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REVIEW

Large Dams Establishment Impacts on Different Environmental Aspects: A Review

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ABSTRACT

The construction of large dams has been an essential component of the development of global infrastructure, offering significant advantages such as ensuring water storage, reducing the risk of flooding, and producing about 20% of the world's electricity through hydropower. On the other hand, these structures have significant and varied environmental effects. The environmental effects of large dams are critically examined in this analysis, with an emphasis on four main areas: fish biodiversity, riparian vegetation, sediment deposition, and water quality. The study estimates the degree of these consequences by examining global case studies and evaluating data from over 145 significant rivers worldwide. It finds that dam-induced silt deposition alone reduces the world's freshwater storage capacity by 0.5–1% annually. The research also emphasizes how fish biodiversity has significantly decreased, with species fragmentation seen in more than 70% of rivers affected by dams, and how riparian vegetation and water quality have severely degraded, leading to increasing eutrophication and hypoxia. Even though dams are necessary for meeting basic human needs, their effects on the environment and water resources make it necessary to reassess current dam structures and proceed cautiously with new dam construction. This study's contribution to this discipline is the synthesis of an all-encompassing, global viewpoint that emphasizes the necessity of incorporating environmentally sustainable methods into dam operations. Policymakers, engineers, and environmental scientists can use this assessment as a crucial resource to support the preservation of river ecosystems while balancing the benefits of development.

Keywords: Environmental impacts, Fish biodiversity, Large dams, Riparian vegetation, Sediment deposition, Water quality

1. Introduction

1.1. Research background

The importance of water needs no explanation or introduction, nowadays, it is believed that water is one of the most essential building blocks of growth, economic success, and social well-being, and its scarcity would have several negative effects. Water shortage would have an impact on several industries, including planning, distribution, conservation management, transmission, storage, control, and water supply. Therefore, researchers have instigated the importance of building dams [1].

At the moment, it has been calculated that roughly eight million small dams (height less than 15 m) and forty-five thousand large dams (height more than 15m) prevent two-thirds of fresh water flowing across the globe from reaching back to the ocean [2]. Fig. 1 Shows the number of large dams in different countries with a height of more than 30 meters, the data is from [3]. Some of the most colossal structures ever built by humans are large dams. Strong representations of modernity, pride in one's country, and human control over the natural world [4]. Although reservoirs and dams have been extensively used for water management since ancient times, large-scale construction of dams did not start before the second half of the 20th century. Large dam construction increased in combination with developments in hydrological analysis, construction technology, and

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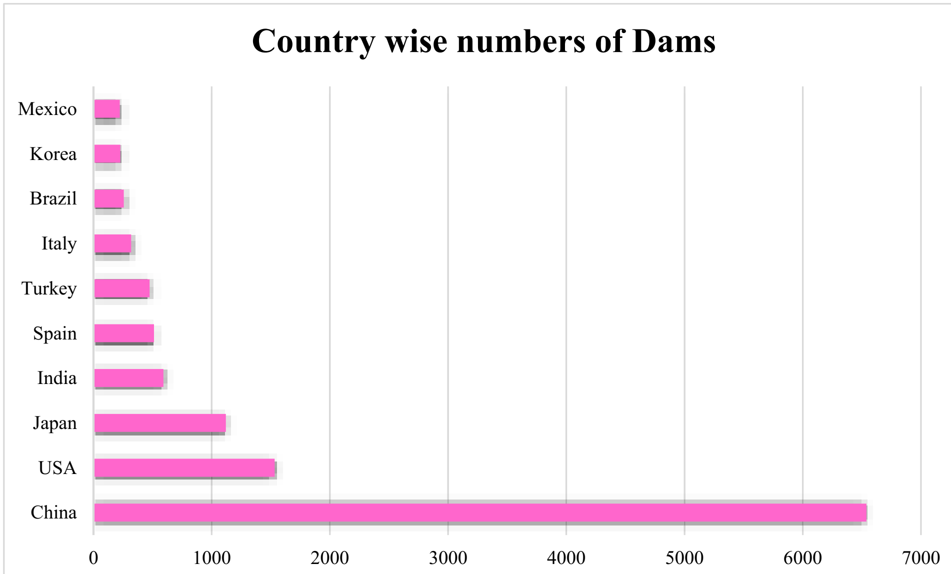

Fig. 1. Country-wise number of dams with a height of more than 30 meters.

technical expertise. With projects like the Hoover Dam, which was built and developed on the River of Colorado at the beginning of the 1930s, the United States entered an era of large dam construction. After World War II was over, the Soviet Union began several large dam projects, motivated by Stalin's belief that nature may be used to advance the communist state. Following this, developing countries such as China and India witnessed a massive increase in the construction of large dams, making them recognized examples of countries involved in dam-building projects [4, 5]. Ten countries with the highest number of dams

The installation of industrial projects or technical structures benefits the ongoing growth of the nation in both social and economic ways [6]. Dams are provided to utilize the potential of water to meet basic needs and goals like drinking, farming, controlling flooding, and enhancing water quantity and quality, they are also responsible for providing water at that time of year when there is no accessible water. These dams offer a variety of other benefits, including improved navigation, the agricultural sector, flood reduction, consistent water supply, and hydroelectric power production.

One of the main purposes of constructing a large dam is to produce hydropower. Approximately 20% of the world's electricity was produced in the 1990s by approximately 640,000 MW of developed hydroelectric capacity [5]. However, river dynamics and the associated ecosystem and environment which they are a part of are being significantly impacted using alteration of hydrological patterns. The emphasis on maximizing the potential for hydroelectric power generation has resulted in particularly noticeable changes to large rivers with their enormous flow rate [7]. It is not enough to focus solely on the project's financial worthwhile planning or executing its development. We also need to consider how the project will affect the local community not to mention wildlife as well as the environment [8].

Expansion in population, technological advancement, urbanization, and infrastructure projects like the construction of big cities, bridges, roads, and dams have resulted in a discrepancy in the ecology and the disruption of natural equilibrium [9]. For a long time, these dams have negatively affected the environment and human society. Since the 1970s, there has been a gradual increase in awareness that large dam projects also have a major negative impact on society and the ecosystem, which only increases with time. Environmentalists addressed the adverse impact of dams due to their construction on society and the environment, such as migration of population and alterations to biodiversity, while hydroelectric project owners claim that dams are excellent sources of renewable energy [10]. The promotion of this understanding has been greatly aided by the 1972 conference by the UN on the topic of the Human Environment which was held in Stockholm and the 1970s Act policy on Environment by the US (NEPA), which helped in the establishment of Environmental Impact Assessment [11–13].

The argument between those in Favor and against large dams grew more intense in the period of 1980s. In the 1990s, the World Bank- which was at the time the primary source of finance for dams-was compelled to set up internal evaluations of its dam project because of several non-governmental organizations (NGOs) organizing complicated global anti-dam campaigns. These reviews bring both negative and positive aspects of dam projects into light [14, 15]. In the USA many of the dams were removed just to restore the flow of affected rivers [16].

Although the majority of a dam's impacts are felt throughout its hundreds of years of operation, there are also many adverse effects on society and the environment during the dam's construction period. These effects also cease to exist even after the construction is completed. Road construction, installation of energy transmission lines, drilling, and other activities may also cause these effects [17].

The global mean sea level has been lowered by several centimeters due to the collective retention of water by these dams [11]. Furthermore, they have even changed the shape of the globe and altered the rotation of Earth significantly [12]. Global warming, sediment deposition greenhouse gas emission, biodiversity loss, and loss in the fertility of the ground, are some prime examples of the adverse effects of these structures on the ecosystem.

The different types of sediments that rivers carry downstream help to create riverside characteristics like silt, deltas, river draft events, dikes, crescent-shaped lakes, and shoreline beaches. Because dams block the flow of these sediments downstream, the riverbed becomes more eroded through this sedimentary environment, and the amount of material that builds up in reservoirs and dams increases [18]. Various dam locations, rivers, and reservoirs experience varying usually comes with a cost since while they help store water, they also collect sediments over time that eventually lower storage capacity. A reduction in the amount of water available for irrigation, reduction in the amount of water available for irrigation, a reduction in the ability to generate hydropower, and the possibility of structural instability that might result in dam failure and detrimental consequences on the river ecology are all examples of cascade effects that could result from this fall in storage capacity. Consequently, to ensure that dams and rivers continue to function and last a long time, as well as to continue providing water and energy and protecting the environment, proactive sediment management strategies must be used [19].

Once a dam gets closed, fish that migrate are annihilated right away since it intervenes with water from the river water, which leaves sensitive fish in danger. Dam construction adversely impacts aquatic organisms, especially fish. Fish population and species will consequently fluctuate, affecting notable local fisheries. Artificial lakes are inhospitable to many aquatic species and fishes; modifications in downstream flow form negatively impact several races; and declining water standards inside or beneath reservoirs (often due to low oxygen concentration) annihilate aquatic life forms and destroy their ecosystems. Because they have less mobility than most fish species, freshwater mollusks, many benthic animals, and crustaceans are significantly more vulnerable to these changes [20].

The primary factors that endanger riparian vegetation, which in turn affects the geomorphology and ecology of rivers, include the building of dams, invasion of weeds, excessive grazing, and agricultural activities [21]. These activities affect the ecosystems and dynamic processes of the river, which modifies the plant survivorship in the riparian zone. River damming is the most significant of these as it is required to forecast the environmental impact over time of an impediment and the prevailing cultural influence on the river system [22]. Because riparian vegetation and discharge stochasticity are closely related, the creation of a manmade reservoir can have a significant impact on it [23].

Both natural and man-made processes surrounding dams have the potential to pollute water upstream, within, and downstream of the reservoir. These processes are agricultural practices such as using pesticides, Insecticides, and fertilizers, Wastewater from cities or industries carrying harmful heavy metals, and defoliants that prevent vegetation from developing in the reservoir [24, 25]. Pollutant concentration in sediments and water turbidity and impacted by altered sediment movement. Pollutant concentration and salinity rise due to extraction and evaporation of water from reservoirs, which impact downstream water quality. Furthermore, the reservoir's nutrient content begins eutrophication. The downstream river's thermal regime is typically altered by the construction of dams [26]. In this review paper, we will discuss the major concerns related to dam construction and its effect on sediment deposition, fish biodiversity, riparian vegetation, and water quality. The flow chart of this study can be seen in Fig. 2.

1.2. Research significance

Large dams are vital for modern infrastructure, offering important advantages like hydroelectric power, water storage, and flood control. Still, they also have major and frequent negative environmental effects that are not fully understood or adequately addressed in existing research at this time. For this reason, this study is essential. The amount of research that is now available, especially regarding sediment deposition, fish biodiversity, riparian vegetation, and

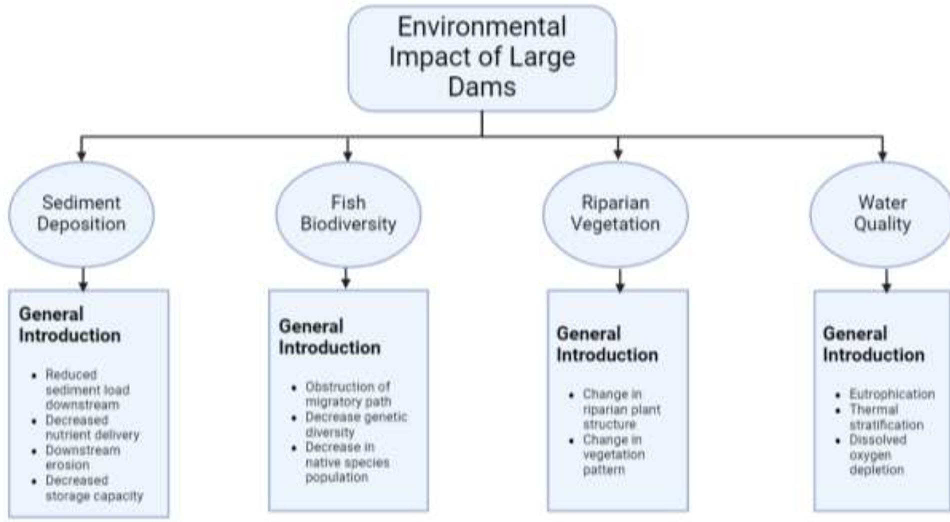

Fig. 2. The flow chart of this work.

water quality, tends to concentrate on specific effects rather than providing a thorough worldwide evaluation of the entire range of effects of dam construction. To provide a comprehensive understanding of these impacts, this study synthesizes global case studies and literature. This helps close this gap and informs future dam construction projects that balance environmental preservation with developmental benefits.

1.3. Research objective

This review was inspired to be established and satisfy the following objectives: (i) To provide a comprehensive assessment of the environmental impacts of large dams globally, with a focus on sediment deposition, fish biodiversity, riparian vegetation, and water quality; (ii) Throughout the presented literature, an evaluation was conducted for the existing published research and case studies; (iii) The survey highlight and reveal the relationship between dam construction, operation, and environmental processes in context with different regions. By identifying significant patterns, trends, and challenges associated with the environmental consequences of large dams, the study aims to address decision-making processes and promote sustainable water resource management practices.

2. Literature review

Around the world, dams have been built for a variety of applications, from irrigation to hydropower production dams have never failed to amaze the world with their excellent gifts to mankind. Even while they have many advantages, like the ability to store water and produce renewable energy, their installation and maintenance can also negatively affect the environment. The same impact on the ecosystem of these structures is being observed in several parts of the globe and is typically not exclusive to a particular place or environment, even though the adverse effects of dams are determined by local factors in addition to the type and largeness of dam constructed. Dams can have detrimental effects on the ecology downstream, upstream, as well as within the reservoirs. Dams have major barrier impacts in addition to degrading or destroying habitat because they obstruct the flow of nutrients and sediment downstream and hinder fish as well as other aquatic organism's migration [27].

2.1. Sediment deposition

General introduction: The process of sedimentation occurs when soil particles are eroded, carried by moving water or other transportation media, and then accumulated as strata of solid material in bodies of water like rivers and reservoirs [28]. The complicated procedure depends on the watershed's sediment supply, transit velocity, and deposition method [29]. River flows and reservoir life expectancy are both shortened by sediment accumulation [30]. A clear profile of sediment deposition is illustrated in Fig. 3. According to research, over 50% of the 145 main rivers in the world exhibit statistically considerably decreased flow trends due to sedimentation. The study focused on important rivers having consistent long-term sediment data [31]. According to a study, yearly reservoir rates of sediment deposition

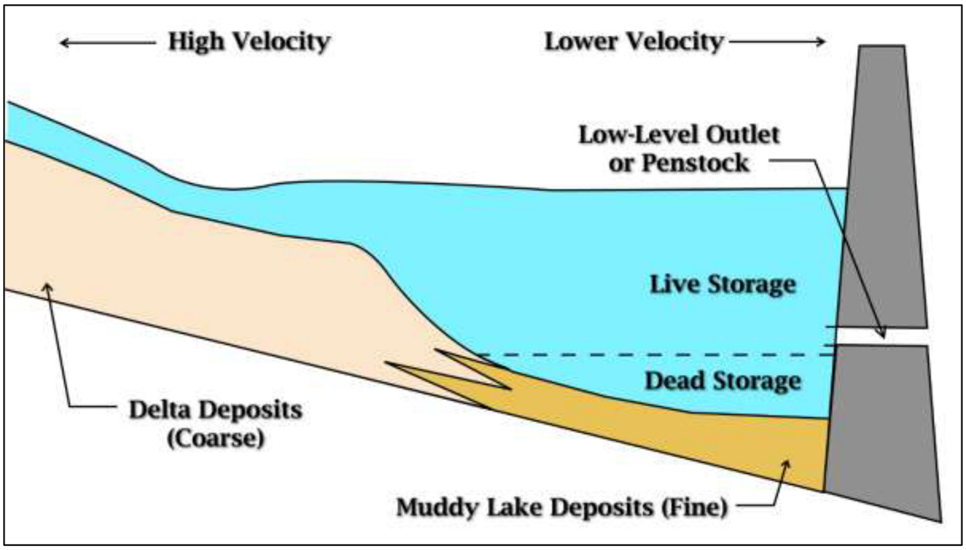

Fig. 3. Typical sediment deposition profile, reproduced from [33].

are around 31 km^3 (0.52%) and the gross storage capacity of reservoirs worldwide is approximately 6000 km^3. This implies that by the year 2100, the worldwide reservoir capacity for storage will be decreased by half due to the current rate of sediment deposition [32].

Sediment deposition has various adverse effects on the environment and the society. For starters, Sediment deposition results in an annual loss of between 0.5-1% of the total 6,800 km^3 of freshwater that is held in reservoirs worldwide. This has led to a sharp decline in worldwide per capita storage of reservoirs since its high about 1980. Storage levels now are comparable to those from about 60 years ago [34]. Reduction of storage in reservoirs impacts the dependability of the water supply and decreases generating flexibility as well as the water supply to the households. Hydroelectric plants will start to rely only on seasonal flows in the absence of storage. One of the main advantages that hydropower has over other renewable energy sources will be lost in such scenarios because this is not possible that such flows will happen when electricity and water supply are needed. Furthermore, the erosion of the oxide layer on the blades of various mechanical devices and hydropower generators by sediment can result in surface imperfections and more severe material deterioration. An extended outage of service for replacement or maintenance may result from this erosion [35].

Like any other man-made project dam construction also has some negative impacts connected to them. A certain amount of downstream sediment starvation will result from any dam construction. Changes in the

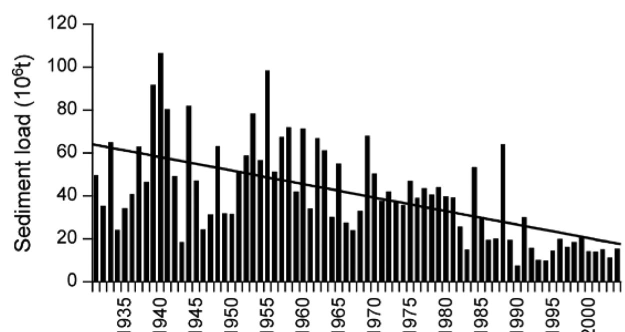

Fig. 4. Reduction in sediment deposition for the period of 1935 to 2000 [37].

flow regime and sediment supply can have an adverse impact on plant as well as animal populations downstream [36]. The reduction in sediment load transfer throughout 65 years can be seen in Fig. 4, the data is for the Danube River at Ceatal Izmail, Romania.

The sediment deposition of this river is only 30% of what it used to be. A relationship between sediment starvation downstream and environmental impacts it has caused. A clear picture of sediment load declination due to the construction of dams over 7 rivers can be seen in the Table 1.

The clean water that leaves the reservoir may carry with it new sediment discharge, eroding the stream bed and shorelines beneath the dam in the process, if sediment deposition is present inside the reservoir. Heterotrophic activity may be suppressed by the removal of organic material from the stream, at least until the reservoir's plankton provides a fresh supply of residue. Suppose plankton development after impoundment has resulted in a depletion of water

Table 1. Relation between decline in sediment load and environmental issues, reproduced from [38].

River basin	Annual sediment load (10^6 t)	River basin area (10^3 km^2)	River length (km)	Annual runoff (km^3)	Effect on environment
Nile	• 120 (Pre-Dam) • 0.02 (Post Dam)	3350	6671	• 80 (Pre-Dam) • 30 (Post Dam)	✓ Erosion of soil ✓ sediment buildup in reservoirs ✓ silting of irrigation channels
Mississippi	• 400 (Pre-Dam) • 145 (Post Dam)	3220	6021	• 490 (Pre-Dam)	✓ Wetland and deltaic land loss ✓ decline in water quality
Rhine	• 7.3 (Pre-Dam)	190	1320	• 74 (Pre-Dam)	✓ Accumulation of hazardous substances ✓ riverbed erosion ✓ reservoir sediment buildup
Volga	• 26 (Pre-Dam)	1380	3700	• 254 (Pre-Dam)	✓ Erosion of soil ✓ seasonal soil freeze-thaw cycles ✓ breaching of earthen dams
Yellow	• 1243 (Pre-Dam) • 149 (Post Dam)	752	5464	• 50 (Pre-Dam) • 10 (Post Dam)	✓ Erosion of soil ✓ sediment accumulation in waterways and reservoirs ✓ flood mitigation
Haihe	• 150 (Pre-Dam) • 0 (Post Dam)	318		• 27 (Pre-Dam) • 0 (Post Dam)	✓ Sediment buildup in reservoirs ✓ shrinking of river mouths ✓ flood management
Liaohe	• 46.4 (Pre-Dam) • 7.9 (Post Dam)	219	1345	• 5.8 (Pre-Dam) • 1.7 (Post Dam)	✓ Sediment accumulation in reservoirs ✓ flood management

nutrients. In that case, the quantity of initial development inside the flow will tend to be lowered, even while the amount of turbidity will likely reduce. However, primary productivity downstream may rise, if flooding introduces more nutrients into the water than the reservoir's plankton can absorb. This effect will only last temporarily [39]. Additionally, turbidity may hinder predatory fish's vision, which can change how they eat. Lastly, the main transporter of suspended contaminants such as heavy metals, phosphorus, and nitrogen is sediment [40].

2.1.1. Related literature

This section explores several case studies that demonstrate the global environmental effects of different dams, refer to Table 2. The environmental problems that these dams cause are illustrated in detail in each case study, including changed deltas, reduced sediment transfer, and coastal erosion. These practical examples highlight the complex relationship between environmental changes produced by dams and provide a thorough grasp of the ways in which large-scale water management systems may affect ecosystems. The study covers a wide range of geographic areas and highlights both typical and unusual environmental effects related to dam building. To assure the validity and applicability of the data provided, actual study references are used to support the analysis.

2.2. Fish biodiversity

Wetlands are essential to the ecosystem of the world [53, 54]. They contribute significantly to the global preservation of biodiversity and offer habitats for life on Earth [55–57]. Only 1% of the Earth's surface is occupied by them, yet 20% of all species, sporadic and endangered ones, find adequate homes there [58]. It is evident that almost one-third of the world's vertebrate species are found in freshwater wetlands when taking into account mammals (such as river dolphins, otters, and platypus), aquatic reptiles (such as turtles and crocodiles), amphibians, and freshwater fish (which make up over 10,000 species and around 40% of all fish variety worldwide) [59]. In addition, wetlands support over half of China's threatened bird species [58, 60].

More so than other human activity, the construction of dams influenced wetland habitats[61, 62]. It affects naturally occurring wetlands globally [63]. Wetland morphology and geomorphology, sediment regimes, and river flow regimes are all inevitably altered by it [64, 65]. Furthermore, these elements create and sustain the world's biodiversity in wetland habitats. Thus, dam advancement affects biodiversity globally [54, 66].

Fish are vulnerable to Dam construction and one of the main effects of dams on them is the obstruction of migratory paths, this can be illustrated with the help of the figure. The dam prevented fish and aquatic animals, including fish like salmon, American shad, Chinese sturgeon, striped bass, and Chinese paddlefish, from migrating upstream [67–69]. It would generally be detrimental to spawning and result in declining fish and aquatic animal populations and biodiversity along the whole river (especially upstream of the dam). For instance, 35 fish species'

Table 2. Case Studies concerned with the effect of sediment deposition.

S. no.	Dam	Location	Environmental impact	References
01	Yantan Dam	Guangxi China	✓ Sediment transport reduction downstream ✓ Deterioration of water's self-purification quality ✓ Increase in primary productivity of the sea coast	[41–44]
02	Sobradinho Dam	Brazil	✓ Altered Deltas ✓ Increased coastal erosion ✓ Reduction in sediment load	[45, 46]
03	Three Gorges Dam	China	✓ Contribution of 64% of total coastal erosion in Yangzi ✓ River banks collapse due to river erosion	[47, 48]
04	Aswan High Dam	Egypt	✓ Sediment Buildup in the reservoir ✓ Irrigation channel silting	[49]
05	Sanmenxia Dam	China	✓ Shrinkage of river mouth ✓ Reservoir capacity reduction	[50]
06	Vetluga Dam	Russia	✓ Soil erosion ✓ Dam breaching	[51]
07	Klingnau Dam	Switzerland	✓ Riverbed Erosion ✓ Hazardous Substance Accumulation	[52]

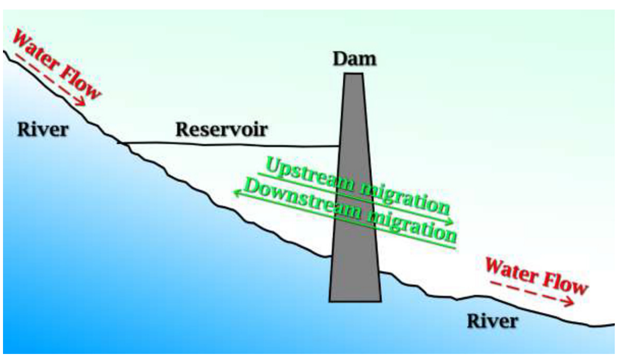

Fig. 5. Illustration of Fish migration obstruction due to dam.

migration pathways will be blocked by the dams now being built in the upper Yangtze River, increasing the chance that Corieus guichenoti would become extinct and decreasing the possibility that Psephurus gladius and Acipenser dabryanus could successfully repopulate [70]. China's 78 dams on rivers in the world's largest inland fisheries site, the Mekong region, would have disastrous effects on fish productivity and biodiversity [71].

Furthermore, limiting migration pathways may result in developing a new interpopulation structure and destroying bidirectional gene flow in fish populations, increasing the risk of diminished diversity in genes and random extinction [72, 73]. The obstruction of migratory paths due to Dams can be seen in Fig. 5. Salminus hilarii, for example, experienced fragmentation and interpopulational structure as a result of segregation brought on by the Gaviao Peixoto Dam [72]. It was simple to ignore the obstruction of downstream migration paths since dam discharge facilitates fish migration to downstream areas [74]. However, according to new research, large dams prevent adult and juvenile fish from migrating downstream. The reason for this was that migratory fish were forced to overcome a different kind of barrier due to large reservoirs and this problem cannot be solved technically [75].

One of the most detrimental effects of dam building is habitat fragmentation [76, 77]. This is so that a wider variety of fish sizes, denser populations, and a higher degree of species diversity may be supported by bigger stream sections [78–80]. In Canada, the species richness was positively connected with the size of river fragments; nevertheless, the severely fractured river did not include any of them [81]. Fish populations would become fragmented because of habitat fragmentation; for instance, the 134 species of fish that are now being dammed along the top Yangtze River would experience population fragmentation [70]. In addition, habitat fragmentation would result in the continuous loss of alleles, which has a detrimental effect on genetic structure [76]. Finally, many of the effects of habitat fragmentation brought on by dam construction happen gradually across multiple generations instead of instantly [77].

Fish growth, population, and assemblage patterns are all impacted by the switch from moving water to still water in the impounded region, which is the primary effect of dam building on fish [75, 82]. The morphology of Cyprinella venusta in reservoirs is highly connected with reservoir size. For instance, Cyprinella venusta inhabiting reservoirs possessed a wider body, shorter head, a narrower dorsal fin base, a more ventral eye location, and a larger antecedent dorsal fin than the one present in streams [83]. Slow development, delayed maturity, and longevity in Labeobarbus aeneus is probable contributing factors to the reservoir's sluggish population growth rates [84]. According to fish assemblage structures, fish species richness often rose right after reservoir

Table 3. Different effects and their impacts on fish biodiversity.

S. no.	Type of effect	Impact on fish biodiversity	References
01	Migration Route Blockage	✓ Negatively affect the spawning of fish ✓ Decrease the quantity and biodiversity of fish	[70, 71]
02	Fragmentation of Habitat	✓ Destruction of Bi-directional flow of gene ✓ Genetic Diversity reduction ✓ Can cause distribution of fish	[72, 73, 76, 77]
03	Change in the behavior of water (Flowing to still)	✓ Negatively affects the population and growth of fish ✓ Loss of habitats and spawning ground	[76, 77]
04	Cold water released from the Reservoir	✓ Upstream migration would be hindered ✓ Reduced survival of newborn fish ✓ Affected performance of Swimming	[86, 88, 90]

development because lentic-suited species—like Wolffish and Brown Hopolo—colonize the reservoir [78, 85]. But as reservoirs get older, fish richness declines [85].

Dams also have the capability of releasing chilly, hypolimnetic water from reservoirs. It would, in general, diminish growth and swimming ability, delay and reduce upstream migration, prevent spawning of fish and development of embryos, lower the likelihood of survival during early life phases and ultimately affect the fish biodiversity [86]. For instance, Mexican Tetra as well as Two-spot tetra were less common and the body weight of females, their length in total, their gonadosomatic index, and fecundity values were comparatively lower in the first 34 km of the Tres Marias dam's downstream section than in the 34–54 km section downstream, which was consistent with variations in the water's temperature [87]. Thirteen fish species' yearly breeding season would be delayed by more than a month due to the low water temperatures brought on by hypolimnetic dam releases in the River of Yangtze. Additionally, there would be fewer possibilities for fish to spawn and thrive [70].

Another effect of dams is changes in the flow of water in downstream areas. It would affect (usually negatively) the population of fish as well as fish behaviors including swimming, spawning, upstream migration, tunneling, and other activities [88–90]. For instance, an excessively big or little outflow hindered carp spawning. The migration of 26 species whose eggs drift negatively was affected by the alteration in flow in the upper Yangtze River due to many nearby dams [70, 91]. This issue can be reduced by adjusting the dam discharge variations [92]. A summary of different effects of dams and their impacts on fish can be seen in Table 3.

2.2.1. Related literature

The case studies in this section include an overview of the global environmental effects of different dams on fish populations and aquatic ecosystems, refer to Table 4. Environmental issues such as major drops in native fish species, changes to habitat, and obstructions to fish migration routes are covered in detail in each case study. These illustrations show how dam building may have a wide range of negative consequences on water biodiversity and ecosystem health. The section examines the environmental effects of dams in both common and special situations through a review of several case studies from various regions.

2.3. Riparian vegetation

The construction of dams on rivers can have major effects on riparian vegetation in deltas. Between the low- and high-water levels, as well as the terrain over the high level of the water that may be impacted by floods or rising water tables, riparian habitats constitute the boundary between aquatic and terrestrial ecosystems [103]. The bio-geomorphological dynamics of these ecosystems, which are not completely understood, are the results of the interactions among river flows, sediment transport, and hydrophilic vegetation [104–106]. Numerous field investigations have demonstrated how river control brought about by the dams' constructed reservoirs may cause i) Vegetation changes as a canal narrows or widens [107–110]. ii) Decline in common plant species of the area and increase in eco-toxicity [109, 110]. iii) Decrease in overall biodiversity of habitats [111, 112]. In riparian regions, there are alternating times of peak floods and extremely low flows (droughts) due to the random fluctuations in the discharge of water experienced by them in uncontrolled rivers (e.g., without dams). Riparian zones become flooded during floods, and plant uses the moisture, nutrients, and seeds available to them [105] nevertheless, burial, anoxia, and uprooting can also harm downstream vegetation [113–117]. When there are no disruptions (like floods) during a drought, vegetation flourishes and spreads into new regions based on the level of the phreatic water table and the content of soil moisture [117–119].

Damming has several negative effects on the surrounding ecosystems in addition to the visible loss

Table 4. Case studies concerned with the effect of dams on fish biodiversity.

S. no.	Dam	Location	Environmental impact	References
01	Three Gorges Dam	China	✓ Significant decline in native fish ✓ Affected fish diversity ✓ Impacted spawning of fish ✓ Migration route blockage	[93]
02	Hoover Dam	USA	✓ Alteration of Habitat and significant decline in fish population ✓ Damaged gills of fish ✓ Damaged mucus layer of fish	[94]
03	Aswan High Dam	Egypt	✓ Reduction in nutrient-rich silt ultimately affects the fisheries	[95]
04	Itaipu Dam	Brazil	✓ Fragmented fish habitat leading to species decline ✓ 70% loss in biodiversity ✓ 60% drop in productivity ✓ Migration of fish obstructed	[96, 97]
05	Tucurui Dam	Brazil	✓ Disruption of the spawning cycle of local fish ✓ Migration blockage	[98]
06	Grand Ethiopian Renaissance Dam	Ethiopia	✓ Ecosystem Disruption	[99]
07	Akosombo Dam	Ghana	✓ Decline in native species ✓ Rise in invasive species	[100]
08	Glen Canyon Dam	USA	✓ Massive alteration in river flow resulting in a decline in native fish species ✓ Invasion of non-native fish	[101]
09	Sardar Sarovar Dam	India	✓ Native fish population decline ✓ Introduction of exotic fish species	[102]

of habitat due to flooding. Free-flowing rivers are transformed into reservoirs by impoundment, which exposes them to quite diverse natural processes. This can impact the nutritional content of both aquatic and terrestrial ecosystems, generate habitat fragmentation, lead to new sedimentation processes that change landforms, and change the local temperature through the "lake effect." By modifying the richness of plant communities as well as structural patterns, damming causes notable alterations in the vegetation along the coast [120–124]. Studies on Sweden's boreal rivers have shown that in comparison to the river stretches, the impoundment coastline has the worst losses in plant cover and species diversity [122]. It is suggested that no plant has developed adaptations to deal with the changed flow regimes since they are so unlike any natural rhythm. It has been demonstrated that the heightened severity and modified timing of water fluctuations have a significant role in upsetting pre-regulation plant zonation patterns. As a consequence, several species can flourish at altitudes below their typically occurring range [122, 125].

As illustrated in Fig. 6, in a reservoir region, plants are affected in several different ways. For instance, the functioning of the dam resulted in the submergence of the majority of the surrounding area and the scattering of plants with characteristics of a sublacustrine environment [126]. When compared to the previous riparian zone, there was a notable loss in both diversity of species and biological richness. After the whole impoundment, for instance, the total amount of tracheophyte species of plant in the Three Gorges reservoir dropped from 175 to 127 [127]. Elevation and slope had a negative relationship with both the relative species number and relative cover [128]. In addition to the quick loss of habitat resulting from dam construction, habitat fragmentation and long-term edge effects from dams also had a significant detrimental impact on animal-plant mutualistic networks [129].

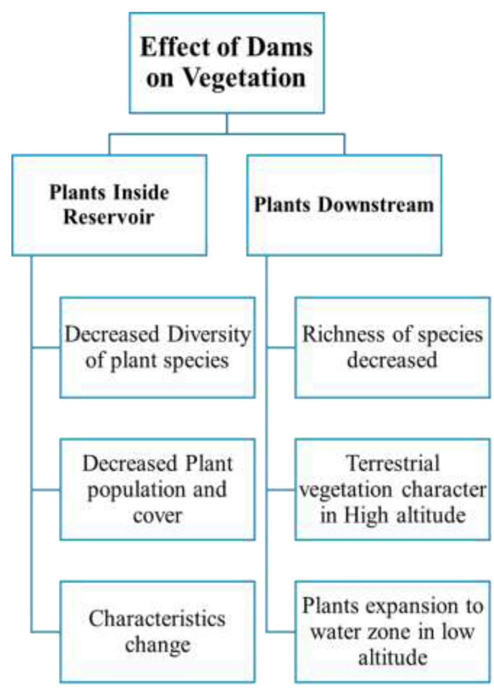

Fig. 6. Effects of dams on vegetation.

Table 5. Case Studies concerned with the effect of dams on riparian vegetation.

S. no.	Dam	Location	Environmental impact	References
01	Warm springs Dam	California	✓ Reduction in riparian vegetation diversity ✓ Increased area of riparian vegetation by 72%	[137]
02	Three Gorges Dam	China	✓ Abundance of native vegetation due to water level alteration ✓ Reduction in diversity of riparian vegetation ✓ Changed plant communities ✓ Loss of vegetation through inundation	[138–140]
03	Aswan High Dam	Egypt	✓ Reduction of plant biodiversity in some areas while increasing in others ✓ Introduction of new plant communities to the shore of Lake Nasser	[123, 141]
04	Glen Canyon Dam	USA	✓ Reduced nutrient availability affects vegetation that can thrive ✓ Shifts in plant species due to changes in water temperature	[142]
05	Hells Canyon Dam	USA	✓ Elimination of certain plant species downstream due to alteration flow ✓ Isolated patches of riparian vegetation ✓ Decline in native vegetation diversity ✓ Introduced some new riparian growth	[143, 144]
06	Bisha Dam	KSA	✓ Alteration of native plant species ✓ Introduction of invasive plant species ✓ More plant diversity as compared to undammed sites ✓ Development of novel plants	[145, 146]
07	Thissavros Dam	Greece	✓ Elimination of low-density vegetation ✓ Improvement in high-density vegetation	[147]

As a result of incision processes, the border of the flooded region often shifts downward towards the thalweg, causing herbaceous plants (for example, grasses and reeds) to grow to the mudflat lower altitude locations in the downstream channel [130]. While in higher altitude locations in which riparian vegetation seems to have a terrestrial character, the recruitment of macrophanerophytes (like cottonwood) was reduced [131]. Additionally, separate research discovered that dams might reduce the diversity of riparian plant species by preventing propagules from spreading their plants through water [132]. Global hotspots for biodiversity may be found in the lake wetlands, particularly the larger ones. Riparian vegetation typically expanded to the water zone in downstream lakes because of dams [133, 134]. For instance, in Dongting Lake, the beginning of the dry season led to the expansion of the sedge to the Phalaris zone and further to the mudflat zone, but in Poyang Lake, the early dry season after the Three-Gorges Dam was constructed caused the expansion of the Phalaris to the mudflat zone [134]. Between 2003 and 2014, the Nanjishan Wetland National Nature Reserve of Poyang Lake saw a 30% shift in total area from water to developing vegetation. Additionally, modifications to the Index of Normalized Difference Vegetation indicated that, during dry seasons, the vegetation in the middle regions thrived while that in the off-water regions was stressed [133].

The hydrologic regimes' severe occurrences are prevented from being carried out because of the control of stream flow brought about by constructing a dam or dams. During the peak of the flood and the wet-to-dry transition phases, there is a notable decrease in discharges [135]. On the other hand, discharges may somewhat rise during the dry season, which lowers the likelihood of droughts. The Nestos River's historical natural flows varied between 0.01 km^3/s in the summer to 1 km^3/s at the highest floods, before the building of the dams. Following the dams' construction, the downstream flow regime was altered, and 0.006 km^3/s is now recommended as the minimal environmental flow [136].

2.3.1. *Related literature*

The environmental effects of different dams on riparian vegetation and plant biodiversity are examined in case studies in this section, refer to Table 5. From decreased native vegetation variety to the introduction of new plant species, each case study sheds light on the ways in which dam developments affect plant ecosystems. Both beneficial and detrimental effects on plant biodiversity are demonstrated by these examples, which demonstrate the complex relationships between terrestrial ecosystems and water management structures. This part provides a thorough knowledge of the ecological changes brought about by dams by looking at several case studies from various geographical areas.

2.4. *Water quality*

The physical composition of the river continuum is fundamentally altered when a river is dammed and impounded. The dam wall causes the river's velocity to decrease, creating a lacustrine system in the constructed reservoir. The physical alteration caused by damming results in chemical alterations inside

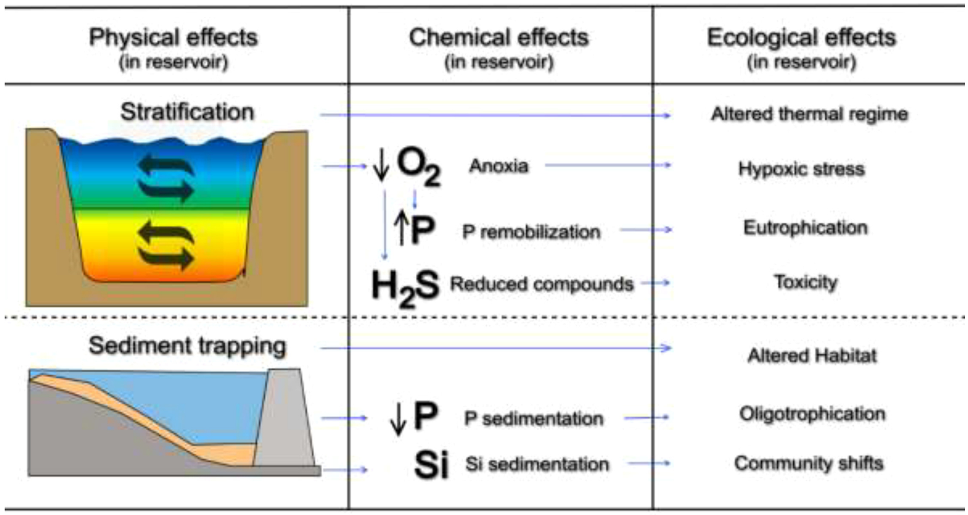

Fig. 7. Various effects of Dam construction on water quality.

the reservoir, affecting the chemical and physical characteristics of the water and having an ecological effect on rivers downstream and the wetlands that are linked with them [148]. The physical, chemical, and biological consequences of dam construction on water quality have received the most research the summary of these consequences is illustrated in Fig. 7.

The construction of a dam has the potential to alter the amount and circulation of contaminants in the reservoir's water by increasing the reservoir's water area, decreasing its diffusion, deepening its water, and slowing its flow rate [149]. Many nutrients are stored in reservoirs, including phosphorus, nitrogen, and hence encouraging the development of algae and potassium. Eutrophication in the reservoir might result from this. Water quality will also be negatively impacted by the expansion of irrigation. The sources and transport of contaminants after water is stored, eutrophication trends, reservoir water quality variations, the enrichment of bottom sediments with pollutants, and the water quality of discharge from the dam and downstream are the primary areas of concern for the effects of dam construction [150].

The temperature, suspended particle content, or any combination of these, as well as the density of the water approaching a reservoir, often vary from the water that is already there. Instead of mixing with the reservoir's water right away, the newly arrived water flows downstream and laterally over, below, or inside of it as an underflow, overflow, or interflow. Density currents are the name given to such flows. Where the incoming water falls below the surface, a convergence line frequently forms. If the variance in turbidity between the surface water and inflow water does not already indicate the location of the convergence line, a compensatory upstream current is created, taking back debris that is trapped between the interaction of two currents. It appears that the Norris Reservoir, the biggest storage reservoir owned by the Tennessee Valley Authority, has the first density currents ever recorded in a reservoir [151].

In lakes that are naturally occurring or that are developed by humans, the chemistry of precipitation and inflows greatly influences the chemical structure of the water, especially the amounts of conservative elements. The extraction of soluble matter from its carrier, however, may have an impact on fresh impoundment. This effect can be temporary if there is little soluble material present and the water retains its moisture for a short time. When soluble material concentrations are high, as they are in Lake Mead, The impounded water's chemistry may remain different from the inflow's for an extended time, particularly if the retention period is lengthy. If the chemical makeup of the incoming water differs from that of the water already in the reservoir, the existence of density currents may result in strange and intricate patterns of chemical stratification [152–154].

Historically, rivers have been thought of as the only channel via which materials may go downstream; blocking this channel has an impact on the biological and physicochemical characteristics of the system [155]. Reservoirs that hold water undergo physical, chemical, and biological changes that have an impact on the quality of the stored water. Within a reservoir, the chemical makeup of the water might change dramatically from that of the inflows. In comparison to the natural river, water that is released from reservoirs downstream may have a different composition and seasonal rhythm [156]. In dry areas, the salinization of water behind dams due to increased evaporation is troublesome and is an issue on wetlands in floodplains when there is no regular flooding to dilute and flush. Elevated salinity will impact aquatic life if it persists for a long enough time [157].

Hypoxic water may be discharged downstream where it may seriously affect the environment if dam intakes are located below the oxycline. Only well-adapted species survive below 2 mg/L, whereas concentrations of oxygen below 3.5 to 5 mg/L usually cause escape behavior in larger creatures. Due to heterotrophic intake and a lack of replenishment from oxic top layers, river impoundment frequently results in the deoxygenation of bottom reservoir water. Hypoxic water may be discharged downstream where it may seriously affect the environment if dam intakes are located below the oxycline. Only well-adapted species survive below 2 mg/L [158]. In the southern United States, 22 dams were the subject of research that revealed that 15 of them regularly issued water with less than 5 mg/L of DO and 7 of them discharged water containing less than 2 mg/L [159].

One significant macronutrient is phosphorus. Aquatic system production is frequently constrained by its scarcity or poor bioavailability to primary producers. On the other hand, dissolved P addition to aquatic environments frequently causes eutrophication, which results in blooms of algae, phytoplankton, or floating macrophytes on water surfaces [160, 161]. Dams appear to generally result in lower downstream nutrient delivery; the occurrence of eutrophication within reservoirs due to internal Phosphorus loading has been widely reported in lakes and reservoirs around the globe. When there are no significant human fertilizer inputs, eutrophication usually subsides a few years after reservoir development. Lake Kariba, the biggest reservoir in the world by volume, is a well-known example of a tropical location. After flooding, Salvinia molesta, a floating macrophyte, covered 10% to 15% of the lake's surface for several years. The blooms were credited by limnologists to the progressive release of phosphorus from aged sediments subjected to an anoxic hypolimnion, as well as the breakdown of organic materials [162].

The ability of the river downstream of the dam to handle contaminants is impeded by the high quantity of reduced chemicals found in water, including reduced iron and hydrogen sulfide (H2S). In addition to being vital for most of the aquatic life, sufficient dissolved oxygen is also required for rivers' oxidative self-purification processes to continue [163, 164]. By serving as a repository for free dissolved oxygen, reduced chemicals restrict the oxidative potential of river water. There have been reports of H2S occurring in the tail waters of dams, but it is challenging to determine how much direct ecological impact this stressor causes because it also coexists with low temperatures and hypoxia [165]. Researchers looking into fish mortality below Arkansas's Greens Ferry Dam discovered H2S concentrations of 0.1 mg/L, which is far higher than the toxicological studies' established fatal values of 0.013 to 0.045 mg/L for fish [166, 167].

2.4.1. Related literature

This section looks at several case studies to understand the environmental effects of different dams on water quality, refer to Table 6. Eutrophication, dissolved oxygen (DO) decrease, pH variations, algal blooms, and other unique problems related to water quality are discussed in detail in each case study. The chemical and physical characteristics of water bodies may be changed by dam construction, which can have an impact on ecosystem health and overall water quality. These examples give a clear grasp of this process. This part examines the many case studies from various regions to show the common and distinctive effects of dams on water quality.

3. Literature review assessment

The literature review in this paper comprehensively addresses multiple sides of dam impacts, with a focus on sediment deposition, fish biodiversity, riparian vegetation, and water quality. Each topic is supported by a considerable number of studies across the globe, indicating a broad search and integration of relevant research. For instance, this review cites studies spanning from historical perspectives to recent research, reflecting a significant temporal coverage. This review integrates findings from various studies to explain the impacts of dam construction. The review illustrates both the worldwide trends and regional variations in dam impacts by presenting case studies and general research findings side by side. This methodology facilitates comprehension of the heterogeneity and uniformity of dam-related environmental alterations in various geographic regions and ecological settings. The literature review identifies any gaps or contradictions in the methods and findings of the listed research by critically examining them. For instance, it discusses the gaps in the knowledge of sediment deposition and how such gaps affect the capacity of the globe to store water. More focus can be placed on the methodological variations across research, which can affect how comparable the results are.

Table 6. Case studies concerned with the effect of dams on water quality.

S. no.	Dam	Location	Environmental impact	References
01	Three Gorges Dam	China	✓ Increase in pH ✓ Increase in COD ✓ Decrease in DO ✓ Decrease in ammonia nitrogen	[168]
02	Hoover Dam	USA	✓ Water stratification ✓ Caused hypoxia	[169]
03	Akosombo Dam	Ghana	✓ Damming on Volta Lake caused eutrophication ✓ Promoted algal bloom ✓ Increased nutrient condition	[170]
04	Aswan High Dam	Egypt	✓ Increase in salinity ✓ Reduction in fertilizing capabilities of water	[95]
05	The Kariba Dam	Zimbabwe	✓ Decrease in level of dissolved oxygen ✓ Creation of thermal stratification	[171]
06	Kama Dam	Russia	✓ Reduction in water clarity ✓ Algal bloom promotion ✓ Caused eutrophication	[172]
07	Afobaka Dam	Suriname	✓ Oxygen depletion ✓ Leaching of tannic acid ✓ Affect pH	[173]
08	Shiroro Dam	Nigeria	✓ Water transparency increased ✓ Decrease in pH ✓ Decrease in DO ✓ Decrease in nitrate and phosphate levels	[174]
09	Aiba Dam	Nigeria	✓ Decrease in total alkalinity ✓ Decrease in turbidity ✓ Decrease in total hardness	[175]

There are numerous and complex consequences of sediment deposition brought on by the construction of dams. Studies show that sediment load downstream is significantly reduced because of dams retaining sediment, which has a negative impact on river morphology and aquatic environments. The absence of sediments can have detrimental effects on river and delta ecosystems, decrease nutrient delivery, and induce erosion downstream. Research has also brought attention to problems that exist inside reservoirs, such as decreased storage capacity and higher maintenance costs because of silt buildup. The example studies—like the ones done on the Yantan and Three Gorges dams of China—provide verifiable proof of these occurrences and highlight how widespread their effects are [30–32, 34, 36, 41, 42, 44, 47, 48].

Fish biodiversity is greatly impacted by dams, especially migratory fish species. One typical problem is the obstruction of migratory pathways, which results in a decrease in genetic diversity and population decreases. The literature places special emphasis on how the disruption of natural flow regimes and habitat fragmentation affect aquatic species' life cycles and spawning patterns. Research on a variety of dams, such as the noteworthy effects noted at the Three Gorges Dam of China and Hoover Dam of the USA, highlights the vital necessity of taking ecology into account while designing and operating dams to reduce these consequences [70, 72, 73, 75, 86, 91, 93, 94].

Riparian habitats are impacted by the hydrology of river systems that are changed by dam construction. The structure of plant communities along riverbanks can vary, vegetation patterns can change, and biodiversity can be lost as a result of dams' effects on water flow and sediment transport. Studies show the immediate effects—like flooding and modified flow patterns—as well as the indirect ones—like alterations in nutrient availability. Among other cases, the Bisha Dam of KSA provides an important illustration of how hydrological modifications due to dam construction can result in notable ecological changes [123, 124, 127, 145, 146, 176].

Water bodies' chemical, physical, and biological characteristics are all altered because of dam construction, having a significant effect on the quality of water. The research addresses how dams might result in problems that impact water use downstream, such as eutrophication and thermal stratification, oxygen depletion, and changes in nutrient dynamics. Particular case studies—such as those on the Aswan High Dam of Egypt and Kariba Dam of Zimbabwe—showcase the difficulties in maintaining sustainable water management in areas affected by dams and the complicated process of controlling the quality of the water in dammed rivers [95, 148–150, 158–162, 171].

Numerous case studies from several continents are included in this analysis, including in-depth analyses of significant dams like the Aswan High Dam in Egypt, the Hoover Dam in the United States, and the Three Gorges Dam in China. These examples range from the desert regions of North Africa to the temperate zones of North America and the heavily populated river basins of Asia. They are chosen not just for their size and importance but also for the distinctive environmental situations they represent. This review offers a more thorough and comparable analysis of the environmental effects of dam construction by quantifying specific impacts, such as the 64% contribution of the Three Gorges Dam to coastal erosion along the Yangtze River delta, or the 90% reduction of sediment transport in the Nile River post-Aswan Dam construction. Moreover, the research emphasizes the shortcomings of existing mitigation approaches, like fish ladders and sediment management schemes, which frequently fail in large-scale implementations. Through the integration of these in-depth analyses with a critical assessment of the methodologies employed in the reviewed studies—such as the differences in sediment measurement techniques or protocols for biodiversity assessment—this review not only highlights gaps in the literature but also supports the need for more standardized and thorough approaches in future studies. This thorough and well-reasoned methodology deepens our understanding of the intricate environmental effects of major dams, increasing the applicability of the findings to a wider range of ecological contexts and their relevance to the continuing international debates on sustainable water management.

This review observes that additional research is needed in several areas, including the long-term ecological effects of dams and the efficacy of mitigation strategies such as fish ladders and sediment management technologies. To elaborate on these points, it would be helpful to recommend specific research methodologies or locations and species that need immediate attention. A critical perspective on dam impacts is supported by a large amount of research, which indicates that although dams provide important advantages like flood control and hydroelectric power, they also have major and long-lasting negative effects on the environment. Improved management techniques that achieve a balance between ecological sustainability and developmental advantages have been suggested by the literature. To reduce negative environmental consequences, this involves integrating ecological modeling and advanced technology during the design and operating phases of dam projects. Using data from several studies and case analyses, this review offers a thorough evaluation of the state of the art regarding the effects of large dams on the environment.

4. Conclusion

This thorough analysis emphasizes that large dams have a substantial negative environmental impact on ecosystems and human populations across the world. Construction of large dams and maintenance have significantly altered natural ecosystems, often irreversibly, even though they have been essential in providing hydroelectric power, flood control, water security, and irrigation, among other developmental demands. Water habitat disturbance, erosion, and loss of deltaic lands are the result of decreased sediment flows downstream brought on by sediment deposition from dam operations. Not only has the geomorphology of river systems changed, but these changes have also affected the biodiversity that these ecosystems sustain, with migratory fish species being particularly affected. There is evidence that fish populations and genetic diversity drop when dams disrupt natural flow regimes, blocking migratory paths. In addition, changes in water levels and flow patterns have resulted in notable alterations to riparian zones, which are essential to the stability of ecosystems. Due to these modifications, native flora is disappearing, and exotic species are proliferating, endangering the ecological equilibrium even more. Large Dams have similarly alarming effects on water quality because they alter the temperature, oxygen content, and nutrient dynamics of bodies of water. These changes result in issues like eutrophication, which impacts the quality of water accessible for use in agriculture and human consumption in addition to water life.

It is important to recognize a few limitations despite the thorough examination this article gave. First off, a lot of secondary data from published works are used in this study; these data can differ in terms of methodology, quality, and scope. This dependence can lead to biases, especially when data is old or regionally localized, which reduces the conclusions' capacity to be applied generally. Furthermore, although the review encompasses a wide range of geographic areas and environmental implications, it does not take into consideration other potential factors, such as anthropogenic activity beyond dam construction or climate change, which could further influence the observed environmental changes. The study also primarily concentrates on large dams, which may cause it to ignore the cumulative effects of smaller dams, which when combined could have major negative effects on the ecosystem. In conclusion, there is a lack of consistency in the assessment of the efficacy of mitigation techniques covered in the literature, which could result in an inadequate comprehension of their success and relevance in real life.

To fully comprehend the long-term ecological changes and the effectiveness of mitigation techniques, longitudinal studies that monitor the environmental effects of dams over longer periods are crucial. More consistent approaches amongst research are also required in order to facilitate more precise comparisons and meta-analyses. Future studies should also examine the combined effects of small and medium-sized dams, especially in areas where these types of constructions are common. A more thorough knowledge of how changes in the environment could either increase or reduce the effects of dams would be possible through the integration of climate change models with dam impact studies. In conclusion, multidisciplinary methods integrating ecological, social, and economic viewpoints are vital for creating more comprehensive and long-lasting water resource management strategies. The planning and management of dam projects around the world will benefit from these directions, which will close current gaps and promote better decision-making.

Future research must concentrate on long-term, multidisciplinary projects that cover both the socioeconomic and direct ecological effects of dams. Methodologies that can accurately evaluate the combined effects and synergistic effects of several dams within river basins must be developed and improved. The efficiency of current mitigating solutions as well as the creation of novel technology and management techniques should be investigated in research to reduce adverse effects. The data in this review emphasizes the need for thorough environmental impact studies to be completed before the construction of new dams and for existing dams to be reassessed. Policy frameworks must include adaptive management techniques that enable dam operations to be changed in response to ongoing environmental monitoring. Furthermore, where appropriate, regulations should encourage the dismantling or modification of dams that are especially detrimental, led by comprehensive cost-benefit studies that take social and ecological valuations into account. In conclusion, large dams have greatly aided in the development of humanity, but they also have significant and sometimes irreversible negative effects on the ecosystem. Dam construction must take into account the long-term viability of river ecosystems in addition to the immediate advantages to humans moving forward. We may strive toward a future in which nature and human populations coexist peacefully by promoting a balance between development and conservation.

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The manuscript is conducted in the ethical manner advised by the targeted journal.

Consent to participate

Not applicable

Consent to publish

The research is scientifically consent to be published.

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