

RESEARCH ARTICLE

Assessment of Nanocellulose Membrane Filters for Improving Water Quality in Silchar City: A Comparative Study with Conventional Methods

Mrutyunjay Padhiary^{1*}, Parthib Ranjan Das², Anamika Yadav¹ and Debapam Saha³

Abstract

The quality of water is a major concern worldwide, especially in areas where polluted water sources present considerable health hazards to the local population. Nanotechnology has emerged as a possible remedy for enhancing water quality, providing advanced techniques to efficiently address complex contamination concerns. This study aims to assess the effectiveness of nanocellulose membrane filters in enhancing water quality parameters of wastewater and groundwater samples, specifically in Silchar city, Assam, India. This study evaluates the efficacy of nanocellulose filters fabricated from waste paper and wood fibre in comparison to conventional methods in terms of their ability to remove contaminants, cost effectiveness, and filtration efficiency. The experimental findings demonstrate that the utilization of a nanocellulose membrane filter led to a significant decrease in several water contaminants. Specifically, the total dissolved solids were reduced by 73.94%, turbidity by 93.42%, iron by 58.82%, nitrate by 20.57%, chloride by 42.86%, hardness by 44.68%, alkalinity by 20.83%, sulphate by 35.19%, and colour by 85.71%. Conventional filters, on the other hand, obtained reductions of 43.76, 84.21, 35.29, 5.29, 26.53, 27.66, 12.50, 19.05, and 71.43% for the identical settings. Moreover, the utilization of nanocellulose filters demonstrates encouraging outcomes in enhancing the overall quality of water and reducing health hazards linked to polluted water sources. The results of this study highlight the potential of using nanocellulose-based filtering technologies as sustainable and efficient solutions for resolving water quality issues in Silchar city and other similar areas.

Keywords: Nanocellulose, Water quality, Membrane filtration, Contaminant removal, Public health

Introduction

Water quality deterioration is a significant and urgent problem worldwide, with wide-ranging consequences for both human health and environmental sustainability (Phanthong *et al.*, 2018; Maharubin *et al.*, 2018). Water supplies worldwide are becoming more polluted due to industrial operations, agricultural runoff, urbanization, and insufficient waste management procedures. This contamination poses a threat to both human health and ecosystems, while also compromising the supply of safe drinking water (Mbakop *et al.*, 2021; Tan *et al.*, 2020).

For centuries, individuals have used traditional methods like boiling, filtration, and chemical treatment to make sure that water is safe to drink and to prevent waterborne infections (Gehrke *et al.*, 2015). Conventional treatment procedures may have difficulties in eliminating new contaminants such as pharmaceuticals, microplastics, and trace levels of heavy metals (Devi & Chaturvedi, 2021). Researchers and engineers have utilized nanotechnology to address the limitations of conventional treating methods (Barhoum *et al.*, 2023; Gopakumar *et al.*, 2019). Nanotechnology comprises the deliberate control and alteration of substances at the nanoscale, which typically spans from 1 to 100 nanometres in magnitude. At the

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microscale, materials display distinctive features and behaviours that can be utilized for a range of applications, such as water treatment (Tan *et al.*, 2020).

Nanotechnology has become increasingly recognized as a viable method for enhancing water quality because it has the capacity to effectively tackle the technical problems

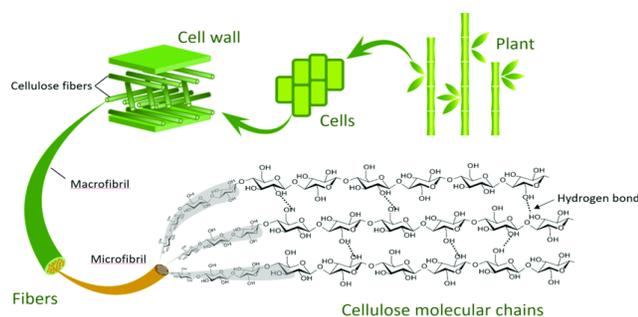


Fig. 1. Structure of Nanocellulose

associated with existing pollution problems (Phanthong *et al.*, 2018; Tan *et al.*, 2020 and Gopakumar *et al.*, 2019). Nanomaterials possess a high surface area-to-volume ratio, which significantly enhances their reactivity and adsorption properties. Consequently, they are highly efficient in eliminating a diverse array of pollutants from water (Mauter *et al.*, 2018). Nanotechnology also opens the door to further development of advanced filtration membranes, catalytic materials, and disinfection technologies that can be more effective, cost-effective, and safe for the environment than current methods of purification (Maharubin *et al.*, 2018). Variations in glucose arrangement and hydrogen bonding create diverse forms of cellulose, with nanocellulose distinguished by its fiber diameter typically under 100 nm (Nasir *et al.*, 2017; Mishra *et al.*, 2018; Mariño *et al.*, 2015 and Shi *et al.*, 2022). Fig. 1 displays the cellular morphology and molecular structures of nanocellulose. Researchers and practitioners are actively investigating the employment of nanomaterials, including Nanocellulose, carbon nanotubes, and metal nanoparticles, in water treatment (Bora & Dutta, 2014; Vu *et al.*, 2017). Through the utilization of nanoparticles' distinctive characteristics, novel filtration methods can be developed to tackle the complicated problems linked to the deterioration of water quality. This would effectively protect public health and conserve valuable water supplies for future generations.

Water quality is one of the important issues in Silchar city of Assam, India especially for villages like Nowaraj village, where the availability of clean and safe drinking water is challenged. The water supplies in these places have been contaminated with diverse pollutants, such as elevated levels of iron, alkalinity, turbidity, and calcium hardness, which present significant health hazards to the local population. The existence of these pollutants in the water supply highlights the urgent requirement for efficient water treatment techniques customized to address the specific difficulties encountered by populations in Silchar city. Iron contamination not only causes unpleasant odours and stains in water, but it also poses serious health risks, especially for persons with iron-sensitive disorders. Furthermore, excessive levels of alkalinity and calcium hardness can result

in the accumulation of scale in pipes and fixtures, which can have a negative impact on water distribution systems and household appliances (Baruah *et al.*, 2019).

Additionally, the occurrence of turbidity in the water supply suggests the existence of suspended particles, which may contain harmful microorganisms and negatively impact the quality of the water (Borah & Dutta, 2014; Hossain *et al.*, 2014). These pollutants not only impact the visual characteristics of water but also elevate the likelihood of waterborne diseases, such as gastrointestinal diseases and dermal infections, among the local population. Conventional purification methods may not be enough to deal with the wide range of pollutants found in water sources; hence, it is necessary to investigate alternate ways, such as filtration techniques based on nanotechnology (Ahmed *et al.*, 2014; Bairagi & Ali, 2020; Duggireddy & Pisharody, 2024). Kunduru *et al.* (2017) reported that carbon nano-adsorbents are effective in eliminating organic pollutants. Additionally, metal-based nanoparticles such as Fe₂O₃, TiO₂, ZnO, and alumina are utilized for the removal of heavy metals. Magnetic nano-adsorbents such as magnetite, hematite, and spinel ferrites are employed to eliminate harmful substances. Nanotechnology offered novel remedies for water purification.

The main issue examined in this study is the insufficient availability of uncontaminated and secure drinking water in Silchar city, which is aggravated by the existence of several pollutants in the water source. The main objective of this study is to evaluate the effectiveness of nanocellulose membrane filters in improving the quality of wastewater and groundwater in Silchar city. Also, to evaluate and compare their performance with conventional purification methods to enhance public health outcomes.

Methodology

Sampling Procedure

Silchar city in Assam, India, serves as the study area (Fig .2), with a focus on Nowaraj village for wastewater samples and K.C. Road for groundwater samples. The sampling dates have been highlighted, with wastewater taken on

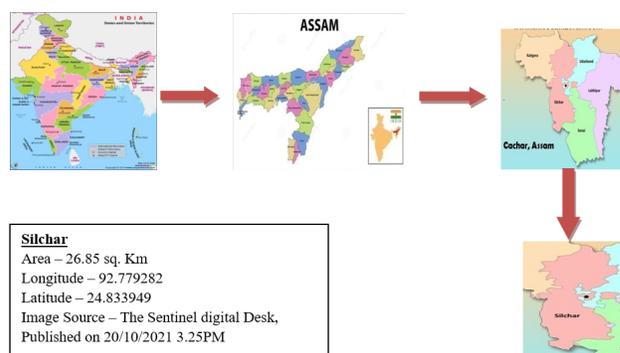


Fig. 2: Sampling location of Silchar city

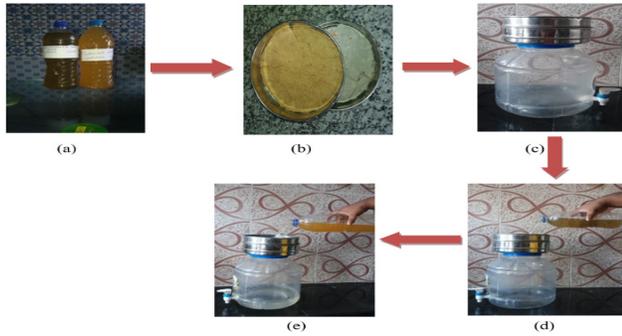


Fig. 3: Wastewater filtration process: a) collected water samples, b) membranes placement in the strainer, c) membranes placed on the container, d) pouring of wastewater, e) pouring of groundwater for filtration

26/04/2024 from Nowaraj village and groundwater collected on 27/04/2024 from K.C. Road. For the purpose of preserving the quality of the samples for future examination, these were kept in 1L plastic bottles. Thus, a total of 3L samples (3 bottles) each collected for wastewater and groundwater separately.

Wastewater samples were collected from a polluted pond in Nowaraj village, Silchar-7 region. Groundwater samples were obtained from a tube well located in the K.C. Road, Silchar-5 region. The samples were found to possess unpleasant attributes, such as colour, odour, and taste. In addition, chemical analysis indicates that specific parameters were above the desired thresholds, suggesting substandard water quality. Fig. 3 illustrates the process of preparing the water sample for purification.

Fabrication Of Nanocellulose Membrane Filter

Nanocellulose was derived from two independent sources: older newspapers and wood fibres. To recover newspaper fibres, sliced pieces are immersed in water, mixed with sodium hydroxide, and then separated through filtration

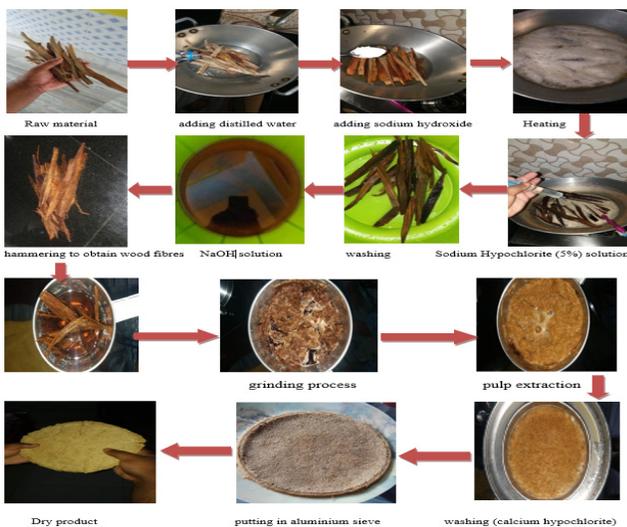


Fig. 4: Nanocellulose extraction process

to obtain nanocellulose membranes. On the other hand, the process of extracting wood fibre includes treating it with sodium hydroxide and sodium hypochlorite solution, and then using mechanical grinding and washing to obtain nanocellulose following the procedure described by Abraham *et al.* (2011). and Kargarzadeh *et al.* (2017). The methodology highlights the adaptability of nanocellulose as a sustainable substance, as depicted in Fig. 4.

Membrane filters made from nanocellulose were created using the extracted nanocellulose. The procedure corresponds to homogenizing nanocellulose with water, uniformly applying the material onto a screen frame, and subsequently permitting it to desiccate. The membranes produced are durable and well-suited for utilization in water filtration applications (Ditzel *et al.*, 2017).

Comparison of Physical and Chemical Parameters

The wastewater and groundwater samples were carefully analysed to determine their physical and chemical characteristics. Analytical techniques such as colorimetry, titration, turbidimetry, and electrometric methods were used to evaluate parameters including iron, alkalinity, turbidity, calcium hardness, total dissolved solids, chloride, total hardness, pH, nitrate, and sulphate. The procedures as described by Ipeaiyeda *et al.* (2017); Nallakukkala & Lal (2022); Ouyang *et al.* (2006) and Ramakrishnan *et al.* (2021); are followed, with slight modifications. The comprehensive analysis offers valuable information on the water quality of the sampled regions.

The effectiveness of nanocellulose membrane filters is being compared to conventional water purification technologies. The evaluation of nanocellulose membranes focuses on their efficacy in enhancing water quality and their implications for public health. The comparison takes into account parameters such as removal efficiency and cost-effectiveness, emphasizing the potential benefits of filtration processes based on nanocellulose.

Results And Discussion

Analysis Of Water Quality Parameters

Following the development of nanocellulose membranes, water samples are collected from wastewater and groundwater sources for laboratory examination. The analysis involves assessing various physical and chemical characteristics, including total dissolved solids, turbidity, nitrate, chloride, total hardness, alkalinity, sulphate, iron content, and colour (Table 1). The study of the wastewater sample revealed an unfavourable colour, odour, and taste. The chemical measurements, including total dissolved solids and turbidity, were beyond the permitted limits, while the total hardness neared the threshold. Although nitrate, chloride, total alkalinity, fluoride, and sulphate levels were within permissible limits, the mere presence of even

Table 1: Analysis of different parameters for wastewater and Groundwater in Silchar

Sl. No.	Parameter	Protocol used	Result for wastewater	Result for Groundwater	Desirable limit	Max. Permissible limit	Unit
1	pH	IS:3025:Part 11 @ 25°C	6.52	5.62	6.5-8.5	No Relaxation	
2	TDS	IS:3025:Part 16	729	750	500	2000	Mg/L
3	Turbidity	IS:3025:Part 10	76	114	1	5	NTU
4	Iron	APHA 3500- Fe B	0.17	2.14	1	No Relaxation	Mg/L
5	Nitrate	IS:3025:Part 34	15.12	7.22	45	No Relaxation	Mg/L
6	Chloride	IS:3025:Part 32	69.48	51.04	250	1000	Mg/L
7	Hardness	IS:3025:Part 21	188	250	200	600	Mg/L
8	Alkalinity	IS:3025:Part 23	96	116	200	600	Mg/L
9	Fluoride	IS:3025:Part 60	0.01	0.09	1.0	1.5	Mg/L
10	Sulphate	IS:3025:Part 24	24.72	26.84	200	400	Mg/L
11	Arsenic	IS:3025:Part 37	Nil	0.004	0.01	0.05	Mg/L
12	Colour	IS:3025:Part 4	70	70	5	15	Hazen
13	Odour	IS:3025:Part 5	Not Agreeable	Not Agreeable	Agreeable	Agreeable	
14	Taste	IS:3025:Part 8	Not Agreeable	Not Agreeable	Agreeable	Agreeable	

small amounts of chloride, alkalinity, and sulphate in the water could lead to unfavourable qualities. Similarly, the groundwater sample displayed undesirable characteristics such as a disagreeable colour, odour, and taste. Additionally, it exceeded the acceptable limits for total dissolved solids, turbidity, iron, and hardness, while its pH levels fell below the desired range. While nitrate, chloride, fluoride, and sulphate levels were within permissible parameters, the measurable presence of chloride and sulphate has the potential to adversely affect the quality of the water. The results demonstrate a notable decrease in these factors following filtration using the nanocellulose membranes in comparison to untreated water samples.

Performance Of Nanocellulose Membrane Filters W.r.t. Conventional Ones

The efficacy of Nanocellulose membrane filters is assessed by their ability to decrease several water quality metrics. The study involves the use of traditional water treatment technologies, namely alum soaking for wastewater and sand-gravel filtering for groundwater, as depicted in Fig.

5. The membrane performances were assessed according to the information provided in Table 2. The experimental research demonstrates that the Nanocellulose filter surpasses traditional filters in its ability to handle wastewater across multiple parameters (Fig. 6a). The Nanocellulose filter obtains a 73.94% decrease in total dissolved solids, which is higher than the 43.76% reduction achieved by conventional filters. It also achieves a 93.42% reduction in turbidity, surpassing the 84.21% reduction achieved by conventional methods. The Nanocellulose filter reduces the concentration of iron by 58.82%, whereas traditional filters achieve a reduction of 35.29%. The Nanocellulose filter exhibits a superior decrease of 20.57% in nitrate compared to the standard filters, which only achieve a reduction of 5.29%. The designed filter reduces chloride levels by 42.86%, whereas traditional filters only achieve a reduction of 26.53%. The Nanocellulose filter demonstrates superior performance in decreasing hardness, achieving a reduction of 44.68%, compared to traditional filters, which only achieve a reduction of 27.66%. The results were in very accordance to the findings of Ahankari *et al.* (2020); Sharma *et al.* (2020) and



Fig. 5: Conventional filtration methods: alum soaking and sand-gravel filtration

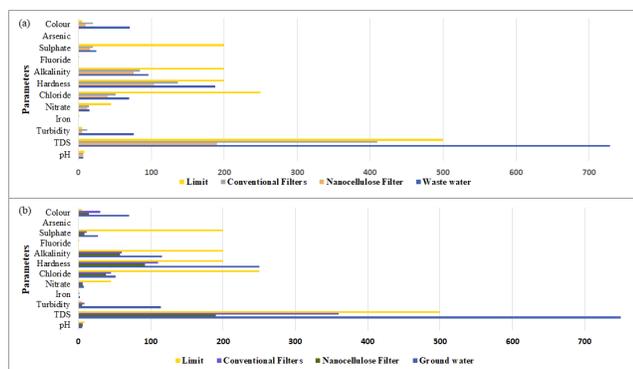


Fig.6: Water quality parameters for nanocellulose and conventional filters: (a) wastewater and (b) groundwater

Salama *et al.* (2021). The proposed filter results in a 20.83% decrease in alkalinity, while conventional approaches only achieve a 12.50% reduction. Both filters effectively eliminate 100% of fluoride. The Nanocellulose filter decreases the concentration of sulphate by 35.19%, while traditional filters only lower it by 19.05%. The Nanocellulose filter obtains an 85.71% decrease in terms of colour, while traditional filters get a 71.43% reduction. The results suggest that the Nanocellulose filter is considerably more efficient in improving the quality of wastewater compared to the alum soaking approach.

Interestingly, when comparing the performance of the proposed filter to typical sand-gravel filtration for groundwater analysis, nearly the same pattern is obtained, as depicted in Fig. 6b. The evaluation of groundwater treatment indicates that the Nanocellulose filter has superior performance compared to traditional filters. Total dissolved solids (TDS) showed a 74.67% decrease with the nanocellulose filter compared to a 52% decrease with conventional filters. Additionally, it achieves a 95.61% decrease in turbidity as opposed to a 92.98% decrease using conventional methods. The nanocellulose filter achieves a 63.55% reduction in iron concentration, while traditional filters only achieve a 43.46% reduction. The nanocellulose filter reduces chloride levels by 24.98%, while traditional filters only reduce them by 11.09%. The nanocellulose filter demonstrates superior performance in decreasing hardness, achieving a reduction of 63.2%, compared to traditional filters, which only achieve a reduction of 56%. The nanocellulose filter reduces sulphate concentration by 69.97%, whereas traditional filters only achieve a reduction of 58.05%. The nanocellulose filter produces a 78.57% reduction in colour, while conventional filters get a 57.14% reduction. The data indicate that our suggested filters are more effective compared to traditional filtration methods; well aligning to the findings of Singh *et al.* (2024); Baruah *et al.* (2020).

Implications For Water Quality Improvement

The utilization of nanocellulose membrane filters carries substantial ramifications for the enhancement of water quality. These membranes may effectively eliminate impurities from wastewater and groundwater, helping to ensure the provision of safer and purer drinking water. Moreover, their environmentally benign characteristics and sustainable manufacturing provide them a possible remedy for tackling water quality issues on a global scale. The comparison of the results from this study with prior investigations on water filtration techniques demonstrates the effectiveness and superiority of nanocellulose membrane filters. Prior studies have also emphasized the potential of filtering systems based on nanocellulose in enhancing water quality, so confirming and underscoring the significance of the current research findings.

Limitations And Future Scope

While the study demonstrates the effectiveness of nanocellulose membrane filters in improving water quality, it does possess significant constraints. Further investigation is required to analyse variables such as the resilience of the membrane, the ability to expand production, and the sustained effectiveness in practical scenarios. Additionally, factors like the sample size and the length of the analysis may limit the study's scope, underscoring the need for additional research and improvement.

Future research in water quality improvement should prioritize the investigation of the long-term durability and performance of nanocellulose membrane filters. Additionally, it should focus on exploring scalable production methods for widespread adoption, assessing the environmental impact and sustainability of nanocellulose-based filtration systems, and investigating novel nanomaterials and advanced filtration techniques. These technological breakthroughs can improve water treatment methods and guarantee universal access to clean and safe drinking water.

Conclusion

This study emphasizes the efficacy of nanocellulose membrane filters in enhancing the quality of both wastewater and groundwater. Nanocellulose membrane filters exhibit considerable potential in mitigating pollutants in wastewater and groundwater samples. Consequently, there have been enhancements in the general quality of water. Nanocellulose membrane filtration has better efficacy in comparison to conventional techniques like alum soaking and sand-gravel filtration. The results emphasize that these filters effectively decrease a range of water quality measures, such as total dissolved solids, turbidity, nitrate, chloride, total hardness, alkalinity, sulphate, iron content, and colour. Nanocellulose membrane filtration has exhibited higher performance in terms of pollutant

removal, pH level maintenance, and user-friendliness, as compared to conventional approaches. The membranes have demonstrated exceptional adsorption capacity and hydrophilic characteristics, enhancing their efficacy in water filtering. Therefore, the utilization of nanocellulose membranes in water treatment represents a noteworthy progress in state-of-the-art water treatment methods, which is crucial for safeguarding public health and promoting environmental sustainability.

Author Contributions

Mrutyunjay Padhiary: Writing- original draft, Writing-review & editing, Conceptualization, Supervision, Software, Resources. Parthib Ranjan Das: Writing Methodology, Investigation, Conceptualization. Anamika Yadav: Writing-original draft, Writing- review & editing, Formal Analysis. Debapam Saha: Writing-original draft, Writing- review & editing, Data curation, and Formal analysis.

Conflict of Interest

The authors would like to state that there is no conflict of interest and that no funding has been invested in this study.

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