Introduction of a nature-based sustainable technology to mitigate climate change-driven water pollution in rivers and lakes

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Abstract

Climate change is intensifying water stress around the world by disrupting the water quantity and quality of surrounding rivers, lakes, and streams. Sustainable water management to adopt climate change and improve global water security needs to focus on technology and innovation. A decentralized, low-energy and sustainable approach to meet both the water quality and quantity demands requires for combating global water scarcity under climate change conditions. The proposed technology is based on the principle that incorporation of nature-based solutions in technological process development can lead to a powerful tool for tackling the climate change-driven water pollution. This technology is an extension version of the patented technology on oil sands tailings water treatment (Canadian Patent 2,952,680). The nature-based entrapped cells submerged reactor is proposed as a sustainable on-site treatment option to manage surface water quality. The process consists of selection and entrapment of suitable bacterial communities found in the natural environment. The submerged reactor containing entrapped naturally occurring bacterial communities is used for improving on-site water quality under aerobic conditions. This nature-based and decentralized microbial technology provides practical solutions like on-site wastewater treatment for achieving the United Nations Sustainable Development Goal.

Keywords: nature-based solution, on-site wastewater treatment, climate resilient water technology, naturally occurring bacteria, cell entrapment

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1. Introduction

The impacts of gradual climate change have been observed on Earth during the last few decades. According to United Nations, climate change affects the world’s water in complex ways like, unpredictable rainfall patterns, shrinking ice sheets, rising sea levels, floods, and droughts. The Intergovernmental panel on climate change (IPCC) Assessment reports confirm the impacts of climate change on the global water cycle and predicted that many people will be exposed to extreme weather events by the end of this century. Climate change has made extreme weather events such as floods and droughts more frequent and more severe. The water quality of the world's rivers and lakes tends to deteriorate due to increased temperature and changed precipitation patterns. Throughout the world climate patterns are modifying the natural water balance and shifting towards the occurrence of extreme weather events. More frequent and more powerful storms will increase polluted runoff from urban and agricultural areas, combined sewer overflow and carry them to nearby waterways are predicted as impacts of future climate change [1-5]. Climate change is intensifying water stress around the world by disrupting the water quantity and quality of surrounding rivers, lakes, and streams. Although the impacts of climate change on water resources will vary between different regions but potential impacts include frequent and severe floods and droughts with declining water quality.

2. Impacts of Climate Change on World’s Rivers and Lakes

To address global water scarcity to meet the United Nation’s Sustainable Development Goal it is crucial to account for both quality and quantity of water resources. Water quality issues significantly change the global water scarcity assessment. The water scarcity levels are higher considering both water quality and quantity (on average 40%) compared to only for water quantity (30%). Global studies found that world’s rivers are getting polluted due to droughts or heatwaves, rainstorms, and multidecadal historical and future climate change by 68%, 51%, and 56%, respectively. The multidecadal climate change causes decrease in dissolved oxygen concentrations and increase in nutrient, and pharmaceutical concentrations in river water whereas concentrations of biochemical oxygen demand, salinity, suspended sediment, metals, and microorganisms varies with fluctuations of water volume in rivers and lakes [6-8].

In Europe, climate change has already started to show impacts on the surface waters as water temperature of the major European rivers and lakes have increased by 1-3°C over the last century. Surface water temperatures are projected to increase further with the warming trends of global temperature. More frequent hydrological extremes events are expected to increase the load of pollutants and in turn reduce the dissolved oxygen concentration in rivers and lakes of Europe. Sewage overflow and surface run-off from urban and agricultural areas will contribute to the pollutants load [9-11]. Climate Status Report for Ireland indicates a gradual rise in sea level, changes in precipitation patterns, increase in heavy precipitation events and flooding will be experienced across the country in coming days. Assessment showed that during the storm events untreated sewage is entering into the surface waters which lead to failure in meeting the European Union's obligations [12].

Climate change is causing more extreme weather across the United States. Very heavy precipitation events have increased nationwide and predicted to increase in all regions. Flooding is reported to intensify in various regions, even in areas where total precipitation is projected to decline. The water quality of rivers and lakes in united states will deteriorate in future due to intense precipitation and/or droughts and increase temperature [13]. Significant changes in water quantity and quality are evident across the country. Surface water quality is declining as water temperature increases and frequent and heavy rainfall events mobilize the pollutants. Frequency of heavy precipitation events in most parts of the United States have increased since 1901 and are projected to increase over this century [14, 15].

The North American Great Lakes are the largest freshwater resources on the planet. The region is already affected by climate change as extreme rainfall events have increased over the last five decades and expected to increase into double by 2100. Great Lakes will experience more harmful algal blooms due to increased temperature and nutrient loadings from surface runoff. Climate change will cause oxygen depletion and formation of deep-water dead zones for fish and other organisms in all lakes due to increased duration of summer stratification [16, 17].

In India, the rivers play a significant role in the lives of its people. The changing climatic conditions in recent decades cause serious threats to river basin hydrology. Severe droughts and devastating flooding events have been observed nationwide. The pollution of river Ganga is one of the most discussed subjects on water pollution for being one of the most contaminated major rivers on earth. The Ganga basin is home to around half a billion people and has been significantly impacted by climate change. The increasing high-intensity rainfall events often create flash flooding events putting the entire basin under severe flood risk. A coupled hydrological and water quality simulation model has predicted a future deterioration of water quality of river Ganga with more than 50% increase in nutrients and BOD, 43.5% increase in risk of eutrophication, and 15% increase in fish kill due to climate change alone by mid-twenty-first century. Kanpur city on the banks of river Ganga is the major pollution hotspots because of industrial discharge and untreated sewage disposal. Agricultural runoff along with climate change further contributes pollution in this industrialised stretch of Ganga. Finally, water quality degradation and ecological distortion are expected over seven major polluted river catchments of India as there will be about 2.3% decrease in dissolved oxygen concentrations for every one degree increase of river water temperature under the influence of climate change [18-21].

Climate change along with anthropogenic activities are responsible for water quality degradation of rivers and lakes in China. The water scarcity levels at various geographic and temporal scales showed a greater inequality across the country and inclusion of water quality parameter leads to a deteriorate assessment of water scarcity. According to water scarcity assessment, the northern part of China often suffers both inadequate water quantity and quality throughout the year, whereas southern portion experiences degraded water quality despite of sufficient amount of water. Total Nitrogen represents a serious pollution problem in most regions of China under the current water quality standards [22, 23].

At present, India, China, Middle East, Mediterranean and Mexico are identified as the most water scarcity hotspots regions considering water quantity and quality issues. Water quality impacts are high in eastern China and India where excessive withdrawals of water resources and its return after degradation intensifies the overall water scarcity. A study on organic pollution (biochemical oxygen demand) in global river networks projected that the number of people affected by organic pollution in river will increase from 1.1 billion in 2000 to 2.5 billion in 2050 with disproportionate effects on developing countries. An innovative and affordable decentralized low-energy approach of wastewater treatment is needed to control the organic pollution since the large-scale wastewater treatment system and environmental regulation implication are always not within the reach of many developing regions [7, 24].

3. Mitigation Strategies for Climate Change-driven Water Pollution

There is considerable evidence that climate change will escalate the threats related to water resources in future. It has been estimated that around 2.06 billion urban residents will face water scarcity by 2050. Climate change is disrupting the global water cycle significantly. Strengthening the ability to adapt to these changes is fundamental to the concept of sustainable development. Assessment of the impacts of climate change on water scarcity is predominantly focussed on water quantity, with much less emphasis on strategies for protecting the water quality. Sustainable development requires advancement of our focus only from water quantity solutions into strategies that strengthen both water quantity and water quality issues. Clean water technologies meet the requirement of both water quantity and water quality demands and can be considered as a key element to mitigate water pollution in rivers and lakes under climate change conditions globally [1, 7].

Sustainable water management to adopt climate change and improve global water security needs to focus on technology and innovation. According to United States Environmental Protection Agency (USEPA), decentralized systems help communities reach the triple bottom line of sustainability: good for the environment, good for the economy, and good for the people. Decentralized systems have the potential to manage urban water cycle in a more economical and sustainable way as it offers low capital, operation, and maintenance costs and wise use of energy and land. These systems can be used as independent facilities or integrated with centralized wastewater treatment systems to add resiliency and diversity in water management for minimizing the effects of climate change and urbanization. Decentralized systems have the main components of resilience such as, robustness, adaptive capacity, and flexibility [5, 25-28].

Nature-based solutions are considered important components of international efforts to combat climate change and can play a leading role in mitigating global water scarcity to meet the United Nation's Sustainable Development Goal. The use of nature-based solutions can accelerate the progress towards present climate goals by up to 30%. Nature-based solutions for water resources management comprise the purposeful and designed use of ecosystem to improve water quantity and water quality. These solutions are more cost-effective and climate resilient than conventional process and can lead to more sustainable solutions for water management. The uncertainties related to climate change can be addressed successfully by nature-based solutions because of its ability to adapt the changes [29-32].

4. Proposed Water Technology

To cope with the rapid changes in global water cycle, development of a wastewater treatment technology which is less expensive and more effective for controlling pollution at local scale or a sustainable and economical on-site technology is necessary to mitigate the water pollution in rivers and lakes globally. The proposed technology is based on the principle that incorporation of nature-based solutions in technological process development can lead to a powerful tool for tackling the climate change-driven water pollution. This technology is an extension version of the Canadian patented climate technology (2,952,680) for oil sands tailings water treatment and generate carbon credits by reducing fugitive methane emission from oil sands tailings pond [33, 34].

climate change is reshaping the seasonal period and extending the exposure of extreme events within a season like, changing precipitation patterns and intense periods of drought and flooding [35]. Combating the climate change-driven water pollution in rivers and lakes is difficult as its occurrence and concentration undergo seasonal fluctuation. Cell entrapment is one of the emerging biotechnologies in wastewater treatment that overcomes many limitations of traditional biological processes. Entrapped cells system can control non-point sources water pollution since it maintains cells viability and degradation capability under substrate limitation [36, 37]. Extreme precipitation events carry a wide variety of wastewater from combined sewer overflow, urban and agricultural runoff to the nearby rivers and lakes. Dealing with these wastewaters and the operational limitations of sewage treatment plants are major concerns of river pollution in world under changed climatic conditions. Thus, a sustainable and on-site technology which incorporates specific microorganisms capable of degrading target pollutants is needed to improve water quality at local and regional scales.

The proposed water technology comprises two processes:

a) Collection of bacterial communities from natural environment:

Careful selection of diversified and potential bacterial species from natural environment significantly increases the treatment scope of wide variety of pollutants present in Sewage overflow and surface run-off. In natural environment, microorganisms are capable to deal with nutrient starvation, temperature variation, drought, and survival without reproduction for a long time. They can alter their properties to adapt available nutrient supply by decreasing their metabolic rate or by using rare nutrient sources, including their own waste products. Depending on available nutrient in the natural environment, the microorganisms become organized into multicellular communities for protection against adverse environment which allows individual cells to modify or differentiate and acquire specific properties such as, phase variation and resistant spore formation. Microorganisms that exist in natural environment are markedly different from those once relocated and cultured in laboratory conditions. The microorganisms undergo complex changes during adaptation to the favourable laboratory conditions like, repression of some protective mechanisms that are essential in natural environment. Thus, use of naturally occurring bacterial communities is more efficient for the treatment of fluctuating concentrations of wide variety of pollutants [38].

b) Entrapment of collected bacterial communities:

Entrapment of microbial cells in polymer matrices is one of the most popular approaches of cell immobilization. Cell entrapment is considered an emerging technology in wastewater treatment. Entrapment of bacterial cells within a polymer matrix increases its toughness by improving the tolerance or protection from physicochemical challenges, such as temperature, pH, toxic substrates, or end-product inhibition [39, 40]. Entrapment also maintains cells viability and degradation capability under fluctuations of pollutants loadings in rivers and lakes.

In addition, the proposed water technology provides a submerged reactor to mitigate climate change-driven water pollution in rivers and lakes which consist of entrapped bacterial communities isolated from natural environment. The nature-based entrapped cells submerged reactor is used as on-site systems for improving water quality at lakes, most polluted river stretches, and drains carrying wastewater into nearby waterways. *Figure1* outlines the processes of water treatment in the proposed technology.

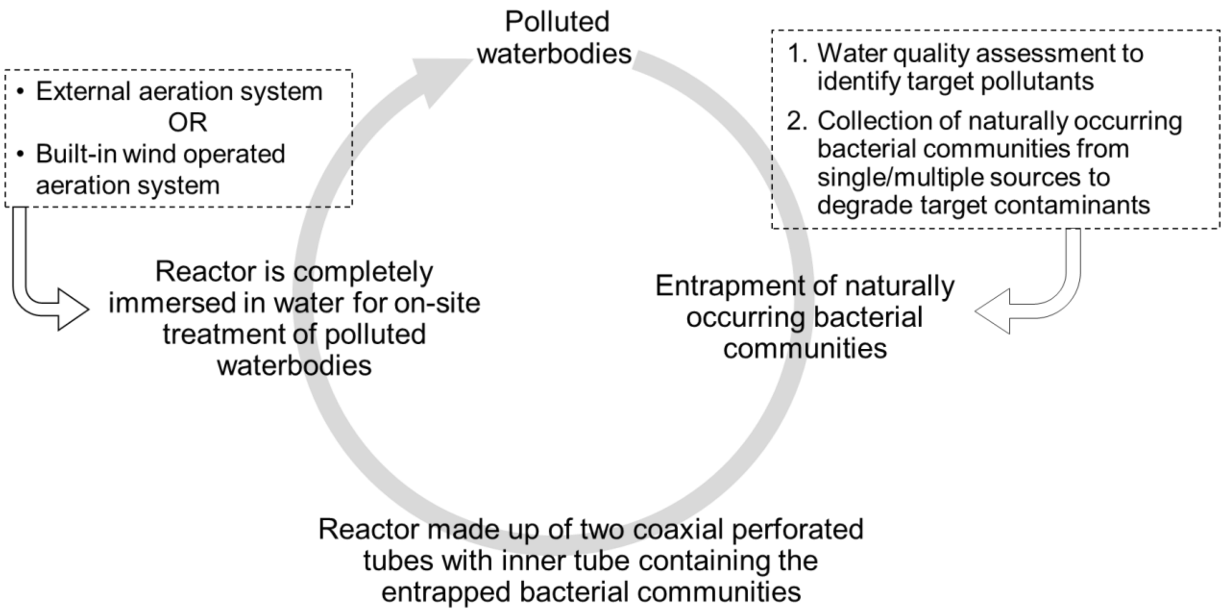

Fig1. Process flow chart of proposed water technology.

4.1. Process Methodology

4.1.1. Identification of target pollutants

Water samples from polluted rivers or lakes is collected and analyzed over an extended period to identify the pollutants of interest or target pollutants. Water samples are collected from the representative sites of the waterbody for assessment. Standard methods are used to assess the physical, chemical, and biological water quality parameters along with introduced pollutants such as, pesticides, metals, nutrients, and toxic substances like heavy metals and organic chemicals. Water quality assessment reveals the possible pollution sources (i.e. industrial discharge, Urban runoff, agricultural runoff, sewage overflows etc.) and target pollutants.

4.1.2. Isolation of bacterial communities

The naturally occurring bacterial communities are isolated from soil, sediment, and water samples of natural environment sites. The inventory of natural environment sites is prepared as per site's contamination history from natural and anthropogenic origins. Target pollutants are the key factor in selection of appropriate environment sites. Bacterial communities are isolated from single or multiple sites for the treatment of target pollutants present in the waterbody. Solid (soil/sediment) samples are homogenised by grinding and mixing thoroughly. Homogenised solid sample is then suspended using pyrophosphate buffer solution and shake vigorously using a vortex mixer at 3200 rpm for 5 min to separate solid particles and to release bacterial cells. The buffer solution and collected water samples are passed through 15μm membrane filter using vacuum filtration. The filtrate liquid is then centrifuged at 5000rpm for 15 min and the settled solids is used as the naturally occurring bacterial communities for entrapment.

4.1.3. Entrapment of naturally occurring bacterial communities

The choice of an appropriate entrapment media is the crucial parameter for the performance of an entrapped-cell-based wastewater treatment process. An appropriate entrapment media creates a protective microenvironment condition for the microbial cells which provides necessary protection to the microbial cells against toxic pollutants while facilitating adequate supply of substrates for the growth of the cells and the rejection of metabolites from cells [41]. The media creates a protective microenvironment condition for the microbial cells that promotes favourable physiological changes for growth and metabolic activity of the cells. Physiological changes associated with certain entrapment media are strategies for the cells to survive or grow well under conditions that are related to key operational and economic factors in wastewater treatment [40, 42-44].

Desirable properties of an entrapment media for application in water pollution control of rivers and lakes are high structural integrity, high porosity, and low biodegradability. Synthetic polymers are the best choice of entrapment media for such application. For entrapment, the isolated naturally occurring bacterial communities is thoroughly mixed with the aqueous solution of selected entrapment media. The mixed bacterial cells suspension is then poured into the cross-linking solution for polymerization and entrapped cells are formed. In polymerization process the pouring technique is controlled to get desired shape and size of the entrapped cells.

4.1.4. Reactor configuration

Figure 2 represents a schematic illustration of the proposed reactor to mitigate water pollution in rivers and lakes under climate change conditions. The reactor consisting of two coaxial perforated tubes. The inner soft perforated tube is loosely packed with entrapped cells of naturally occurring bacterial communities. Size of perforation of the inner tube must be less than the desired size of the entrapped cells. The outer layer of the reactor is made up of a firm perforated tube. The outer perforated tube protects the inner tube from damage caused by suspended debris that may present in surface water bodies. The perforated design of the reactor allows the flow of water through the reactor where polluted water meets the entrapped naturally occurring bacterial communities and biological degradation of target pollutants occur. Configurations of the proposed reactor are scalable and adjustable for on-site treatment of water at lakes or polluted river stretches or drains carrying wastewater into nearby waterways.

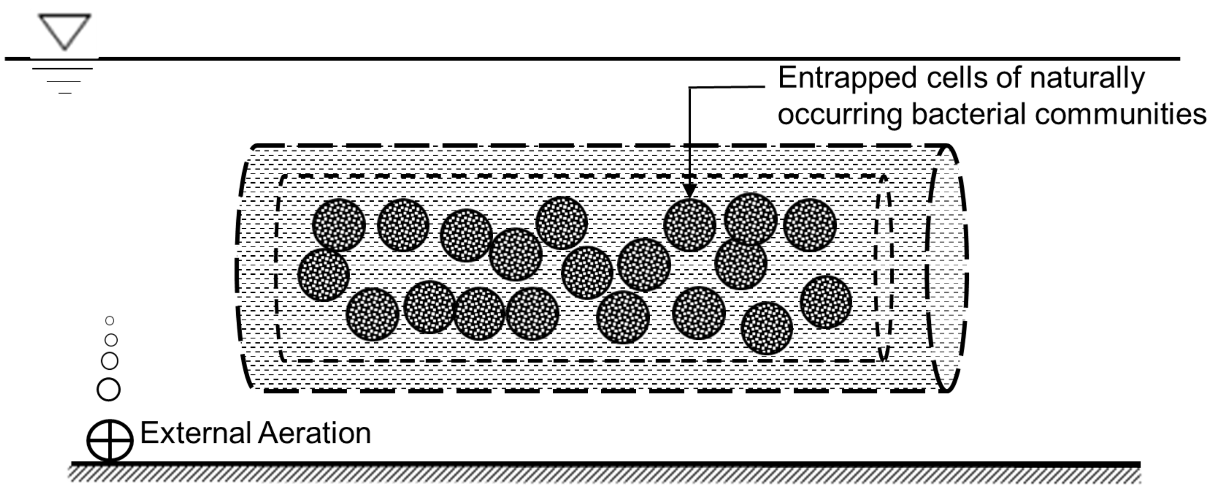

Fig 2. Schematic diagram of the reactor with external aeration system (not to scale).

4.1.5. Reactor installation

The nature-based entrapped cells reactor is installed for in-situ treatment of water at polluted waterbodies in submerged condition. Aerobic condition is created by installing an external aeration system to enhance the bacterial degradation of target pollutants present in water. The addition of a wind operated aeration system makes the technology more sustainable. *Figure 3* depicts the proposed reactor containing a built-in aeration system.

Wind driven aeration system is assembled in between the two coaxial perforated tubes of the reactor.

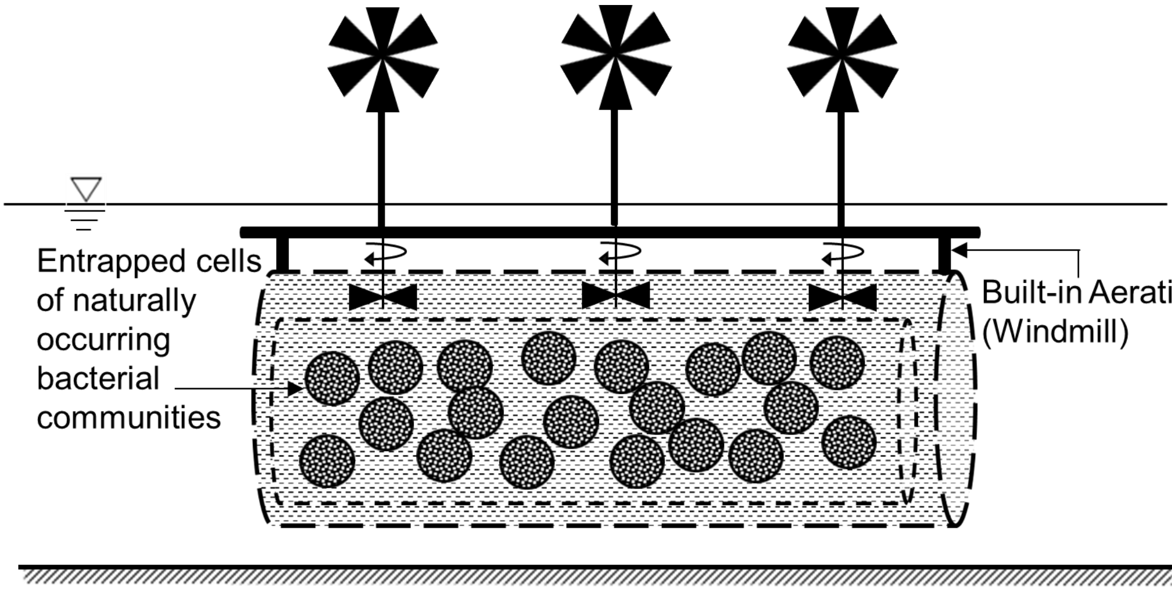

Fig 3. Schematic diagram of the reactor with built-in (windmill) aeration system (not to scale).

4.1.6. Reactor operation and maintenance

Successful application of entrapped cell systems mainly depends on the durability of the entrapment media and high cell viability. Synthetic polymers are strong, durable, lightweight, and inexpensive to manufacture. Synthetic polymer is used for the entrapment of naturally occurring bacterial communities to ensure longevity of the treatment system for more than a decade. Maintenance of the reactor mainly include the operation of the external or in-built aeration system. Modular designing of the prefabricated reactor can be customized and installed at site to handle anticipated flow and pollutants loading in a cost-effective and sustainable way.

4.2. Technology Discussion

To confront climate change-driven water pollution it is necessary to develop an economical, technically feasible, and sustainable water treatment process which would be within the reach of many developing regions. The proposed decentralized and nature-based water technology is designed to mitigate global water scarcity to meet the United Nation's sustainable development goal. The United Nation's guide for climate change adaptation technologies to strengthen resilience in the water sector provides two general criteria groups of costs and benefits which further subgroups as, low capital and operational cost, simple need of infrastructure, less requirement of human resources and knowledge, broad application extent, negative environmental impact, social acceptance etc. [5]. Sustainable water management of rivers and lakes to adopt climate change demands an efficient and scalable remediation solution which is easy to implement and maintain for improving the global water security.

The decentralized nature or on-site application of this submerged reactor meet the requirements of low costs (installation, operation, and maintenance), reduced human resources requirements, simple infrastructure, and wise use of land. The built-in aeration system of the reactor makes it more energy efficient or sustainable. The selection of naturally occurring bacterial communities for entrapped cells leads to resilience like more efficient, flexible, and adaptive water treatment process under fluctuating concentrations of various hazardous pollutants. The entrapment process further improves the robustness of naturally occurring bacterial communities. In natural environment bacterial communities organize themselves into multicellular communities. Extracellular DNA (eDNA) is a major structural component of these multicellular communities which has various important roles such as, disseminating genes amongst different microorganisms, storing nutrients, genetic responses for resistance against adverse conditions [45, 46]. The productions of eDNA in bacterial cells are substantially higher when cells are in entrapped condition than in multicellular communities or biofilms [47]. Key features of the water treatment technology to adopt climate change-driven water pollution in rivers and lakes are listed in table 1.

The key problem of environmental remediation is the extent of pollution, or the wide-scale area covered by the pollution needs restoration which often becomes expensive and that's where bioremediation comes in. In present days, the use of synthetic biology is gaining popularity to brings an improvement of bioremediation processes to address the worldwide problems of environmental pollution in a sustainable way. Synthetic biology is a scientific field based on designing of tailor-made organisms with enhanced features to achieve higher uptake rate of targeted pollutants. Several studies are already performed with the aim to increase the metabolic activity of microorganisms that naturally consume toxic compounds [48-50].

The major challenges of applying synthetic biology in environmental remediation lies on higher-than-expected costs of the technology, uncertain environmental consequences of releasing the engineered microbes in nature and approval of regulators and shareholders about deployment of engineered microorganisms in natural environment. Synthetic biology is committed to resembling artificial biological systems that do not exist in nature. The United States Environmental Protection Agency (EPA) has subjected the genetically engineered microorganisms to extensive risk assessment protocols and there are questions about the legitimacy of synthetic biology applications [51-54]. The genetically engineered microorganisms are engaged in risks or difficulties while entering a natural environment from controlled laboratory conditions like, gene contamination, toxicity, and competition with native species. The possibility of horizontal gene transfer from engineered organisms to wild-type organisms has also not been consistently evaluated in laboratory or field studies, therefore little is known about its risk potential. All living organisms act according to ever changeable and unpredictable evolutionary principles. In natural environment, most microorganisms work in complex interactions within the ecosystems rather than work in isolation and thus each subjected to random evolutionary mutations [55, 56]. The on-site applications of engineered microbes may cause unintended consequences of irreversible environmental damage and pose significant geopolitical threats since the future of engineered microorganisms outside the laboratory such as, survival, reproduction, potential mutation are not yet fully known. In this instance, the effects of uncertainties related to climate change on engineered microorganisms and its ability to adapt the changes are also not known to us. Thus, safe, and effective deployment of engineered microbial technologies for on-site remediation requires responsible management of unknown risks and careful ethical considerations [54, 57].

Intrinsic biocontainment is often referred by scientific studies as a tool for safe deployment of engineered microbes for on-site environmental remediation that limits and controls the spread and persistence of the microbes. But the implementation of engineered intrinsic biocontainment outside of closed environments or its translation to real-world deployment is the key challenge as there are limited test data and metrics available for evaluating the effectiveness of biocontainment technologies in the laboratory. Moreover, the laboratory developed testing methods of assessing biocontainment effectiveness are difficult and potentially costly to translate into complex, real-world environments and intrinsic biocontainment is not a universal approach to ensuring environmental biosafety [56]. Consequently, the application of engineered microorganisms for cleaning up of contaminated environments like, polluted surface water bodies or tailings water storage on the earth's surface may not be a sustainable, economical, and technically feasible approach. Table 2 summarizes the application potential of water technologies in combating climate change-driven surface water pollution.

4.3. Practical/Real-world Application of the Technology

Climate change is dangerously affecting the available freshwater resources on Earth by disrupting the seasonal flow of rivers. The extreme storm events lead to sewer overflows in communities where stormwater and sewage are transported together and releasing the raw sewage and polluted stormwater into nearby rivers and lakes. The increased inflow rates significantly impact the operations of wastewater treatment plants. A reliable wastewater treatment system requires adaptation actions to reduce vulnerability and build resilience to withstand the effects of climate change. Strengthening the ability to adapt climate change is the fundamental concept of sustainable development. On-site wastewater treatment is considered more economical and sustainable process as it offers low capital, operation, and maintenance costs and decreases energy and physical footprint. The proposed nature-based water technology can be used independently as an on-site treatment for improving freshwater quality or can be integrated with centralized wastewater treatment systems to add resiliency and diversity to manage surge flows caused by extreme weather events.

For application of entrapped cells system in a full-scale treatment process, judiciously chosen entrapment medium can be used for more than a decade. In practice, bacterial cells entrapment has been successfully used for nitrification/denitrification at municipal and industrial wastewater treatment plants in Japan and a steady nitrification had been observed for 15 years in continuous wastewater treatment process [58, 59]. Thus, entrapped cells system has been successfully used to control point sources water pollution. However, the ability of this technology to control non-point sources water pollution has been overlooked. The proposed technology is designed to control non-point sources water pollution of river and lakes for the first time.

An example of real-world application of the proposed on-site water technology would be pollution control of river Ganga in India. Ganga, the largest river in India is getting polluted everyday by millions of liters of wastewater generated from several non-point sources such as, urban runoff, untreated domestic sewage, industrial effluent discharge, and agricultural runoff. Wastewater treatment plants have been constructed along the riverbanks to reduce the water pollution; but there is an enormous gap between the amount of generated wastewater and treatment capacity of the plants. Consequently, several million liters of wastewater is discharged into the river daily. Sewage treatment capacity of some plants is poor because of the operational problems. Sewage is also not reaching in some of the plants due to the absence of appropriate connection between the plants and the sewage transport systems. The proposed technology is a feasible unconventional approach of improving the water quality of Ganga river, which has become an important national need over the past decades.

The Ramsar site, East Kolkata Wetlands (EKW) is a natural sewage treatment facility and multifunctional wetland ecosystem in Kolkata, West Bengal, India. The EKW has been recognized as a potential source of very diversified bacterial communities of enormous potential starting from oil degradation, metal accumulation to repair the radiation induced DNA double strand break which are biotechnologically important [60-63]. In Ganga, almost 85% of the river pollution is caused by sewage and the contribution of industrial pollution is nearly 20% which comprises toxic and recalcitrant pollutants of much greater significance. The industrial pockets along the riverbanks are responsible for contributing significant toxicity at some stretches of the river [64]. Thus, selection of a very diversified and potential East Kolkata Wetlands bacterial communities for proposed entrapped cells submerged reactor will enhance the bioremediation processes of wide variety of complex pollutants at most polluted river stretches or at drains carrying wastewater into the river. The on-site bioreactor adds resiliency and diversity in water quality management of river Ganga and adopt the impacts of climate change and urbanization on river water quality in a sustainable way.

5. Conclusion

The freshwater scarcity is one of the major environmental challenges as water resources of our planet are increasingly being threatened with the rapid growth of urban population and industrialization under climate change conditions. To combat climate change, development of a less expensive and more effective wastewater treatment technology for controlling pollution at local scale is necessary. The uncertainties related to climate change can be addressed successfully by nature-based solutions because of its ability to adapt the changes. In this study, an on-site nature-based entrapped cells submerged reactor is proposed to control non-point sources water pollution in rivers and lakes for the first time. Carefully selected microorganisms from natural environment followed by an appropriate entrapment procedure could be a promising sustainable biological process to control surface water pollution in adverse or uncertain conditions related to climate change. This nature-based sustainable technology provides an efficient, technically feasible, and cost-effective water treatment process for substantial volume of wide variety of polluted runoff at rivers and lakes, or most polluted river stretches, or drains carrying wastewater into nearby waterways. The on-site submerged bioreactor will introduce a sustainable alternative option for water quality management in rivers and lakes under climate change conditions. The proposed water technology has a potential global impact because polluted runoff from urban and agricultural areas, combined sewer overflow and carry them to nearby rivers and lakes are predicted as impacts of future climate change throughout the world.

Table1. Key features of the proposed water technology

Key Features	*Description*
Economical	Simple infrastructure of the reactor Reduced requirements of human resources for operation Decentralized system Involves biological treatment process
Sustainable	Energy efficient and use of renewable energy source Nature-based biological treatment process Decentralized system
Resilience	Involves efficient, flexible, and adaptive bacterial communities from natural environment
Robust	Entrapment improves cells viability and degradation capability under adverse operational conditions like, fluctuating concentrations of various hazardous pollutants in rivers and lakes
Efficient	Involves most suitable naturally occurring bacterial communities for target pollutants
Scalable	Scalable, modular, and portable reactor configurations for onsite application in various surface waterbodies

Table2. Application potential of water technologies in combating climate change-driven surface water pollution

Proposed water technology	*Synthetic biology technologies*
Benefits 1) Involves most suitable naturally occurring bacterial communities for uptake of target pollutants. 2) Requires simple biological techniques, and human knowledge and skills. 3) Entrapped nature-based bacterial communities are resilient, sustainable, and robust in preserving the treatment efficiency in adverse or uncertain conditions related to climate change. Limitations After initial exposure of pollutants, the naturally occurring bacterial communities may take some time for the acclimation process.	Benefits Capable to achieve rapid and high uptake of target pollutants in controlled conditions. Limitations 1) An interdisciplinary approach that requires advanced research skills and knowledge. 2) Developments of commercial genetically engineered organisms are costly and tedious process. 3) Key challenge associated with engineered microbes is limited knowledge about its risk potential or uncertain consequences once release into the natural environment. 4) On-site deployment of engineered microbial technologies require regulatory approvals and ethical considerations.

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The author declares that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

The author confirms that the data supporting the findings of this study are available within the manuscript. The data that support the findings of this study are openly available.