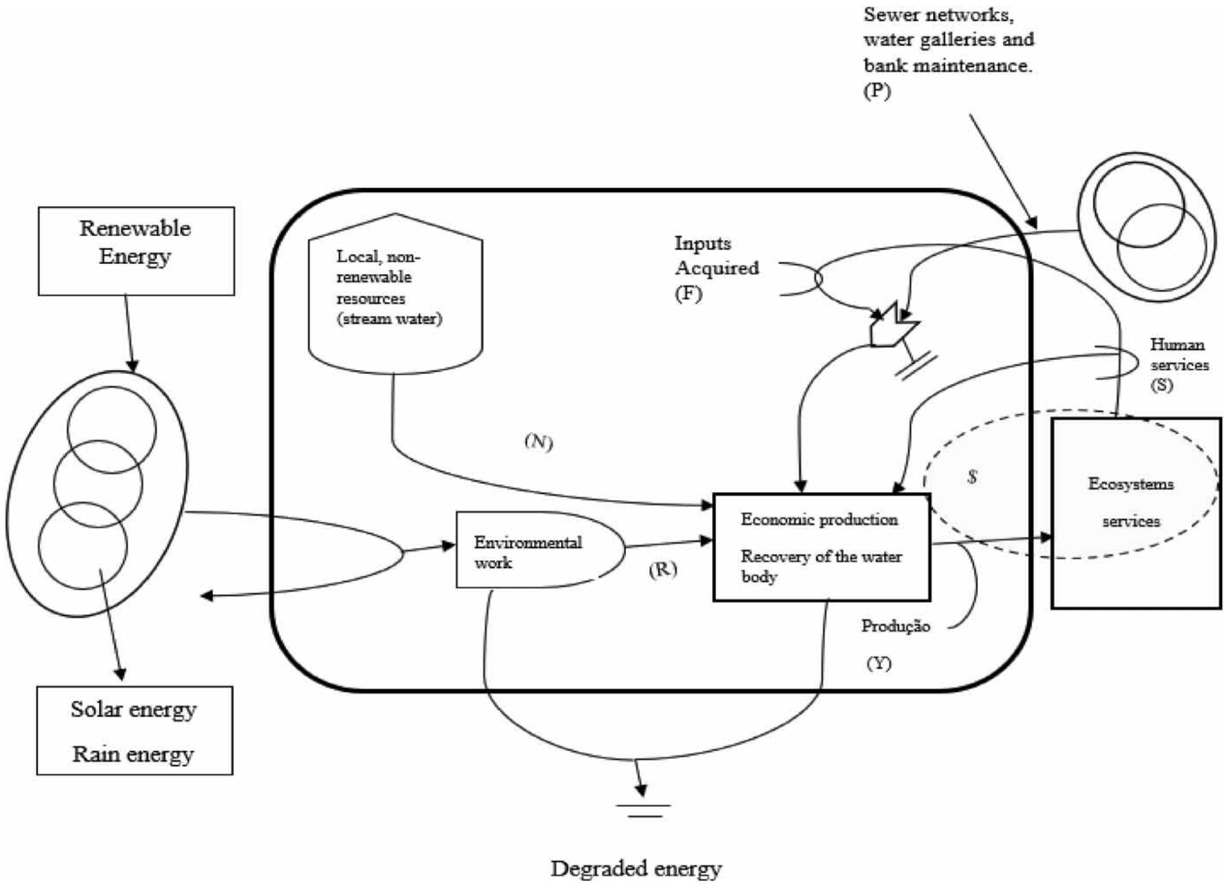

Figure 7 | Systemic diagram of the flow of energy in the de-pollution of urban rivers (adapted from Odum (1996)).

The emergetic indices should be calculated from the survey of the parameters: nature's resources (I): renewables (R) + non-renewable (N); economy resources (F): services (S); and the energy of the products (processes) of the system (Y) which is the sum of nature's resources and economy's resources (Odum 1996; Zhang *et al.* 2017).

These are known as emergetic indexes:

A: Free renewable energy from environmental inputs, such as sun, rain, and wind, in this study will use the volumes of water in the streams and the biological oxygen demand (BOD) index pointed out before the intervention to clean up the streams.

N: Non-renewable free energy of the resources coming from the environment of the analyzed system site, such as soil, wood, and minerals, when they are used faster than they are produced. In this study, we will use, as free energy, the rate of sewage removed from the body of water.

S: Energy from services paid for people (human resources used in the de-pollution process).

I: Resources of nature: $I = R + N$ (solar energy and river water before and after revitalization).

F: Resources of the economy: $F = P$ (purchased products) + S.

Y: Products of the system: $Y = I + F$.

The proposed use of emergetic indicators adopted in this work was developed from studies that used the emergetic theory in similar studies as shown in Table 2, from the development of an emergetic assessment in the process of urban river de-pollution.

4.1.1.1. Step 1: Natural resources. The natural resources adopted in the presented model determine fundamental parameters incorporated in the calculation of transformative and emergies in an urban river de-pollution process (Tables 1 and 2). Solar energy, rainfall index, and water quality (BOD) are part of the natural contribution to the emergetic assessment of human economic and social development (Lv *et al.* 2018).

Table 2 | Emergies indicators

Indicators	Emergies (formulas)	Unit	Concept	Reference
Transformity (Tr)	Tr = Y/Ep	sej/J	Evaluate the quality of the energy flow and allow comparisons with other forms of energy and with other systems	Chen *et al.* (2009), Lv *et al.* (2018)
Emergy renewability or sustainability (%R)	%R = R/Y	%	Renewability is the ratio of the emergy of renewable resources to the total emergy used. Systems with higher sustainability indexes have greater chances of survival	Sun *et al.* (2019)
Emergy yield ratio (EYR)	EYR = Y/F	–	It indicates the emergy yield of the system or the gain in primary energy made available to the economy that will consume the product. If its value is close to one, the system consumes as much energy as it makes available to the economy	Song *et al.* (2021)
Environmental load rate (ELR)	ELR = (N + F)/R	–	It is an important index because it evaluates the pressure that the productive system causes the ecosystem. High ELR indexes indicate greater pressure from the economic system on the ecosystem	Lv *et al.* (2020)
Energy investment ratio (EIR)	EIR = F/(N + R)	–	This ratio indicates the degree of savings when using savings investments compared to an alternative. To be economical, the process must have an EIR value similar to the average value of activities in the region	Pan *et al.* (2020)
Emergy sustainability index (SI)	SI = EYR/ELR	–	Indicates whether the system contributes energy to the detriment of the environmental balance or whether the impacts can be absorbed by the system	Li *et al.* (2021)
Energy exchange ratio (EER)	EER = Y/[unit production × price × (emergy/dollar)]	–	Products from the work of nature tend to have a higher EER value than products from human labor	Zhan *et al.* (2018)

Zeng *et al.* (2010) demonstrated the contributions of natural resources inserted in a watershed context from the emergetic assessment, as the flow and water quality of rivers directly related to ecosystem health, being fundamental to the preservation and provision of ecosystem services (provision, regulation, support, and cultural) essential to sustain life.

The emergetic assessments conducted in the Yellow River basin in China have shown that volume, as well as water body quality (BOD) after sediment removal, directly interfere with the emergence and transformative indicators used to measure the eco-economic resources used in that region (Di *et al.* 2019).

Studies have identified that a lack of water resource management and planning has potentially negative effects and consequences that may lead to tradeoffs among some ecosystem services. However, it has been shown that watersheds should have conservation programs and integrated efforts to improve overall water efficiency (Zhong *et al.* 2018; Liu *et al.* 2019).

From an analysis conducted to verify the deterioration of Zengchang, China, it was shown that emergetic assessment has technical feasibility and scientific validity, characteristics necessary to assess ecological damage, providing parameters for developing actions aimed at protection and evaluate actions taken to measure river revitalization (Zhang *et al.* 2017).

4.1.1.2. Step 2: Revitalization actions. Research conducted in a watershed in Italy presented emergetic indicators used to enhance and evaluate production processes effectively, enabling the measurement of the contributions of human actions performed during the process of revitalization of water bodies, directly reflecting values related (Tables 1 and 2) to human activities during and after revitalization (Pulselli *et al.* 2011).

Emergetic assessment is a technical and economic analysis method that can measure the contribution of nature to human economic and social development. The contribution rate of water resources calculated by the emergetic method is beneficial to evaluate the real benefits and contributions of water resource revitalization as found by Lv *et al.* (2018).

The study by Sun *et al.* (2019) identified that the results seen at the sites where the emergetic assessment was conducted show the measurement of complex aspects (such as water quality, investment, and construction costs) in wetlands that after restoration show reliance on renewable resources and improvement in sustainability.

Revitalization actions embedded in the construction of emergetic indicators contribute to the determination of control parameters that evaluate operational efficiencies (purification, water distribution), investments, and the impact that the built infrastructure (sewer and stormwater networks) has on the revitalized ecological environment, as assessed by Wu *et al.* (2019).

4.1.1.3. Step 3: Data collection. The results of the calculations, using emergetic indicators, from the data collected on water quality show that the value of the sustainability index for wetlands after restoration goes far beyond the value presented before restoration, demonstrating the impact of revitalization actions (Sun *et al.* 2019).

The emergy evaluation carried out to describe the revitalization of a watercourse along a hydrographic basin reflected the capacity and efficiency, in terms of the number of resources needed per unit of production of these sites to revitalize the river or stream from the incorporation of materials necessary for the cleaning action (Pulselli *et al.* 2011).

Emergy can understand how infrastructure influences operational and management indicators, such as the state and contribution of the surrounding environment. More specifically, emergy investment analysis assesses aspects such as the significance of river eco-environmental benefits and clarifies the composition of river eco-environmental benefits from both on- (water quality) and off-river (riverbanks, neighborhood) locations (Wu *et al.* 2019).

Emergetic assessments have been used in studies that quantify natural and anthropogenic (material and energy) flows supporting the presence and/or production of water to appreciate the role of energy and matter required for water supply under different contextual conditions (Pulselli *et al.* 2011).

4.1.1.4. Stage 4: Indicator set. The set of emergetic indicators adopted in revitalization actions in water bodies established the urban ecosystem boundary based on administrative divisions and information availability, collecting data for various internal and external system flows through field investigations (secondary data) compiled by the granting authority and sanitation service providers, drawing the energy system diagram, and calculating the emergy (Su *et al.* 2013).

The different emergetic indicators (Tables 1 and 2) presented by Pan *et al.* (2020) may be used in similar studies as reference values because they reflect the characteristics of natural systems that evaluate the emergy of water in rivers or streams. The values presented can change according to man-made infrastructures such as sewage networks, storm water networks, and detours that are along the watercourse.

The study (Su *et al.* 2020) demonstrated that emergy indicators allow for long-term monitoring, and evaluation of the effects of wetland restoration projects in the future, from determining the technical feasibility and scientific validity needed to ease ecological damage and provide data for river health assessment.

The application of an emergy-based scientific assessment method circumvents the major barriers preventing sustainable watershed management by assessing sustainability and indicating a sustainable pattern with increasing environmental loads in the long term (Zhong *et al.* 2018).

The emergetic assessment identified that ecosystem services in negatively affected watershed regions show improvements after human actions for revitalization. The emergetic indicators adopted allow for the measurement of ecosystem services in these interventions and show increases in the calculated emergy rates (Song *et al.* 2021).

The proposed emergetic indicators (Table 2) contribute to understanding the complete revitalization of a watershed, providing valuable technical, social, and political information for decision-makers so that more appropriate policies for sustainability and watershed management can be raised considering local realities.

5. DISCUSSION

The potential of the emergy analysis identified in the existing literature by this study demonstrates the viability of applying the methodology of emergy indicators for the analysis of ecosystem services in de-pollution processes of urban rivers, since the methodology has similar applications (Zhong *et al.* 2018; Pulselli *et al.* 2011), although these works have not directly dealt with the de-pollution of urban rivers.

The procedure for emergy evaluation proposed by this work presents aspects to improve the de-pollution process of urban streams. The scientific literature related to the application of emergy in water bodies presented other approaches, such as the valuation of rivers (Chen *et al.* 2009) and the analysis of environmental benefits in watersheds (Wu *et al.* 2019). Therefore, this study contributes to the introduction of a new use of emergy in an unprecedented area of knowledge when adopted in the de-pollution of an urban stream.

The emergy assessment can be adopted to measure practical indicators that can be periodically monitored to evaluate the process and the costs involved. The emergy indicators present results that demonstrate the impact of the de-pollution of an urban stream, contributing to the relationship of the local population with the revitalized environment.

The results obtained and the proposed application of the emergy assessment demonstrates the existing potential for applying the methodology of emergy indicators for the analysis of ecosystem services in de-pollution processes of urban rivers, as adopted in the verification of emergy indicators in wetlands by Song *et al.* (2021), although the adoption of an emergy sustainability assessment to demonstrate ecosystem services in urban river de-pollution processes was not identified by this study.

This study contributes to the theory by presenting the use of emergy in the de-pollution processes of urban rivers, in addition to demonstrating the applicability of emergy evaluation in revitalization processes based on complex studies involving engineering, climate issues, and society, as presented by Pulselli *et al.* (2011) in their work on urban water scarcity.

With regard to contributions to society itself, the study by Zhang *et al.* (2017) demonstrated that improving investments to revitalize watersheds helps in the correct disposal of investments, sustainability and in improving the relationship between the environment and humans.

The use of emergy analysis can contribute to the economic costs included in the process of de-pollution of urban rivers, as proposed by this study and identified in studies such as Di *et al.* (2019) who presented the evaluation of the costs of transporting sediments in watersheds, using emergy indicators, as well as Wu *et al.* (2019) who used emergy to assess river resources in an ecosystem.

6. CONCLUSION

The results and the proposal for the application of the emergy assessment show the potential for the application of the emergetic method indicators for the analysis of ecosystem services in urban river de-pollution processes. The adoption of an emergetic sustainability assessment to show ecosystem services in urban river clean-up processes was not identified by this study.

The results contribute to theory by presenting the use of emergy in urban river de-pollution processes, besides showing the applicability of emergetic assessment in revitalization processes based on complex studies involving engineering, climate issues, and society.

Regarding the contributions to society itself, the study presented shows that the improvement of investments for the revitalization of urban rivers assists in the correct disposal of investments, sustainability, and relationship improvement between the environment and human beings.

The contribution of this study to organizational practices that promote urban river revitalization is related to the simultaneous application of the following five actions:

(i) Analyze all the energy flow inserted in a de-pollution process, from water quality (before and after de-pollution) to the costs for the enlargement of the sewage networks;
(ii) Evaluate the renewability of the system and the sustainability of the process from the calculated emergencies;
(iii) Identify economically whether the process is consuming or making electric power available to the environment, identify the economic pressure on the ecosystem;
(iv) Assess whether the investments made are sustainable; and
(v) Indicate if the system contributes to environmental balance or if the impacts can be absorbed by the system.

In establishing an ideal model to jointly evaluate the revitalization of water, the control of costs inserted in the process and the ecosystem services that the stream provides the integration relationship between all aspects inserted in the system, according to the characteristics of each parameter creates a main link to foster a sustainable process. In this context, the use of emergy assessment can contribute to the coupling of aspects and allows the analysis of the system without creating difficulties for those responsible.

When analyzing the process of improvement in the water quality of the stream studied from the emergy indicators, the positive effects and influences of water in the economic, social, and ecological environment can be described in a comprehensive way and propitiate the continuity of the process in a sustainable way.

This study shows some paths for future research, as well as practical and theoretical contributions from the use of a procedure for emergetic evaluation in the de-pollution of urban rivers. Thus, in the de-pollution process of urban rivers, the major gaps identified are sustainability indicators that show improvements after the de-pollution process; analysis of ecosystem services inserted in the de-pollution of urban rivers from sustainability indicators; application of emergencies indicators in ecosystem services associated with the de-pollution of urban rivers.

The study of these gaps can contribute to the improvement of urban river revitalization processes, increasing control over the costs involved and complementing the process through the association of ecosystem service indicators for the sustainable development of the process.

The proposed application of the emergencies indicators in the urban river and stream de-pollution processes observes the aspects studied in the systematic review and their effective use of an urban hydrological system.

Further studies should apply the emergetic assessment in places where there is an urban river de-pollution process to analyze the indicators and develop the procedure as a sustainability tool in urban water body restoration.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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First received 4 July 2023; accepted in revised form 16 September 2023. Available online 4 October 2023