MINI REVIEW

Liquid Tree and its Importance in Metro Cities – A Mini-Review

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Abstract

Urbanization and air pollution are significant challenges affecting metropolitan cities globally, leading to increased temperatures and deteriorating air quality. Traditional green solutions, such as planting trees, often fall short in densely populated areas due to limited space and poor soil conditions. Liquid trees, a novel solution using microalgae in photobioreactors (controlled systems designed for cultivating photosynthetic organisms under optimized conditions), present a viable alternative, present a viable alternative for enhancing urban air quality. These systems utilize microalgae's high photosynthetic efficiency to absorb carbon dioxide and release oxygen, making them 10 to 50 times more effective than conventional trees. Liquid trees can be implemented in compact urban spaces, including rooftops, facades, and public areas, providing continuous air purification without the constraints of soil and space. Additionally, they offer benefits like biofuel production, biosorption of heavy metals, and wastewater treatment. This innovative approach addresses key urban challenges such as pollution, climate change, and the heat island effect while contributing to sustainable urban development. By integrating liquid tree systems into urban planning, cities can improve resilience, adapt to environmental stressors, and ensure a cleaner and healthier environment for residents. The adaptability and efficiency of liquid trees position them as a critical component of future urban area development strategies, providing a scalable solution to modern environmental challenges, along with ensuring sustainable development.

Highlights

- Liquid trees offer a sustainable solution for urban air purification.
- They are 10 to 50 times more efficient in carbon sequestration than traditional trees.
- Compact, modular design enables integration into urban environments.
- Innovative design facilitates enhanced green infrastructure and improved air quality.

Keywords: Liquid trees, Microalgae, Urban air purification, Photobioreactor, Sustainable urban development

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Introduction

We have been discussing global warming, temperature rise, pollution, urbanization, etc., among ourselves. The trend of temperature in recent years has not been the same in most major cities. It is generally observed that air pollution contributes to the increase in temperature in cities. Urban heat islands (UHI) are a phenomenon experienced by urban areas that result in extreme weather conditions and higher pollution leading to increased temperatures (Kankaria *et al.*, 2023). Urban elements such as impermeable surfaces, traffic, and lack of open spaces because what is called the heat island effect are responsible for making cities much warmer than their surrounding areas (N. Dave *et al.*, 2022). Apart from this, cities concentrate on the key sources of air pollution like traffic and industrial activities resulting in high levels of nitrogen dioxide, ozone, and particulate matter (Vicedo-Cabrera & Chen, 2020). Other studies have shown a strong positive relationship between temperature and air pollutants especially particulate matter (Asta *et al.*, 2019; Kovaliova *et al.*, 2020). This combination of hot weather conditions and poor-quality air makes it possible for the population's health to suffer causing an elevated risk for developing certain outcomes such as cardiovascular disease. Therefore, measures ought to be taken aimed at reducing emissions of pollutants into the atmosphere and protecting outdoor workers during their working hours. The novelty of this study lies in its comprehensive analysis of liquid tree technology as an innovative solution for urban environmental challenges. While previous studies have focused on individual aspects of microalgae-based systems, this review uniquely synthesizes the technological, environmental, and implementation aspects of liquid trees in metropolitan contexts. Moreover, it provides a critical assessment of their adaptability across different climate zones and presents a proportional analysis with traditional urban greening methods, offering valuable insights for urban and environmental managers.

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Methodology

This review was conducted following a systematic literature search approach. The following databases were consulted:

- Web of Science
- Scopus
- Google Scholar
- ScienceDirect
- ResearchGate

Search terms included combinations of keywords:

"Liquid trees", "microalgae photobioreactor", "urban air purification", "carbon sequestration", "sustainable urban development", "city", "climate change", "air pollution"

The literature search covered publications from 2015 to 2024, focusing on peer-reviewed articles, conference proceedings, and technical reports. Selection criteria included:

- Relevance to urban air quality improvement
- Focus on microalgae-based systems
- Applications in metropolitan areas
- Technical feasibility studies
- Implementation case studies

From an initial pool of 151 papers, 45 were selected for detailed review based on their direct relevance to liquid tree technology and urban applications. A bibliometric analysis was conducted using VOS viewer to understand the research landscape and relationships between key concepts. The analysis revealed eight major interconnected themes in the literature: air pollution, city, climate change, green roofs, liquid trees, plants, urban areas, and vertical gardens. The strongest connections were observed between air pollution and city (strength: 57.0), followed by green roofs and vertical gardens (strength: 60.0). Notably, research on liquid trees showed recent emergence with an average publication year of 2023, compared to more established topics like vertical gardens (2018) and green roofs (2018.6). The analysis demonstrated that liquid tree research is closely linked with urban areas and air pollution mitigation strategies, supporting its relevance for metropolitan applications.

The clustering analysis (Figure 1) revealed two distinct groups: one focused on environmental challenges (including air pollution, climate change, and urban areas) and another centered on green infrastructure solutions (including green roofs, vertical gardens, and plants). Liquid trees emerged as a bridging concept between these clusters, suggesting their potential role in connecting environmental challenges with practical solutions.

Present scenario

Throughout the previous few decades, air pollution and climate change have developed as critical worldwide issues. Urban clusters are highly responsible for the amount of air pollution in the atmosphere and climate change. Air pollution is a significant human activity that reduces air quality. It emanates from diverse activities including alteration of land use and cover, combustion of fossil fuels/incineration of residue, power plants, roadside dust particles, and automobiles (Kaur & Pandey, 2021). The massive expansion of motor vehicles has led to degradation in environmental quality and human health. Major traffic areas have concentrations of pollutants exceeding permissible limits. Severe respiratory diseases as well as other deadly cardiovascular diseases are facing the Indian community at large Immediate needs for vehicular air pollution monitoring and control strategies for urban cities are necessary. PM10, PM2.5, SOx, NOx, HC, CO2, and CO were found to be major pollutants responsible for vehicle emission-related pollution along with some meteorological parameters like Ambient Temperature, Humidity, Wind direction, and Wind Speeds (Desai, 2018).

Certainly, urban areas are affected by environmental threats such as acid rain, global warming, and depletion of the ozone layer. These threats have negative implications for performance and well-being in urban areas. The extent and rate of these changes in the global environment are contributed to by rapid population growth, uncontrolled urbanization, and unplanned industrialization (F. Dave, 2023). Urbanisation quickly becomes unsustainable thus water stress, scarcity, high use of, pollution of air and water sources, climate change as well and loss of urban

Figure 1: Bibliometric network visualization of research themes related to liquid trees and urban environmental solutions.

biodiversity (Rashed, 2023) Additionally, overpopulation leads to pollution floods earthquakes, and occurrence of urban heat island effects that make environmental hazards in cities even worse (Varma *et al.,* 2021) Due to temperature variations and precipitation changes that occur due to climate change pose a major challenge towards sustainable urban development and green infrastructure aimed at mitigating it (Sahu & Debsarma, 2023). In ASEAN countries air pollution climate change and water pollution are critical concerns that affect regional integration processes requiring initiatives targeted at their mitigation measures (Alcheikh Mahmoud *et al.,* 2019).

This is an urgent issue that requires attention: no new plants are growing on city sites. Urban areas are facing the challenge of an aging infrastructure and the emergence of new cities, which highlights the need for increased green spaces. Cities are recognizing the importance of green spaces and are taking action to increase them, as they provide functional benefits and improve quality of life (Braiterman, 2011). With high-density development and construction, there is limited available land for planting new vegetation. Buildings, roads, and infrastructure take up most of the space, leaving little room for green spaces or gardens. Urban soils are often compacted, contaminated, or lacking in nutrients due to construction activities, pollution, and lack of organic matter. This makes it challenging for new plants to establish themselves and thrive. Urban environments can be harsh for plant life due to factors like air pollution, heat island effects, limited water availability, and lack of sunlight in heavily shaded areas. Prioritization of development: In many cities, urban planning and development prioritize buildings, transportation infrastructure, and economic activities over the creation and preservation of green spaces and natural areas. Because all these urban green spaces are decreasing there is no more space to plant new plants in these places or other urban spaces and implementing new urban spaces is difficult even with advanced planning. Urban trees provide immense benefits to cities, from filtering air pollution and sequestering carbon to cooling the urban heat island (UHI) effect and minimizing unconditional climatic patterns. However, many cities around the world suffer from an acute lack of adequate tree cover and green space due to the spatial constraints of dense urban built environments. Expanding urban tree canopies is a major challenge facing cities as they work to increase climate resilience and liveability (Ahmed *et al*., 2024; George, 2023). It takes time for these trees to become effectively productive to change the conditions of these urban areas in cities. This highlights the need for an urgent and rapid solution that does not consume space and time. It should be economically beneficial and should interlink with city planning.

Liquid Tree – the alternative

Planting trees is a commonly used strategy for companies and governments to lower CO_2 in the air. Pollution kills three times as many people a year as HIV/AIDS, tuberculosis, and malaria combined," according to the IHME Global Health Data Exchange Tool (Monagas, 2022). The liquid tree is a novel instrument created by Serbian scientists that reduces greenhouse gas emissions and enhances air quality, LIQUID 3. A photobioreactor is a fermenter tank used to cultivate microorganisms that require a passive source for photosynthesis. It runs on 600 liters of water and uses microalgae to produce pure oxygen through photosynthesis and bind carbon dioxide. The gadget contains an integrated lightning system that is fueled by solar panels mounted on the tanks which collect light and transform it into electrical energy. The bioreactor, allows the microalgae to carry out photosynthesis non-stop all year round, even during winter when sunlight is scarce (*Liquid Tree*, n.d.). The other notable components of the Liquid 3 design include a pressure pump and a bubble column. The pressure pump is used to pump the polluted surrounding air into the tank.

The CO_2 is provided to the microalgae utilizing a pump that captures polluted air and spurges it through the water to nourish the algae. This technology is based on a carbon sequestration mechanism which reduces the level of CO_2 and releases Oxygen into the atmosphere. Furthermore, this technology seems to uptake other harmful gases. The biosorption in microalgae, allows them to passively filter out heavy metal contaminants in the air. A temperature regulation system would be necessary if climate conditions were to become too extreme for sustaining microalgae life is also integrated with this photobioreactor which works in solar power.

The microalgal classification tree (Figure 2) demonstrates a systematic hierarchical organization with microalgae as the root node, branching into two primary environments: Marine and Freshwater. Each environment further subdivides into three distinct groups: Cyanobacteria, diatoms, and green algae. This tree structure effectively visualizes the taxonomic relationship, where each level represents a different structural tier. The marine branch, positioned on the left side of the tree, connects to its three subgroups (Cyanobacteria, Diatoms, and Green algae), while the freshwater branch on the right mirrors the same subgroup pattern. The tree's design employs a color-coded system where blues represent marine-associated groups and greens represent freshwater-associated groups, making the visualization both hierarchically clear and environmentally intuitive. The varying node sizes in the visualization correspond to the relative distribution percentages of each group within their respective environments, providing an immediate visual understanding of their ecological significance.

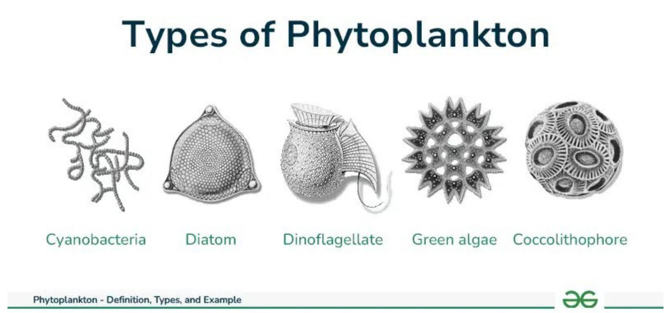


Figure 2: Microalgae chart for the successful representation of Liquid Tree (https://www.geeksforgeeks.org/phytoplankton-definition-type/)

Distribution Patterns of Marine and Freshwater Microalgae: A Global Overview

Microalgae exhibit distinct distribution patterns across marine and freshwater ecosystems Table 1, with approximately 70% dominance in marine environments (de Vargas *et al*., 2015). In marine ecosystems, diatoms constitute the largest group at 35%, followed by cyanobacteria at 25%, and green algae at 10% (Falkowski *et al*., 2004). The freshwater distribution, comprising 30% of total microalgal presence, shows a different pattern with cyanobacteria at 12%, green algae at 10%, and diatoms at 8% (Paerl & Paul, 2012). This distribution is influenced by various environmental factors including temperature, light availability, nutrient availability, pH levels, and salinity (Beardall *et al*., 2009).

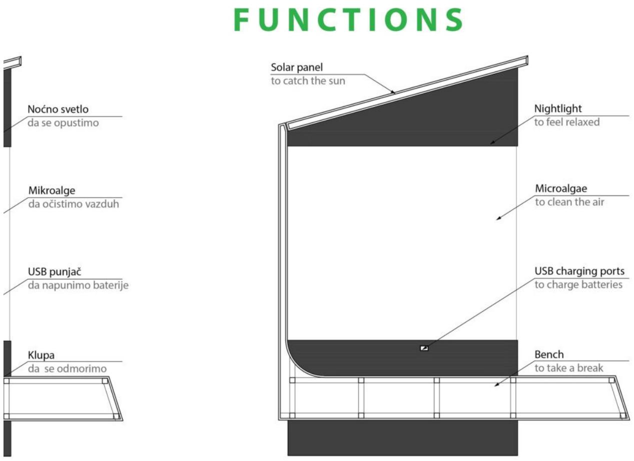
Difference between Liquid Tree and other modern alternatives

Vertical gardens around the world, cities are increasingly incorporating green facades, walls, and roofs. Plants grown in supported vertical systems that are typically affixed to an exterior or interior wall, though they can occasionally stand alone, make up a vertical garden or green wall. Vertical gardens integrate drainage, irrigation, growing media, and plants into a single system, similar to many green roofs. Unlike green facades, which rely on a smaller number of plants that climb and spread to give cover, vertical gardens use several "zed containerized" plantings to generate the vegetative cover. 'Green walls', 'living walls', and 'bio-walls'. There are several reasons why green roofs are built: as architectural elements, as areas for people to utilize, to enhance property value, or to accomplish specific environmental goals (such as capturing and retaining stormwater, increasing species diversity, or insulating a building from heat gain or loss). Depending on the weight capacity of the building's roof and the design goals, the depth of the growing substrate—a specifically made soil substitution medium—in which vegetation is planted on green roofs can vary from 50 mm to over a meter. Consistent, dependable, and sustainable irrigation and drainage systems are necessary for producing various plant species, either seasonally or perennially; ideally, these systems include a fertigation schedule in addition to sprinklers or overhead irrigation (Sarkar, 2018). For growing different types of plants- either perennially or annually there is a need to supply constant, reliable, and sustainable systems of irrigation and drainage; preferably with a fertigation scheduling along with the sprinklers or overhead irrigation system (Sarkar, 2018). Herein lies the advantage that liquid tree possesses over its competitors. The integration of vegetation into the built environment has gained popularity in urban areas due to the advantages of vertical gardens green roofs walls and facades however liquid tree systems offer a more sophisticated and effective method. With liquid trees, plants are grown in a nutrient-rich water solution in a controlled environment using a hydroponic system as opposed to conventional green infrastructure which uses soil-based growing media and external irrigation systems. By enabling the vertical stacking of several layers of vegetation this not only maximizes space efficiency but also allows for precise control of elements like temperature humidity lighting and nutrient supply guaranteeing ideal growing conditions and increased yields. Liquid trees also function on a closed-loop system which reduces water usage and does away with the requirement for intensive soil preparation or fertigation scheduling. Liquid trees can be easily incorporated into urban settings thanks to their modular and scalable design which allows them to adjust to changing space constraints and offer a steady supply of fresh produce all year long despite seasonal fluctuations. Liquid trees provide a more technologically advanced and environmentally sustainable solution for urban agriculture and greening initiatives by addressing the drawbacks of conventional urban greening techniques such as water requirements soil management and environmental fluctuations (Bakay, 2015).

Table 1: Distribution of microalgae groups in aquatic ecosystems

Environment	*Group*	*Percentage (%)*
Marine	Diatoms	35
	Cyanobacteria	25
	Green algae	10
Freshwater	Cyanobacteria	12
	Green algae	10
	Diatoms	8

Two ten-year-old trees or 200 square meters of lawn are replaced by these microalgae. Its function is essentially mimicked by the LIQUID 3. Microalgae have the advantage of being 10–50 times more efficient than trees (Dhar *et al*., 2023). Microalgae revealed a photosynthetic carbon dioxide binding efficacy that is 10 to 50 times higher than traditional trees (Villalba *et al*., 2023). Furthermore, when pollution thresholds are exceptionally raised, trees often struggle to survive, whereas microalgae exhibit notable resilience, continuing air purification efforts. These algae exhibit resistance to heavy metals and can purify a substantial volume of air, ranging from 300 to 3000 cubic meters, as indicated by research conducted by (Dhar *et al*., 2023; Farinati *et al*., 2022). According to the LIQUID 3 team, they intend to use this technology to fill in the urban areas where there isn't enough room for trees to be planted, not to replace forests or tree planting initiatives. Algae do not suffer in high pollution levels where trees struggle. By efficiently absorbing and storing carbon dioxide from the atmosphere these small systems can significantly reduce greenhouse gas emissions and the effects of climate change. Through photosynthesis, they take in carbon dioxide and expel oxygen thereby enhancing the quality of air in contaminated urban areas where conventional greenery has limited space. Furthermore, when wastewater is run through the systems the microalgae can function as organic matter phosphorus and nitrogen-removing natural bio-filters. Certain species of microalgae can yield valuable bioactive compounds with substantial medicinal applications when grown in these regulated bioreactors. Additionally, liquid trees may be used in spacecraft to produce fresh food for astronauts on space exploration missions as well as to remove CO2 and create oxygen. Additionally, the compact design of these green infrastructures makes it possible to introduce visually beautiful greenery into densely populated areas while also benefiting from air purification. Liquid trees capitalize on the inherent properties of microalgae within a system that has been designed



Source: https://www.undp.org/serbia/news/first-algae-air-purifier-serbia

Figure 3: Schematic diagram of Liquid Tree Bioreactor in Serbia

to meet specific needs. These applications range from space exploration and biotechnology to carbon capture and urban air purification (Dhar *et al.,* 2023). Compared to traditional trees liquid trees have many advantages, particularly in crowded urban areas where pollution and limited space make it difficult for plants to grow. Liquid trees do not mind a small space or contaminated environment in contrast to trees that need recently exposed soil to grow. Liquid trees completely avoid allergies asthma and hay fever even though trees can spread these conditions through their pollen. Moreover, the biomass generated by photosynthesis in microalgae can be used for many purposes such as the creation of biofuels compost for green spaces wastewater treatment and excellent fertilizers. Liquid trees are a compelling substitute for conventional trees in urban environments because of their adaptability resilience to pollution and improvement (Figure 3) (*Liquid Tree*, 2024; *The First Algae Air Purifier in Serbia*, n.d.)

Climate Zone Adaptability of Liquid Trees

The implementation of liquid tree systems across different climatic zones shows promising potential. While the initial success was demonstrated in Serbia's temperate climate, recent research indicates adaptability to various climate conditions through technological modifications and species selection (Villalba *et al*., 2023).

The system's effectiveness in different climate zones is achieved through:

Temperature Control Systems

Advanced temperature regulation mechanisms enable operation across varied climate conditions (Dhar *et al*., 2023).

Species Selection

Different microalgae species are selected based on their tolerance to specific climate conditions (Farinati *et al*., 2022).

Design Modifications

The photobioreactor design can be adapted to local climate conditions while maintaining efficiency (George, 2023).

These adaptations ensure that liquid tree systems can maintain their air purification capabilities across different urban environments, making them a versatile solution for metropolitan areas worldwide (Villalba *et al*., 2023).

Implementation Case Studies

Several successful implementations of liquid tree systems have demonstrated their effectiveness in different urban contexts. These case studies provide valuable insights into the practical application and performance of liquid tree technology Table 2.

These implementations demonstrate the versatility and effectiveness of liquid tree systems across different urban contexts and climatic conditions. The Belgrade installation, being the first of its kind, has served as a prototype for subsequent implementations, while adaptations in other cities have shown the technology's potential for customization to local needs and conditions.

Integration of Liquid tree concepts into metro cities

In India, the metro cities such as Kochi, Delhi, Chennai, and Kolkata there are numerous urban challenges, and some be effectively addressed by liquid trees. Liquid trees optimize the use of limited land resources by creating vertical structures that maximize space thereby producing food efficiently and adding greenery to densely populated urban areas. They provide vital benefits for cities suffering from extreme air pollution because they absorb pollutants and reduce the urban heat island effect

Table 2: Notable implementations of liquid tree systems worldwide

Location	*System type*	*Key features*	*Performance metrics*	*Reference*
Belgrade, Serbia	LIQUID 3	600L capacity photobioreactor\n- Solar-powered lighting\n- Temperature control system	Equivalent to 10 mature trees\n- Processes 300-3000 m^3 air daily	The First Algae Air Purifier in Serbia (n.d.)
Barcelona, Spain	Urban Photobioreactor	Facade integration\n- Modular design\n- Smart monitoring	90% CO_2 reduction in immediate vicinity\n- 25% reduction in local air pollutants	Villalba *et al*. (2023)
New Delhi, India	Pilot Installation	Heat-resistant design\n- Automated nutrient delivery\n- Air quality monitoring	15-20% PM reduction\n- Enhanced oxygen production in high-pollution conditions	Dhar *et al*. (2023)
Geneva, Switzerland	BioPod System	Climate-controlled environment\n- Integrated water recycling\n- Real-time monitoring	Year-round operation\n- Processes 200 m^3 air/hour	Farinati *et al*. (2022)

through evapotranspiration and shading. Liquid trees that run on closed-loop hydroponic systems encourage water conservation and lessen the burden on already thin water supplies. With their controlled environments and effective resource use liquid trees improve resilience and adaptive capacity as big cities continue to be vulnerable to the effects of climate change. By adding green areas and natural elements to cityscapes liquid trees not only have practical benefits but also enhance aesthetics and promote well-being. Liquid trees become an indispensable part of the solution for sustainable urban development in metropolitan areas by tackling urgent problems like food insecurity climate change urbanization and environmental degradation.

These can be integrated into various spaces within the urban environments. Also being a photobioreactor, these are modular photobioreactors and can be restructured accordingly (Villalba *et al.,* 2023). Rooftops and terraces of residential, commercial, or industrial buildings are ideal spaces for them. The addition of liquid trees can improve the general green infrastructure and produce aesthetically pleasing landscapes in public parks plazas and open areas that already exist. Liquid tree installations can be installed in underutilized areas that are frequently found close to transportation hubs such as train stations bus terminals and airports. The incorporation of liquid trees can enhance the indoor environments of shopping malls office lobbies and commercial centers by offering a revitalizing green space and better air quality. Schools, colleges, and universities can implement liquid tree systems as part of their sustainability initiatives, promoting environmental education and urban agriculture. Ideally, they are one of the best options to provide clean air and regulate temperature in highly crowded places in urban areas.

Conclusion

Liquid trees present a groundbreaking solution to the environmental challenges faced by modern urban areas. These compact photobioreactor systems, even in highly polluted environments where traditional vegetation struggles, efficiently capture carbon dioxide and release oxygen, thereby improving air quality. In addition to air purification, liquid trees produce biofuel and treat wastewater, providing a multitude of ancillary benefits.

Their modular design allows for seamless integration into various urban settings, from building facades to public parks. By leveraging the potential of microalgae, liquid tree technology offers a promising pathway for cities to achieve climate resilience and sustainable development, circumventing the limitations of conventional green infrastructure.

For successful implementation, urban planners, legislators, and stakeholders must collaborate to integrate liquid trees into current and future infrastructure projects. Embracing this innovative urban greening technique is a significant step towards creating more resilient, liveable, and sustainable cities.

While liquid tree technology shows promising potential, several key limitations and challenges require attention. Initial installation costs remain high, requiring substantial investment in infrastructure and specialized maintenance expertise. Temperature control systems demand significant energy input, potentially impacting operational sustainability. Technical challenges include optimizing microalgal species selection for different climate zones and maintaining consistent performance under varying pollution levels. Future developments should focus on reducing costs through advanced manufacturing processes, developing automated maintenance systems, and improving energy efficiency in photobioreactor design. Research priorities include developing climate-resilient microalgal strains and establishing standardized performance metrics. As this technology evolves, creating comprehensive regulatory frameworks and maintenance protocols will be essential for its successful integration into urban environmental management strategies.

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Author Contributions

Sethu M. R. contributed to the design, implementation, review, and editing of the research. Alok K contributed to the design and the writing of the manuscript. V.P. Limna Mol conceived the original idea, supervised the drafting of the manuscript and carried out necessary editions.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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