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Water pollution and the assessment of water quality parameters: a review

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ABSTRACT

The entry of pollutants into the water bodies has deteriorated the quality of freshwater which led to the occurrence of water pollution. The factors of water pollution due to natural processes are climate change and natural disasters. The anthropogenic activities that affect water quality are urbanization, development of infrastructures, industrial applications, agricultural activities, and sediment runoff. The severity of water pollution is measured using physical, chemical, and biological parameters. For biological parameters, metagenomics analysis is associated with bioinformatics in detecting, identifying, and characterizing the microorganisms present in the environment. The methods carried out from the data analysis through the bioinformatics study are bacterial abundance, rarefaction curve, core microbiome, clustering analysis and diversity analysis. Turbidity, temperature, electrical conductivity (EC), and total dissolved solids (TDS) are the physical parameters whereas pH, nutrients (ammoniacal nitrogen and phosphorus), dissolved oxygen (DO), and heavy metals are the chemical parameters. A thorough and detailed study needs to be done to correlate the sources of water pollution and the water quality of freshwater. Therefore, proper treatment can be carried out to improve the water quality of the freshwater according to the class in DOE-WQI.

Keywords: Water pollution; Biological parameters; Physical parameters; Chemical parameters; Water quality

1. Introduction

In the past, water was a vital substance for the formation of civilization, but nowadays, water plays a part in determining the residential area [1]. With the increment in the human population and economic development, the main priority in sustaining human daily life is global freshwater [2]. Moreover, the global water demand had escalated by 600% over the past 100 y with an annual increment rate of 1.8% [2].

The entry of pollutants into the water bodies has led to the occurrence of water pollution. The occurrence of water pollution has disturbed the natural function and the beneficial use of the water which led to the shortage of freshwater [3]. The pollutants can be present in two forms which are biodegradable and non-biodegradable forms [4]. Biodegradable pollutants are compounds caused by the short-term impact which can be degraded by microorganisms through enzymatic activities [5] whereas non-biodegradable pollutants are compounds that persistent in the environment and cannot be degraded through biological activities [4,6].

To fulfil the needs of living organisms, specific requirements on the quality and condition of the water need to be reached and maintained. The Department of Environment (DOE) is the governmental authority in Malaysia which has the responsibility for monitoring and evaluating the water quality of the water. Two systems have been developed and applied which are the Water Quality Index (WQI) and the

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Interim National Water Quality Standards (INWQS) for the assessment of water quality [7]. WQI helps in assessing the condition and status of the water while INWQS is used to classify the beneficial uses of the water courses by referring to WQI data [7,8]. From INWQS data, the water quality of water bodies is divided into six different classes (Class I, Class IIA, Class IIB, Class III, Class IV, and Class V) in which Class I indicate the excellent condition of the water whereas Class V has the worst water condition that needs large-scale treatments.

2. Source of water pollution

Two factors that can cause the phenomenon of water pollution are natural factors and anthropogenic factors.

2.1. Natural processes

The occurrence of water pollution due to natural factors is mainly a result due to the changes in the environment throughout the year. There are two categories of water pollution due to natural processes which are climate change and natural disasters [9]. As climate change happens, there are extreme weather events such as increased water temperature and heavy rainfall which affect the chemical processes in the surface water together with the increment in the pH level [9]. During heavy rainfall, there was high gas solubility, high water viscosity and wind dynamics which led to the phenomenon of surface run-off pollution, increase in precipitation and changes in water flow [10].

For Malaysia, droughts and floods are common natural disasters which create changes in the water conditions through the dilution or concentration of dissolved substances [10]. The flow rates of water and the temperature of water influence the dissolved substances concentration and dissolved oxygen in the water. The phenomenon of droughts happens when there are low flow rates and high-water temperatures, the number of dissolved substances escalates, however, the concentration of dissolved oxygen depletes [11]. As the period of droughts increases, the temperature rates also increase which brings an enormous impact on water resources [9]. Due to this situation, the rainfall distribution is affected which increases the probability of the flooding phenomenon occurring in which the river can no longer accommodate the rainwater that enters the river [12]. The overflow of the water carries different types of contaminants such as human sewage, chemical, livestock waste and other impurities which bring detrimental impacts towards the quality of the water [12].

2.2. Anthropogenic activities

Anthropogenic factors are caused by human activities which affect and degrade the quality of water bodies due to the interference of contaminants in the ecosystem. Urbanization has become the main cause of water pollution through anthropogenic activities. Examples of urbanization are the conversion of land into croplands, wetlands, forests, pastures and grasslands for commercial, and industrial use, the development of residential areas, and transportation practices which intensify the areas of impervious surfaces [10]. High loadings of nutrients occur due to the increase of impermeability and runoff from the urbanized area along with the discharges of the effluents from municipal and industrial activities [13]. Municipal practices, land development, forestation, and deforestation are the activities which are correlated with urbanization. Many human activities and socio-economic areas generated municipal wastes either in liquid or solid forms [14]. These wastes are created on a daily basis either released from domestic dwellings, business premises, or establishments in residential areas such as schools and hospitals.

The development of infrastructures such as construction, pipelines, highways, and roads are related to land use activities that affect the water systems. Due to the transformation of the landscapes, the alteration in the water balance occurs which gives an impact on the solute mass flows and quality [15]. Additionally, the concrete and compacted surfaces have generated elevations in the storm run-offs and decreases in diffuse inflow and evapotranspiration [9]. If there is improper land use management, clear-cutting of forests and vegetation activities for urbanization can occur which led to the incident of soil erosion [10]. Once this incident happens, the hydrological regime of the river changes and disrupts due to the entry of soil which increases the water turbidity and siltation takes place at the downstream area [10].

Industrial applications also become one of the concerning issues due to the production of high amounts of effluents that pose potential hazards and drawbacks to the nearby water bodies especially mills, factories, and mining sectors. As reported by [16], industrial activities and urban uses occupy approximately 3% of the land surface including the mineral extraction and exploration areas. Manufacturing industries generate more waste, especially mining activities compared to urban and agricultural practices because these industries create a high amount of waste all over the world [15]. Solid or liquid waste, mining wastes, spills, and leaks are the sources of water contamination in industrial activities. Furthermore, accidental spills and leaks in the manufacturing product tanks and pipelines can deteriorate the water condition as the chemical and hazardous waste (benzene, toluene, and xylene) enter the nearby water resources [17]. For the mining industries, the excavation of solid waste, heavy use of water in processing the ore, seepage from tailings, waste rock impoundments, and water pollution from discharged mine effluent affect surface water and groundwater [18]. Mine-water drainage contains a high amount of sulfate, iron, and other metal concentration along with the creation of acidic conditions in the water bodies which indicated the severity of this condition [18]. Along with that, there can be the accumulation of harmful compounds in the water as a large amount of water is used in reducing the mine dust, equipment cooling, washing, and processing [9].

In agricultural activities, a large number of fertilizers and pesticides are required to produce a high number of crops. Pesticides are used in controlling pests in community gardens, agricultural areas, and other public areas [19]. Pesticides are needed for plant protection against insects, increase crop yields and allow the plant to be cultivated on the same land multiple times in a year [20]. Nevertheless, there is a drawback to the usage of pesticides in which the high solubility of pesticides enables this compound to move over a wide geographical area which can easily pollute the water bodies [9]. The excessive use of fertilizers leads to the increment of nitrogen (N) and phosphorus (P) which cause impairment in the water resources [9]. Nitrate that is present in soluble form can be mobile and simply extracted from the soil with percolating water while phosphorus can move easily with the soil under certain conditions [9]. The clearance of land to perform agricultural activities raises the issue related to the salinity in the catchment. Water salinity escalated along with acidic conditions due to the decomposition of the organic matter [21]. Furthermore, monocultural plantations such as rubber plantations, palm oil plantations, and paddy plantations have generated an abundance of nitrate in shallow aquifers [22,23].

Next, with the occurrence of sediment runoff, the capacity for the water resources to accommodate the water reduces due to the high amount of sediment entering the water resources [4]. In addition, there are also disturbances in the water ecosystem in which there is a depletion of light penetration as oxygen is unable to pass through the water due to the escalation of water turbidity [4]. Lastly, the increment in water temperature is also triggered by thermal pollution. The industries involved with this pollution are nuclear power and electric power plants, petroleum refineries, steel-melting factories, coal-fired power plants and boilers from industries [13]. The high amount of heat was discharged from these industries which converted the characteristics of the water physically, chemically, and biologically [13]. The result of this pollution is the reduction of oxygen in the water resources which disrupts the reproductive cycles, and respiratory and digestive rates of the aquatic organisms.

3. Water quality parameters

To measure the severity of water pollution, three parameters can be used which are physical, chemical, and biological parameters [24]. For the physical parameters, the examples are turbidity, temperature, colour, taste and odour, solids, electrical conductivity (EC), total suspended solids (TSS) and total dissolved solids (TDS) whereas chemical parameters are pH, nutrients (ammoniacal nitrogen, nitrate, sulfate, sulfide and phosphorus), dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), heavy metals (iron, manganese, copper, zinc), toxic organic and inorganic substances and radioactive compounds [21]. The physical and chemical parameters also known as physicochemical parameters are commonly measured together. As for biological, it involves identifying the microorganisms present in the contaminated environments and their abundance.

3.1. Biological parameters

Examples of biological parameters are bacteria, algae, viruses, and protozoa present in the water bodies [24]. Referring to [25], fecal coliform and groups of microorganisms can be used to measure the water contamination that occurs in water resources. Fecal coliform is known as the bacteria which can be found in human and animal wastes [26]. *Escherichia coli* (*E. coli*), *Streptococcus faecalis* (*S. faecalis*) and *Clostridium perfringens* (*C. perfringens*) are usually used as indicators of organisms as these bacteria are always present in fecal contaminated water [27]. With the high amount of these bacteria in the river water, there is also the presence of pathogenic organisms which can cause adverse health effects on human beings [27].

3.1.1. Metagenomics study

For the traditional approach, coliform bacterial abundance or *Escherichia coli* (*E. coli*) is used as a proxy to monitor the pollution that happens in the water bodies [28]. Nonetheless, a few difficulties emerge such as the occurrence of false-negative results and longer time for culturing process and the correlation between faecal indicators and waterborne pathogens [29]. The false-positive and false-negative results are produced when the viable bacteria are in a stress state [30]. Besides, the culturing process needs 24–48 h for the targeted microbes to grow to the level that facilitates enumeration [29]. The presence of pathogens cannot be measured precisely as the fecal indicators do not occur at the frequencies that correlate with the pathogens [29]. [31] mentioned that traditional culture-based methods are unable to detect all the microorganisms present in polluted areas due to their limitations. In laboratory growth, less than 1% of the bacterial species from the environmental sample can be cultured [32] and several populations of *E. coli* have been environmentally adapted in aquatic environments [28]. Therefore, *E. coli* seems to be unreliable to be used as the biological indicator in water quality studies.

The development of metagenomics analysis is one of the approaches that can be used to facilitate water quality studies. Metagenomics analysis is the study of the collective genome of microorganisms [33] that helps with the direct genetic analysis of the genome of microorganisms that are present in the environmental sample [34,35]. This analysis is classified as a culture-independent approach and only requires the DNA of the tested microorganisms [36]. From metagenomics analysis, information on the taxonomic level, phylogenetic information, and function gene diversity can be gathered [29]. At the diversity level, the richness and evenness of the microbes can be assessed while microbial composition provides information on the taxa and gene's presence in the contaminated water [28,30]. There are functional differences in communities that can be detected through metagenomics studies across land use, eutrophication, and the gradients of pollution [37]. Through metagenomics studies, new insights into the metabolic versatility of microorganisms in aquatic sediments, their roles in biogeochemical cycles and adaptation to a different environment can be identified [37].

The association between metagenomics analysis and bioinformatics allow the identification, detection and characterization of the microorganisms that are present in the environment. Bioinformatics is described as the software to seize and interpret biological data [38]. To perform metagenomics analysis, the microbial target (viruses, bacteria, or protozoa) must be identified as different sample preparation measures and extraction protocols are needed to maximize the yield of DNA from the microorganisms [29]. Metagenomics analysis is a single-genome sequencing [29] which involves only targeted genes such as 16S rRNA or 18S rRNA [39]. From the analysis, the genetic information on the potentially novel biocatalysts or enzymes, the genomic linkage between functions, the phylogeny for uncultured organisms, the evolutionary profiles of the community function and structure, novel hypotheses of microbial function can be obtained [34]. Additionally, the metatranscriptomics or metaproteomic approaches can be complemented with metagenomics analysis to describe the expressed gene [34].

Various methods can be obtained from the data analysis through the bioinformatics study such as bacterial abundance, rarefaction curve, core microbiome, clustering analysis and diversity analysis. The visualization of bacterial abundance is the common method for identifying the changes in the taxa among the study groups [40]. Thus, the information on the quality of the water and the source of the contamination can be recognized [41]. The rarefaction curve compares the species richness of the microorganisms due to the differences in the number and density of the taxa in area, volume, or sampling efforts [42]. Budka et al. [43] mentioned that the part of the curve associated with the rarefaction standardizes the biodiversity measures to a fixed smaller variety of samples for the reason of evaluation amongst datasets with uneven sample units. From the rarefaction curve data, the diverse bacterial communities can be compared as the graph represents the relationship between the number of OTUs (species richness) and the number of sequences [44]. As the rarefaction curves are approaching the plateaus, it shows that there are highly diverse microbial communities present in each sample [44].

For the core microbiome, it is the set of taxa which have a higher relative abundance that is above the given abundance threshold [26]. The association between two or more microbial communities in each environmental sample indicates that the shared taxa have high ecologically and functionally crucial microbial associates with the environments [45,46]. A few factors influenced the core microbiome which is the proportion of the samples that share a set of microbial taxa, the relative abundances of the shared taxa across the samples, or the combination of both conditions [45]. As for the clustering analysis, this method aims to recognize the group of clusters that have more similarity to each other than other clusters [47]. Through this process, the objects are divided into groups with high heterogeneity and the similarity between the objects in the same group is evaluated [48]. A hierarchical cluster is the clustering method which combines objects that are similar and combine the most similar clusters [48,49]. The distance between the objects is calculated and identification of the cluster needs to be done for the clustering process. Objects with high similarities are grouped in one cluster while objects with low similarities are in different clusters [48]. To simplify, the homogeneity with a similar cluster is high but the homogeneity between the cluster is low.

Two forms of clustering can be used which are the dendrogram form and the heatmap form. The dendrogram is in form of a tree-like structure that is broken into different levels to show different clusters of data sets [47] while the heatmap is the comparison between taxonomic composition in the area and the correlation between them [50]. The colour in the heatmap box determines the correlation between the taxonomic composition either positive or negative referring to the distance measure methods [51]. The hierarchical agglomerative clustering methods are different depending on the calculation of the similarity between the two clusters either by using a single link, complete link, group average, or Ward's method [49]. For the distance method, three different methods can be used to calculate the distance, which is Euclidean, Pearson and Minhowski. Euclidean distance is the most common distance method used in clustering [48,49].

Alpha diversity and beta diversity is the example of diversity analysis in metagenomics. Alpha diversity is defined as the analysis which provides a comprehensive indicator of the species richness and uniformity in the community ecology [52] and can be described as the structure of an ecological community concerning its richness, evenness, or both [53]. Species richness helps in measuring the number of individuals per unit area or per sample and the specific content of the area. According to [54], species richness indices are higher for species-rich communities whereas equitability indices depict the relative abundance of different species of a community. The evenness index is high when the number of individuals of different species is equal in the community, however, the evenness index is low when only one or few species are in terms of the number of individuals dominating the community [54]. The examples of diversity metrics in alpha diversity are Observed richness, Chao1, Simpson and Shannon [55]. The observed richness and Chao1 reflect the OTUs number in a sample and values that positively correlate with the species richness of the sample while Simpson and Shannon reflect the uniformity of the abundance of the different species in a sample [52]. Beta diversity functions in evaluating the bacterial diversity and species complexity differences that occur between samples [56]. There are a few distance metrics in beta diversity such as UniFrac (Unweighted UniFrac Distance and Weighted UniFrac Distance), Bray-Curtis Index, Jensen-Shannon Divergence and Jaccard Index [55]. Moreover, four statistical methods can be used which are ANOSIM, PERMANOVA, Mantel and PERMDISP [57]. ANOSIM method is used to determine whether the distances between groups are greater than within groups while PERMANOVA method is used to determine whether the distance differs between groups [57].

The advantages of using metagenomics analysis are the comprehensive understanding of the microbial communities in the water resources along with the recognition of the changes in microbial communities during the monitoring phase [31]. The number of raw reads available is increasing while the associated costs are rapidly declining through the sequencing systems [29]. Finally, massive data sets that reveal the genes and functional diversities in a nontargeted manner can be collected due to the availability of bioinformatic tools to facilitate the analysis of the metagenomic data [29].

3.2. Physicochemical parameters

3.2.1. Dissolved oxygen

Dissolved oxygen (DO) portrays the self-purification capacity of the water body [58]. DO is correlated with the water body as it gives both direct and indirect information regarding the bacterial activity, photosynthesis activity, nutrient availability, and stratification (Patil, 2012). During the progress of summer, the amount of dissolved oxygen depletes due to the increment of temperature and microbial activity [59]. According to [59], the solubility of the dissolved oxygen is also influenced by the thermal regime. The dissolved oxygen becomes less soluble when the temperature of the water increases.

As mentioned by [60], DO is also being influenced by the water flow and season in a year. When seasonal changes occur, there will also shift in the water flow of the river water. In Malaysia, there are two seasons which are the wet season and the dry season. During the wet season, there will be heavy rainfall which causes a high amount of rainwater to enter the river water. Due to this condition, the river flow becomes faster which also increases the turbulence of the water. Thus, the amount of dissolved oxygen in the water becomes higher [61]. [62] also emphasized that with the elevation of the river flow, there will be a reduction of the organic matter as dilution impacts happen. As this condition takes place in the river water, the amount of dissolved oxygen will increase. Moreover, there is also a correlation between dissolved oxygen and biological oxygen demand (BOD) [63]. As the DO in the water declines, the BOD of the water increases. This is because dissolved oxygen is consumed by the aerobic microorganism to carry out the oxidation and degradation process. The lower amount of DO in the water indicates that the amount of pollutants in the river water is higher [64].

3.2.2. pH

pH value helps in determining the acidity and the alkalinity of the water in the river [65]. The water is claimed as acidic when the pH of the water is in the range of 1 to 6 whereas, for the alkaline condition, the pH of the water is within 8–14. The neutral condition occurs when the pH of the water is 7. Geiger and Mesner [66] clarified that the water becomes acidic when the concentration of the hydrogen ions (H^-) in the water is higher. Contrary to the alkaline condition, the water contains a high amount of hydroxyl ions (OH^-) which increases the pH of the water. According to WHO and NDWQS, the permissible and safe limit for water to be consumed by humans is between 6.5 to 8.5. On the other hand, when rainfall occurs in the area, the pH of the water drops and becomes acidic. The possibility of this circumstance might be due to the leaching of acid and metals which concurrently enter the water [67].

The pH of the water is also being influenced by the solubility and availability of the plant nutrients, pesticides and herbicides performances and the decomposition of inorganic and organic matter [68]. Chemical, petrochemical, and mining industries are the industrial activities that affect the pH of the water. These industries discharge their effluent into the river which contains multiple chemicals that deteriorate the quality of the water. Improper treatment of the effluents enables a high amount of effluents to enter the river and drop the pH of the water [69]. The pH of the soil also correlates with the pH of the water. This is due to the capability of the soil in holding and supplying nutrients or the anion and cation exchange (ion exchange) in the water [68].

3.2.3. Temperature

The water temperature has the ability to control the rate of all chemical reactions and affect the growth of aquatic organisms [70]. Ma et al. [58] stated that temperature can influence the oxygen content in the water. When there is the discharge of wastewater at a high temperature into the river, certain reactions in the water body might speed up. Thus, the solubility of the oxygen declined whereas the odor in the river water amplified due to the occurrence of the anaerobic condition. Examples of industries that cause the occurrence of thermal pollution in river water are thermoelectric power plants and coal-fired power plants [71]. To generate electricity, these plants produce steam through the boiling processes. Then, these power plants are relying on cool river temperatures to maintain optimal thermal efficiency [72]. From these processes, the steam is converted into liquid and later electricity is generated. The development of solar photovoltaic power systems could also lead to an increment in the water temperature [73]. The conductive heating from the panels caused the temperature in the air space to increase. This is because only 13%–20% of the solar radiation is converted into electricity whereas the remaining is converted into heat which causes a drastic increment in the panel temperature. Due to this condition, the temperature of the water increases as the temperature of the air space between the PV panels and the water surface increases [73].

3.2.4. Turbidity

Turbidity can be understood as the amount of particulate matter that is suspended in the water [69] which come from different sources such as clay, silt, finely divided organic and inorganic matter, soluble colored organic compound, plankton, and algae [63]. As the value of the turbidity increases, the penetration of the light into the river water decreases which causes sunlight to reach the aquatic plants to carry out photosynthesis [74]. There are also occurrences of temperature and dissolved oxygen stratification when the turbidity of the water increases [75]. The incident of soil runoff can affect the turbidity of the water. Due to the mismanagement of land use, there will be a high possibility of runoff and erosion to happen [63]. This is because, during construction, there is an increase in runoff rates which causes the erosion of the cliff and increases the turbidity of the water [76]. With a high amount of substances entering the river water, the river becomes shallower which bring negative effects on the benthic ecosystem and organism in the area around the river [63].

The industries that become the contributor to the turbidity concentration in the river water higher are mining industries and agro-based industries. As for mining industries, there is the runoff of mine spoils and coal washing which affects the number of suspended contaminants in the river water [77]. These compounds contain hazardous elements such as heavy metals (Pb, Cu and Zn) which can easily precipitate or adsorbed onto the suspended materials or organic matter that eventually move to the bottom sediments via sedimentation. When there is a high amount of mine spoils and coal washing moves into the river water, the amount of sediment becomes higher, and the water becomes more turbid [77]. For agro-based industries, the topsoil is washed from the soil during the tillage and cultivation activities [78]. This condition becomes worse when rainfall is happening in which a high amount of the topsoil in the crops area is carried by the water into the river [10]. Therefore, there is an increment in the water cloudiness and siltation taking place in the downstream area which causes disruption of the hydrological system in the river [78].

3.2.5. Salinity and conductivity

Salinity is understood as the salts which are soluble in water [79] while conductivity acts as the indicator to show the total salt content in the water bodies [58]. As the conductivity of the water is higher, the amount of salt in the river water is higher. Salts are consisted of positively and negatively charged ions which dissociate when the salts are dissolved in the water. There are two types of salinity which are primary salinity and secondary salinity. Primary salinity occurs due to natural phenomena such as weathering of the rocks, winds and rains that deposited salts for thousands of years [79]. Secondary salinity happens due to the accumulation of excess salt from the primary sources which alters the natural hydrological patterns [80].

Extensive land clearance and inappropriate land use practices are the main factors that exacerbate the occurrence of secondary salinity [79]. Patil [70] stated that pH value, total hardness, total solid, total dissolved solids (TDS) and chemical oxygen demand (COD) are the factors that influence the EC in water bodies. The inorganic dissolved solids (calcium, chloride, aluminium cations, nitrate, sulfate, iron, magnesium, sodium) and organic compounds (oil, alcohol, phenol, sugar) and temperature are other factors that affect the EC of the water. According to [64], the temperature of the water becomes higher when the conductivity of the water increases. When the temperature of the water increases, the mobility of the ions in the water increases but the viscosity decreases. Along with that, the number of ions also increases due to the dissociation of the molecules [81].

3.2.6. Nutrient analysis

3.2.6.1. Nitrogen and phosphorus

Nitrogen (N) and phosphorus (P) act as the dominant rate-limiting nutrients in most natural systems and are important components that help in determining the quality of the water [82]. Both nutrients create direct and indirect impacts on plant growth, oxygen concentration, water clarity and sedimentation rate. As for plant growth, these nutrients are used as agrochemical fertilizers in agricultural activities [82]. The most common issue related to N and P is the occurrence of eutrophication. This phenomenon occurs due to the overabundance of nutrients which triggers the growth of algae in the water bodies at a fast rate [83]. A toxic environment is created along with the presence of foul-smelling phytoplankton that deteriorates the water quality of the water bodies.

Various human activities created the occurrence of nitrogen pollution such as industrial, municipal, residential, and agricultural activities [84]. The combustion of fossil fuels causes the atmospheric deposition of nitrogen to the surface water while for industrial, municipal and residential, the sewage effluents discharged into the water contain a high number of nitrogenous compounds. Agricultural activities affect the concentration of nitrogen in the river water due to the usage of fertilizers, nitrogen-fixing crops, and soil erosion due to deforestation and grassland reclamation [84]. Ammoniacal nitrogen (NH_3N) is a crucial parameter in determining the water quality of the river. Measuring the presence of NH_3N in the river water implies the status of the nutrients in the river water [85]. The NH_3N can be in two different forms which are molecular ammonia (NH_3) or ammonium ions (NH_4^+) depending on their solubility in the water [86]. NH_3N is pH and temperature-dependent [87]. When the temperature and pH value of the water increase, the amount of NH_3N also increases. The escalation of pH level causes the ionized ammonia to escalate which increases the toxicity in the water [86]. Due to the presence of surfeit ammonia in the water, the water becomes acidic as there is the release of hydrogen ions during the nitrification process [88]. The presence of nitrite ions helps in the formation of nitric acid which causes the pH of the water to lower and become acidic [88].

Nitrate is an odorless, colorless and tasteless compound that consists of nitrogen and oxygen [89]. In aerobic conditions, nitrate can exist through the nitrification processes in which ammonia is converted into nitrite by the ammonia-oxidizing bacteria. Next, the nitrite is transformed into nitrate by nitrite-oxidizing bacteria [90]. Nitrate is the main component of fertilizers that are used in agricultural activities as it is necessary for plant growth and plant uptake [88]. Nitrate acts as the source of nutrients for algae and other plants to form plant protein which later can be used by animals to form animal protein [58].

For the growth of plants, phosphorus is required during the photosynthesis process in which sunlight is converted into usable energy [91]. The anthropogenic activities that raise the amount of phosphorus in the river water are the usage of chemical fertilizer in agricultural activities, sewage discharge and landfill for domestic waste [92]. Additionally, the occurrence of soil runoff, erosion and leaching from agricultural activities are also sources of phosphorus. According to [93], households and industries are the primary sources of phosphorus pollution including phosphorus-based detergents. For the natural process, phosphorus is present in the soil due to the weathering of residual minerals [91].

Orthophosphate (PO_4^{3-}) ions are the common phosphate that is found in groundwater due to their thermodynamic stability compared to other P^{5+} ions that are commonly found in natural water [94]. Orthophosphate can be found naturally in rivers, streams and lakes that recharge aquifers. The aquifer substances come from the erosion of rocks, the recycling of animal waste and the tissue of plants and animals [95]. Agricultural activities are the human activities that contribute to the escalation of orthophosphate in the surface water. Through the usage of chemical phosphorus fertilizers, manure and composted materials, the concentration of the orthophosphate in the water face increments which led to the occurrence of phosphorus pollution [94].

3.2.7. Heavy metals

Heavy metals are referred to as metallic elements that have a relatively high density and atomic weight compared to water [96]. These elements also include metalloids that can induce toxicity at low exposure levels [96]. This is due to the presence of interconnection between heaviness and toxicity in heavy metals. Heavy metals are divided into two groups which are essential and non-essential heavy metals. Examples of essential heavy metals are manganese (Mn), iron (Fe), copper (Cu) and zinc (Zn) while the non-essential heavy metals, examples are cadmium (Cd), lead (Pb), and mercury (Hg) [97]. The natural processes that raise the number of heavy metals is the weathering process, volcanic eruption, metal corrosion, metal evaporation from the soil and water, soil erosion and sediment re-suspension [98]. Metals are released from the rocks through the weathering process which is known as a part of the natural biogeochemical cycle [99]. These metals are cycled through a variety of environmental compartments by both biotic and abiotic processes. Finally, these heavy metals eventually find their fate in the oceans as sediments [99].

Anthropogenic activities are the main sources of heavy metal pollution in water bodies. The primary industries are mining and smelting operations, foundries, metal-based industries, and the occurrence of the leachate of metals in different sources [100]. The source of the leachate is the landfills, waste dumps, excretion, livestock and chicken manure, runoffs, automobiles, and road works [100]. The smelting activities cause the release of arsenic, copper, and zinc while automobile exhaust releases lead into the environment. Other examples are the release of arsenic from insecticides and the burning of fossil fuels that release nickel, vanadium, mercury, selenium, and tin [98]. Compared to natural processes, anthropogenic activities contribute more to heavy metal pollution due to urbanization and industrial activities for economic development. Heavy metals can accumulate in the sediment in the river contaminating the river water. The organic matter in the sediment is capable of adsorbing and trapping heavy metals from the environment which later accumulate the heavy metals [101]. As the abundance of heavy metals is higher in the river water, the ecological health of the aquatic organisms is affected. This is due to the ability of heavy metals in contaminating the food chain [97]. Heavy metals are persistent in the environment and can cause bioaccumulation and biomagnification in food chains which later disrupt the ecosystem and affect the health of living organisms [97].

4. Conclusion

To sum up, the occurrence of water pollution has limited the source of freshwater for human beings. Climate change and natural disasters are the natural factors in the occurrence of water pollution whereas urbanization has become the main contributor to anthropogenic factors. The biological, physical and chemical parameters need to be measured annually to ensure the water quality of freshwater is at an acceptable level according to WQI and INWQS. Through metagenomics analysis and bioinformatics, the microorganisms present in freshwater can be identified and characterized. The visualization of bacterial abundance, rarefaction curve, core microbiome, clustering analysis and diversity analysis are helpful methods in analyzing the data through bioinformatics. Dissolved oxygen (DO), pH, temperature, turbidity, salinity and conductivity, nutrients (nitrogen and phosphorus), and heavy metals are the physicochemical parameters which can be used to measure the quality of the water. From the value of physicochemical parameters, the water quality of the freshwater can be classified according to DOE-WQI. All the parameters need to be in an appropriate value which enables it to be consumed by the human being. A thorough and detailed study needs to be done to correlate the sources of water pollution and the water quality of freshwater. Therefore, proper treatment can be carried out to improve the water quality of the freshwater and prevent the occurrence of water pollution.

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References

[1] Z. Kılıç, The importance of water and conscious use of water, Int. J. Hydrol., 4 (2002) 239–241.
[2] A. Boretti, L. Rosa, Reassessing the projections of the World Water Development Report, npj Clean Water, 2 (2019), doi: 10.1038/s41545-019-0039-9.
[3] L. Schweitzer, J. Noblet, Chapter 3.6 – Water Contamination and Pollution, Green Chemistry: An Inclusive Approach, Elsevier Inc., Amsterdam, The Netherlands, 2018, pp. 261–290.
[4] F.N. Chaudhry, M.F. Malik, Factors affecting water pollution: a review, J. Ecosyst. Ecography, 7 (2017) 1–3.
[5] J.H. Song, R.J. Murphy, R. Narayan, G.B.H. Davies, Biodegradable and compostable alternatives to conventional plastics, Phil. Trans. R. Soc. B, 364 (2009) 2127–2139.
[6] M.E. Emetere, O. Aimudo, Pollution from non-biodegradable electrical wastes: risk analysis of lead (Pb) contaminants, IOP Conf. Ser.: Earth Environ. Sci., 563 (2020), doi: 10.1088/1755-1315/563/1/012003.
[7] Y.F. Huang, S.Y. Ang, K.M. Lee, T.S. Lee, Quality of Water Resources in Malaysia, T.S. Lee. Ed., Research and Practices in Water Quality, InTechOpen, 2015. Available at: https://doi.org/10.5772/58969.
[8] A.B. Idris, A.A. Mamun, M. Amin, M. Soom, W. Noor, W. Azmin, Review of water quality standards and practices in Malaysia, Pollut. Res., 22 (2003) 145–155.
[9] N. Akhtar, M.I. Syakir Ishak, S.A. Bhawani, K. Umar, Various natural and anthropogenic factors responsible for water quality degradation: a review, Water (Switzerland), 13 (2021) 2660, doi: 10.3390/w13192660.
[10] N. Khatri, S. Tyagi, Influences of natural and anthropogenic factors on surface and groundwater quality in rural and urban areas, Front. Life Sci., 8 (2015) 23–39.
[11] L. Prathumratana, S. Sthiannopkao, K.W. Kim, The relationship of climatic and hydrological parameters to surface water quality in the lower Mekong River, Environ. Int., 34 (2008) 860–866.
[12] Q. Sholihah, W. Kuncoro, S. Wahyuni, S. Puni Suwandi, E. Dwi Feditasari, The analysis of the causes of flood disasters and their impacts in the perspective of environmental law, IOP Conf. Ser.: Earth Environ. Sci., 437 (2020), doi: 10.1088/1755-1315/437/1/012056.
[13] A. Gupta, M.R. Singh, Water Pollution-Sources, Effects and Control, Centre for Biodiversity, Department of Botany, Nagaland University, 2016.
[14] H.I. Abdel-Shafy, M.S.M. Mansour, Solid waste issue: sources, composition, disposal, recycling, and valorization, Egypt. J. Pet., 27 (2018) 1275–1290.
[15] N.M. Burri, R. Weatherl, C. Moeck, M. Schirmer, A review of threats to groundwater quality in the anthropocene, Sci. Total Environ., 684 (2019) 136–154.
[16] J. Mateo-Sagasta, S.M. Zadeh, H. Turral, J. Burke, Water Pollution From Agriculture: A Global Review, Executive

Summary, Published by the Food and Agriculture Organization of the United Nations Rome, 2017 and the International Water Management Institute on Behalf of the Water Land and Ecosystems Research Program Colombo, 2017.
[17] M.S. Holt, Sources of chemical contaminants and routes into the freshwater environment, Food Chem. Toxicol., 38 (200) 21–27.
[18] M.K. Jain, A. Das, Impact of mine waste leachates on aquatic environment: a review, Curr. Pollut. Rep., 3 (2017) 31–37.
[19] M.A. Hassaan, A. El Nemr, Pesticides pollution: classifications, human health impact, extraction and treatment techniques, Egypt. J. Aquat. Res., 46 (2020) 207–220.
[20] K.H. Kim, E. Kabir, S.A. Jahan, Exposure to pesticides and the associated human health effects, Sci. Total Environ., 575 (2017) 525–535.
[21] M. Camara, N.R. Jamil, A.F. Bin Abdullah, (2019). Impact of land uses on water quality in Malaysia: a review, Ecol. Processes, 8 (2019), doi: 10.1186/s13717-019-0164-x.
[22] T.E. Garba, R.L. Richard, N.E.A. Thani, M.A.A. Majid, M. Lawal, N.A. Yelwa, Geological effects on water quality: a review of issues and challenges in Malaysia, Sains Malaysiana, 50 (2021) 1857–1870.
[23] A. Kurunc, S. Ersahin, N.K. Sonmez, H. Kaman, I. Uz, B.Y. Uz, G.E. Aslan, Seasonal changes of spatial variation of some groundwater quality variables in a large irrigated coastal Mediterranean region of Turkey, Sci. Total Environ., 554 (2016) 53–63.
[24] N.H. Omer, Water Quality Parameters, K. Summers, Ed., Water Quality-Science, Assessments and Policy, InTechOpen, 2019, pp. 1–34.
[25] J.P. dan Saliran, Study on the River Water Quality Trends and Indexes in Peninsular Malaysia, Water Resources Publication No. 21, 2009.
[26] A. Tiwari, A.M. Hokajärvi, J.S. Domingo, M. Elk, B. Jayaprakash, H. Ryu, S. Siponen, A. Vepsäläinen, A. Kauppinen, O. Puurunen, A. Artimo, N. Perkola, T. Huttula, I.T. Miettinen, T. Pitkänen, Bacterial diversity and predicted enzymatic function in a multipurpose surface water system – from wastewater effluent discharges to drinking water production, Environ. Microbiomes, 16 (2021), doi: 10.1186/s40793-021-00379-w.
[27] C. Ramesh, S. Jain, Which Physical, Chemical and Biological Parameters of Water Determine Its Quality?, Solid Liquid Resource Management in Smart Cities View Project, 2017. Available at: https://doi.org/10.13140/RG.2.2.29178.90569.
[28] J.F. Curran, L. Zaggia, G.M. Quero, Metagenomic characterization of microbial pollutants and antibiotic- and metal-resistance genes in sediments from the canals of Venice, Water (Switzerland), 14 (2022), doi: 10.3390/w14071161.
[29] P.-Y. Hong, D. Mantilla-Calderon, C. Wang, Metagenomics as a tool to monitor reclaimed-water quality, Appl. Environ. Microbiol., 86 (2020), doi: 10.1128/AEM.00724-20.
[30] T.V. van Rossum, M.A. Peabody, M.I. Uyaguari-Diaz, K.I. Cronin, M. Chan, J.R. Slobodan, M.J. Nesbitt, C.A. Suttle, W.W.L. Hsiao, P.K.C. Tang, N.A. Prystajecky, F.S.L. Brinkman, Year-long metagenomic study of river microbiomes across land use and water quality, Front. Microbiol., 6 (2015), doi: 10.3389/fmicb.2015.01405.
[31] K.D. Brumfield, N.A. Hasan, M.B. Leddy, J.A. Cotruvo, S.M. Rashed, R.R. Colwell, A. Huq, A comparative analysis of drinking water employing metagenomics, PLoS One, 15 (2020), doi: 10.1371/journal.pone.0231210.
[32] C. Staley, M.J. Sadowsky, Application of metagenomics to assess microbial communities in water and other environmental matrices, J. Mar. Biol. Assoc. U. K., 96 (2016) 121–129.
[33] T. Hidayat, M.A.A. Samat, M.A. bin. Elias, T. Hadibarata, Metagenomic analysis of 16S rRNA sequences from selected rivers in Johor Malaysia, J. Appl. Sci., 12 (2012) 354–361.
[34] T. Thomas, J. Gilbert, F. Meyer, Metagenomics – a guide from sampling to data analysis, Microb. Inf. Exp., 2 (2012), doi: 10.1186/2042-5783-2-3.
[35] B. Usharani, Metagenomics study of the microbes in constructed wetland system treating sewage, Int. Lett. Nat. Sci., 74 (2019) 26–48.
[36] N.S.M. Rizal, H.M. Neoh, R. Ramli, P.R.A.L.K. Periyasamy, A. Hanafiah, M.N.A. Samat, T.L. Tan, K.K. Wong, S. Nathan, S. Chieng, S.H. Saw, B.Y. Khor, Advantages and limitations of 16S rRNA next-generation sequencing for pathogen identification in the diagnostic microbiology laboratory: perspectives from a middle-income country, Diagnostics, 10 (2020), doi: 10.3390/diagnostics10100816.
[37] L. Biessy, J.K. Pearman, S. Waters, M.J. Vandergoes, S.A. Wood, Metagenomic insights to the functional potential of sediment microbial communities in freshwater lakes, Metabarcoding Metagenomics, 6 (2022) 59–74.
[38] A. Bayat, Science, medicine, and the future-bioinformatics, BMJ-Br. Med. J., 324 (2002) 1018–1022.
[39] J. Lluch, F. Servant, S. Païssé, C. Valle, S. Valière, C. Kuchly, G. Vilchez, C. Donnadieu, M. Courtney, R. Burcelin, J. Amar, O. Bouchez, B. Lelouvier, The characterization of novel tissue microbiota using an optimized 16S metagenomic sequencing pipeline, PLoS One, 10 (2015), doi: 10.1371/journal.pone.0142334.
[40] J.T. Barlow, S.R. Bogatyrev, R.F. Ismagilov, A quantitative sequencing framework for absolute abundance measurements of mucosal and lumenal microbial communities, Nat. Commun., 11 (2020), doi: 10.1038/s41467-020-16224-6.
[41] M.O. Alotaibi, A.E. Mohammed, K.H. Eltom, Metagenomic analysis of bacterial communities of Wadi Namar Lake, Riyadh, Saudi Arabia, Saudi J. Biol. Sci., 29 (2022) 3749–3758.
[42] R.W. Plotnikoff, Rarefaction of Benthic Macoinvertebrate Taxonomic Lists: Impact of Changes to the Taxon List and on B-IBI Scores, Snohomish County Public Works, Surface Water Management Division, Everett, WA, 2020.
[43] A. Budka, A. Łacka, K. Szoszkiewicz, The use of rarefaction and extrapolation as methods of estimating the effects of river eutrophication on macrophyte diversity, Biodivers. Conserv., 28 (2019) 385–400.
[44] S. Xu, J. Yao, M. Ainiwaer, Y. Hong, Y. Zhang, Analysis of bacterial community structure of activated sludge from wastewater treatment plants in winter, BioMed Res. Int., 2018 (2018), doi: 10.1155/2018/8278970.
[45] A.T. Neu, E.E. Allen, K. Roy, Defining and Quantifying the Core Microbiome: Challenges and Prospects, Proceedings of the National Academy of Sciences of the United States of America, 2021. Available at: https://doi.org/10.1073/pnas.2104429118/-/DCSupplemental
[46] A. Shade, J. Handelsman, Beyond the Venn diagram: the hunt for a core microbiome, Environ. Microbiol., 14 (2012) 4–12.
[47] C. Tokatli, E. Kose, A. Cicek, O. Emiroglu, Y. Bastatli, Use of cluster analysis to evaluate surface water quality: an application from downstream of Meric river basin (Edirne, Turkey), Int. J. Adv. Sci. Eng. Technol., 3 (2015) 33–35.
[48] B. Warsito, S. Sumiyati, H. Yasin, H. Faridah, Evaluation of river water quality by using hierarchical clustering analysis, IOP Conf. Ser.: Earth Environ. Sci., 896 (2021), doi: 10.1088/1755-1315/896/1/012072.
[49] N. Abu-Khalaf, S. Khayat, B. Natsheh, Multivariate data analysis to identify the groundwater pollution sources in Tulkarm area/Palestine, Sci. Technol., 3 (2013) 99–104.
[50] R. das Kangabam, Y. Silla, G. Goswami, M. Barooah, Bacterial operational taxonomic units replace the interactive roles of other operational taxonomic units under strong environmental changes, Curr. Genomics, 21 (2020) 512–524.
[51] Z. Ren, F. Wang, X. Qu, J.J. Elser, Y. Liu, L. Chu, Taxonomic and functional differences between microbial communities in Qinghai Lake and its input streams, Front. Microbiol., 8 (2017) 2319, doi: 10.3389/fmicb.2017.02319.
[52] X. Tao, F. Guo, Q. Zhou, F. Hu, H. Xiang, G.G. Xiao, D. Shang, Bacterial community mapping of the intestinal tract in acute pancreatitis rats based on 16S rDNA gene sequence analysis, RSC Adv., 9 (2019) 5025–5036.
[53] A.D. Willis, Rarefaction, alpha diversity, and statistics, Front. Microbiol., 10 (2019), doi: 10.3389/fmicb.2019.02407.
[54] A.K. Thukral, A review on measurement of Alpha diversity in biology, Agric. Res. J., 54 (2017) 1, doi: 10.5958/2395-146x.2017.00001.1.

[55] F. Ju, T. Zhang,16S rRNA gene high-throughput sequencing data mining of microbial diversity and interactions, Appl. Microbiol. Biotechnol., 99 (2015) 4119–4129.

[56] S. Zlatković, O. Medić, D. Predojević, I. Nikolić, G. Subakov-Simić, A. Onjia, T. Berić, S. Stanković, Spatio-temporal dynamics in physico-chemical properties, phytoplankton and bacterial diversity as an indication of the Bovan Reservoir water quality, Water (Switzerland), 14 (2022), doi: 10.3390/w14030391.

[57] I. Anderson, B. Held, A. Lapidus, M. Nolan, S. Lucas, H. Tice, N.C. Kyrpides, Genome sequence of the homoacetogenic bacterium *Holophaga foetida* type strain (TMBS4 T), Stand. Genomic Sci., 6 (2012) 174–184.

[58] J. Ma, S. Wu, N.V.R. Shekhar, S. Biswas, A.K. Sahu, Determination of physicochemical parameters and levels of heavy metals in food wastewater with environmental effects, Bioinorg. Chem. Appl., 2020 (2020) 8886093, doi: 10.1155/2020/8886093.

[59] A. Rajwa-Kuligiewicz, R.J. Bialik, P.M. Rowiński, Dissolved oxygen and water temperature dynamics in lowland rivers over various timescales, J. Hydrol. Hydromech., 63 (2015) 353–363.

[60] S.J. Kulkarni, A review on research and studies on dissolved oxygen and its affecting parameters, Int. J. Res. Rev., 3 (2016) 18–22.

[61] R. Girardi, A. Pinheiro, E. Torres, V. Kaufmann, L.H.P. Garbossa, Evolution of the concentration of physical-chemical species in the watercourse after intense precipitation events obtained by high-frequency monitoring, RBRH, 21 (2016) 653–665.

[62] H. Allafta, C. Opp, Spatio-temporal variability and pollution sources identification of the surface sediments of Shatt Al-Arab River, Southern Iraq, Sci. Rep., 10 (2020), doi: 10.1038/s41598-020-63893-w.

[63] N. Yaakub, M.N.A. Raoff, M.N. Haris, A.A.A. Halim, M.K.A. Kamarudin, Water quality index assessment around industrial area in Kuantan, Pahang, J. Fundam. Appl. Sci., 9 (2017) 731–749.

[64] F. Al-Badaii, M. Shuhaimi-Othman, M.B. Gasim, Water quality assessment of the Semenyih river, Selangor, Malaysia, J. Chem., (2013), doi: 10.1155/2013/871056.

[65] N. Rahmanian, S.H.B. Ali, M. Homayoonfard, N.J. Ali, M. Rehan, Y. Sadef, A.S. Nizami, Analysis of physiochemical parameters to evaluate the drinking water quality in the state of Perak, Malaysia, J. Chem., 2015 (2015), doi: 10.1155/2015/716125.

[66] J. Geiger, N. Mesner, Utah Stream Team, 2000.

[67] C.K. Yap, M.W. Chee, S. Shamarina, F.B. Edward, W. Chew, S.G. Tan, Assessment of surface water quality in the Malaysian Coastal Waters by using multivariate analyses (Penilaian Kualiti Air Permukaan di Perairan Pantai Malaysia Menggunakan Analisis Multivariat), Sains Malaysiana, 2011.

[68] A. McCauley, C. Jones, J. Jacobsen, Soil pH and Organic Matter, Nutrient Management Module, 8 (2009) 1–12.

[69] S.U.K. Ab Wahab, S.H. Shaibullah, M.A. Abu Samah, M.S. Mohd Aris, An assessment of surface water quality and heavy metals involving the rare earth elements in Sungai Tunggak and Sungai Balok, Int. J. Appl. Chem., 12 (2016) 146–151.

[70] P.N. Patil, Physico-chemical parameters for testing of water-a review Int. J. Environ. Sci., 3 (2012) 1194–1207.

[71] M.A. Rosen, C.A. Bulucea, N.E. Mastorakis, C.A. Bulucea, A.C. Jeles, C.C. Brindusa, Evaluating the thermal pollution caused by wastewaters discharged from a chain of coal-fired power plants along a river, Sustainability (Switzerland), 7 (2015) 5920–5943.

[72] A. Miara, C.J. Vörösmarty, J.E. Macknick, V.C. Tidwell, B. Fekete, F. Corsi, R. Newmark, Thermal pollution impacts on rivers and power supply in the Mississippi River watershed, Environ. Res. Lett., 13 (2018), doi: 10.1088/1748-9326/aaac85.

[73] P. Yang, L.H. Chua, K.N. Irvine, M.T. Nguyen, E. Low, Impacts of a floating photovoltaic system on temperature and water quality in a shallow tropical reservoir, Limnology, 23 (2022) 441–454.

[74] R.J. Davies-Colley, D.G. Smith, Turbidity suspended sediment, and water clarity: a review, JAWRA J. Am. Water Resour. Assoc., 37 (2001) 1085–1101.

[75] T.A. Mohammed A, Assessment of physico-chemical water quality of Bira Dam, Bati Wereda, Amhara Region, Ethiopia, J. Aquacult. Res. Dev., 5 (2014), doi: 10.4172/2155-9546.1000267.

[76] S. Suratman, M.I.M. Sailan, Y.Y. Hee, E.A. Bedurus, M.T. Latif, A preliminary study of water quality index in Terengganu River Basin, Malaysia (Kajian Awal Indeks Kualiti Air di Lembangan Sungai Terengganu, Malaysia), Sains Malaysiana, 44 (2015).

[77] C.A. Marove, R. Sotozono, P. Tangviroon, C.B. Tabelin, T. Igarashi, Assessment of soil, sediment and water contaminations around open-pit coal mines in Moatize, Tete province, Mozambique, Environ. Adv/. 8 (2022) 100215, doi: 10.1016/j.envadv.2022.100215.

[78] H. Zia, N.R. Harris, G.V. Merrett, M. Rivers, N. Coles, The impact of agricultural activities on water quality: a case for collaborative catchment-scale management using integrated wireless sensor networks, Comput. Electron. Agric., 96 (2013) 126–138.

[79] A. Velmurugan, P. Swarnam, T. Subramani, B. Meena, M.J. Kaledhonkar, Water Demand and Salinity, M.H.D.A. Farahani, V. Vatanpour, A.H. Taheri, Eds., Desalination-Challenges and Opportunities, InTechOpen, 2020.

[80] W.D. Williams, Environmental threats to salt lakes and the likely status of inland saline ecosystems in 2025, Environ. Conserv., 29 (2002) 154–167.

[81] I.A. Sukamari, B. Kwaji, J. Alheri, I.O.E. Abia, Application of Water Quality Index to Assess the Potability of Some Domestic Water Supply Sources in Mubi North, Nigeria, 2020. Available at: www.ijert.org

[82] M.S. Guignard, A.R. Leitch, C. Acquisti, C. Eizaguirre, J.J. Elser, D.O. Hessen, P.D. Jeyasingh, M. Neiman, A.E. Richardson, P.S. Soltis, D.E. Soltis, C.J. Stevens, M. Trimmer, L.J. Weider, G. Woodward, I.J. Leitch, Impacts of nitrogen and phosphorus: from genomes to natural ecosystems and agriculture, Front. Ecol. Evol., 5 (2017), doi: 10.3389/fevo.2017.00070.

[83] E. Doster, R. Zitomer, M.F. Chislock, Eutrophication: Causes, Consequences, and Controls in Aquatic Ecosystems, Effects of a *Saccharomyces cerevisiae* Fermentation Product on Liver Abscesses, Fecal Microbiome, and Resistome in Feedlot Cattle Raised Without Antibiotics View Project MEGARes: An Antimicrobial Resistance Database for High Throughput Sequencing View Project, 2013. Available at: https://www.researchgate.net/publication/285683019

[84] Q.S. Wang, D.B. Sun, W.P. Hao, Y.Z. Li, X.R. Mei, Y.Q. Zhang, Human activities and nitrogen in waters, Acta Ecol. Sin., 32 (2012) 174–179.

[85] A. Saat, Z. Hamzah, Evaluation of heavy metal contamination levels of Balok river sediments in Pahang, Malaysia based on geoaccumulation index and supported with enrichment factor, Malays. J. Anal. Sci., (2015). Available at: https://www.researchgate.net/publication/281232829

[86] A. Rezagama, M. Hibbaan, M. Arief Budihardjo, Ammonia-nitrogen (NH_3–N) and ammonium-nitrogen (NH_4^+–N) equilibrium on the process of removing nitrogen by using tubular plastic media, J. Mater. Environ. Sci., 8 (2017) 4915–4922.

[87] L. Zhou, Investigations of Ammonia Nitrogen in Aquaculture: The Methodology, Concentrations, Removal, and Pond Fertilization, A Dissertation Submitted to the Graduate Faculty of Auburn University, 2015.

[88] P. Kumar, S.H. Lai, J.K. Wong, N.S. Mohd, M.R. Kamal, H.A. Afan, A.N. Ahmed, M. Sherif, A. Sefelnasr, A. El-Shafie, Review of nitrogen compounds prediction in water bodies using artificial neural networks and other models, Sustainability (Switzerland), 12 (2020) 4359, doi: 10.3390/su12114359.

[89] B. Orarm, Water Research Center – Nitrate Nitrite Nitrogen in Surfacewater and Drinking Water, Water Research Center, 2014. Available at: https://www.water-research.net/index.php/nitrate%0Ahttps://water-research.net/index.php/nitrate

[90] S.W. How, S.Y. Lim, P.B. Lim, A.M. Aris, G.C. Ngoh, T.P. Curtis, A.S.M. Chua, Low-dissolved-oxygen nitrification in tropical sewage: an investigation on potential, performance and functional microbial community, Water Sci. Technol., 77 (2018) 2274–2283.

[91] G.L. Mullins, Phosphorus, Agriculture & The Environment, 2019.
[92] A.L. Singh, A.K. Tripathi, A. Kumar, V.K. Singh, Nitrate and phosphate contamination in ground water of Varanasi, Uttar Pradesh, India, J. Ind. Res. Technol., 2 (2012) 26–32.
[93] F. Bouamra, N. Drouiche, D.S. Ahmed, H. Lounici, Treatment of water loaded with orthophosphate by electrocoagulation, Procedia Eng., 33 (2012) 155–162.
[94] J.L. Domagalski, H. Johnson, Phosphorus and Groundwater: Establishing Links Between Agricultural Use and Transport to Streams, US Geological Survey Fact Sheet 3004, 2012.
[95] R. Kent, T.D. Johnson, M.R. Rosen, Status and trends of orthophosphate concentrations in groundwater used for public supply in California, Environ. Monit. Assess., 192 (2020), doi: 10.1007/s10661-020-08504-x.
[96] P.B. Tchounwou, C.G. Yedjou, A.K. Patlolla, D.J. Sutton, Heavy metal toxicity and the environment, Exp. Suppl., 101 (2012) 133–164.
[97] H. Ali, E. Khan, I. Ilahi, Environmental chemistry and ecotoxicology of hazardous heavy metals: environmental persistence, toxicity, and bioaccumulation, J. Chem., 2019 (2019) 6730305, doi: 10.1155/2019/6730305.
[98] V. Masindi, K.L. Muedi, Environmental Contamination by Heavy Metals, H. El-Din M. Saleh, R.F. Aglan, Eds., Heavy Metals, InTechOpen, 2018. Available at: https://doi.org/10.5772/intechopen.76082
[99] R.G. Garrett, Natural sources of metals to the environment, Hum. Ecol. Risk Assess.: Int. J. (HERA), 6 (2000) 945–963.
[100] J. Briffa, E. Sinagra, R. Blundell, Heavy metal pollution in the environment and their toxicological effects on humans, Heliyon, 6 (2020), doi: 10.1016/j.heliyon.2020.e04691.
[101] Z. Huang, C. Liu, X. Zhao, J. Dong, B. Zheng, Risk assessment of heavy metals in the surface sediment at the drinking water source of the Xiangjiang River in South China, Environ. Sci. Eur., 32 (2020), doi: 10.1186/s12302-020-00305-w.