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Methods for Determining the Water Quality Index in Developing Asian Countries: A Review

Sudarno[1*], Mochamad Agung Wibowo[2], Pertiwi Andarini[1], Dionisius Veda Priya Kurniatama[3], Natasya Ghinna Humaira[3]

[1] Department of Environmental Engineering, Faculty of Engineering, Diponegoro University, Prof. Soedharto, S.H. Street, 50275, Tembalang, Semarang, Indonesia

[2] Department of Civil Engineering, Faculty of Engineering, Diponegoro University, Prof. Soedharto, S.H. Street, 50275, Tembalang, Semarang, Indonesia

[3] Environmental Sustainability Research Group, Department of Environmental Engineering, Faculty of Engineering, Diponegoro University, Prof. Soedharto, S.H. Street, 50275, Tembalang, Semarang, Indonesia

* Corresponding author's email: sudarno@live.undip.ac.id

ABSTRACT

Clean water quality is a problem, especially for developing countries in Asia. Their efforts to maximize various sectors to become a developed country, for example in industrial activities, result in negative environmental impacts, especially for water quality. The wastewater that is directly discharged into river bodies without any treatment causes river water quality to become increasingly worse. The water quality index (WQI) is one of the tools used to assess river water quality. There have been many studies that examined the river water quality in Asia, but there are still few studies that discuss the river water quality as a whole in Asia, especially for developing countries where industrial activities are massive. This study discussed the trends in river water quality in developing countries in Asia. The results obtained showed that most river water quality in Asia falls into the medium to poor category, even poor in some situations, especially in the areas with dense populations and in the areas around rivers which are full of domestic and industrial activities. For this reason, there is a need for a more advanced WQI assessment which is carried out using scientific analysis using fuzzy logic so that the WQI value can be more accurate and QGIS can provide broader information. There needs to be cooperation and good relations between the community, stakeholders and the government in an effort to overcome river pollution which will become even worse by providing stricter regulations, establishing proper water treatment so that industrial or domestic waste water does not directly enter water bodies, and create appropriate policies. Therefore, it is important to be able to develop a river water quality assessment system, such as WQI to be more accurate so that these actions can be carried out.

Keywords: water quality, river water, water parameter.

INTRODUCTION

Water is one of the essential things that contains many nutrients and minerals that support human life for many purposes [Chidiac et al., 2023; Grönwall & Danert, 2020; Uddin et al., 2023]. The problems related to water have become a global problem [Anh et al., 2023; Reljić et al., 2023]. The problem of clean water pollution affects almost half of the world's human population, causing the deaths of up to five to ten million people every year [Ahuja, 2021]. This water quality problem is caused by several factors, both natural and human activities [Ahuja, 2021; Hou et al., 2013; Qasemi et al., 2023]. The huge population growth and rapid urbanization in several Asian countries is one of them [Liyanage & Yamada, 2017; Sajil Kumar, 2017]. The industrialization process that developing countries continue to promote in their efforts to move towards becoming developed countries, is also one of the causes of the bad water pollution produced

[Puspita et al., 2023; Wahyuningrum et al., 2023]. Industrial activities often have a negative impact on water bodies, especially industrial wastewater which carries many dangerous pollutant contaminants [Fida et al., 2023; Hadiwidodo et al., 2023; Ilyas et al., 2019]. The demand for agricultural productivity, which has the effect of massive agricultural activities on the Asian Continent, also produces chemical waste that is dangerous for the quality of clean water [Parris, 2014; Varol & Tokatlı, 2023; Wang et al., 2023]. This need for good water quality requires comprehensive monitoring to provide the information and assessments on water quality, specifically river water, the primary water source for several regions [Barakat et al., 2016; Budihardjo et al., 2022]. Nevertheless, quantifying river water quality is a significant challenge owing to the extensive array of potential factors employed to characterize it. More financial resources, particularly in developing nations, pose a significant obstacle to comprehensive monitoring of all water quality parameters in rivers due to the labor-intensive and costly nature of the task [Ho et al., 2019].

Water quality indices (WQIs) have historically been employed as a prevalent method for assessing the water quality of a certain water body [Gholizadeh et al., 2016; Gitau et al., 2016; Sutadian et al., 2018]. The Water Quality Index (WQI) is a numerical representation that indicates the condition of water quality in a certain water body, such as a river; it is calculated by combining the measured values of various water quality parameters that have been chosen for assessment [Misaghi et al., 2017; Rana & Ganguly, 2020; Trach et al., 2022]. WQI is used to explain the status of river water quality and has been used since the beginning of 1965 [Chidiac et al., 2023; Mishra, 2023]. It has become an effective way of communicating information about water quality status [Uddin et al., 2023; Wu et al., 2018]. Although WQI is not yet able to evaluate water quality for all types of uses and hazards, it is able to provide many benefits, such as a comparison medium between water sources that can be used to report quality status that can be understood more quickly and simply [Birva & Hemangi, 2018], this makes it easier for water policymakers to make decisions [Gitau et al., 2016; Ocampo-Duque et al., 2006; Unigwe & Egbueri, 2023]. Because each WQI method is created for various purposes, locations and expert assessments, the results of WQI assessments using each method can be different for the same water source [Seifi et al., 2020]. One of them occurred in the research conducted by Darvishi et al. [2016] assessing the water quality in the Talar River using the OWQI and NSF methods. The results of the two water qualities are different from each other, even though they were carried out the same in the Talar River. The appropriateness of using the WQI method depends on the source, parameters, weights given, classification and final interpretation [Rana & Ganguly, 2020; Wu et al., 2018]

Gaining a comprehensive understanding of the present water quality condition in developing Asian nations is of utmost importance, as it establishes the basis for making well-informed decisions and implementing effective policies [Bassi & Kumar, 2017; Choe et al., 2019]. The primary objective of this study is to offer a thorough and all-encompassing analysis of the current water quality condition within the specified region. This will be achieved by thoroughly examining many aspects, including trends, patterns, and any existing regional discrepancies. This analysis explores the intricacies of water quality management, highlighting the imperative of comprehensive strategies that encompass pollution mitigation and the equitable provision of clean water access. This compilation of research and analysis will not only enhance the comprehension of the water quality situation in developing Asian countries but also provide a significant resource for policymakers, researchers, and stakeholders.

Several papers have discussed the river water quality in developing countries in Asia (Figure 1). Marselina et al. [2022] used three different WQI methods, namely the National Sanitation Foundation WQI (NSF WQI), Canadian Council of Ministers of the Environment WQI (CCME WQI), and the Oregon water quality index (OWQI) to examine the quality of river water in the Citarum river, West Java. Hasan et al. [2015] examined the water quality of the Pelus River in Malaysia using the JPS River Index. Jehan et al. [2020] evaluated the water quality of the Swat River in Northern Pakistan using multivariate statistical techniques and WQI Model Sutadian et al. [2018] tried to develop one of the WQIs, namely the West Java Water Quality Index, to be used as an index throughout West Java by creating a limit and considering water quality more effectively in terms of costs. However, more is needed to thoroughly discuss the broad picture of river water quality in developing countries in Asia. For this reason, this paper aimed to provide a comprehensive understanding

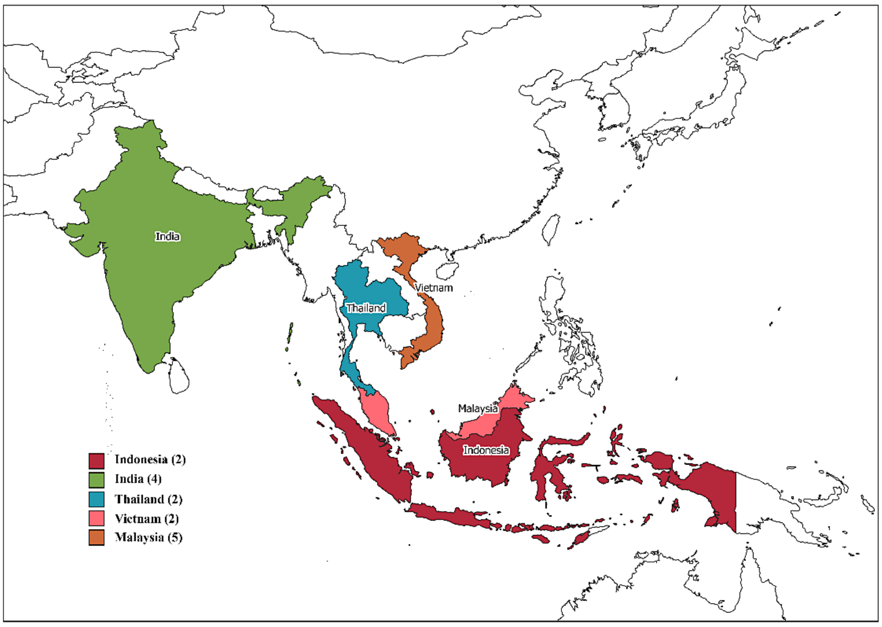

Figure 1. Geographical distribution of water quality studies

of river water quality in developing countries in the current situation and the future considerations.

WATER QUALITY OVERVIEW: INDONESIA

In their study, Marselina et al. [2022] used several WQI methods to assess which WQI method was most suitable to be applied in evaluating river water quality in Indonesia. In their research, Marselina et al. [2022] used the Citarum River as a case study. The study area in this study is the Citarum River, especially in the upper part, using sixteen parameters, namely dissolved solids, pH, suspended solids, DO, pH, COD, BOD, free ammonia, total phosphate, nitrate, detergent, oil and grease, phenol, fecal coliform, free chlorine, and total coliform. This river is the longest river in West Java, Indonesia with a length of 297 km; also known as one of the most polluted rivers in the world [Sholeh et al., 2018]. One of the methods used is the National Sanitation Foundation Water Quality Index (NSF WQI), which is commonly used to assess river water quality globally [Misaghi et al., 2017; Ratnaningsih et al., 2016]. The second method used is the Canadian Council of Ministers of the Environment WQI, which is taken based on surface water quality standards in Indonesia, and the last is the Oregon Water Quality Index, which was previously used by Rahayu et al. [2021] in assessing the water quality in the Sutami reservoir. On the basis of the results Marselina et al. [2022] obtained, it was found that the water quality status was better in the rainy months than in the dry months. This is caused by rainwater, which is able to make surface water quality better, because it dilutes naturally existing pollutants [Chapman et al., 2019; Nurjanah, 2018]. However, what is interesting is that in dry years the river water quality is better in than a wet year. In fact, if there is more rainfall in a year, the quality of river water will be better. This is due to the inconsistency of monitoring carried out on the Citarum River. On the basis of the assessment of the three methods used from 2011 to 2019, it can be said that, in general, the condition of the Citarum River is classified as bad, even very bad in OWQI method. Only a few years are classified as fair, namely in 2015 and 2016 in the NSF WQI method and 2015 in the CCME method; the rest are in a bad category, in fact, all of them were very bad category on OWQI throughout 2011-2019. The issuing of Cooperation Agreements between 10 cities and the West Java Environmental Service about the integration of water quality monitoring, which each city is required to carry out, is one of the factors supporting this rule. By using the same quality indicators in all monitoring activities conducted by each local authority through which the Citarum River flows, it is possible to integrate the findings of water quality monitoring. When the study findings align with the parameters used in the NSFWQI calculation, the local administration may be required to monitor specific water quality metrics.

Sutadian et al. [2018] also researched the condition of river water quality in West Java. In his study, he tried to develop a water quality index to make it more suitable for rivers in West Java Province. Some of the rivers in the study area are the Citarum, Ciliwung, Cileungsi, Cimanuk, Cilamaya, Citanduy and Cisadane rivers. These rivers are vital in Indonesia because they are a source of water for agricultural and food needs. Unfortunately, these rivers are very vulnerable to pollution by agricultural, industrial and livestock activities. (Juwana 2014). Sutadian et al. [2018] developed a quality assessment method using four steps, namely selecting parameters based on statistical assessments, obtaining sub-index values, weighting parameters, and aggregating sub-indices to find the final index result. Using the new WQI method called the West Java Water Quality Index, Sutadian et al. [2018] assessed eight rivers using data from 2001 to 2011. The results obtained showed that the water quality of most of these rivers was far from satisfactory. The results showed that the Citarum, Cileungsi and Cilamaya rivers had better water quality than other rivers in West Java. There are 13 parameters used, namely faecal coliform, zinc, mercury, lead, detergent, phenol, chloride, dissolved oxygen, chemical oxygen demand, suspended solids, temperature, detergent and nitrite. This is actually not too surprising, considering that there are so many industrial areas that in West Java, such as food and textiles. Only Bandung and Cirebon have sewer systems in West Java. More than 46.16 per cent of households in West Java do not have access to sanitation in West Java. In general, industrial, domestic and agricultural activities are the most significant contributors to poor air quality in these rivers [Tiwari et al., 2018].

WATER QUALITY OVERVIEW: THAILAND

Tian et al. [2019] researched one of the river water qualities in Northeastern Thailand, namely the Mun River. The Mun River, one of the largest tributaries of the Mekong River in Thailand, has a length of around 800 km [Penny et al., 2023]. The methods used by Tian et al. [2019] were the Kendall Test and the Water Quality Index. Kendall Test was conducted to check the trend of concentration of water quality parameters. Meanwhile, WQI was used to comprehensively evaluate water quality status. Several parameters used in this assessment included total coliform bacteria (TCB) and fecal coliform bacteria (FCB). DO, BOD, nitrate-nitrogen (NO_3-N), ammonia nitrogen (NH_3-N), and suspended solids. The results that Tian et al. [2019] obtained were that the quality of the Mun River water parameters varied greatly both spatially between higher and lower areas and also temporally, namely between flood seasons and non-flood seasons. Under higher conditions, several parameters that have a significant influence on water quality are BOD, DO, and TP, while at lower areas they are DO, BOD, and NH_3-N. Overall, the parameters that influence the water quality in the Mun River differ between high and low altitudes. Meanwhile, the WQI value during flood season is usually the worst, indicating poor water quality. Meanwhile, the river areas with higher conditions have worse quality scores. Agricultural land contributes significantly to phosphorus content. The urban area has a very close correlation with TCB, FCB and BOD, and the numbers are significant, even very large. This shows that urban areas have a significant influence on water pollution.

Most water quality surveys are carried out by the Pollution Control Department using several physical and chemical properties in their assessments. Leelahakriengkrai and Peerapornpisal [2011], in their study, reported on the river water quality covering six regions, namely the Tapee River in the southern region, the Kwai River in the western region, the Chi River in the northeast region, the Tha Chin River in the central region, and the Ping River in the Northern Region. The water quality of the Utamma River in Thailand in 2008-January 2009 showed promising results from clean to moderate. In their investigation, the Ping, Chi, Kwai, Chanthaburi and Tapee Rivers can be used for agricultural and industrial activities, as can the Tha Chin River, although they require special treatment.

WATER QUALITY OVERVIEW: INDIA

The Ganga River is the longest river in India and in South Asia, with a length of 2.525 km, which passes through four countries, including India, Bangladesh, Nepal, and China, with a total of 80 percent of this river area being in India [Chakraborti et al., 2018; Singh et al., 2018]. Matta et al. [2020] carried out sampling with a total of 120 water samples, which took place during the rainy season, namely November-February monsoon in July-August, post-monsoon September to October, in 2015–2016. Matta et al. [2020] uses NSFWQi as a method for assessing the water quality of the Ganga River. On the basis of the results obtained, if using Indian Standards, the Ganga River water is unsuitable for drinking. The results from NSFWQI state that the upstream is classified as good, namely in the Gangotri and Uttarkashi areas during the rainy season and dry season. However, pollution occurs downstream in Jatwara and Haridwar during the monsoon season.

The water quality of the Gaghara River was assessed using WQI [Ravi et al., 2023]. The procedure used in this research was carried out following the process attached by Chandra et al. [2017]. According to its length and volume, the Gaghara River is the second largest tributary of the Ganga River [Dwivedi et al., 2017]. The Gaghara River is one of the rivers with the most people living around its riverbanks, namely 25,864,970 people, based on a census conducted in 2011. Sampling was carried out at a total of 18 sampling points, with 54 samples divided into pre-monsoon, namely in September 2018 and during Monsoon and post-monsoon in July and September 2019, respectively. In accordance with the results Ravi et al. [2023] obtained in pre-monsoon conditions, the WQI value ranges from 19 to 49. This indicates that the river water quality is classified as excellent (0–25) and good (26–50). During Monsoon, the WQI values obtained varied between 11 and 70, which indicates that some are classified as good and some are classified as poor (51–70). Then, at post-monsoon time, the WQI value varied from 53 to 142, this indicates that someone is in the poor, very poor category (71–90) and also unsuitable for drinking. In the post-monsoon season, fluoride and PH concentrations greatly influenced the resulting WQI values. The high PH value in this river increases the dissolution process of fluoride-bearing minerals, which leads to increased fluoride levels in this river. In general, the water quality of the Gaghara River is below the safe quality standards issued by WHO and is not suitable for use in industrial activities, but is still suitable for irrigation use. Special attention and strict assessment are needed to reduce water deterioration. There is a need for good water treatment, such as increasing the amount of waste and wastewater treatment plants along with population growth. Degradation of the Garagha River can also be reduced by reducing untreated wastewater from certain points.

The Mahananda River is one of the most important rivers for the people of India, as well as Bangladesh [Anonna et al., 2022; Rangarajan et al., 2019]. However, there is still little information regarding the water quality of this river. For this reason, Shil et al. [2019] tried to assess the water quality of the Mahanda River using WQI. The Mahananda River is located in the northern part of West Bengal, India, with more than half of its basin area in India, while the rest is in Bangladesh with a total length of 360 km. Some urban areas around this river include Barsoi, Dalkhola, Kishanganj, Siliguri town, and Malda. Sampling was carried out for two different durations, namely pre-monsoon and post-monsoon, in 2016, with a total of 14 sampling stations. Several parameters assessed in this assessment are temperature, PH, DO, TDS, nitrate, phosphate, sulfate, Mg, Ca, EC, chloride, and hardness. On the basis of the results obtained in the pre-monsoon, WQI values ranged from 17.63 to 93.50 and 18.25 to 94.50 in the post-monsoon season. Sampling station S-2 has very poor values both pre-monsoon and post-monsoon. This is because the S-2 location is in Siliguri City downstream and accommodates a lot of municipal effluent. Seasonally, the post-monsoon values have slightly better quality because some of the soluble pollutants are carried away by rain. Overall, the water quality of this river is quite good, except for several locations close to residential areas. Several indications reveal that this river water is not suitable for agricultural activities but can be used for industry if processed appropriately. The Mahananda River requires management to protect and prevent the quality of the river from deteriorating.

The Noyyal River is a river located in Tirupur District, southern India, with a relatively dense population [Sreelakshmy et al., 2023]. The Noyyal River flows into a larger river, namely the Cauvery River, with a length of about 175 km, which flows from Mount Vellingiri [Shanmugamoorthy et al., 2023]. Tirupur is famous for its location, which is filled with textile factories and industries [Prabha et al., 2017; Pranaw et al., 2014]. Textile industry is one of the largest and supports the country's economy [Ghosh & Devi, 2018]. Many industrial activities dump their effluent into this river without going through a treatment process [Prabha et al., 2017]. For this reason, this Krishnamoorthy et al. [2023] carried out an investigation regarding the water quality of the Noyyal River using the Underground Water Quality Index

(UWQI) with eleven main parameters, namely, total hardness, TDS, chloride, nitrate, bicarbonate, calcium, total alkalinity, magnesium, and pH, DO, and sulfate. According to the results obtained from fifteen samples that were tested, the UWQI value ranged from 62 to 125.7. This indicates that the quality of the UWQI varies from being classified as good, namely between 50–100, and being classified as bad, namely between 101 and 200 [Lukhabi et al., 2023]. Some of the main parameters that are the reason for the poor quality of this river water include total alkalinity, chloride, TDS, and total hardness. Several parameters that are other reasons are magnesium, bicarbonates, and sulfate. This is mainly due to massive textile and industrial activities due to discharged effluent [Madhav et al., 2018]. In addition, municipal waste and community activities also affect the quality of underground water. There is a need for further studies to assess the actions taken to protect the Noyyal River from industrial and municipal waste in greater depth.

WATER QUALITY OVERVIEW: VIETNAM

The Bach Dang River basin in Quang Ninh Province accommodates clean water for community use and aquaculture [Vu et al., 2022]. However, because there are still few quality assessment studies on this river water, Nguyen et al. [2023] conducted research and assessed the water quality of the Bach Dang River basin using the water quality index. The Bach Dang River is part of the Thai Binh River, which has its headwaters in the Da Bac and Gia Rivers and empties to the south on Vu Yen Island for 43 km. This river is the main river in Quang Ninh Province, which has several tributaries, including the Uong River, Cam River, and Khoai River. Sampling was carried out for 23 water samples, which were carried out in the rainy season and dry season. Some of the parameters reviewed are pH, alkalinity, temperature, NH_4^+, BOD, COD, DO, phosphate, coliform, electrical conductivity (EC), and heavy metals. There are five WQI levels in Vietnam, namely Level 1, where the WQI is between 0-25, categorized as dirty, and requires treatment before use. Level 2 has a value between 26 and 50, which can be used for transportation. Level 3 has a value of 51 to 75; the water can be used for irrigation purposes; level 4 has a value of 76 to 90, which means the water can be used for domestic purposes. Level 5, with a value of 91 to 100, means the water can be used for household water. In general, the results obtained in the dry season and rainy season are classified as very good; only a few posts are classified as average. The WQI results in the rainy season are better than during the dry season; this may be due to increased runoff from community and agricultural activities. In the rainy season, the WQI value varies between 76 to 91, while in the dry season, it is 61 to 93. This indicates that the quality of river water in the Bach Dang River is good in both the dry and rainy seasons, but treatment is needed at several points to ensure that the results remain good. Nguyen et al. [2023] recommends ongoing monitoring to maintain a safe water supply for the community.

The Ray River is one of the rivers in the Vung Tau Province. This 120 km long river flows from the Chua Chan mountains. Several tributaries of the Ray River are Soui Mon Coum, Suoi Cao, and Suoi Sap. Due to the lack of studies regarding the water quality index on the Ray River, Thuy et al. [2021] conducted a study on assessing river water quality in the Ray River based on two seasons, namely the dry season and the rainy season, with ten sampling points and 13 parameters. Sampling was carried out in four periods, namely March, June, October and December in 2019. According to the results obtained, the water quality in Ray River is better in the dry season compared to the rainy season. The water quality of the Ray River is greatly influenced by anthropogenic activities, namely agriculture (phosphate), livestock, and industrial wastewater. This occurs at the M2 sampling point location, which has WQI values for both seasons. The location of the M2 sampling point is close to domestic activities and livestock. The location of M2 is a very polluted point. Overall, the water quality of the Ray River is in the poor and bad categories; the WQI values ranks higher in the dry season. Thuy et al. [2021] states that preventive measures and appropriate management are needed to maintain as well as improve the quality of river water, which is slowly entering a critical condition.

WATER QUALITY OVERVIEW: MALAYSIA

Malaysia is a developing country where many industrial activities, mining, and domestic sewage cause a lot of water contamination [Abdul Maulud et al., 2021; Ismanto et al., 2023]. Abdul

Maulud et al. [2021] tries to assess the water quality for the Kelantan River, one of the 248 km long rivers in Malaysia, using the water quality index. Several tributaries of the Kelantan River are Galas, Pergau, Lebir and Nenggiri. Agricultural and livestock activities dominate activities around the Kelantan River. In this study, sampling was carried out at 27 sampling stations spread throughout the Kelantan River. The study results were obtained with six parameters, namely BOD, COD, DO, SS, and pH. Water quality in the dry season for all sub-catchments in the Kelantan River is class three. Meanwhile, when the season changed to the rainy season, the classes changed to classes 4 and 5 for the upstream section. Extensive water treatment is required for the Kelantan River throughout all seasons if it is to be used for domestic activities.

The rivers in Selangor, Malaysia, are experiencing contamination due to the dense population [Al-Badaii & Shuhaimi-Othman, 2014]. The contamination that occurs is caused by industrial, livestock, and agricultural activities [Anyadoh-Nwadike et al., 2015]. One of them is the Tekala River, which is a recreational river. This river is located 50 km from the capital city of Malaysia, Kuala Lumpur. Kim et al. [2022] assessed the quality of river water from the Tekala River using several parameters, namely COD, BOD, DO, pH, temperature, ammoniacal-nitrogen (NH_3N), total suspended solids (TSS), total dissolved solids (TDS), coliform, conductivity, macroinvertebrate, and coliforms. Sampling was carried out in May 2017 and October 2017 with a total of 18 water samples. The WQI value of the Tekala River varied between 85.45 and 94.86, which means that the condition of this river can be said to be classified as class 1 and class 2. Differences in ammoniacal nitrogen, pH, and temperature had the greatest significance. The WQI value gradually decreased from upstream to downstream due to the large number of pollutants. Therefore, Hanafiah et al. [2018] stated that this river is recommended as a safe river for recreational activities.

Another study conducted in assessing the water quality of the river in Malaysia was conducted by Jamal et al. [2023] to assess the water quality of the Masai River, Johor. This study tried to assess the quality of river water along an urban area, namely 1.5 km long, involving a lot of industrial activities, factory construction, and dense population. Sampling was carried out in three consecutive weeks starting in November 2022 from three different stations. Sampling was done once a week during rainy and non-rainy conditions. Several parameters assessed in this study were COD, BOD, NH_3N, DO, pH, and TSS. According to the results obtained, the water quality of the Masai River, Johor, is unsuitable for aquatic life, or it could be said that the results did not meet the standards set by the Malaysian DOE WQI for marine creatures to live in. Overall, the WQI value results varied between 59.34 to 74.47. The poor water quality of the Masai River, especially downstream, is caused by the large amount of polluted water that is discharged into this river. Without processing, this river can be used for fishing or agricultural activities but can become a source of drinking water if the right processing process is applied.

The Terengganu River is located in the northeastern part of Peninsular Malaysia [Abd Wahaba et al., 2019]. This river is the main river that originates from Lake Kenyir and empties into the South China Sea. Several tributaries of the Terengganu River include Telemung, Tersat, Nerus, and Berang. This river passes through different socioeconomic areas ranging from industrial activities, livestock, forests, agriculture, and so on. Suratman et al. [2015] conducted monthly sampling with a total of 10 samplings in 2008. Some of the parameters assessed were BOD, DO, COD, pH, TSS, and AN. The results showed that the DOE-WQI value varied between 71.5% and 94.6%, i.e. from slightly polluted to clean. Low water quality was found in the middle and downstream, while the upstream had high river water quality.

Wong et al. [2020] conducted a study to compare the water quality index in ASEAN to assess the water quality of the Selangor River in Malaysia. Several countries that already have their own WQI systems are Malaysia, Thailand, and Vietnam, while Indonesia has adopted the WQI system. Wong et al. [2020] assessed the river water quality with twelve parameters, which were plotted into the WQI systems. The first of these WQI systems was DOE-WQI (Malaysia), which has six physicochemical parameters, including ammoniacal nitrogen (AN), COD, BOD, pH, DO, and suspended solids [Sim & Tai, 2018]. Meanwhile, PCD-WQI (Thailand) has five main parameters, namely BOD, DO, AN, FCB, and TCB. MONRE WQI (Vietnam) has nine parameters, namely BOD, DO, COD, PO_3^{-4}, An (chemical), turbidity and SS (physical), TCB (biological), and pH. Indonesia adopted the Storage and Retrieval and

Water Quality Data System (Storet) and Pollution Index (PI) in assessing the quality of its river water [Barokah et al., 2017]. Meanwhile, the twelve parameters assessed in this study were COD, BOD, DO, NO_3, AN, pH, PO_4^{-3}, SS, turbidity, TCB, and water temperature. In general, the downstream experiences a large amount of pollution caused by community activities and sand mining activities. Meanwhile, stations five and six are greatly influenced by biological parameters due to the large amount of domestic and industrial wastewater. MONRE-WQI (Vietnam) and STORET & PI (Indonesia) appear to be more stringent water assessment systems compared to DOE-WQI (Malaysia) and PCD-WQI. WQI, which assesses all biochemical and physicochemical aspects, tends to give consistent results, namely very poor. In contrast, the systems that assess biochemical or physicochemical, such as DOE WQI and PCD-WQI, give better evaluation results (fair-poor). Wong et al. [2020] believes that there is a need for integration between WQIs and GIS for more in-depth analysis and to be able to provide more comprehensive information.

STRATEGIES AND FUTURE CONSIDERATIONS

On the basis of evaluations and assessments of river water quality in developing countries in Asia, such as Indonesia, Vietnam, Malaysia, Thailand, and India, the WQI results obtained are quite varied. Several reasons cause these quite varied results; the first is that the assessment of the use of the WQI is different from one country to another [Zotou et al., 2020]. For example, the water quality index in Malaysia using DOE-WQI is different from the water quality index held by Vietnam, namely PCD WQI [Wong et al., 2020]. The type of parameters and number of parameters used also differ from one another. The results of the river water quality will be different, even though the source is from the same river water; this is in line with what Wong et al. [2020] said in his study, namely comparing WQI between countries in Southeast Asia. This difference is also caused by the fact that river conditions are different. Overall, river water quality assessment results were obtained in the rainy season compared to the dry season, except for those in Citarum and Vietnam, which showed different results [Marselina et al., 2022; Thuy et al., 2021]. These better results can be caused by pollutants being diluted in heavy rainwater [Abdul Maulud et al., 2021]. Meanwhile, the research that was conducted on the Citarum River states that the dry season is better than the rainy season; this may be due to the lack of comprehensive and complete data collection carried out [Marselina et al., 2022]. WQI, which has played a role as a tool to help assess water quality, has undergone many developments to obtain more accurate results. The weighting must be determined according to the use of the water. In other words, a Universal WQI definition cannot be carried out. In other words, the use of WQIs will experience limitations, such as being biased, not specific, or there is no relationship between parameters. Using fuzzy logic can be done to help obtain more accurate WQI results [Chaudhary, 2020; Quiñones-Huatangari et al., 2020]. Therefore, the development of WQI as a tool for assessing river water quality must be developed by including statistical analysis [Kachroud et al., 2019]. This approach is able to analyze the impact of these variables on river water quality. Using WQIs and GIS simultaneously can also be a solution for carrying out more in-depth analysis in evaluating river water quality [Ram et al., 2021]. River water quality assessments and efforts to restore river water quality also need to be carried out more comprehensively with full collaboration between researchers, stakeholders, and the government in order to make future decisions and policies [Choe et al., 2019; Miller & Hutchins, 2017]. At the same time, good waste water treatment is also needed for all polluted water that will enter the river, starting from industrial and domestic waste. Summary of the results is presented in the Table 1.

CONCLUSIONS

According to the results obtained, the quality of river water in Asia generally has a poor value downstream, because it is close to densely populated locations full of activities, such as industry, agriculture, and animal husbandry. Several parameters of WQI are also strongly influenced by anthropogenic activities. For this reason, to prevent river water conditions from deteriorating, it is necessary to tighten the regulations for industry in discharging wastewater into river bodies. Overall, the condition of river water in Asia, especially in developing countries, falls

Table 1. Results summary

Countries	Studies	Approaches	Findings
Indonesia	Water quality index assessment methods for surface water: A case study of the Citarum River in Indonesia [Marselina et al., 2022]	Several WQI methods (NSF WQI, CCME WQI, OWQI) were used to assess which WQI is most suitable for application in Indonesia.	• NSF WQI is the most suitable WQI assessment method for determining Indonesian surface water quality rather than CCME WQI and OWQI (the WQI obtained each year constantly fluctuates • Wet months indicate better WQI, but dry years tend to have better WQI.
	Development of a water quality index for rivers in West Java Province, Indonesia [Sutadian et al., 2018]	The development of the West Java Water Quality Index (WJWQI) was carried out to address the limitations faced by the indicators currently used.	• WJWQI is considered robust after testing its robustness using sensitivity and uncertainty tests (Monte Carlo). • Rivers in West Java Province have been experiencing water quality deterioration significantly.
Thailand	Water Quality of the Mun River in Thailand –Spatiotemporal Variations and Potential Causes [Tian et al., 2019]	The Kendall Test and Pollution Control Department (PCD) WQI were used to assess Mun River's water quality.	• Upper reaches have significant decline values of FCB and NH_3; lower reaches have high NO_3 and NH_3; agricultural land plays a significant role. • August (flood season) has the lowest (flood season) WQI values; lower reaches higher WQI.
India	Water quality assessment using NSFWQI, OIP and multivariate techniques of Ganga River system, Uttarakhand, India [Matta et al., 2020]	Using NSFWQI and Overall index of pollution (OIP) in assessing the water quality of the Ganga River	• After the dataset was converted into equivalent unit data and numeric index values, the WQI and multivariate statistical models were shown to be valuable methods for classifying the geographical and temporal change in river water quality. • The WQI results indicate that the Ganga River water varies from the medium to good categories. • Used agricultural water, untreated wastewater, and anthropogenic activities are the main contributors to the decline in Ganga water quality
	Application of water quality index (WQI) and statistical techniques to assess water quality for drinking, irrigation, and industrial purposes of the Ghaghara River, India [Ravi et al., 2023]	Using the Weighted Arithmetic water quality index to assess the water quality of the Ghagara River	• WQI results vary between «unsuitable for drinking" to 'excellent'. Based on RSI, this river water is corrosive and unsuitable for industrial activities. • Restricting the discharge of untreated wastewater and tapping drains are needed to minimize further degradation of water quality.
	Water quality assessment of a tropical river using water quality index (WQI), multivariate statistical techniques and GIS [Shil et al., 2019]	Evaluating the water quality of the Mahanda River for drinking, agricultural, and industrial purposes using WQI	• River water quality has a poor value when close to residential areas. • Water quality cannot be used for industrial purposes unless treatment is carried out
	Assessment of underground water quality and water quality index across the Noyyal River basin of Tirupur District in South India [Krishnamoorthy et al., 2023]	Using the Underground Water Quality Index to assess the water quality of the Noyyal River	• The condition of underground water quality is greatly influenced by the Noyyal River, which is contaminated by the presence of industry near the river, mainly in the textile industry
Vietnam	Surface water quality assessment in the Bach Dang river basin, Vietnam: using water quality index and geographical information system methods [Nguyen et al., 2023]	Using Vietnam WQI to assess the Bach Dang River	• The water quality of the Bach Dang River is still relatively good; continuous monitoring is needed to maintain public safety. Agricultural and industrial water runoff contributes to a role in reducing water quality. • This paper only assesses surface water quality and requires a more advanced assessment regarding groundwater.
	Water quality assessment using water quality index: a case of the Ray River, Vietnam [Thuy et al., 2021]	Using WQI to assess Ray River water quality	• Water quality is greatly influenced by anthropogenic activities, namely agriculture (phosphate), livestock, and industrial effluents. • WQI values have high values during the dry season.
Malaysia	A study of spatial and water quality index during dry and rainy seasons at Kelantan River Basin, Peninsular Malaysia [Abdul Maulud et al., 2021]	Using the National Water Quality Standards for Malaysia (NWQS) in analyzing Kelantan River water quality	• River water quality is better in the three dry seasons (class III) than the rainy season (class 4 and 5)
	Water Quality Assessment of Tekala River, Selangor, Malaysia [Hanafiah et al., 2018]	Using the NWQS to assess the water quality of the Tekala River	• The water quality of this river is safe for recreational purposes, but further studies are recommended to use more parameters to get better assessment results.
	Assessing The River Water Quality of Sungai Masai, Johor by Using Water Quality Index [Jamal et al., 2023]	Using the NWQS to assess the water quality of the Masai River	• Most are in class three and can be used as a source of drinking water if they undergo further treatment.
	A preliminary study of water quality index in Terengganu River basin, Malaysia [Suratman et al., 2015]	Department of Environment/ NWQS is used to assess Terengganu River water quality	• The river water quality is classified as slightly polluted to clean; there is a need for continuous monitoring
	Comparison among different ASEAN water quality indices for the assessment of the spatial variation of surface water quality in the Selangor river basin, Malaysia [Wong et al., 2020]	Comparing ASEAN WQI in assessing Selangor River water quality	• MONRE WQI (Vietnam) and STORET PI (Indonesia) appear to be more rigorous compared to DOE-WQI (Malaysia) and PCD WQI; systems that assess biochemical or physicochemical (DOE and PCD) give better evaluation results. • Integration between WQIS and GIS is needed for more in-depth analysis and to provide more information

into the medium and poor categories, even bad at several sampling points from these rivers. Industrial development, massive agricultural activities, especially in Southeast Asian countries, agricultural activities, and domestic waste are some of the root causes of poor river water quality in Asia. The river sections with densely populated residential areas tend to have poorer river water quality. This is because much waste that comes from various sources such as industry, domestic, animal husbandry, and agriculture does not go through a treatment process and is directly discharged into water bodies. Proper treatment is needed to deal with the wastewater from both industrial and domestic sources. The efforts of developing countries to transform into developed countries through industrial development must proceed without forgetting the environmental impacts they cause, especially in relation to discharges into water bodies. The development of WQIs as a tool for assessing river water quality is also needed so that the WQI used can be suitable for the river to be studied. This development must also be carried out in conjunction with scientific analysis, such as fuzzy logic, to assess how the parameters in the WQI affect the final value. Using WQIs and GIS together is also considered capable of providing a more thorough and complete analysis. Therefore, a more comprehensive study needs to be carried out in order to produce a more credible assessment of river water quality. Collaboration between the community, stakeholders, and the government plays a significant role in water quality restoration efforts, which are in line with the sixth SDGs, namely clean water and sanitation.

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REFERENCES

1. Abd Wahaba, N., Kamarudina, M.K.A., Torimanb, M.E., Juahira, H., Saada, M.H.M., Ataa, F.M., Ghazalia, A., Hassana, A.R., Abdullaha, H., Mauludc, K.N. 2019. Sedimentation and water quality deterioration problems at Terengganu River Basin, Terengganu, Malaysia. Desalination Water Treat, 149, 228-241.
2. Abdul Maulud, K.N., Fitri, A., Wan Mohtar, W.H.M., Wan Mohd Jaafar, W.S., Zuhairi, N.Z., Kamarudin, M.K.A. 2021. A study of spatial and water quality index during dry and rainy seasons at Kelantan River Basin, Peninsular Malaysia. Arabian Journal of Geosciences, 14, 1-19.
3. Ahuja, S. 2021. Overview: modern water purity and quality. Handbook of Water Purity and Quality, 1-18.
4. Al-Badaii, F., Shuhaimi-Othman, M. 2014. Heavy metals and water quality assessment using multivariate statistical techniques and water quality index of the Semenyih River, Peninsular Malaysia. Iranian (Iranica) Journal of Energy & Environment, 5(2).
5. Anh, N.T., Nhan, N.T., Schmalz, B., Le Luu, T. 2023. Influences of key factors on river water quality in urban and rural areas: A review. Case Studies in Chemical and Environmental Engineering, 100424.
6. Anonna, T.A., Ahmed, Z., Alam, R., Karim, M.M., Xie, Z., Kumar, P., Zhang, F., Simal-Gandara, J. 2022. Water quality assessment for drinking and irrigation purposes in Mahananda River Basin of Bangladesh. Earth Systems and Environment, 1-12.
7. Anyadoh-Nwadike, S., Okereke, J., Odah, R., Obijekwu, O., Okorondu, S., Obasi, K. 2015. Bacteriological quality of water contaminated with faecal wastes from livestock. Science Journal of Public Health, 3(5), 29-33.
8. Barakat, A., El Baghdadi, M., Rais, J., Aghezzaf, B., Slassi, M. 2016. Assessment of spatial and seasonal water quality variation of Oum Er Rbia River (Morocco) using multivariate statistical techniques. International Soil and Water Conservation Research, 4(4), 284-292.
9. Barokah, G.R., Ariyani, F., Siregar, T.H. 2017. Comparison of STORET and pollution index method to assess the environmental pollution status: a case study from Lampung Bay, Indonesia. Squalen Bulletin of Marine and Fisheries Postharvest and Biotechnology, 12(2), 67-74.
10. Bassi, N., Kumar, M.D. 2017. Water quality index as a tool for wetland restoration. Water Policy, 19(3), 390-403.
11. Birva, D., Hemangi, D. 2018. Evaluation of Water Quality Index for Ground Water of Residential Area of Surat City, Gujarat, India. SSRG International Journal of Agriculture & Environmental Science, 5, 1-5.
12. Budihardjo, M.A., Arumdani, I.S., Puspita, A.S., Ambariyanto, A. 2022. Improving Water Conservation at Universitas Diponegoro, Indonesia. Journal of Sustainability Perspectives, 2, 277-284.
13. Chakraborti, D., Singh, S.K., Rahman, M.M., Dutta, R.N., Mukherjee, S.C., Pati, S., Kar, P.B. 2018. Groundwater arsenic contamination in the Ganga River Basin: a future health danger. International journal of environmental research and public health, 15(2), 180.

14. Chandra, D.S., Asadi, S., Raju, M. 2017. Estimation of water quality index by weighted arithmetic water quality index method: a model study. International Journal of Civil Engineering and Technology, 8(4), 1215-1222.
15. Chapman, P.J., Kay, P., Mitchell, G., Pitts, C.S. (2019). Surface water quality Water resources (pp. 99-150): Routledge.
16. Chaudhary, J.K. 2020. A comparative study of fuzzy logic and WQI for groundwater quality assessment. Procedia Computer Science, 171, 1194-1203.
17. Chidiac, S., El Najjar, P., Ouaini, N., El Rayess, Y., El Azzi, D. 2023. A comprehensive review of water quality indices (WQIs): history, models, attempts and perspectives. Reviews in Environmental Science and Bio/Technology, 22(2), 349-395.
18. Choe, K., Whittington, D., Lauria, D.T. (2019). The Economic Benefits of Surface Water Quality Improvements in Developing Countries:: A Case Study of Davao, Philippines The Economics of Water Quality (pp. 371-389): Routledge.
19. Darvishi, G., Kootenaei, F.G., Ramezani, M., Lotfi, E., Asgharnia, H. 2016. Comparative investigation of river water quality by OWQI, NSFWQI and Wilcox indexes (case study: the Talar River–Iran). Archives of Environmental Protection, 42(1), 41--48.
20. Dwivedi, A.C., Khan, S., Mayank, P. 2017. Stressors altering the size and age of Cirrhinus mrigala (Hamilton, 1822) from the Ghaghara River, India. interactions, 39, 42.
21. Fida, M., Li, P., Wang, Y., Alam, S.K., Nsabimana, A. 2023. Water contamination and human health risks in Pakistan: a review. Exposure and Health, 15(3), 619-639.
22. Gholizadeh, M.H., Melesse, A.M., Reddi, L. 2016. A comprehensive review on water quality parameters estimation using remote sensing techniques. Sensors, 16(8), 1298.
23. Ghosh, B., Devi, K.K. 2018. Coexistence of Firm Competitive Advantage and Priorities: A Study amongst the Textile Units in Tirupur. Asian Journal of Research in Business Economics and Management, 8(1), 129-139.
24. Gitau, M.W., Chen, J., Ma, Z. 2016. Water quality indices as tools for decision making and management. Water resources management, 30, 2591-2610.
25. Grönwall, J., Danert, K. 2020. Regarding groundwater and drinking water access through a human rights lens: Self-supply as a norm. Water, 12(2), 419.
26. Hadiwidodo, M., Sutrisno, E., Hartini, S., Budihardjo, M.A., Ramadan, B.S., Puspita, A.S., Rachmawati, F., Efriani, F.R. 2023. Feasibility Study for Mining Waste Materials as Sustainable Compost Raw Material Toward Enhanced Landfill Mining. Polish Journal of Environmental Studies, 32(3).
27. Hanafiah, M., Yussof, M., Hasan, M., AbdulHasan, M., Toriman, M. 2018. Water quality assessment of Tekala River, Selangor, Malaysia. Applied Ecology & Environmental Research, 16(4).
28. Hasan, H.H., Jamil, N.R., Aini, N. 2015. Water quality index and sediment loading analysis in Pelus River, Perak, Malaysia. Procedia Environmental Sciences, 30, 133-138.
29. Ho, J.Y., Afan, H.A., El-Shafie, A.H., Koting, S.B., Mohd, N.S., Jaafar, W.Z.B., Sai, H.L., Malek, M.A., Ahmed, A.N., Mohtar, W.H.M.W. 2019. Towards a time and cost effective approach to water quality index class prediction. Journal of Hydrology, 575, 148-165.
30. Hou, W., Gu, B., Lin, Q., Gu, J., Han, B.-P. 2013. Stable isotope composition of suspended particulate organic matter in twenty reservoirs from Guangdong, southern China: Implications for pelagic carbon and nitrogen cycling. Water research, 47(11), 3610-3623.
31. Ilyas, M., Ahmad, W., Khan, H., Yousaf, S., Yasir, M., Khan, A. 2019. Environmental and health impacts of industrial wastewater effluents in Pakistan: a review. Reviews on environmental health, 34(2), 171-186.
32. Ismanto, A., Hadibarata, T., Widada, S., Indrayanti, E., Ismunarti, D.H., Safinatunnajah, N., Kusumastuti, W., Dwiningsih, Y., Alkahtani, J. 2023. Groundwater contamination status in Malaysia: level of heavy metal, source, health impact, and remediation technologies. Bioprocess and Biosystems Engineering, 46(3), 467-482.
33. Jamal, N.Z.A., Rosli, M.A., Rahman, M.A.A. 2023. Assessing The River Water Quality of Sungai Masai, Johor by Using Water Quality Index (WQI). Journal of Advanced Industrial Technology and Application, 4(1), 80-86.
34. Jehan, S., Ullah, I., Khan, S., Muhammad, S., Khattak, S.A., Khan, T. 2020. Evaluation of the Swat River, Northern Pakistan, water quality using multivariate statistical techniques and water quality index (WQI) model. Environmental Science and Pollution Research, 27, 38545-38558.
35. Kachroud, M., Trolard, F., Kefi, M., Jebari, S., Bourrié, G. 2019. Water quality indices: Challenges and application limits in the literature. Water, 11(2), 361.
36. Kim, D., Wang, Z., Brugger, J., Blum, D., Wetter, M., Hong, T., Piette, M.A. 2022. Site demonstration and performance evaluation of MPC for a large chiller plant with TES for renewable energy integration and grid decarbonization. Applied Energy, 321, 119343.
37. Krishnamoorthy, N., Thirumalai, R., Sundar, M.L., Anusuya, M., Kumar, P.M., Hemalatha, E., Prasad, M.M., Munjal, N. 2023. Assessment of underground water quality and water quality index across the Noyyal River basin of Tirupur District in South India. Urban Climate, 49, 101436.

38. Leelahakriengkrai, P., Peerapornpisal, Y. 2011. Water quality and trophic status in main rivers of Thailand. Chiang Mai Journal of Science, 38(2), 280-294.
39. Liyanage, C.P., Yamada, K. 2017. Impact of population growth on the water quality of natural water bodies. Sustainability, 9(8), 1405.
40. Lukhabi, D.K., Mensah, P.K., Asare, N.K., Pulumuka-Kamanga, T., Ouma, K.O. 2023. Adapted water quality indices: limitations and potential for water quality monitoring in Africa. Water, 15(9), 1736.
41. Madhav, S., Ahamad, A., Singh, P., Mishra, P.K. 2018. A review of textile industry: Wet processing, environmental impacts, and effluent treatment methods. Environmental Quality Management, 27(3), 31-41.
42. Marselina, M., Wibowo, F., Mushfiroh, A. 2022. Water quality index assessment methods for surface water: A case study of the Citarum River in Indonesia. Heliyon, 8(7).
43. Matta, G., Nayak, A., Kumar, A., Kumar, P. 2020. Water quality assessment using NSFWQI, OIP and multivariate techniques of Ganga River system, Uttarakhand, India. Applied Water Science, 10, 1-12.
44. Miller, J.D., Hutchins, M. 2017. The impacts of urbanisation and climate change on urban flooding and urban water quality: A review of the evidence concerning the United Kingdom. Journal of Hydrology: Regional Studies, 12, 345-362.
45. Misaghi, F., Delgosha, F., Razzaghmanesh, M., Myers, B. 2017. Introducing a water quality index for assessing water for irrigation purposes: A case study of the Ghezel Ozan River. Science of the Total Environment, 589, 107-116.
46. Mishra, R.K. 2023. Fresh water availability and its global challenge. British Journal of Multidisciplinary and Advanced Studies, 4(3), 1-78.
47. Nguyen, M.H., Tran, T.A., Van, H.T., Hoang, T.H.N., Phan, P.C.M., Nguyen, C.L., Nguyen, D.T., Pham, T.H. 2023. Surface water quality assessment in the Bach Dang river basin, Vietnam: using water quality index and geographical information system methods. Environmental Research Communications, 5(7), 075015.
48. Nurjanah, P. 2018. Analisis Pengaruh Curah Hujan Terhadap Kualitas Air Parameter Mikrobiologi dan Status Mutu Air di Sungai Code, Yogyakarta.
49. Ocampo-Duque, W., Ferre-Huguet, N., Domingo, J.L., Schuhmacher, M. 2006. Assessing water quality in rivers with fuzzy inference systems: A case study. Environment International, 32(6), 733-742.
50. Parris, K. 2014. Impact of agriculture on water pollution in OECD countries: recent trends and future prospects. Water Quality Management, 33-52.
51. Penny, J., Alves, P.B., De-Silva, Y., Chen, A.S., Djordjević, S., Shrestha, S., Babel, M. 2023. Analysis of potential nature-based solutions for the Mun River Basin, Thailand. Water Science and Technology, 87(6), 1496-1514.
52. Prabha, S., Gogoi, A., Mazumder, P., Ramanathan, A., Kumar, M. 2017. Assessment of the impact of textile effluents on microbial diversity in Tirupur district, Tamil Nadu. Applied water science, 7, 2267-2277.
53. Pranaw, M.K., Tripathi, M.P., Sahu, M.R., Saxena, M.P. 2014. Pollution of Surface Water in Tirupur and its Adjacent Areas by Textile Effluents. Centre for Science and Environment, New Delhi.
54. Puspita, A.S., Budihardjo, M.A., Samadikun, B.P. 2023. Evaluating coconut fiber and fly ash composites for use in landfill retention layers. Global Nest Journal, 25(4), 1-7.
55. Qasemi, M., Darvishian, M., Nadimi, H., Gholamzadeh, M., Afsharnia, M., Farhang, M., Allahdadi, M., Darvishian, M., Zarei, A. 2023. Characteristics, water quality index and human health risk from nitrate and fluoride in Kakhk city and its rural areas, Iran. Journal of Food Composition and Analysis, 115, 104870.
56. Quiñones-Huatangari L., Ochoa T.L., Milla-Pino, M.E., Bazán C.J., Gamarra T.O., Rascón J. 2020. Water quality index using fuzzy logic Utcubamba River, Peru. Revista de Ciencias Agrícolas, 37(1), 6-18.
57. Rahayu, G.P., Sayekti, R.W., Sholichin, M. 2021. Studi penentuan sebaran kualitas air dengan metode DOE-WQI, IP, Oregon-WQI, dan Prati index di Waduk Sutami. Jurnal Teknologi dan Rekayasa Sumber Daya Air, 1(2), 786-799.
58. Ram, A., Tiwari, S., Pandey, H., Chaurasia, A.K., Singh, S., Singh, Y. 2021. Groundwater quality assessment using water quality index (WQI) under GIS framework. Applied Water Science, 11, 1-20.
59. Rana, R., Ganguly, R. 2020. Water quality indices: challenges and applications—an overview. Arabian Journal of Geosciences, 13(22), 1190.
60. Rangarajan, S., Thattai, D., Kumar, H., Satish, N., Rustagi, R. 2019. Evaluation of water quality index for River Mahananda West Bengal India. Int. J. Innov. Technol. Explor. Eng, 8, 1307-1309.
61. Ratnaningsih, D., Hadi, A., Asiah, A., Lestari, R.P., Prajanti, A. 2016. Penentuan parameter dan kurva sub indeks dalam penyusunan indeks kualitas air. Ecolab, 10(2), 70-79.
62. Ravi, N.K., Jha, P.K., Varma, K., Tripathi, P., Gautam, S.K., Ram, K., Kumar, M., Tripathi, V. 2023. Application of water quality index (WQI) and statistical techniques to assess water quality for drinking, irrigation, and industrial purposes of the Ghaghara River, India. Total Environment Research Themes, 6, 100049.
63. Reljić, M., Romić, M., Romić, D., Gilja, G., Mornar,

V., Ondrasek, G., Bubalo Kovačić, M., Zovko, M. 2023. Advanced Continuous Monitoring System—Tools for Water Resource Management and Decision Support System in Salt Affected Delta. Agriculture, 13(2), 369.

64. Sajil Kumar, P. 2017. Geostatistical modeling of fluoride enrichment and nitrate contamination in the groundwater of Lower Bhavani Basin in Tamil Nadu, India. Modeling Earth Systems and Environment, 3, 1-10.
65. Seifi, A., Dehghani, M., Singh, V.P. 2020. Uncertainty analysis of water quality index (WQI) for groundwater quality evaluation: Application of Monte-Carlo method for weight allocation. Ecological Indicators, 117, 106653.
66. Shanmugamoorthy, M., Subbaiyan, A., Elango, L., Velusamy, S. 2023. Groundwater susceptibility assessment using the GIS based DRASTIC-LU model in the Noyyal river area of South India. Urban Climate, 49, 101464.
67. Shil, S., Singh, U.K., Mehta, P. 2019. Water quality assessment of a tropical river using water quality index (WQI), multivariate statistical techniques and GIS. Applied water science, 9, 1-21.
68. Sholeh, M., Pranoto, P., Budiastuti, S., Sutarno, S. (2018). *Analysis of Citarum River pollution indicator using chemical, physical, and bacteriological methods.* Paper presented at the AIP Conference Proceedings.
69. Sim, S.F., Tai, S.E. 2018. Assessment of a physicochemical indexing method for evaluation of tropical river water quality. Journal of Chemistry, 2018, 1-12.
70. Singh, P., Singh, D.S., Shukla, U.K. 2018. Ganga: The Arterial River of India. The Indian Rivers: Scientific and Socio-economic Aspects, 75-92.
71. Sreelakshmy, M., Dhanusree, M., Thangamani, V. 2023. Application of GIS techniques to understand the geomorphometric characteristics of a tropical watershed in South India. Geology, Ecology, and Landscapes, 7(2), 161-173.
72. Suratman, S., Sailan, M., Hee, Y., Bedurus, E., Latif, M. 2015. A preliminary study of water quality index in Terengganu River basin, Malaysia. Sains Malaysiana, 44(1), 67-73.
73. Sutadian, A.D., Muttil, N., Yilmaz, A.G., Perera, B. 2018. Development of a water quality index for rivers in West Java Province, Indonesia. Ecological Indicators, 85, 966-982.
74. Thuy, P.T.T., Viet, N., Phuong, N.K.L., Lee, C.-H. 2021. Water quality assessment using water quality index: a case of the Ray River, Vietnam. TNU Journal of Science and Technology, 226(06), 38-47.
75. Tian, H., Yu, G.-A., Tong, L., Li, R., Huang, H.Q., Bridhikitti, A., Prabamroong, T. 2019. Water quality of the Mun river in Thailand—Spatiotemporal variations and potential causes. International Journal of Environmental Research and Public Health, 16(20), 3906.
76. Tiwari, A.K., Singh, A.K., Mahato, M.K. 2018. Assessment of groundwater quality of Pratapgarh district in India for suitability of drinking purpose using water quality index (WQI) and GIS technique. Sustainable Water Resources Management, 4, 601-616.
77. Trach, R., Trach, Y., Kiersnowska, A., Markiewicz, A., Lendo-Siwicka, M., Rusakov, K. 2022. A study of assessment and prediction of water quality index using fuzzy logic and ANN models. Sustainability, 14(9), 5656.
78. Uddin, M.G., Nash, S., Rahman, A., Olbert, A.I. 2023. Performance analysis of the water quality index model for predicting water state using machine learning techniques. Process Safety and Environmental Protection, 169, 808-828.
79. Unigwe, C.O., Egbueri, J.C. 2023. Drinking water quality assessment based on statistical analysis and three water quality indices (MWQI, IWQI and EWQI): a case study. Environment, Development and Sustainability, 25(1), 686-707.
80. Varol, M., Tokatlı, C. 2023. Evaluation of the water quality of a highly polluted stream with water quality indices and health risk assessment methods. Chemosphere, 311, 137096.
81. Vu, H.M., Van Pham, Q., Nguyen, L.M., Van Dau, T. (2022). Assessment of changes in the structure and distribution of mangroves caused by aquaculture activities at the Bach Dang estuary, Vietnam: Vietnam.
82. Wahyuningrum, I.F.S., Humaira, N.G., Budihardjo, M.A., Arumdani, I.S., Puspita, A.S., Annisa, A.N., Sari, A.M., Djajadikerta, H.G. 2023. Environmental sustainability disclosure in Asian countries: Bibliometric and content analysis. Journal of Cleaner Production, 137195.
83. Wang, W., Chen, Y., Wang, W., Zhu, C., Chen, Y., Liu, X., Zhang, T. 2023. Water quality and interaction between groundwater and surface water impacted by agricultural activities in an oasis-desert region. Journal of Hydrology, 617, 128937.
84. Wong, Y.J., Shimizu, Y., He, K., Nik Sulaiman, N.M. 2020. Comparison among different ASEAN water quality indices for the assessment of the spatial variation of surface water quality in the Selangor river basin, Malaysia. Environmental monitoring and assessment, 192, 1-16.
85. Wu, Z., Wang, X., Chen, Y., Cai, Y., Deng, J. 2018. Assessing river water quality using water quality index in Lake Taihu Basin, China. Science of the Total Environment, 612, 914-922.
86. Zotou, I., Tsihrintzis, V.A., Gikas, G.D. 2020. Water quality evaluation of a lacustrine water body in the Mediterranean based on different water quality index (WQI) methodologies. Journal of Environmental Science and Health, Part A, 55(5), 537-548.