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Understanding Water Pollution in the Kelani River Basin: A Comprehensive Literature Review on Causes, Ecological Impact, and Management Strategies

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ABSTRACT

A growing body of research indicates that water pollution affects aquatic ecosystems negatively and is a widespread problem. This research focuses on the Kelani River basin in Sri Lanka since there are serious problems with water pollution there, despite the fact that contamination impacts many water bodies globally. This research primarily relies on secondary data collection methods, including research articles, journals, publications, annual reports, and official internet sources. The collected secondary data underwent qualitative analysis, which subsequently contributed to the presentation of descriptive findings in this study. Through the research, the researcher identified two main causes of water contamination in the Kelani River basin: point sources and non-point sources. Over 9,000 industrial establishments contribute significantly to pollution. Additionally, hydropower construction affects 30% of the river's course. Furthermore, the Kelani River basin holds ecological significance as a habitat for numerous endangered and endemic species, including critically endangered and narrow-range endemics such as Balanocarpus kitulgalensis, Vetica luwesiana, Pethia bandula, and Systomus asoka. Recognizing the urgency of water conservation, we propose comprehensive strategies: stringent regulations, sustainable land use, effective waste management, critical ecosystem protection and restoration, and community engagement. Furthermore, maintaining the ecological integrity of the Kelani River and its benefits to human well-being requires tackling both point and non-point causes of pollution.

KEYWORDS: Disposal, Industries, Construction, Waste Management, Water Pollution

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INTRODUCTION

Water, an indispensable resource for all life forms, exists in various forms, including rivers, glaciers, rainwater, and groundwater. A multitude of variables combine to make managing the freshwater supplies that are available and preventing their degradation an increasingly difficult task. These factors encompass the burgeoning global population, heightened water demand, climate change, deforestation, urbanization, pollution, geological and topographical variations, and soil characteristics (Dudgeon, 2000 (01)). Notably, anthropogenic influences emerge as the primary drivers disrupting water quality and the management of freshwater resources. Consequently, this exerts additional pressure on water service providers, particularly in developing nations, to ensure water quality and the sustainable management of freshwater sources. Unintentional results of human activity eventually end up in rivers, streams, and oceans as toxins via runoff and effluent discharge. Two major elements that have a direct impact on the availability of water sources for all living things are changes in land use and climate (Malmqvist & Rundle, 2002; Dudgeon, 2000 (01)).

Let us now turn our attention to Sri Lanka, which has 103 rivers in total. Of these, 29 flow straight into the sea, while the remaining 103 connect to major rivers, lagoons, salt marshes, or lakes (Katupotha & Gamage, 2020). Many of these rivers are still underutilized, but a small number are subject to strict regulations for hydropower production, irrigation, and household use (Eriyagama et al., 2015). Notably, there are serious pollution problems with the heavily used rivers that flow through highly inhabited and urbanized areas. Rivers including the Gin Ganga (Kumar et al., 2019), the Walawe River (Illeperuma, 2000), the Mahaweli River (Abeygunawardane et al., 2011; Bandara et al., 2011; Wickramasinghe et al., 2018), and the Malwathu Oya (Zoysa & Weerasinghe, 2016) all exhibit this problem. But the unenviable title of being Sri Lanka's most polluted river goes to the Kelani River (Ileperuma, 2000; Abeysinghe & Samarakoon, 2017; Kumar et al., 2019). With a length of 144 kilometers, the Kelani River is the fourth longest river in Sri Lanka and provides over 80% of the water used in Colombo (Kumar et al., 2019). The Sri Pada Mountain range is the source of the Kelani River, which flows through the hill country before emptying into the ocean near Colombo. The Kelani River performs a number of essential tasks in addition to providing drinkable water, including transportation, hydropower production, agriculture, fisheries, sewage disposal, and sand extraction. Furthermore, the river's aquatic biodiversity is extremely significant since it supports a wide range of common, threatened, endemic, and point endemic species (Narangoda, et al., 2023).

However, the Environmental Foundation Limited (EFL) has released a grave assessment designating the Kelani River as Sri Lanka's most contaminated and endangered watercourse. A number of sources contribute to pollution: runoff from agriculture, wastewater from homes and businesses, and discharges from more and more industry near the river (Dudgeon, 2000 (01)). Alarming trends indicate that the Kelani River's contamination is on an alarming upward trajectory due to the escalating release of pollutants into its waters. Consequently, there exists a looming threat that the river may reach a point where it can no longer serve as a reliable source of drinking water or safeguard the endemic aquatic species. This potential crisis assumes paramount importance given the Kelani River's pivotal role in supplying drinking water to people and conserving Sri Lanka's unique aquatic biodiversity (Dudgeon, 2000 (02)). Therefore, this study aims to comprehensively investigate the causes, ecological significance, and water management strategies essential for preserving the Kelani River. By doing so, we can ensure the provision of clean water for future generations and the conservation of Sri Lanka's endemic aquatic species.

RESEARCH PROBLEM

Recent years have seen a worrying reduction in the world's renewable water resources, which has been mostly linked to reasons such as pollution, deforestation, urbanization, climate change, increased water demand, and a growing global population (Gebeyehu, et al., 2018). Many aquatic ecosystems in both developed and developing countries have become contaminated as a result of this depletion. A significant fraction of the population in underdeveloped nations is frequently forced to use river basins and canals as their main sanitation systems due to a lack of sanitary facilities, which exacerbates the problem. Additionally, household and industrial waste finds its way into these water bodies, compounding the problem (Dybern, 1974). According to research by Sikder et al. (2013), dissolved metals, organic waste, and fecal contamination have a significant effect on rivers in impoverished nations.

One such critical waterway facing these challenges is the Kelani River in Sri Lanka, renowned for its significance as a primary river in the region. Nevertheless, the escalating demands of urbanization, driven by rapid population growth, have taken a toll on the water quality of this vital river. Many studies have connected river water quality degradation to point source pollution (direct discharges from land use categories that include residential, industrial, and agricultural operations) as well as non-point source pollution (urban stormwater runoff; Dudgeon, 2000 (01)). The situation is made much more difficult by the fact that the Kelani River

is home to numerous aquatic endemic species that are exclusive to Sri Lanka and provide the local population with a major source of drinking water. As a result, the current study problem relates to the pressing requirement for efficient conservation measures to manage the Kelani River's increasing pollution in Sri Lanka. The need to protect this priceless water resource, guarantee the availability of clean drinking water, and maintain Sri Lanka's rich aquatic biodiversity is highlighted by this problem.

RESEARCH OBJECTIVE

The Researcher aims to focus on water pollution in the Sri Lankan Kelani River Basin, with a specific focus on identifying and analyzing the causes of pollution, understanding the ecological significance of the river ecosystem, and proposing effective management strategies.

RESEARCH METHODOLOGY

The research primarily relies on secondary data collection methods. Relevant secondary data, such as research articles, journals, publications, annual reports, books, and official internet sources, have been gathered and analyzed. Additionally, to supplement the secondary data, references have been drawn from pertinent literature and research papers both nationally and internationally, all of which are relevant to the subject matter of this study. The collected secondary data underwent qualitative analysis, and the findings are presented descriptively in this study.

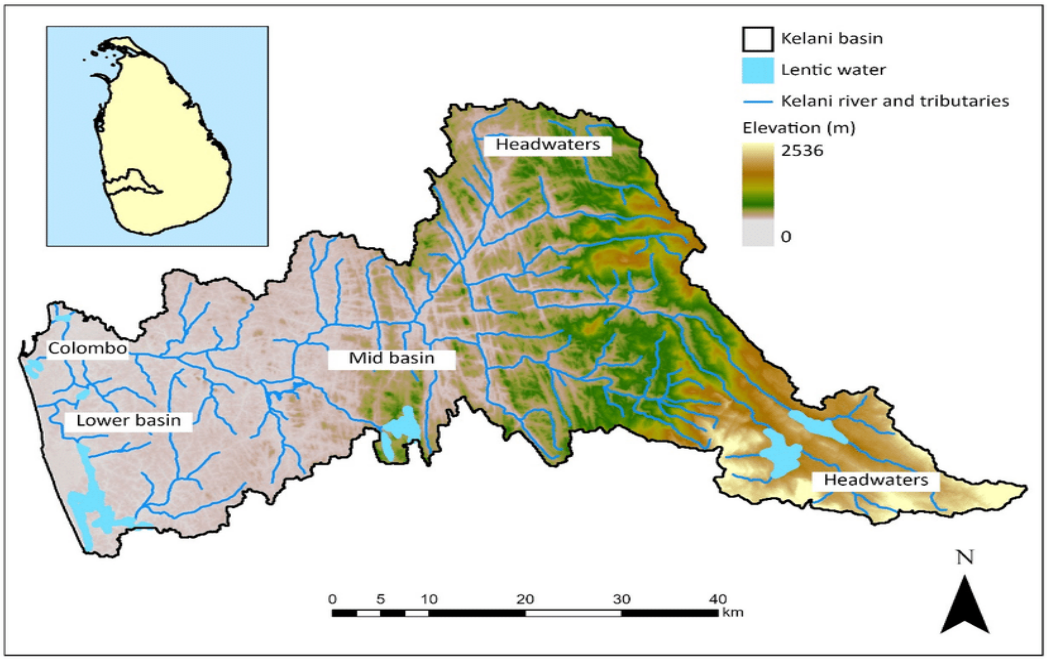
Study Area

The Kelani River basin spans 2230 km2 and is situated between the northern latitudes of 6° 47' to 7° 05' and the eastern longitudes of 79° 52' to 80° 13' (Mahagamage & Manage, 2018). Flowing through several districts, including Nuwara Eliya, Kandy, Ratnapura, Kegalle, Kalutara, Colombo, and Gampaha, it is one of Sri Lanka's longest rivers. This comprehensive coverage, which includes 37 Divisional Secretariat districts, demonstrates the river's important impact on a wide-ranging and diversified geographic area. Starting in the central hills of Sri Lanka, more precisely in the Nallatanniya region, this important river travels 144 kilometers to end up in the capital city of Colombo, which is the country's most important commercial metropolis (Narangoda, et al., 2023). To better understand catchment behavior, the entire Kelani River basin has been chosen as the study area for this research and separated into three regions (Figure 01). These areas comprise low-order top reaches with forested central highlands, mid-reaches with

low-moderate intensity development, and lower reaches with Colombo, Sri Lanka's capital (CEA, 1985).

Within Sri Lanka's hydrological landscape, the Kelani River assumes paramount significance as it caters to more than 80% of Colombo's water demand, underlining its vital role in sustaining urban life. Moreover, the Kelani River serves multiple essential purposes, including facilitating transportation, supporting irrigation, sustaining fisheries, and enabling hydropower generation. Its discharge exhibits notable seasonal variability, fluctuating from 800 to 1500 cubic meters per second during the monsoon seasons and decreasing to 20–25 cubic meters per second during dry periods. This dynamic flow regime hinges upon the operation of three strategically located reservoirs within the river's expansive catchment area (De Zoysa & Inoue, 2008).

Figure 1: Map of Kelani River Basin, Sri Lanka



Source: Surasinghe, et al., 2019

The whole mainstem, significant tributaries, and associated lentic systems of the Kelani River Basin in Sri Lanka are depicted in the above figure. The geographic expanse of the basin includes Colombo, the commercial hub of Sri Lanka. Moreover, the boundaries of the upper, lower, and midbasins are all distinct.

RESULTS AND DISCUSSION

1. Introduction to Kelani River

The Kelani River, which flows through the districts of Gampaha and Colombo in Sri Lanka, is an important river in an area with a significant concentration of industrial activity. Because so many people in the nation depend on the waters of the Kelani River for their daily needs, it is critical for water resource managers to comprehend the complex interplay between land use and surface water quality. The 144-kilometer-long Kelani River is extremely important economically to the people of Sri Lanka since it supports a wide range of residential, industrial, and agricultural activities. Encompassing two fast industrializing and heavily populated urban districts, Gampaha and Colombo, the river basin is the second largest in Sri Lanka and is located within its lower-middle part (Narangoda, et al., 2023). The Peak Wilderness Sanctuary and the western side of the central uplands in Horton Plains National Park are its source areas, and it drains a sizable region that is roughly 2,292 square kilometers in size. The flow dynamics of the river display significant seasonal fluctuations, with a range of 800 to 1500 cubic meters per second during the monsoon season and 20 to 25 cubic meters per second during the dry season. The latter is dependent on the state of operation of three reservoirs situated within its catchment region. Interestingly, between 600,000 and 800,000 cubic meters of sand are extracted from the river each year; this process is done solely by hand labor, albeit it does cause a steady 10-centimeter annual sinking of the riverbed (De Zoysa & Inoue, 2008).

The Kelani River plays a pivotal role in providing a spectrum of essential water resources, encompassing drinking water requirements, electricity generation, agricultural needs, industrial processes, household consumption, recreational activities, and other critical environmental utilities. Furthermore, it contributes significantly to the preservation of a robust ecosystem, renowned for hosting nationally important habitats that accommodate a diverse array of common, endangered, endemic, and point endemic species. Several major water intakes are strategically positioned along the Kelani River, serving locales such as Avissawella, Kosgama, Biyagama, Pugoda, and Ambatale. In the districts of Gampaha and Colombo, the National Water Supply and Drainage Board (NWSDB) uses the waters of the Kelani River to provide drinkable water to a sizable metropolitan population. The Kelani River's resources are also utilized by well-known businesses including American Waters, Pepsi, Coca-Cola beverages, and Ceylon Cold Stores PLC, all of which primarily rely on water as their principal production ingredient. But there's a serious environmental problem with the river's

increasing contamination, which is caused by industrial waste that is released during production (Dudgeon, 2000 (02)).

2. Causes of water pollution in Kelani River

The Kelani River, a pivotal freshwater resource in Sri Lanka, has recently grappled with a formidable environmental challenge in the form of pollution. The river, historically integral to local communities for drinking water supply, agricultural sustenance, industrial applications and habitat for aquatic endemic species, now confronts a complex and pressing issue - pollution (Surasinghe, et al., 2019). This multifaceted issue arises from a complex interplay of factors, stemming from both point and non-point sources of pollution. In this comprehensive analysis, we delve into the causes of water pollution in the Kelani River, categorizing them into point and non-point sources, to shed light on the challenges this vital Sri Lankan waterway faces.

Picture 1: Source CITATION Rod16 \l 1033 *(Rodrigo, 2016)*

Picture 2: Source CITATION Dai15 \l 1033 *(Daily Mirror, 2015)*

Picture 3: Source CITATION Col20 \l 1033 *(Page, 2020)*

Point - Sources

When examining the point sources of water pollution in the Kelani River basin, several key contributors come to the forefront. These include industries, waste disposal practices, hydrological changes and overexploitation. Let's delve into how each of these elements contributes to water pollution in the Kelani River basin,

I. Industrial Discharges

Industrial discharge, a ubiquitous facet of contemporary industrialization, poses a significant threat to water ecosystems worldwide. The release of effluents from industrial activities introduces a spectrum of pollutants into water bodies, with ramifications for both aquatic ecosystems and human well-being. The Kelani

River emerges as a critical focal point of water pollution stemming from industrial activities within its basin. Though widely acknowledged as one of Sri Lanka's most polluted rivers, the Kelani River serves as the main supply of water for Colombo, the country's commercial centre. Thus, it has been shown how sensitive the Kelani River basin is to the environment, from Glencorse (6.9643◦ N, 80.1877◦ E) to the river mouth (6.9787◦ N, 79.8700◦ E) (Narangoda, et al., 2023). This emphasis stems from the necessity of maintaining acceptable limits for the concentrations of water quality. The catchment area, which has been identified based on its environmental value, faces a contradiction because of the significant concentration of private and governmental industrial businesses, which are primarily located in Sri Lanka's Western Province (CEA, 2023). In addition to taking up a substantial chunk of the Kelani River basin, this industrial presence also makes a major contribution to the current problems with water pollution (Mallawatantri, et al., 2016). According to the Central Environmental Authority (CEA, 1992), the Kelani River basin hosts an extensive industrial presence, numbering over 9000 establishments categorized into three groups based on their pollution potential: Category A comprises highly polluting industries, Category B includes medium polluting industries, and Category C encompasses low polluting industries. Interestingly, 2600 industries are under Category A, 3500 are under Category B, and 3000 are under Category C. Over 6,000 enterprises in this vast industrial environment immediately release garbage into the river (Justice, 2015; Dissanayake & Rajapakse, 2019; Gunawardena, et al., 2017). According to Gunawardena et al. (2017), this combined discharge results in an estimated daily point-source discharge surpassing 414,600 cm3, which causes a significant biological oxygen demand above 11,600 kg daily.

Seethawaka and Biyagama are home to two sizable industrial zones with centralized waste treatment facilities (Picture 04). Furthermore, a significant number of industries line themselves along the river's path and spread outside these specified zones. Numerous enterprises discharge both treated and untreated industrial effluents into the waters of the Kelani River, which serves as the drainage basin for the most densely populated province in the nation. Interestingly, a number of major industries that produce wastewater are housed in the Biyagama Export Promotion Zone. These industries include those that produce raw rubber, rubber latex, textiles, food and beverage, steel, fertilizer, and other industrial operations (Mahagamage et al., 2014). Water quality measurements at the Thulduwa and Seethawaka ferry monitoring sites surpassed specified criteria (CEA, 2015). The parameters under scrutiny comprised of Chemical Oxygen Demand (COD) surpassing standards 37% of the

time, Biological Oxygen Demand (BOD) exceeding standards 13% of the time, Dissolved Oxygen levels falling below standards 43% of the time, and Heavy Metal concentrations surpassing standards 7% of the time. According to Mallawatantri et al. (2016), the Seethawaka ferry site's receipt of industrial effluent from the Seethawaka industrial zone is a significant contributing factor to the decline in water quality at these two locations over the previous three years.

II. Improper Waste disposal (Sewage waste and Solid waste)

One of the main point sources of water pollution, especially in the lower and mid-reaches of the Kelani River, is the inappropriate disposal of waste, which includes both solid waste and sewage waste. Water bodies can get contaminated as a result of the careless disposal of solid waste and sewage, which is a serious environmental risk. The Kelani River basin's overall ecological health and water quality are being negatively impacted by insufficient waste management techniques, which are exacerbating the problem. This has been a serious problem, with documented cases of uncontrolled trash disposal dating back to the 1980s, primarily in the busy city of Colombo (Peters, et al., 2016; Pompeu & Alves, 2005). Due to their discharge of untreated or inadequately treated sewage as well as household wastewater into the river, at least four major municipalities in the basin have been implicated in the problem (Illeperuma, 2000; Bandara, 2003). This method has caused an excessive build-up of organic waste, which has raised the Biological Oxygen Demand (BOD) considerably (Vaughn, 2005). At least four significant municipalities in the basin have been shown to be involved in the issue, as they release residential wastewater and untreated or partially treated sewage into the river (Illeperuma, 2000; Bandara, 2003). Due to this technique, organic waste has accumulated excessively, significantly increasing the Biological Oxygen Demand (BOD) (Vaughn, 2005).

An essential element of this problem is urban runoff, which exacerbates the dynamics of water contamination. Numerous contaminants that are physiologically dangerous are present in the discharge, such as oils, hydrocarbons, heavy and trace metals, and more. The gravity of this concern is well-documented, both in contemporary (2007) and historical (1985) contexts (Gunawardena, et al., 2017). Consequently, a slew of adverse water quality parameters has been recorded at various junctures along the Kelani River. The residential and industrial areas of the Kelani River have been found to have significantly higher conductivity (between 0.006 and 0.009 Sm−1), chemical oxygen demand (11.8 to 19.4 mg L−1), biological oxygen demand (between 1.7 and 2.9 mg L−1), and total coliform bacteria (between 30,600 and 51,000 cells

per 100 mL). Furthermore, it is concerning that some urban areas do not meet the necessary standards for the quality of their drinking water (Herath & Amaresekera, 2006). This confluence of issues underscores the pressing need for effective remediation strategies and stringent regulations to address waste disposal concerns, a critical imperative in safeguarding the water quality and ecological integrity of the Kelani River.

III. Hydrological Changes and Overexploitation

The Kelani River, a lifeline in Sri Lanka, confronts a multifaceted array of challenges rooted in hydrological changes and overexploitation, which collectively cast a significant shadow on its water quality and ecosystem health. These intertwined factors, although interconnected, exert distinct pressures on this vital waterway.

Hydrological Changes:

One salient facet of hydrological change in the Kelani River basin centers around the establishment and operation of hydropower infrastructure. The harnessing of the river's flow to generate electricity has led to profound modifications in its natural flow regime, ushering in a series of far-reaching consequences. The controlled release of water for power generation disrupts the river's innate flow patterns. This disruption, particularly when water is released during peak electricity demand, creates disharmony with the river's natural rhythms. The ramifications of such flow modification are particularly pronounced during periods of low flow, affecting downstream ecosystems. Moreover, hydropower installations, such as dams and reservoirs, have the capacity to trap sediment, curtailing the downstream transport of sediments (Zubair, 2003). This sediment deprivation significantly alters the river's geomorphological characteristics and impacts the habitats of aquatic organisms reliant on sediment deposition. Additionally, the release of cold water from deep reservoirs by hydropower plants can significantly lower downstream water temperatures, posing challenges for aquatic organisms adapted to specific temperature ranges.

Overexploitation: Simultaneously, overexploitation of the Kelani River's resources adds to the complexity of the challenges. This overutilization encompasses various dimensions, and one of the most striking facets is witnessed in the domain of fisheries. Excessive fishing pressure, including illegal and unsustainable practices, has resulted in the depletion of fish populations within the river. This depletion cascades through the river's food web, impacting local livelihoods that depend on fishing activities. Moreover, the loss of certain

fish species reverberates through the ecosystem, affecting nutrient cycling dynamics.

Hydrological Changes and Overexploitation in Detail:

Going beyond the broad overview, it's imperative to scrutinize the nuanced aspects of these challenges in the Kelani River basin. The construction of five major hydropower reservoirs since 1950 and the establishment of 32 mini-hydropower plants since 2000 have collectively imposed impediments on the river's natural flow. Additionally, flood levees and dikes have been instrumental in further modifying the river's discharge patterns (Zubair, 2003; Silva. et al., 2005). These blockages to flow ultimately result in changes to flood pulses, conductivity, dissolved oxygen, and alkalinity in the water, as well as changes to discharge regimes. The alterations have an effect on the habitat structure of the river, affecting not only the river channel but also the nearby floodplains (Abeysinghe & Samarakoon, 2017). In some tributaries of the Kelani River, a startling 60% of the tributary length has been converted into low-flow or dead zones behind mini-hydropower dams. Because of these impoundments, almost 30% of the total course of the Kelani River is compromised. According to Silva et al. (2005), the effects of these impoundments range from the disruption of the flow of sediment and organic matter to areas downstream to the conversion of lotic systems upstream of dams into lentic systems. The natural balance of the river is further upset by the fact that fish and macroinvertebrates find it harder to spawn in reservoirs created by hydroelectric projects. Changes in the structure of fish communities, such as the tailwater areas' shift from cyprinids to cichlids, highlight the extensive consequences of hydrological changes (Silva, et al., 2005).

Non - Point sources

Indeed, alongside the point sources of water pollution in the Kelani River basin, several non-point sources significantly contribute to the pollution of this vital waterway. Let's take a brief look at these sources and how they contribute to pollution in the Kelani River basin.

I. Population rising

The escalating population within the Kelani River basin represents a notable demographic factor contributing to various environmental challenges, including those related to water resources. The steady increase in human inhabitants exerts pressure on the basin's ecosystems and associated water bodies, engendering intensified anthropogenic activities and heightened demand for

water resources. This population rise introduces complexities in resource management, necessitating a nuanced understanding of its implications on water quality, availability, and overall ecological equilibrium within the Kelani River basin. The escalation of population within the Kelani River basin emerges as a pivotal contributor to the escalating water pollution predicament. Approximately 25% of the nation's total population is concentrated within this basin, with the highest population density observed in the latter reaches encompassing the densely populated districts of Colombo and Gampaha (Mahagamage & Manage, 2015). The nexus between population density and pollution extent is conspicuous across the watershed. The integrated pollution index in the lower basin, home to over 6 million people that is, more people per square kilometer than in any other area consistently fails to meet water-quality criteria set for drinking water, recreational use, and the preservation of aquatic biodiversity (Liyanage & Yamada, 2017). The burgeoning population in this region significantly exacerbates various forms of water pollution. The absence of adequate sanitation facilities for local communities compounds the problem. Moreover, the extensive use of agrochemicals in agricultural practices, characterized by the improper application of fertilizers and pesticides, further exacerbates pollution concerns. Ineffective solid waste management practices, coupled with inadequately treated wastewater discharges, pose additional risks to the integrity of water sources (CEA, 1992).

Specifically, Chandrathilake and Silva (2011) have established that the head region's tea plantations are vulnerable to dangers related to improper use of agrochemicals and poor sanitation. Moreover, Madduma Bandara et al. (1987) have compiled a list of the environmental issues in the lower basin, where high population densities, including the growth of illegal colonies inside Colombo city, are linked to the expansion of shanty towns along canal banks. Given these considerations, human density becomes apparent as a potent cause of water contamination in the Kelani River watershed.

II. Urbanization

Urbanization represents a formidable force shaping the environmental landscape of the Kelani River basin. This basin encompasses metropolitan Colombo, the largest city in Sri Lanka, boasting a population of approximately 6.6 million residents and an astonishing population density of 134,680 individuals per square kilometer. This urban sprawl presents a complex interplay of challenges for the river ecosystem due to its remarkable coverage of impervious surfaces, which account for nearly 40% of the urban built-up land cover (Senanayake & Moyle,

1982). Urbanization exerts a multifaceted influence on water pollution within the Kelani River basin, predominantly driven by heightened anthropogenic activities associated with urban development (Picture 02). The surge in population density, a hallmark of urbanization, precipitates an increase in waste generation. Notably, the escalation in household waste and solid waste production becomes pronounced, with subsequent disposal practices contributing significantly to water pollution. The indiscriminate release of such waste into water bodies compounds the environmental challenges faced by the Kelani River basin. Furthermore, the surge in human waste, particularly from drainage systems, intensifies during rainy periods, further contaminating water bodies. Pollutant loads into the Kelani River are increased by the combination of urban rainwater runoff and raw sewage. This dynamic interaction between urbanization and water pollution necessitates a comprehensive understanding of the pathways through which urban-generated waste degrades water quality. The proliferation of factories in urban zones also plays a pivotal role in water pollution within the Kelani River basin. Industrial activities contribute diverse pollutants to water bodies, including chemicals, heavy metals, and effluents. In urban areas adjacent to the Kelani River, the cumulative impact of numerous factories discharging waste directly into the water exacerbates the pollution challenge. The contamination stemming from industrial discharges further underscores the intricate relationship between urbanization and water quality degradation. Moreover, urban centers often host healthcare facilities, generating a substantial volume of medical waste. Improper disposal practices within these urban areas lead to the infusion of hazardous substances into the Kelani River, posing additional threats to water quality.

The ramifications of Colombo's urban growth are felt throughout the basin, leading to significant changes in the land cover. Between 1989 and 2016, there was a notable 25% increase in the built-up area of the Colombo metropolis. The biological equilibrium of the Kelani River and its environs is significantly impacted by these changes in land use (Dearman, et al., 2013). A notable feature within the Kelani basin is the prevalence of homesteads, collectively occupying a quarter of the basin's area. In closer proximity to the river mouth, the floodplain is marked by the presence of shanties and slums. These human settlements, while reflecting the region's demographic dynamics, bring their own set of challenges to the forefront (Management., 2018). The amalgamation of urbanization and its concomitant land-use alterations not only shapes the physical landscape but also engenders a confluence of environmental threats. The vulnerability of the Kelani River to multifaceted risks is heightened as urban expansion continues (Surasinghe, et al., 2019). Mitigating the adverse impacts of urbanization on water

quality and ecosystem health necessitates the implementation of comprehensive strategies rooted in sustainable urban planning and environmental management practices.

III. Wetland Degradation

The issue of wetland degradation occupies a prominent position among the complex array of factors contributing to the escalating pollution challenges faced by the Kelani River. Wetlands, characterized by their distinctive hydrological dynamics and rich biodiversity, hold significant roles in the regulation of water quality, flood mitigation, and providing a wide variety of aquatic and avian species with habitat (Semlitsch & Semlitsch, 2013). Within the context of the Kelani River basin, historical transformations to the landscape have induced substantial alterations in wetland ecosystems. Over time, many of these once-thriving wetlands have succumbed to drainage, filling, or dredging, primarily to accommodate burgeoning urban expansion and intensified agricultural practices (Semlitsch & Semlitsch, 2013). The loss of wetlands in the Kelani River basin, particularly in the Colombo Metropolitan area, has been significant over the past fifty years due to urbanization and agricultural expansion. These wetlands, once a mosaic on the Kelani floodplain, have been filled, dredged, or drained, leading to a 52% decline in freshwater habitats. Urban expansion in Colombo has surged by 25% from 1989 to 2016, exacerbating the challenges faced by wetlands (Derana, 2022). A comprehensive analysis indicates that around 63% of the wetlands in the Colombo Metropolitan Region have been adversely impacted. This highlights the complex interplay between urbanization, environmental changes, and hydrological dynamics.

IV. Deforestation

In the Kelani River basin, deforestation is a major cause of water contamination with far-reaching ecological effects. Urbanization and infrastructural development in the lower basin, as well as activities related to agriculture in the upper and mid-basins, have been the main drivers of this phenomenon (Mallawatantri, et al., 2016). Because of the Kelani basin's distinct vegetation and forest cover, the effects of deforestation are especially noticeable. Urbanization and infrastructural development have been identified as the main drivers of deforestation in the Kelani River basin, with the lower basin being more affected. Concurrently, there has been a notable decline in the amount of forest cover in the upper and mid-basins due to agricultural operations. The riparian vegetation found on the outskirts of Colombo is characterized by a restricted diversity of vegetation, primarily consisting of short grasses, bushes, and scrub (Department of Census

and Statistics, 1994). This is noteworthy. Today, only a mere 10% of the Kelani basin retains its forest cover, with much of the forest loss occurring in the post-colonial period (Dammalage & Jayasinghe, 2019). The remaining forest areas are mostly sub-montane and montane moist evergreen forests, and they are mainly located in the upper basin (Management, 2018). In order to lessen the negative effects of deforestation on water quality and the general health of the Kelani River, it is imperative that these special ecosystems be preserved and restored. This is demonstrated by the disproportionate distribution of wooded areas.

3. Ecological significance of Kelani River

Comprehensive biodiversity surveys within the Kelani River Basin, focused on systematic documentation, remain notably absent. Nonetheless, sporadic studies carried out by scientists to fulfill different goals have gradually helped to build an ecological significance profile for the Kelani River Basin. It is essential to recognize that the information presented herein is contingent upon a limited dataset. Consequently, the ecological significance of the Kelani River Basin might surpass the reported findings. Previous surveys indicate the presence of point endemism, endemism, and threatened species of fauna and flora within the Kelani Basin. The Kelani River basin contains a wide variety of inland and coastal wetlands in addition to a range of nationally significant habitats, such as mountain springs, ephemeral headwater streams, and huge permanent rivers. The northern wet lowlands, the foothills of Adam's Peak and Ambagamuwa, and the Adam Peak highlands are the three main floristic zones that are covered by this amazing diversity. According to Jayasuriya et al. (2016), the river passes through three different forest communities in these areas: tropical wet evergreens, tropical moist upper montane forests, and tropical submontane evergreens. Balanocarpus kitulgalensis, an indigenous species found only in the riparian woods of the Kelani basin, is one of the basin's most notable and severely endangered species (Mallawatantri, et al., 2016). The unique plant Vetica luwesiana and the fish species Pethia bandula and Systomus asoka are among the other ecologically noteworthy species present in the ecosystems of the Kelani River (Perera, 2018)

Picture 4: Pethia bandula Source: CITATION Bio14 \l 1033 *(Biodiversity, 2014)*

Picture 5: Systomus asoka CITATION Sri16 \l 1033 *(Sri Lanka , 2016)*

Table 01: The Kelani River Basin's list of vulnerable species (*IUCN, 2013*)

Species	Total Number	Critically Endangered (CR)	Endangered (EN)	Vulnerable (VU)
Dragonflies	16	8	7	1
Butterflies	23	1	10	12
Freshwater Fish	27	8	15	4
Amphibians	9	0	6	3
Reptiles	11	1	6	5
Birds	25	0	10	15
Mammals	28	1	14	13

Source: Mallawatantri, et al., 2016

Table 01 gives a summary of the IUCN's National Red List's vulnerable species in the Kelani River basin as well as information on their state of conservation. This basin is home to a wide variety of wildlife, including amphibians, reptiles, birds, butterflies, dragonflies, and freshwater fish. Notably, three freshwater crabs species, Ceylonthelphusa nata, Clinothelphusa kakoota, and Perbrinckia cracens, as well as many species of damselfly, such as Archibasis oscillans, are listed on the IUCN's National Red List (Perera, 2018). Although freshwater fish in the Kelani River basin are particularly important, contamination poses serious threats to them. The majority of Sri Lanka's indigenous freshwater fish species are found in the southwestern ichthyological province, which includes this basin (Senanayake & Moyle, 1982). Thirty of the sixty freshwater fish species found in

the Kelani basin are indigenous, according to a thorough assessment of the literature. This varied fish community, which represents 27 different families, makes up 63% of Sri Lanka's freshwater fish variety. Remarkably, according to the Environment (2012), 24 of these fish species are threatened, with 8 being classified as critically endangered, 15 as endangered, and 4 as vulnerable.

Two of the freshwater fish in the Kelani River basin are microendemics: Systomus asoka (Asoka barb) (Picture 06) and Pethia bandula (Bandula barb) (Picture 05), both of which have a very limited range (Surasinghe, et al., 2019). The former can only be found in a restricted area near a single tributary (at Galapitamada, Kegalle District) in the middle of the basin, whereas the latter have been found in several foothill tributaries of the Kelani River (Kithulgala and Deraniyagala, Kegalle District). Fish species including Garra ceylonensis (Ceylon stonesucker), Systomus pleurotaenia (Black lined barb), and Schistura notostigma (Banded mountain loach), are specialized for highly-oxygenated, swiftly flowing cold waters which are at risk due to hydrological alterations and pollution. Furthermore, species like Pethia nigrofasciata (Black ruby barb), which require streams with canopy cover, may be impacted by habitat loss, especially in riparian forests. Fish kills in the lower reaches have occasionally been documented as a result of home and industrial garbage discharge (Herath & Amaresekera, 2006). At least 25 alien freshwater fish species have been established in Sri Lanka, therefore, the Kelani River basin is not immune to their presence. The biodiversity of native freshwater ecosystems is impacted by these invasive species. Particularly, the basin's residential and urban areas are home to a variety of alien fish species, such as Helostoma temminkii (Kissing gourami), Oreochromis mossambicus (Mozambique Tilapia), O. niloticus (Nile Tilapia), Trichopodus pectoralis (Snakeskin gourami), and Pterygoplichthys cf. disjunctivus (Vermiculated Sailfin Catfish) (Pethiyagoda, 1994).

On top of that, the formerly common Macrognathus pentophthalmos, or Lesser Spiny Eel, is now extremely rare in Sri Lanka, especially in the lowland floodplains of the Kelani River basin. This species' current rarity is probably due to historical reasons, such as the presence of contaminants and invading predatory species. Due to their increased capacity to retain sediment, accumulate organic matter, decrease water clarity, lower dissolved oxygen levels, and increase evaporation rates, invasive aquatic plants like the water hyacinth (Eichhornia crassipes) have made ecological problems worse (Silva et al., 2015). Significant alterations in habitat structure and wetland hydroperiod have resulted from the widespread invasion of alien aquatic plants by numerous urban wetlands in the Kelani River watershed, particularly those in metropolitan Colombo (Marambe, et al., 2001). It

is imperative to acknowledge that the elevated level of pollution within the Kelani River watershed presents a significant threat to biodiversity. While some species may have already suffered extinction, others may yet be uncovered. Because of this, it is crucial to take the appropriate safety measures to preserve and safeguard biodiversity, both known and unknown, in the face of rising pollution levels.

DISCUSSION AND CONCLUSION

Upon examining the noteworthy findings of this study, it becomes evident that the Kelani River, a crucial freshwater resource in Sri Lanka, is grappling with an alarming level of pollution attributed to a complex interplay of both point and non-point sources.

Specifically focusing on point source pollution, industrial discharges emerge as a significant contributor. The basin hosts over 6,000 industries, releasing an estimated daily point-source discharge exceeding 414,600 cm3. A significant biological oxygen requirement that surpasses 11,600 kg daily is the consequence of this. The presence of extensive industrial zones, such as Seethawaka and Biyagama, coupled with inadequate waste management, exacerbates the pollution burden. Improper waste disposal, including sewage and solid waste, is another significant concern, especially in urban areas, leading to elevated levels of contaminants in the river. And also, hydrological changes in the Kelani River basin, primarily driven by hydropower infrastructure and overexploitation, further compound the challenges. The natural flow regime of the river has been significantly altered as a result of the building of five large hydropower reservoirs since 1950 and the installation of 32 mini-hydropower plants since 2000. Because of this disturbance and overexploitation, a startling 60% of the tributary length below mini-hydropower dams has become low-flow or dead zones, which has an effect on downstream ecosystems. Overfishing pressure, including illicit and unsustainable fishing methods, has negatively impacted the river's fisheries and reduced fish populations.

The Kelani River basin deals with a complex web of issues related to non-point causes of water pollution, including as urbanization, population growth, deforestation, wetland degradation, and cattle farming. With approximately 25% of Sri Lanka's total population concentrated in the basin, particularly in densely populated districts like Colombo and Gampaha, the escalating anthropogenic activities significantly contribute to pollution. The population density, exceeding 2500 individuals per square kilometer in the lower basin, exacerbates various forms of water pollution due to inadequate sanitation, agrochemical misuse in

agriculture, and inefficient waste management practices. Urbanization, particularly in Colombo, the largest city in Sri Lanka, with a population of around 6.6 million and a density of 134,680 individuals per square kilometer, presents a multifaceted challenge. The expansive urban sprawl covers nearly 40% of impervious surfaces, leading to increased waste generation. In the Kelani River watershed, the combined effects of untreated sewage, inappropriate waste management, and industrial discharges severely deteriorate the water quality (Senanayake & Moyle, 1982; Dearman, et al., 2013).

Wetland degradation is another pressing issue within the basin, with historical transformations for urban and agricultural development leading to a significant reduction in wetland ecosystems. The adverse impacts are evident in the decline of floodplain wetlands and freshwater marshes. Over the last five decades, approximately 63% of the wetlands in the Colombo Metropolitan Region have been adversely impacted, emphasizing the intricate relationship between urbanization, environmental transformations, and hydrological dynamics (Semlitsch & Semlitsch, 2013; Derena, 2022). And deforestation, stands out as a major contributor to water pollution, being mostly driven by urbanization in the lower basin and agricultural activity in the upper and mid-basins. Today, only 10% of the Kelani basin is covered in forest, and the region's distinctive vegetation highlights the negative ecological effects of deforestation. The moist evergreen forests of the upper basin are sub-montane and montane, and they are essential to preserving the water quality and general health of the Kelani River (Mallawatantri, et al., 2016; Dammalage & Jayasinghe, 2019).

The basin's ecological significance is profound, featuring diverse habitats from mountain springs to wetlands across distinct floristic regions. Home to numerous endangered and endemic species, including critically endangered Balanocarpus kitulgalensis and unique species like Vetica luwesiana, the riparian forests are crucial. The basin's freshwater fish ecosystem, comprising 60 species (30 endemics), constitutes over half of Sri Lanka's endemic freshwater fish diversity. However, pollution, habitat changes, and invasive species threaten these species. Altered hydrology, industrial and residential pollution, and habitat loss, particularly in riparian forests, pose challenges to native fish species. Invasive aquatic plants, like water hyacinth, further disrupt ecosystems by altering habitats and degrading water quality.

In light of these formidable challenges, it is imperative to enact comprehensive conservation measures. These measures should encompass rigorous regulations, sustainable land-use practices, and effective waste management.

Protecting and restoring critical ecosystems assumes paramount importance. Additionally, fostering community awareness and engagement is indispensable for safeguarding this invaluable resource. The ecological integrity of the Kelani River must be preserved, and its ongoing benefits to the environment and its people depend on addressing both point and non-point causes of pollution.

Strategies for Mitigating Water Pollution in the Kelani River Basin

The depletion of water resources and the degradation of water availability and quality are the main causes of problems with water pollution. To solve challenges relating to water, the Sri Lankan government has launched a number of programs. That being said, Colombo is the only city in Sri Lanka with a working sewage system at the moment. The started efforts are displayed in Table 02. Additionally, the nation has improved septic systems and sewage disposal techniques, increased public awareness of the environmental harm caused by Kelani River pollution through workshops and training programs, authorized the Ministry of Environment to monitor and license industries along the river's banks, and strengthened river monitoring by expanding the number of sampling sites and automating the monitoring process (Narangoda, et al., 2023).

Table 02: Sri Lankan environmental laws pertaining to the preservation and administration of the Kelani River basin.

Name of Statute	Concerns Regarding Inland Aquatic Resources	Using the Agency	Year of the Last Amendment's Enactment
Comprehensive Environmental Laws			
National environmental Act	provisions for monitoring, protecting, and managing the environment. projects are approved by supervising environmental impact assessment techniques.	Central Environmental Authority	1980 (2000)

National Environmental Policy and Strategies	Gives guidelines for managing and conserving the environment in all its forms, especially with relation to sustainable agriculture. This includes fisheries, forestry, wildlife conservation, and other aquatic resources.	Ministry of Mahaweli Development and Environment	2003
Cleaner Product Policy	Reduce waste and overuse in order to increase the efficiency of your water and energy usage.	Ministry of Mahaweli Development and Environment	2005
National Forest Policy Forest Conservation Ordinance Amendment Act	Save woods for their aesthetic, historical, cultural, religious, and biological benefits. They also provide soils and water. Boost forest productivity and tree cover. amplify sustainable forestry's impact on the country's economy and rural development.	Forest Conservation Department	1995 1907 (2009)
National Wildlife Policy Fauna and Flora Protection Ordinance Amendment Act	Prevent overuse by protecting water biodiversity and habitats. Preserve genetic variety and ecological processes. Mark out conservation areas, taking into account embedded aquatic	Department of Wildlife Conservation	2000 1937 (2009)

	systems. Involve the neighborhood in the administration of protected areas.		
	Statues at the Watershed or Basin Scale		
National Watershed Management Policy	Watersheds should be preserved, restored, and managed while keeping an eye on their vital environmental dynamics.	Ministry of Mahaweli Development and Environment	2004
National Land-use Policy National Policy on Protection and Conservation of Water Sources, their Catchments and Reservations in Sri Lanka.	Create land-use regulations at the watershed level. All water sources should be preserved and restored, with watersheds being an exception. Encourage responsible governmental organizations and communities to manage their water resources in a way that promotes sustainable usage. Determine which regulations need to be changed. Address the shortcomings of current policies and encourage the management of inland aquatic resources throughout the watershed.	Ministry of Land and Land Development	2007 2014

Source: Developed by the Author

1. **Stringent Regulatory Framework**

- Environmental Impact Assessments (EIA): Mandate the conduct of EIAs for all proposed industrial and infrastructure projects within the basin to evaluate potential pollution risks comprehensively (Surasinghe, et al., 2019).
- Regular Audits and Inspections: Institute routine audits and inspections of industrial facilities to verify compliance with water quality regulations and standards.

2. **Sustainable Land-Use Practices**

- Precision Agriculture: Encourage precision agriculture techniques, including the use of GPS-guided machinery and remote sensing, to optimize resource utilization and reduce chemical inputs.
- Crop Rotation and Cover Crops: Promote crop rotation and cover cropping as practices that not only reduce pollution but also enhance soil health.
- Addressing pollution in the Yamuna River necessitates improved agricultural practices. The indiscriminate use of chemical fertilizers, insecticides, and pesticides has been a significant contributor to the issue. To mitigate these effects, adopting organic or biological farming methods is crucial. This involves prohibiting the use of harmful chemicals in the river basin. Awareness campaigns for farmers, facilitated through programs like the Kisaan Call Centre, provide scientific guidance on agriculture practices, emphasizing reduced chemical usage. Promoting bio-fertilizers, which contain fewer chemical constituents, is essential. Additionally, efforts to curb soil erosion in the river catchment area, achieved through measures like developing greenways along the drains, contribute to overall river conservation. (Sharma & Kansal, 2011).

3. **Effective Waste Management**

- Hazardous Waste Identification: Develop a comprehensive hazardous waste classification system to ensure the safe disposal of toxic substances.
- Public-Private Partnerships: Establish partnerships with private sector entities to facilitate the construction and operation of advanced waste treatment facilities.
- Addressing the pollution in the Yamuna River requires a comprehensive strategy for proper sewage management. Current challenges stem from untreated or partially treated sewage discharges. To combat this, a total

ban on such discharges and robust legislation are essential. Both building new, larger-capacity facilities and expanding the capacity of currently operating sewage treatment plants are part of the strategy. Using cutting-edge technologies is also essential to bringing biochemical oxygen demand (BOD) levels below 10 mg/L. Delhi's water authorities have initiated a forward-looking master sewage plan for 2031, encompassing sewered and unsewered areas, to effectively manage wastewater in the National Capital Territory. This multifaceted approach aims to protect the Yamuna River ecosystem from the adverse impacts of untreated sewage (Sharma & Kansal, 2011).

4. **Urban Planning and Management**

- Permeable pavements and green roofs: To reduce pollution and surface runoff, mandate the inclusion of permeable pavements and green roofs in urban development plans.
- Green Certification: Introduce a green certification program for urban developments, offering incentives for sustainable designs.

5. **Community Engagement and Education**

- Citizen Science Programs: Establish citizen science programs to involve local communities in water quality monitoring and data collection (Narangoda, et al., 2023).
- Public Workshops: Organize workshops and seminars to educate residents on the importance of pollution prevention and sustainable water management practices.

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