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A Review on Water Quality Analysis by Artificial Intelligence

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Abstract

Water quality encompasses various factors that determine water's suitability for different purposes and its impact on the environment and human health. It includes chemical, physical, biological, and radiological characteristics. Studying water quality is vital for ensuring safe drinking water, supporting ecosystems, sustaining agriculture and industries, facilitating recreational activities, and adhering to regulatory standards. Techniques for assessing water quality involve measuring physical parameters like temperature and turbidity, chemical analysis for pH, dissolved oxygen, nutrients, and heavy metals, biological assessments using indicators like macroinvertebrates, microbiological testing for bacterial contamination, remote sensing, flow measurement, and data analysis methods. The Water Quality Index (WQI) simplifies complex water quality data into a single value or category, offering an accessible assessment of overall water quality conditions. It combines various parameters, assigns weights based on their importance, and aggregates them into an index value or qualitative classification, aiding in effective understanding and communication of water quality information. Artificial intelligence (AI) significantly contributes to water quality analysis by leveraging machine learning, data analytics, and neural networks. AI processes vast amounts of water quality data, predicts changes, identifies patterns, optimizes monitoring systems, supports decision-making, improves water treatment processes, and enhances early warning systems. Using AI enables analysts to gain more efficient, accurate, and timely insights into water quality conditions, enabling better-informed management strategies and the conservation of water resources for human and environmental well-being.

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waterborne diseases, biodiversity, contaminants, agriculture, irrigation systems.

Introduction

Water quality pertains to the overall characteristics of water, encompassing its chemical, physical, biological, and radiological aspects that determine its suitability for different uses. Understanding and analysing water quality are crucial due to its wide-ranging impacts. Clean and safe drinking water is essential for (Miller *et al.,* 2023) human health, making it imperative to monitor and maintain water quality to prevent waterborne diseases and health hazards. Additionally, water quality significantly influences ecosystems and biodiversity; contaminants can harm aquatic life and disrupt natural habitats, underscoring the importance of studying and preserving water quality for environmental health. In agriculture, irrigation systems rely on water quality to sustain crop growth and soil health. Industries also heavily depend on water, requiring diligent monitoring to prevent contamination and comply with environmental regulations. Beyond practical uses, water quality plays a vital role in recreational areas, as poor water quality can negatively impact tourism and local economies.

Furthermore, understanding the impact of climate change on water quality is essential, as it can alter precipitation patterns and water levels. Finally, adhering to regulatory standards necessitates ongoing monitoring to identify pollution sources and ensure compliance, emphasizing the continuous need to study and maintain water quality for multiple societal and environmental reasons.

Assessing water quality (Ahamad *et al.,* 2023) encompasses a diverse array of techniques to comprehensively analyse various parameters defining water conditions. Physical parameters are evaluated through temperature monitoring and turbidity assessment, while chemical analysis involves pH testing, measurement of dissolved oxygen, nutrient analysis, and heavy metal testing. Biological assessments rely on biotic indices, observing indicators like macroinvertebrates or algae. Microbiological testing identifies bacteria such as *E. coli* through different testing methods. Remote sensing techniques employ satellite imagery to monitor larger water bodies for quality changes and pollution sources.

Sensory evaluation detects any unusual odours or tastes in water. Additionally, flow measurement gauges the volume and rate of water flow in rivers or streams, and water sampling gathers samples for laboratory analysis. Finally, data (Meenakshi and Ambiga, 2022) analysis and modelling tools use statistical methods and mathematical models to interpret collected data and predict water quality changes under different scenarios. These combined techniques offer a comprehensive understanding of water conditions, aiding in effective management and conservation strategies.

A Water Quality Index (WQI) serves as a numerical scoring system that condenses complex water quality data into a single value or a small set of values to represent overall water quality conditions. It offers a simplified assessment understandable to the public, policymakers, and scientists. Calculating a WQI involves amalgamating data from diverse water quality parameters such as pH, dissolved oxygen, turbidity, nutrient levels, heavy metals, and bacteria into a singular value or category. Each parameter receives a weight based on its significance to water quality and human health. Developing a WQI includes steps like parameter selection, data collection through regular (Kumar *et al.,* 2018) sampling, normalization, and standardization of data, assigning weights, aggregating parameter values, and interpreting the final index value for qualitative or numerical classification. This index aids in comprehending the overall health of water bodies, allowing easier comparisons, trend identification, prioritizing management actions, and effectively communicating water quality information to stakeholders and the public. Variations in WQI exist, tailored to specific contexts or purposes based on regional priorities, available data, and environmental concerns.

Artificial intelligence in water quality analysis

Artificial intelligence (AI) plays a significant role in water quality analysis by offering advanced tools and techniques to process, analyse, and interpret large volumes of complex data. AI technologies, including machine learning, neural networks, and data analytics, contribute to improving the efficiency, accuracy, and speed of water quality assessment. Here are several ways AI is applied in water quality analysis:

Data Processing and Integration
Prediction and Forecasting
Pattern Recognition
Optimization of Monitoring Systems
Early Warning Systems
Quality Control in Water Treatment
Decision Support Systems
Image Analysis and Remote Sensing

Artificial Neural Networks (ANNs)

Artificial Neural Networks (ANNs) have demonstrated remarkable efficiency in predicting Water Quality Index (WQI) and critical parameters like Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), chloride, alkalinity, and Nitrates in various water bodies (Nayak *et al.,* 2023) globally. ANNs' adaptability and robustness allow them to model multiple parameters using diverse input variables, such as temperature, pH, and electrical conductivity. Studies have highlighted the (Chauhan and Verma, 2015) effectiveness of ANN optimization techniques, including determining the ideal number of hidden neurons and dataset length, improving predictive accuracy significantly. In summary, ANNs offer a promising and versatile approach for water quality prediction and assessment across different geographic locations.

Salim Aijaz's research delved into Wular Lake's water quality, utilizing global water quality index parameters. The study highlighted pesticide usage's significant impact on altering water quality parameters, emphasizing the necessity of understanding these fluctuations to assess the lake's environmental health. In alignment, Chaudhry *et al.,* (2017) study analysed water quality parameters, emphasizing the adverse effects of expanding industries and heightened pesticide usage. This research stressed the urgent need for prompt mitigation measures to safeguard the local population's well-being against these impacts.

The collaborative research efforts led by Kumar and Hemanth (2018) and other studies have collectively illuminated diverse dimensions of global water quality challenges. Rashid *et al.,* flagged concerns (2023) about water quality changes attributed to pesticide use and harmful chemicals, resonating with other studies that benchmarked water quality against global indices. Ali's exploration highlighted varied pollution sources, advocating for a tailored approach to effectively combat pollution (2019). Meanwhile, Chaudhry *et al.,* (2017) employed artificial neural networks to model the Water Quality Index (WQI) for the Akaki River, demonstrating the model's precision in pinpointing areas requiring targeted interventions. Additionally, the utilization of AI for predicting water contamination (2017) and adherence to WHO guidelines for water quality analysis in the Patna-based study underscored the importance of technology-driven approaches and standardized protocols. Together, these studies provide a holistic comprehension of water quality challenges by emphasizing diverse factors influencing alterations in water bodies, predictive modelling for WQI, technology integration for contamination prediction, and adherence to standardized protocols. Conducted across varied geographical locations and water sources (Choudhary *et al.,* 2023), these investigations showcased the complexities and vulnerabilities of water ecosystems.

They illustrated the substantial impact of pesticides, industrial contributions, and heavy metal pollutants on water quality, signalling distressing effects on aquatic life. These endeavours underscore the necessity for comprehensive assessments considering multiple parameters and perspectives to address mounting stress on water ecosystems worldwide.

Furthermore, by Madan *et al.,* (2022) a range of investigations across different locations shed light on the multifaceted influences of human activities on water quality delved into water quality parameters in Bhopal, noting fluctuations in pH, alkalinity, hardness, chloride, nitrate, calcium, and magnesium levels in Kerwa and Kaliasote water samples.

Chauhan and Verma (2015) emphasized phosphorus loss from soils as a significant contributor to freshwater quality degradation. Moreover, Babuji (2023) scrutinized the impact of agriculture and agrochemicals on the water quality of the Keta lagoon in Ghana, revealing the repercussions of these practices on aquatic ecosystems.

Hassan *et al.,* (2022) assessment in Wullar Lake, Kashmir, underscored the influence of land use on water chemistry, emphasizing the influx of fertilizers into the lake, which led to decreased dissolved oxygen levels.

Several studies conducted by the Chauhan and Verma, (2015) have shed light on concerning water quality issues across different regions in India. Solanki *et al.,* (2022) investigation of the Ayad River in Udaipur, Rajasthan, (2023) revealed heightened levels of faecal coliforms and Biochemical Oxygen Demand (BOD), signifying increased pollution primarily sourced from organic elements discharged through sewage and domestic effluents. Similarly, Chaudhry *et al.,* (2017) examined the River Krishna in Sangli, Maharashtra, identifying significant alterations in physico-chemical parameters. They found that activities like idol immersion, domestic waste discharge, sewage mixing, and sand dredging contributed to these observed changes. Additionally, Chaudhry *et al.,* (2017)analysis of the Mula-Mutha River in Pune (2018) highlighted alarmingly high pollution levels attributed to municipal and industrial sewage influx, compounded by agricultural runoff, posing substantial environmental risks. Moreover, evaluations of treatment plant efficiencies for various parameters underscored differences in performance among different plants. Fatehsagar exhibited the highest average efficiency at 65.84%, while Titardi displayed the lowest at 54.88%. Fatehsagar, Gulab Bagh and Titardi demonstrated efficiencies below 60%, while other treatment plants recorded rates surpassing 60%.

Solanki *et al.,* (2022) introduced a Water Quality Prediction system utilizing AI techniques like artificial neural networks (ANN) and support vector machines (SVM) for forecasting water quality components in the Tireh river in southwest Iran.

Ahamad, *et al.,* (2023) presented an Efficient Water Quality Prediction framework employing supervised machine learning for assessing Water Quality Index (WQI).

Aswathi *et al.,* (2021) introduced a Water Quality Monitoring system integrating Machine Learning and IoT for preventing contamination in residential overhead tanks. Kumar and Hemanth (2018) proposed a Classification Model for Water Quality Analysis using decision tree techniques to evaluate water quality data from diverse Kenyan regions.

Studies by Chaudhry *et al.,* (2017) showcased notable improvements in water quality and quantity in various Indian rivers, notably the Ganga River, during the lockdown period. These improvements were attributed to reduced human activities. However, (Singh *et al.,* 2022) contrasting reports on variations in domestic and non-domestic water consumption during the COVID-19 pandemic highlight the complex impact of the lockdown on water usage patterns and quality across different regions and economic sectors (RSPCB, 2021).

A study conducted by Vasistha, (2020) highlighted significant improvements in water quality observed in various beaches across (2019) Bangladesh, Maldives, Malaysia, Indonesia, and Thailand during the lockdown period. Reductions in pH levels, electric conductivity (EC), Biological Oxygen Demand (BOD), and Chemical Oxygen Demand (COD) ranged approximately from 1–10%, 33–66%, 45–90%, and 33–82%, respectively, across monitoring points. These reductions were primarily attributed to substantial decreases in pollution load from major sources such as industrial waste disposal, crude oil, heavy metals, and plastic during the lockdown (Vasistha, 2020). The investigation involving Biochemical Oxygen Demand (BOD) levels indicated notable exceedances of permissible limits, registering 3-5 times higher levels. Elevated BOD primarily stemmed from natural organic waste inflows, aligning with previous research. Other parameters (Chauhan and Verma, 2015) like Cl-, SO4--, BOD, NO3--, EC, and TDS displayed notable variations. While Cl-, SO4–, and TDS remained within acceptable limits, NO3-- exceeded limits at one site (S-3) but remained within range at others (S-1 & S-2). Elevated EC levels surpassed permissible limits for Class-B water category at all sites, attributed to human activities, religious events, and seasonal factors (Chauhan and Verma, 2015). The assessment of Water Quality Index (WQI) values indicated unsuitability for various human uses due to human negligence, contamination from various activities, religious rituals, and unregulated tourism. The study highlighted the urgent need for stringent measures to address human-induced pollution and safeguard water resources.

Water analysis by Sharma (2020) revealed varying parameters such as pH, electrical conductivity, alkalinity derived from carbonate and bicarbonate ions, total dissolved solids (TDS), ion concentrations of calcium, magnesium, sulphate, sodium, potassium, nitrate, and chloride in different water bodies. Notably, Sambhar Salt Lake exhibited notably elevated levels of chloride, sodium, and dissolved solids. Efficient strategies are imperative for controlling water pollution in India's urban areas. Global experiences advocate for resource availability, political determination, wastewater recycling (Sharma and Choudhary, 2021), stringent effluent discharge laws, environmental education programs, and tailored technologies suited for Indian conditions to effectively manage water quality. Irresponsible (Saini *et al.,* 2022) human actions continuously contaminate crucial ecosystems like lakes and rivers, threatening both aquatic life and human existence. Heavy metal concentrations in water samples surpassing regulatory limits pose significant concerns for Indian rivers, warranting immediate intervention to prevent further degradation.

In specific lakes like Jalmahal, Amer, Galta, Ana Sagar, and others, water quality analysis by Solanki *et al.,* (2022) revealed varying levels of pollution, rendering some unsuitable for drinking or supporting wildlife. Municipal sewage, calcium and magnesium salts from detergents, and abnormal colours or unpleasant odours attributed to pollution were among the identified causes, rendering water unfit for domestic use or harmful to aquatic life. The studies across various lakes and (2021) dams in Rajasthan during the lockdown period revealed significant improvements in water quality at specific locations such as Pushkar Lake, Upstream of Chhapi Dam, and Piplaz Dam. Parameters like BOD, COD, and DO exhibited positive changes, signalling overall enhancement (2018). Variations in pH and TDS across seasons and sites were observed, indicating potential impacts on aquatic ecosystems and highlighting the necessity for conservation measures (2015).

A study conducted by Chauhan and Verma (2015) revealed that land use patterns significantly influenced water characteristics, with urban areas contributing to higher pH levels possibly due to waste disposal and forested areas showing lower pH influenced by dense vegetation. These findings underscore the importance of robust measures to curb pollution and sustain water bodies. Understanding water quality dynamics across seasons and land use is crucial for effective management. Fluctuations in surface water pH mirrored patterns documented in other studies (Choudhary *et al.,* 2023 and Lin *et al.,* 2022), such as the correlation between high pH levels in summer and lower pH during rainy seasons, attributed to reduced water volume and dilution effects from rainwater.

Specifically, the study on Sukhna Lake's water quality conducted by Maansi *et al.,* (2022), validated its suitability for various purposes according to Indian Standards. It highlighted varying parameter concentrations based on land use, emphasizing the necessity for regular monitoring to mitigate potential pollution risks from diverse sources.

The investigation conducted by Ahamad, *et al.,* (2023) emphasized the significant impact of human activities, particularly untreated waste discharge (2022) from residential and industrial areas, leading to higher pollution levels in Dal Lake compared to Nigeen Lake. Continuous monitoring and wastewater treatment initiatives were deemed imperative to counteract the adverse effects on these important water bodies (Lin *et al.,* 2022). This study urges further research into understanding human activity contributions to pollution indicators, emphasizing the urgency to protect disturbed sites like Kondabal and Hanji Mohalla. Elevated concentrations of certain substances pose threats to water quality, correlating with waterborne diseases and highlighting the immediate need for corrective measures.

The research conducted by Wang *et al.,* (2023) proposed a two-layered model stacking approach to predict beach water quality across various locations and seasons. Their neural network model achieved high accuracy in predicting the Water Quality Index (WQI), except for one upstream location, showcasing generally low water quality across the studied areas.

Similarly, Choudhary *et al.,* (2023) developed a hybrid machine learning method, BA-RT, to forecast monthly WQI in a humid climate region of northern Iran. They identified faecal coliform and total solids as significant factors affecting forecasting IRAQIs (Iranian River Aquatic Quality Index), achieving a high R2 value using the BA-RT model. Building upon these methodologies, the current research employs machine learning techniques to predict urban lake water quality based on extensive two-decade data. This study integrates Regression Models, Neural Networks, and Ensemble Methods to accurately predict water-quality changes and identify key pollution contributors in urban lakes. The aim is not only precise prediction but also to provide insights for decision-making in urban planning and environmental protection initiatives, showcasing machine learning's potential in addressing water quality concerns for sustainable urban development. The analysis identifies key factors influencing river water quality, emphasizing attributes such as NH3-N, TCB, FCB, BOD, DO, and Sal through the AR (Analysis of River) method. (Babuji *et al.,* 2023) The SVM linear method achieved exceptional accuracy in classification, showcasing reliability with consistently high accuracy levels during validation exercises. Aswathi *et al.,* 2021 work also contributed to predictive modelling approaches, achieving a high accuracy rate in predicting the Water Quality Index (WQI) using supervised machine learning algorithms.

Mohammad, (2015) introduced an Innovative Water Quality Prediction Framework, utilizing supervised machine learning techniques. This framework cantered on temperature, turbidity, pH, and total dissolved solids to evaluate the Water Quality Index (WQI) from a dataset sourced from PCRWR, focusing on Rawal Lake in Pakistan. The study employed regression and classification algorithms (Mohammad, 2015) to estimate WQI and categorize samples based on predefined Water Quality Classes (WQC), demonstrating the effectiveness of various supervised AI algorithms in water quality assessment.

Hassan *et al.,* (2021) introduced a Robust Classification Model for Water Quality using Advanced Machine Learning Techniques, particularly focusing on the Kinta River's water quality in Perak, Malaysia. Their study evaluated various AI algorithms and models to classify water quality, with the Lazy model employing the K Star algorithm exhibiting the highest accuracy at 86.67%.

This highlights the threat posed by wastewater and emphasizes the need for scientific models (2022) to address this issue effectively. Moreover, an analysis utilizing the AR method identified crucial factors significantly influencing river quality, including parameters like NH3-N, TCB, FCB, BOD, DO, and Sal, registering substantial impacts ranging from 0.80 to 0.98. On the other hand, factors like TDS, Turb, TN, SS, NO3-N, and Cond showed contributions between 0.25 to 0.64 during the classification process. The SVM linear method displayed exceptional classification results, achieving an accuracy of 0.94 and averaging 0.84 for precision, recall, and F1-score. Validation confirmed the potency of AR-SVM, maintaining high accuracy levels between 0.86 to 0.95 with three to six characteristic parameters.

Manoiu *et al.,* (2022) utilized an artificial neural network to simulate the Water Quality Index (WQI) for the Akaki River, accurately predicting the WQI with an impressive accuracy of 0.93. Additionally, Aswathi *et al.,* 2021 introduced a novel hybrid machine learning method, BA-RT, forecasting the monthly Water Quality Index (WQI) in a humid climate, emphasizing the influence of faecal coliform and total solids on WQI forecasts.

These studies collectively aim to comprehend water quality dynamics and predict water quality using various parameters and machine learning methodologies. They highlight the significance of evaluating different aspects of water quality to mitigate pollutants' impact and ensure safe water access worldwide.

Device Methodologies Proposed (prev.)

The research conducted by Vaishnavi V. Daigavane and Dr. Gaikwad. M.A. utilized an optimization methodology (Vaishnavi *et al.,* 2017), employing datasets from Kaggle focused on Indian water quality data. The aim was to comprehend crucial aspects within the data while addressing missing values using Random Forest, a technique effective in managing such occurrences. The workflow began with Min-Max Normalization to enhance data quality across all datasets and involved calculating the Water Quality Index (WQI) crucial for evaluating water quality. A Histogram visually represented the dataset's distribution pattern.

Correlation analysis measured consistent variations between pairs of variables. The dataset was then split into training and testing segments. Five machine learning algorithms—Neural Network, Random Forest, Multinomial Logistic Regression, Support Vector Machine, and Bagged Tree Model—were employed to train the dataset. Feature importance was highlighted using six different colour signals. The research conducted by Mohamad (2015) and Nayak *et al.,* (2023) aimed to model and predict urban lake water quality by combining various machine learning (2021) algorithms known for handling high-dimensional, non-linear, and complex datasets. Multiple Linear Regression (MLR) and Artificial Neural Networks (ANNs) (2023) were incorporated, mimicking the brain's structure with interconnected layers of nodes to process information.

Results and Discussion

The variations align with typical atmospheric conditions, and no aberrations or irregularities were observed during this period of analysis.

The comprehensive consolidation of collective findings (Sun *et al.,* 2023) obtained from an extensive evaluation of diverse parameters in lake water over a specified study duration is detailed in this report. Initially, the recorded data indicates a higher temperature in November, followed by a gradual decline in December and January. Subsequently, a noticeable rise in temperature is observed in February. These temperature variations correspond harmoniously with typical atmospheric conditions, without any detected irregularities or aberrations during this analytical period.

The researchers found in their studies that the effectiveness of Artificial Neural Networks (ANN) heavily relies on how data is segmented. They highlighted the necessity of having a sufficiently large training dataset that represents the entire population and a testing set chosen randomly, mirroring the characteristics of the (Nayak *et al.,* 2023) training data. The studies effectively validated this approach, showcasing a positive correlation between a higher percentage of the training set and improved model performance. However, dealing with small datasets posed inherent challenges, notably the risk of overfitting.

The researchers noted a positive trend in the overall water quality of several canals and rivers, including the Main Canal of River Narmada, IGNP, Gang Canal, River Chambal at Akelgarh, Kota, River Kali Sindh near M/s CFCL, Kota, River (Vasistha, 2020) Gambhari near the old bus stand, and River Berach near Hotel Padmani, Chittorgarh. This improvement in water quality was plausibly linked to the lockdown measures imposed on industrial activities and a significant reduction in community bathing and washing activities around these canals and rivers.

Overall, these studies highlighted the intricacies related to data division in ANN models, emphasizing the importance of a well-represented dataset and the challenges (Vasistha, 2020) posed by limited data availability. Furthermore, they underscored the positive impact of lockdown measures on enhancing the water

quality of various canals (Singh *et al.,* 2022) and rivers, illustrating the complex interplay between human activities and environmental parameters.
The study extensively analysed seasonal variations in Water Quality Index (WQI) values across four sampling sites, consistently noting parameters (Saini, 2022) such as Total Dissolved Solids (TDS), Electrical Conductivity (EC), and Biological Oxygen Demand (BOD) surpassing the permissible limits set by the Bureau of Indian Standards (BIS). Alkalinity levels exceeded limits specifically at site S1.

Additionally, the research examined the presence of pharmaceutical compounds in drinking water, indicating minimal risk to human health but identifying potential concerns for infants aged 0–3 months. Noteworthy heavy metals like cobalt, cadmium, chromium, copper, mercury, nickel, zinc, and lead were found, with cadmium posing the highest cancer risk.

The study done by the researchers concluded to the effectiveness of Wang *et al.,* (2023) specific algorithms, such as Bayesian regularization and Ensemble methods, in predicting WQI. Bayesian regularization slightly outperformed, showcasing superior generalization ability in water quality prediction. Machine learning algorithms were instrumental in identifying crucial water quality indicators and forecasting future trends based on existing data patterns.

While the study provided valuable (Vaishnavi *et al.,* 2017) insights, there are opportunities for enhancement. Future investigations could consider diverse data factors like rainfall patterns, temperature fluctuations, land usage alterations, and demographic shifts to enrich predictive models. Deploying embedded devices for continuous monitoring is recommended for real-time data collection, analysis, and integration within a smart environment. Such devices would facilitate connectivity, enabling accessible monitoring and management via Wi-Fi. This highlighted the efficiency of applied models in predicting water quality parameters, particularly with MLR demonstrating high accuracy (Mohammad *et al.,* 2023). Future research aims to combine this approach with deep learning techniques for improved predictive accuracy and efficiency in the selection process.

Future Scope

- In future we use IOT concept in this project
- Detecting the more parameters for most secure purpose
- Increase the parameters by addition of multiple sensors
- By interfacing relay, we control the supply of water.

"Our mission is to revolutionize the monitoring and remediation of Fateh Sagar Lake's pollution through cutting-edge AI technology. By harnessing the power of advanced AI-based devices, our goal is not just to monitor but to actively control, reduce, and cleanse the pollution plaguing this cherished water body. Amidst heavy tourism impacting its pristine beauty, our innovative solution aims to restore Fateh Sagar Lake to its former glory, ensuring a sustainable and vibrant ecosystem for generations to come.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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