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Best Practices in River Water Restorations from Industrial Pollutions in Developing Countries

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ABSTRACT: The main problems faced by damaged rivers in developing countries are the deterioration of water quality due to the release of domestic and industrial pollutants and changes in hydrological processes caused by the construction of hydraulic structures. The main objective of this study was to provide an overview of the best river restoration methods for developing countries and outline the best process that can be used in planning the river restoration process. The study adopted the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) and a literature review approach. This research identified the best river restoration methods that have been in use in developed countries and can be used by developing countries with similar economic and climatic conditions to restore their river resources. The study presents descriptions and conclusions useful for environmental restoration experts to understand better the processes and river restoration methods in developing countries. This research material groups the river restoration methods into physical, chemical, biological-ecological, and aquatic vegetation rehabilitation methods. The research also discusses the challenges likely to be faced while assessing a river restoration project's success.

KEYWORDS: Developing countries, River restoration, Water pollution.

1. INTRODUCTION

Rivers fulfil many functions such as water supply, food production, sediment transport, power generation, shipping, sightseeing, etc.; therefore, they play an essential role in human life and agricultural production [1]. Due to the rapid growth of industry and agriculture, the intensity of the exploitation and use of rivers by people has gradually increased. Therefore, the rivers are under intense pressure from people, and some of the functions serving them tend to deteriorate. River restoration can be defined as the process of eliminating anthropogenic damage to the diversity and the river ecosystems' dynamics. According to [2] many developing countries are struggling to restore their polluted rivers due to lack of relevant government institutions, limited resources, legal frameworks, and regulatory capacity.

In recent years, river managers have shifted their focus from integrated engineering solutions to environmental remediation measures to Improve degraded waters [3]. To restore the damaged river ecosystem to a healthy state, it is necessary to take adequate measures to restore the environment. Therefore, there is a need to clarify the recovery planning process, define the goal of recovery, and prioritize restoration actions [4]. The first step in a restoration program is to identify the damaged rivers' impaired functions and the extent of the river systems' damage and limitations. Then, it is necessary to prioritize recovery goals and develop recovery measures. The main problems damaged rivers face are the deterioration of water quality due to the release of pollutants or changes in hydrological processes caused by the construction of hydraulic structures

It is also important to note that many industrialized countries have more well-organized river rehabilitation options when compared to the developing countries. This is because the developed countries have stronger government sectors and institutions and a greater availability of resources [2]. For instance, in many developed countries, rigorous engineering approaches mitigate risk effectively but require significant maintenance, investment, and environmental costs. On the other hand, most developing nations do not have the financial capital for implementation of the same strategies in industrialized nations [5]. Hence, traditional approaches to river restoration in developing countries focus mainly on low-tech engineering solutions such as bank restructuring, riverbed construction, or local expansion [6]. Therefore, a different approach to river rehabilitation, appropriate to developing countries' unique conditions, is needed. The main problems that are faced by polluted rivers in developing countries are the deterioration of water quality due to the release of pollutants, domestic and industrial, and changes in hydrological processes caused by the construction of hydraulic structures. River restoration aims to improve the river ecosystem's structure and productivity by increasing its biodiversity. However, methods of ecological restoration are poorly documented for developing countries, hence the need of this research. This research identifies the best river restoration methods that have been in use in developed countries and can be used by developing countries to restore their river resources.

2. Materials and Methods

The main objective of this article was to provide an overview of the best river restoration methods for developing countries. The study also aimed to develop the best plan for river restoration exercises in developing countries. The study adopted the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) and a literature review approach to achieve this goal. This study searched selected databases for peer-reviewed articles, books, and grey literature. A literature review revealed research gaps that influenced the search strategy used. Eligible literature was thoroughly reviewed and discussed. Finally, the extract excerpts in the thematic analysis were a result of the pooled results

2.1 Literature Review

The study conducted a systematic review following the approach of [7]. This approach details the methods of analysis, collection, viewing, and reporting.

This review aimed to identify methods and plans for developing successful river restoration projects in developing countries. Also, the study includes a river restoration plan containing various principles, techniques, and steps for planning river restoration in developing countries, particularly their implications for environmental, economic, and social aspects in this context. It also includes an analysis of the challenges associated with assessing river restoration exercises. These aspects relate to how each maintains river health, ecosystem well-being, and community safety by coping with water pollution, the impact of informal settlements, and floods.

Determining a river restoration planning strategy is essential, especially at the commencement of the restoration exercise. Restoration experts must clearly define the goals of the recovery plan before setting a strategy. Some restoration experts argue that the river restoration objectives depend on the environmental conditions of the project. In contrast, others state that river restoration's fundamental goal is to improve ecological integrity [8]. In any case, according to [9], a planning strategy can include up to 5 stages: strategic planning, scoping, project planning, execution, and use.

The high cost of traditional wastewater management technologies has left many developing countries in a critical situation. Traditional centralized modern wastewater treatment systems that are commonly used in industrialized countries are usually not appropriate for developing countries due to the complex operation and management required [10] and [11]. In many developed countries, state owned centralized systems collect and later treat big volumes of wastewater using large structures, ditches, pipes, and wells. On the other hand, developing countries lack the funds and technical expertise to build, operate and manage these facilities centrally [10]. Also, traditional discharge systems, currently in use in developing countries, adversely affect ecosystems, such as loss of clean water, eutrophication, health risks associated with pathogens, and decreased tourism [11].

The review also used a thematic analysis approach by [12] to extract and select potential converging topics for a systematic review. The selected literature was qualitatively analyzed to reflect the various methods that have been successfully used in river restoration in developed countries and may also be applied in developing countries.

3. RESULTS

3.1 The process of River Restoration

River restoration has become significant as people appreciate that changes in hydrology, water chemistry, and river biology have unintended consequences for urban [13] and other zones [3]. These efforts require restoring natural hydrology and understanding how the dynamic equilibrium of geomorphology can be restored to ensure the lasting system’s stability. One form of river restoration developed into a more common one is removing dams to return the river to natural runoff. Restoration objectives should consider geomorphology, the life cycle of species of interest to managers [14], and the desired ecosystem functions [15]. Complete restoration will also consider natural heterogeneity, landscape interconnectedness, and interactions at the ecological level [16]. This is necessary for rivers to provide ecosystem services such as flood protection [17]. New high-frequency sensing techniques allow managers to evaluate restored runoff conditions and water chemistry with a much greater ability to detect differences between restored and unrecovered systems [18]. Although managers often try to reconstruct morphology, recovery of flow dynamics is less likely [19]. However, the restoration of their morphology is necessary for the restoration of services offered by ecosystems that are associated with flowing waters [20]

River systems are complex and depend on what lies within them, their history, and the environment [21]. Therefore, to achieve ecologically efficient river restoration within the constraints imposed by anthropogenic systems, the principles of ecological restoration must be incorporated into the restoration process. If restoration is well planned, implemented, and monitored properly every river restoration project should be a successful one and be able to contribute to the progress of river restoration ecology as science.

a) Planning Phase

In ecological restoration, the aim is to restore natural processes in the river and its sustainability. The planning phase is the most critical stage during the river restoration process since its goals and objectives are formulated here. The objectives are arrived upon by coming up with an overall idea of what the polluted river ecosystem could possibly be restored to. The objectives can also be derived based on the original undisturbed state of the river before disturbance and pollution by human activities, and then narrowing the emphasis on what could be attained given the constraints [22]. The river restoration exercise goals should address issues with the river ecosystem's overall integrity as identified by scientists or managers or reported by interested people. The specific recovery methods and monitoring programs are developed based on the set goals, so the goals should be broad enough. Such goals include restoring local fish populations and reducing nutrient and sediment loads. It is necessary to define measurable goals with specific time frames when the goals are set. Setting particular, quantifiable goals helps to determine the essential recovery methods and the appropriate monitoring scheme.

Recovery planning includes assessing the historical conditions and the projected changes in situations resulting from future developments and changes in climatic conditions. Old aerial photographs, past survey data, and old maps can also provide information about historical conditions. Planning how to achieve this goal within the constraints imposed requires the public participation of the concerned groups. Such stakeholders include river managers, scientists, people living near or on the riparian land, individuals using the river for recreation or cultural activities, and businesses that rely on the river's resources for survival. Communication between these stakeholders is vital when planning the river restoration work. One of the most significant challenges faced by those planning the recovery projects is effective communication between stakeholders [22]. Also, project developers should include a cost-benefit analysis because small, localized projects can have relatively low costs and not benefit.

b) Implementation Phase

Environmentalists advocate that, with whatever methods used during the restoration process, rivers should not be harmed. The methods identified during the design phase are now implemented during this phase of the river restoration project. Reaching river restoration objectives often requires methods that transcend direct riverbed impact [22]. These off-channel methods have not been historically utilized in river restoration projects, although they are often more practical in improving river systems' standard than channel manipulation [21].

c) Monitoring phase

During this phase, data is collected and critically analyzed. Environmental restoration experts then use this analyzed data to determine the success of the restoration exercise and whether the recovery project has achieved the goals and objectives that were identified during the planning phase. At this stage, the baseline information collected during the planning stage is very vital. Assessing river restoration's ecological success may be difficult in practice, even though conceptually simple, and may be an important research topic within river restoration ecology. This subject is of interest because, given the ever-increasing demand for recovery and limited financial resources, it is essential to understand if recovery improves environmental conditions so that money is often spent effectively.

3.2 Ecological restoration of damaged river

River water pollutants mainly include organic pollutants, nutrients (i.e., nitrogen, phosphorus, and others), and heavy metal pollutants. There are three main methods for remediation of polluted rivers: 1) chemical methods, which include chemical flocculation, the addition of chemical algicide, lime dosing, and on-site chemical reaction method; 2) physical methods, which involve catching and dredging of wastewater, sheltering, removing algae by mechanical methods, draining water.; and 3) bioecological techniques, which include biomanipulation techniques, aquatic plant restoration, biomembrane techniques, microbiologically advanced techniques, activated sludge techniques, land cultivation techniques, and aeration.

a) Physical methods

When it comes to river restoration, *streambank stabilization* is the overall goal of watercourse restoration projects, even though a river bank's erosions generally considered beneficial to the sustainability and diversity of aquatic and coastal habitats [23]. Ecologists achieve bank stabilization by installing riprap, gabions, or by use of revegetation and/or bioengineering methods. The streambank stabilization and restoration program is designed to demonstrate effective, low-cost vegetative and biotechnological techniques to limit stream banks' erosion. The streambank stabilization technique can be used in cases where a stream reach is very difficult or highly confined or where infrastructure is threatened [24].

Wood or stone structures are usually used to install *deflectors* at the base of the riverbank. These deflectors extend towards the centre of the river to concentrate the stream from the banks. Flow deflectors slow down the speed of the water and cause sedimentation. They, therefore, can be used to limit coastal erosion and create varying flow conditions in depth and speed, positively affecting the fish habitat [25].

Mechanical algae removal methods can be used to directly clean large areas of blooming algae without significant adverse effects on aquatic ecology. Therefore, in the event of pollution emergencies, mechanical methods are usually applied in algae removal. Removal of algae by electrocoagulation-flotation (ECF) has been found to be an effective method. In regions where blue-green algae are abundant, algae can be efficiently removed using mechanical methods like gas flotation, Plocher's system, ultrasound, stationary mechanical devices, or moving vessels [26]. *Step pools, weirs and grade-control structures* built with rocks or wood can be used to lower the stream's elevation and dissipate flow energy gradually, and thereby reducing flow velocity [24]. In addition, the step pools, weirs and grade-control structures can help limit bed degradation.

Compared to pollution from point sources, pollution from non-point sources is difficult to control due to its large amount and wide range of pollution. Typically, pollution from point sources is mainly controlled by interceptors through *sewage interception and dredging*. As pollution continues, pollutants accumulate at the bottommost of the river channels. Dredging of contaminated bottom sediments can remove contaminants from the bottom of the reservoir, reducing sediment-induced pollution, thereby improving water quality [27].

By applying the *water diversion method*, contaminants in polluted rivers can be diluted, diffused, and transported by importing large volumes of clean water from elsewhere, resulting in improved water quality and higher dissolved oxygen concentrations. After draining the water, the river remains in its current state and can maintain a higher level of dissolved oxygen concentration and the ability to self-purify. Thus, biological oxidation in the water column and bottom sediments is improved, and the release of reducing materials and nutrients can be reduced [28].

b) Chemical Methods

Heavy metal ions can be fixed *in-situ through chemical reaction techniques* such as reduction, oxidation, precipitation, and adsorption. [29]. Commonly used substances in this technique include lime [$Ca(OH)_2$], ash [KOH], sodium sulphide [Na_2S]. Acidification of water occurs mainly through fossil fuels' combustion. In acidic water, *lime dosing* is a quick, simple, and effective way to restore water quality [30]. The *addition of a chemical algicide* is a simple, convenient, and effective method. The most common algicides used in the restoration process are potassium permanganate, copper sulphate, liquid chlorine, ozone, chlorine dioxide, and hydrogen peroxide [31]. It should be noted that the application of this method can lead to secondary pollution and toxic effects on other aquatic organisms.

c) Biological – ecological methods

In *bio-manipulation technique*, or simply food chain manipulation, the number of fish feeding on zooplankton is reduced by excluding fish feeding on zooplankton or adding predatory fish, thereby regulating the zooplankton community structure, i.e., filtration efficiency. Ultimately, the efficiency of eating zooplankton for phytoplankton increases, and the biomass of phytoplankton decreases. The introduction of submerged plants also contributes to zooplankton and macroinvertebrates' development, as plants can serve as various habitats and food sources. Zooplankton and macroinvertebrates can effectively suppress phytoplankton development [32]. *Activated sludge* can be divided into aerobic activated sludge and anaerobic granular activated sludge. Activated sludge has a high capacity for adsorption and decomposition, so it can be used to purify and purify wastewater [33]. Dissolved oxygen is lacking in polluted rivers. Artificial *aeration* is an excellent solution to this problem. When water is artificially filled with air or oxygen, water reoxygenation is accelerated, the viability of aerobic microorganisms is restored, and the water in the river is purified [34].

The microbial enhancing technique is used when the water is heavily contaminated, and microorganisms are absent. Dosing the microorganisms into the water can promote the pollutants' decomposition [35]. [36] investigated the effect of the bioavailability of 2-methylpyridine (2-MP) on the biodegradation of Arthrobacter sp. Good results were obtained in removing contaminants. *The land treatment technique* uses the land as a treatment facility and purifies the water through adsorption, filtration, and purification of the soil and plant system [37]. Practical applications have confirmed that land treatment systems can effectively remove organic compounds (especially organic chlorine and ammonia).

d) Aquatic vegetation rehabilitation

Aquatic plants can control eutrophication by absorbing nitrogen, phosphorus and heavy metal ions, and heterotrophic microbes in plant roots can remove organic pollutants through assimilation and catabolism [38]. According to plant growth characteristics, three main types of macrophytes are distinguished: above-water, floating, and underwater. Before using this technique, it is necessary to reduce the load on the reservoir with nutrients; otherwise, artificially restored aquatic plants will not come to a stable state. Clearing native coastal vegetation and removing large woody debris from streams can cause widespread detrimental effects on riverine geomorphology and aquatic ecology.

3.3 Challenges in Evaluating River restoration

One of the difficulties in assessing environmental success is the need to measure river processes and their variability. Since the sustainability of biological communities depends on river processes, the river restoration process's assessment provides a good indication of the likely long-term success of the project [21]. Monitoring of the success of a river restoration project is often difficult because the best methods for assessing processes are not agreed upon or simply unknown.

Another challenge in assessing a river restoration project's success is that the data collected from the rehabilitated section of the initially damaged river needs to be compared with the data obtained before the restoration of the river. This data is usually compared to that in the adjacent section of the river upstream of the remediation section or with available reference data for several rivers. If reference rivers are used, they need to be carefully selected. This is because geomorphological and hydrological conditions and land use can vary significantly across river basins. Recent research recommends that the choice of reference rivers can change conclusions about the success of restoration.

A third difficulty is that, ideally, recovery needs to be assessed at the watershed scale. Specific attention should be paid to whether the individual project has contributed to an overall improvement in environmental conditions at the local and downstream levels. Recovery at a catchment scale can take a couple of years or the process may even end up running for decades. Therefore, this will require long-term monitoring of conditions on a large spatial scale to appropriately evaluate river recovery success. Even when part of a small local project, monitoring should be carried out over many years to ensure that the rehabilitated section of the river is rehabilitated and that the variability of system characteristics over time is adequately assessed.

The success of restoration should not be solely judged by ecological characteristics. Non-ecological aspects, such as aesthetics or improved health, also play a significant role. Monitoring success based on these characteristics requires a shift in focus towards people's attitudes towards recovery rather than solely on ecosystem properties. The inclusion of consistent monitoring of these criteria in more river restoration projects will not only contribute to the development of the science of restoration ecology but also foster a more holistic approach to restoration assessment.

4. DISCUSSION

Ecological restoration projects are needed to achieve several objectives. River restoration aims to improve the river ecosystem's structure and productivity by increasing its biodiversity [39]. Ecological river restoration projects should improve the entire ecosystem rather than focus solely on improving water quality. Water resource management is accelerating the transition from water quality management to water ecosystem management through the continuous implementation of the concept of harmony between man and nature.

Chemical, physical and bioecological methods are commonly used to clean up polluted rivers around the world. Among these methods, chemical methods are considered palliative. They can easily cause secondary pollution and should only be used as an emergency measure to control flash pollution [30] and [31]. If physical methods are used, the costs are relatively high [40]. In comparison, bioecological methods do not cause secondary pollution; they combine environmental restoration with landscape improvement and create an excellent environment for uniting humanity and nature [41] and [42]. Thus, bioecological methods are currently the most popular methods for the rehabilitation of polluted rivers. The river ecosystem is threatened by environmental influences on the coast, including human activities and natural processes [43]. River restoration needs to be carried out at the catchment scale, complex river ecosystems and terrestrial ecosystem. The scale of ecological restoration has increased - from individual sites to entire river basins. Multipurpose planning, design, scheduling, operations and management have become an understandable trend [1].

5. CONCLUSION

This study aimed to identify methods and strategies for developing successful river restoration plans in developing countries. The study presents descriptions and conclusions useful for environmental restoration experts to understand better the processes and river restoration methods in developing countries. Practitioners should continue their professional education and development and adapt their approaches as more data becomes available from post-project assessment and monitoring. At the time of this writing, the greatest threats to future progress appear to come from population growth and climate change, which could stifle recovery efforts. While this study provides valuable insights, there is a need for more comprehensive and concrete research, including real-life examples of each proposed method in developing countries. Such research could form a significant part of future studies on river restoration in developing countries. Furthermore, applying the restoration concept from a developed country to a specific area, such as developing countries with similar economic conditions, the same climate, or a certain catchment size, will enable more reliable research into the applicability of these methods from one place to another. This emphasis on real-life examples and applicability issues can pave the way for future advancements in river restoration practices.

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