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Case Report

Influences of key factors on river water quality in urban and rural areas: A review

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ABSTRACT

Water quality in rivers is deteriorating in urban and rural areas due to natural and anthropogenic factors. Understanding how changes and factors affect river water quality is crucial for managing water quality in river basins. This review focuses on analyzing key factors affecting water quality, and the temporal and spatial variations of water quality in rivers flowing in rural and urban areas. Natural processes such as weathering of rocks, evapotranspiration, atmospheric deposition, climate change, and natural disasters cause changes in the quality of river water. Anthropogenic factors could stem from industrial effluents, domestic activities, and agricultural activities such as the application of fertilizers, manures, pesticides, animal husbandry activities, irrigation practices, deforestation, and aquaculture. The seasonal variations in river water quality are discussed, and land use or cover could affect water quality parameters in a negative or positive way. In addition to traditional contaminants such as biodegradable organic matter, heavy metals, and pathogens, emerging and persistent pollutants such as organochlorine pesticides (OCPs), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), perfluoroalkyl and polyfluoroalkyl substances (PFASs), and phamaceutic active compounds (PhACs) has been found in many rivers, which could pose a threat to human and animal health. The comparison of key factors and parameters in urban and rural areas is also clarified, which provides authorities and policymakers with a deep understanding and supports decision-making in sustainable water management.

1. Introduction

In the context of urbanization, emerging environmental problems could have impacts on all aspects of daily life. Water pollution is a common issue in many parts of the world [1]. Since surface water is one of the main sources of water supply for the population, maintaining surface water quality is crucial for daily use in every household. River water sources could be influenced by natural factors and human activities [2]. Land use patterns could have a positive or negative impact on physicochemical water quality parameters. Land clearing, livestock waste, and farming activities can release sediment, nutrients, organic matter, heavy metals, and pathogens through runoff or irrigation [3,4]. Population growth and rapid urbanization have put more pressure on ecosystems as well as the aquatic environment. Industrial activities have been promoted to meet the needs of population growth, which can release wastewater and emissions into the environment [5,6]. Pollutants from wastewater or emissions could result in deteriorating river water quality. Climate conditions (temperature and precipitation) vary according to locations or seasons, which leads to spatio-temporal variations in river water quality [7,8]. In addition, extreme weather events such as droughts and floods affect the discharge or dilution capacity of streams, and the amount of substances reaching rivers [9,10]. Catchment conditions and transport processes could affect the delivery of pollutants to surface water. In particular, runoff formation depends on its topographic setting and the intensity of rainfall, which could introduce these pollutants to water bodies. Waterbody conditions characterized by stream flow and water exchange also have an impact on water quality [2]. Landscape characteristics were found to significantly affect

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water quality in catchments, and three key processes can include the presence of pollution sources, the mobilization of constituents from these sources, and their delivery to surface water. The pollution sources can be present in the catchment or external sources. Mobilization of constituents could occur in the presence of low-energy processes such as desorption and mineralization, high-energy processes such as erosion and landslides, and some instream processes (e.g., organic matter decay, or nutrient cycling). These processes help these constituents detach from sources, while delivery is the movement of constituents from sources to surface water through surface, subsurface flows, or drainage systems [11] (see Fig. 1).

Traditional pollutants such as organic matter, heavy metals, and pathogens can stem from domestic or industrial waste and wastewater. These substances can be released through direct discharge, runoff, or irrigation [12]. Notably, recent studies have found the occurrence of emerging pollutants (EPs) in the water environment thanks to the advancement of detection technologies. EPs can be classified into the prominent classes of pharmaceuticals and personal care products (PPCPs), plasticizers, surfactants, fire retardants, nanomaterials, and pesticides [13]. For instance, the levels of pharmaceuticals, personal care products, and steroid hormones were detected due to the release of treated wastewater effluents in rivers [14,15]. Some emerging and persistent organic pollutants such as polycyclic aromatic hydrocarbons (PAHs), organochlorine pesticides (OCPs), polychlorinated biphenyls (PCBs), and perfluoroalkyl and polyfluoroalkyl substances (PFASs) were also found in river water, and the discharge of waste or wastewater from industrial and agricultural activities in river basins was the main source of these pollutants [16–18]. The potential negative effect of EPs on ecosystems has been confirmed in previous studies. Endocrine-disrupting chemicals (EDCs), which are EP classes, include PCBs, bisphenol A, pharmaceutical products, pesticides, phthalates, polybrominated compounds, alkylphenol ethoxylates, and alkylphenols. EDCs can affect the endocrine systems of living organisms and stimulate or inhibit hormone production and metabolism [19–21]. In addition, the accumulation of OCPs and other pesticides was associated with an increased risk of human cancer, diabetes, genotoxicity, and mental and psychomotor development [22,23]. However, the monitoring programs of river water mainly focus on traditional contaminants because there is a lack of published health guidelines, and existing facilities for detecting and treating emerging pollutants (EPs) [24]. The current challenges are related to the limitations of detection and treatment systems [25], so identifying factors and transport processes is important for preventing these substances from entering river water.

Urban areas have some characteristics, such as high-density residential areas, rapid growth of population, production activities in industrial zones, and a high percentage of impervious areas. The results from the previous studies found that these characteristics have negative impacts on the variations in river water quality through different pathways [8,26–28]. Rural areas are often characterized by low density residential areas, a high percentage of forest land or vegetation cover, and the predominant presence of agricultural activities. These factors have negative or positive influences on river water [29–31]. However, most of the research has focused on the investigation of some factors or selected parameters. It is necessary to provide an overview of key factors affecting river water and their differences between urban and rural rivers.

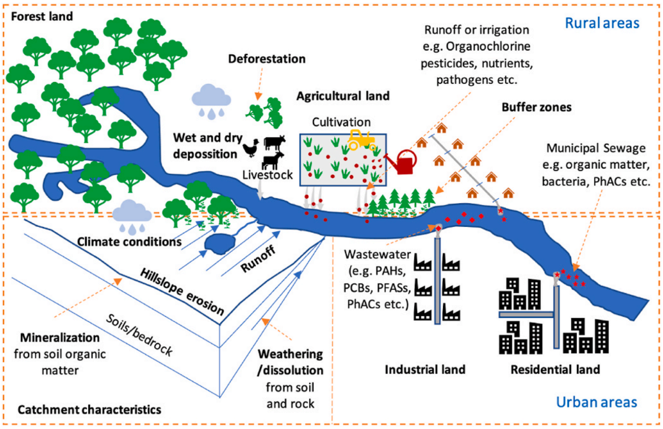

Fig. 1. Factors and pollution sources affecting river water quality.

The common approach to assessing water quality is to compare with the levels of the guideline standards or a single factor assessment. The standard for surface water quality is often used for comparing the analytical results of each river water quality parameter. This approach is convenient and easy to do, but it provides conservative evaluation results [32]. The water quality index (WQI) has been used to convert a lot of water quality data into single values that illustrate and classify water quality in rivers [33–35]. However, this method can only assess the status of river water quality, the sources or factors affecting can not be identified. In recent years, statistical methods such as correlation analysis (Pearson or Spearman), factor analysis (FA), principal component analysis (PCA), and cluster analysis (CA) have been employed for assessing, interpreting water quality datasets, and identifying pollution sources or factors [36,37]. While CA can categorize the monitoring sites based on the differences or similarities of parameters, PCA/FA can be applied to determine the most meaningful parameters in principal components, which support the identification of potential pollution sources [7,8,38]. In recent years, machine learning algorithms such as artificial neural network (ANN), support vector machine (SVM), decision tree (DT), naive Bayes, k-nearest neighbor (KNN), random forest (RF), and extreme gradient boosting (XGBoost) have been applied for analyzing complex water quality datasets to acquire information from possible patterns [39]. Machine learning has been applied for recognizing the most significant paramters and idenfying the main pollution sources in the case studies [40,41]. Therefore, it is necessary for discussing these application in assessing the variations, identifying key factors or pollution sources to river water.

In previous studies, key factors affecting river water quality have been identified, such as land use or land cover [26,29,42], urbanization [6,43,44], catchment characteristics [31,45], climate conditions, and atmospheric deposition [10,17,46]. However, there is no study on the overview analysis of key factors affecting river water quality and the differences in pollution sources or factors between urban and rural rivers. What key factors are affecting river water quality in urban and rural areas, and are there any differences in key factors and parameters in the variations in river water quality? Therefore, this review focuses on analyzing the influences of key factors and parameters on the water quality of urban and rural rivers through the current methods of water quality assessment. In addition, the occurrences and origins of emerging and persistent pollutants in rivers are also discussed in this study. Understanding how changes and key factors affect river water quality is crucial for managing water quality and controlling pollutants in river basins.

2. Significant problems of water quality in river basin

2.1. The occurrence of emerging and persistent organic pollutants in rivers

The Stockholm Convention published a list of persistent organic pollutants, including pesticides (aldrin, dieldrin, endrin, DDT, chlordane, heptachlor, mirex, and toxaphene), industrial chemicals (PCBs and hexachlorobenzene), and unintended manufacturing by-products (PAHs, dioxins, and furans). The $\sum$OCPs concentrations were found to range from 2 ng/L to 245 ng/L and 12–154 ng/L in the Bramaputra and Hooghly rivers in India, respectively [17]. However, lower levels of $\sum$OCPs were detected in rivers in Jiuxi Valley, China, with concentrations of 4.07 ng/L– 30.1 ng/L [30]. Similarly, the OCP levels ranged from 0.45 to 6.98 ng/L in the Volturno River, Southern Italy [47]. The past usage in agricultural areas and atmospheric deposition were the main sources of OCPs in these case studies. In addition, the occurrence of PCBs was found with a $\sum$19 PCBs level of 39–161 ng/L in the Bramaputra River and 57–233 ng/L in the Hooghly River, India [17]. Another study in the Volturno River, Italy found the presence of PCBs at levels of 2.28–10 ng/L. Atmospheric deposition and industrial activities (electronic wastes, port activities, combusted coal, and industrial wastes) were linked to releasing PCBs into the Bramaputra and Hooghly rivers [17,47]. In case of PAHs, both natural sources such as forest fires and volcanic eruptions and human activities such as the incomplete combustion of organic matter can produce them [48]. For instance, the levels of PAHs were detected in Diep rivers, South Africa, at levels of 0–72.38 μ g/L, and pyrogenic sources (e.g., the combustion of fossil fuel or coal, waste incinerators) and petrogenic sources (crude oil and petroleum products) can release the concentrations of PAHs in river water [16]. In contrast, very low concentrations of PAHs were found in the Euphrates River, Iraq, with levels of 646–992 ng/L, and the pollution of these compounds originated mainly from petroleum product combustion [48]. The main sources of emerging pollutants are often linked to anthropogenic activities such as domestic, industrial, and agricultural activities. The detection of perfluorooctanesulfonate (PFOS) and perfluorooctanoate (PFOA) in river water was confirmed at levels of 1.2–4.4 ng/L and 10–42 ng/L in Japan [49], and the levels of FPASs were 1.3–15.9 ng/L in the Ganges River, India [50]. The higher levels of PFOS and PFOA were found in river water in Spain, with concentrations of 1.1–11,120 ng/L and 4.2–130 ng/L, respectively [18]. Industrial and municipal waste, and atmospheric deposition may be important sources contributing to the concentrations of PFASs. The study in four Spanish Rivers found the presence of PhAC concentrations. Llobregat and Ebro rivers were the most polluted in PhACs with corresponding total concentrations of 13.022 μ g/L and 12.028 μ g/L. The figures for Guadalquivir and Júcar were lower, with levels of 1.702 μ g/L and 0.759 μ g/L, respectively. The population and livestock were found to be linked to the concentrations of PhACs [51].

Due to their toxicity, high environmental persistence, widespread emissions, and bioaccumulation, EPs and POPs have the potential to harm ecosystems and human beings. For example, organochlorine pesticides (OCPs), which are chlorinated hydrocarbon derivatives, are widely used in both the chemical and agricultural sectors. High lipophilicity, bioaccumulation, and lengthy half-lives of these pesticides raise the risk of contamination of air, water, and soil even after extensive use [52]. In addition, Expose to these substances has major consequences, including a number of chronic illnesses that cause disorders and sickness (cancer, diabetes, obesity, cardiovascular disease). Many aquatic species are most affected in terms of reproduction, development, and behavior [53]. Although emerging and persistent organic pollutants were found in river basins, there are no standards or monitoring programs for controlling these substances in many countries. Therefore, understanding key factors affecting and pollution sources helps prevent these chemicals from reaching river water.

2.2. *The concentration of traditional pollutants in rivers*

2.2.1. *Physical characteristics in river water*

The dissolved oxygen (DO) levels in river water depend on various factors such as turbulence, temperature, salinity, and altitude. The DO concentration of 4 mg/L or more was found to be suitable for aquatic ecosystems [31,54]. The low level of DO could be due to the high concentration of organic contaminants from discharging untreated wastewater in urban areas in Galing River, Malaysia (2.10–4.02 mg/L) [27]. Additionally, the low levels of DO often occur in the dry season due to climate effects [55]. With the higher temperatures in the summer season, microbial activity is enhanced to degrade organic matter in river water. As a result, microorganisms will consume more oxygen, which leads to a decline in DO concentration [8]. In contrast, High levels of DO were found in other rivers, such as the Himalayan watershed (4.7–10.38 mg/L) [31], the Maotiao River Basin, China (7.2–8.1 mg/L) [29], the Shuangji River, China (7.57–8.85 mg/L) [56], Setikhola Watershed, Nepal (4.7–10.38 mg/L) [31], and the Siriri River Basin, Brazil (5.21–7.27 mg/L) [7]. The high concentrations of DO were explained by the factor of basin characteristics such as high elevation regions, steeper slope, and cooler temperature that result in higher turbulence [31]. In addition, the characteristics of buffer zone and less effects from urban areas were also confirmed the important determinants contributing to the high levels of DO in some rivers [7,31]. The conductivity of river water acts as a measure of anions' availability, including alkali, chlorides, sulfides, and carbonate compounds. As the water temperature increases, conductivity tends to rise. Input water (runoff) exposed to more soil surface washes more ions, leading to a higher level of conductivity [31]. In addition, natural erosion and sediment transport processes lead total suspended solids (TSS) to accumulate in river water; a waterbody with higher TSS levels may be contaminated by either natural or human activities [55]. TSS levels are often detected at higher levels in rainy seasons because of the occurrence of runoff during rain events [57]. For instance, the TSS levels were 3.9–139 mg/L in Pucang River, Indonesia [58]. In the dry season, domestic and industrial wastewater could be the major cause for the elevated levels of TSS. In another case study in Burío River, Costa Rica, TSS levels ranged from 129 to 392 mg/L [8]. High levels of TSS can affect the performance in bacteriological removal and the increase in chemical consumption in drinking water treatment plants [59].

2.2.2. *Nutrients and organic pollution*

Nutrients and organic matter originate from natural and human activities. However, anthropogenic activities such as wastewater discharge from urban areas and intensive farming are the main sources that could cause organic pollution in the surface water [60]. The high levels of biological oxygen demand (BOD_5) were detected in different river basins. Particularly, the levels of BOD_5, total nitrogen (TN), and total phosphorus (TP) were 2.0–9.0, 0.95–8.47, 0.01–0.3 mg/L in the Maotiao River Basin, China, respectively. The findings concluded that water quality was poor in the summer drought season, and improved in the rainy season thanks to runoff dilution [29]. Another case study in the Geum River in South Korea confirmed that the eutrophic state occurred in downstream areas during the summer season due to the high level of nutrients. The concentrations of TP, TN, BOD_5 and chemical oxygen demand (COD) were detected at 18.4–85.5 mg/L and 1.48–3.87 mg/L, 0.76–7, and 3–18 mg/L, respectively. Intensive agricultural and built-up areas were determined to be the main sources of nutrients and organic pollution, especially in downstream areas [55]. In Galing River, Malaysia, the high average levels of COD (29.6 mg/L), TP (2.63 mg/L), total inorganic nitrogen (4.12 mg/L) and low DO average concentration (3.04 mg/L) were found in river water due to untreated or partially treated sewage [27]. Moreover, the study estimated that about 2.5 million people would be affected by organic pollution in 2050. Untreated wastewater from urban areas and livestock farming were found to be the main sources of releasing organic pollutants into rivers around the world [12].

2.2.3. *Heavy metal pollution*

Heavy metals may be released into the aquatic environment as a result of human activities such as the discharge of wastewater from factories, agriculture, and settlement. In addition, heavy metals from natural sources (leaching and weathering) could enter the environment, but these sources are often less important [54,61]. Untreated industrial wastewater and household sewage are the main contributors to heavy metal pollution. Wastewater from industries such as metal industries, paints, pigment, varnishes, pulp and paper, tannery, distillery, rubber, thermal power plants, steel plants, and mining industries could introduce heavy metals to water bodies, including zinc (Zn), arsenic (As), copper (Cu), lead (Pb), cadmium (Cd), mercury (Hg), nickel (Ni), and chromium (Cr) [62]. Table 1 shows the concentrations of most heavy metals present in river water, but the levels were sometimes above the guideline values [29,63–65]. For instance, the study in Aji-Chay River, Iran, detected high levels of As, Cr, As, and other heavy metals that could be the result of the weathering of volcanic formations, and industrial discharges. The content of As, Cr, and Pb were 0.0008–0.046 mg/L, 0.005–0.175 mg/L, and 0.021–0.075 mg/L, which exceed the guideline values of WHO [64]. The high metal concentrations can be traced back to wastewater discharged by mining activities. Drainage water and wastewater from mining regions caused a dramatic increase in heavy metal levels in the Voghji River basin in Armenia. As a result, river water was sharply worsening with the elevated concentrations of heavy metals such as, Cu, Cd, and Pb [65]. These substances can leach into surface water or groundwater, be absorbed by plants, and form semi-permanent bonds with soil constituents like clay or organic matter that later have an impact on human health. After entering waterbodies, heavy metals can be harmful to aquatic organisms, and accumulate in the sediment [65]. Although the levels of heavy metals are increasing in river water due to anthropogenic activities, but the levels of some heavy metals are above the limits of WHO in many case studies as shown Table 1.

2.2.4. *Microbial pollution*

Pathogens, including bacteria, viruses, or parasites, may originate in humans and animals. Microbial hazards can be introduced into water bodies from human feces, agricultural activities, wildlife, and from using water for recreational activities [2]. Pathogens may enter rivers from different sources, but identifying their pathways and origins is difficult. They could originate from point sources (sanitary sewer flows and wastewater treatment plant effluents) or non-point sources (livestock and agricultural activities) [66]. In general, pathogenic organisms exist in all ecosystems, but microbiological contamination with fecal bacteria from anthropogenic activities is considered a crucial problem in rivers. *Escherichia coli* (E. coli) and fecal coliforms (FCs) are monitored in standards, and these parameters are considered indicators of fecal pollution [2]. For instance, the study conducted in the main river of Ecuador detected very high levels of E. coli and total coliform with a range of 5 x 10^3–2.5 x 10^4 CFU/100 ml and 2.13 x 10^4–6.38 x 10^4 MPN/100ml. This is due to the discharge of untreated waste and wastewater from dense urban areas. Geographical locations and ambient temperatures may contribute to the growth of bacteria in surface waterways [67]. Coliform bateria occurred at a lower level of 0.014–920 MPN/100ml in Pucang River, Indonesia, this is due to domestic wastewater from residential areas, industrial and agricultural activities [58]. These figure are above the guideline values of WHO, which could pose a threat to human health through drinking water without proper treatment. E. coli pathotypes are responsible for numerous illnesses among the population in developing nations. Consumption of contaminated food and water has been linked to the spread of certain E. coli pathotypes [67].

3. The factors affecting river water quality

3.1. *Some common approaches to assessing surface water quality*

The common approach to assessing water quality is to compare with the levels of the guideline standards or a single factor assessment. The standard for surface water quality is often used for comparing the analytical results of each river water quality parameter. This approach is easy to do and convenient, but it provides conservative evaluation results [32]. The water quality index (WQI) can be used to convert a lot of water quality data into single values that illustrate and classify water quality in rivers. This method can assess the pollution levels of different sections of urban and rural rivers [33–35]. In recent years, statistical multivariate analysis methods such as correlation analysis (Pearson or Spearman), Multivariable linear regression, factor analysis (FA), PCA, and CA have been employed for the assessment of variations and the

Table 1
The pollution levels of some parameters in river water.

Parameters	Concentration (mg/L)	WHO (mg/L)	References
TSS	3.9–139	50	[58]
	129–392		[8]
DO	7.2–8.1	4–6	[29]
	4.7–10.38		[31]
	7.57–8.85		[56]
	4.59–5.98; 3.95–6.24; 2.10–4.02		[27]
	5.21–7.27		[7]
BOD$_5$	2.0–9.0	4	[29]
	∼ 0.76 – 7		[55]
	2.3–27.1		[58]
	0.9–172.0		[8]
Total N	0.95–8.47	–	[29]
	1.48–3.87		[55]
	1.45–2.76		[7]
Total P	0.01–0.3	–	[29]
	0.0184–0.0855		[55]
	0.1–0.38		[56]
	0.042–1.781		[8]
	0.03–0.12		[7]
COD	∼3–18	10	[55]
	8.83–32.08		[56]
	5.75–17.5; 13.5–31.8; 7.50–54.0		[27]
Fe	0.0069–1.87	0.3	[63]
	0.038–0.076		[65]
As	0.00022–0.00238	0.01	[29]
	0.0016–0.0030		[56]
	0.0008–0.046		[64]
	0.000616–0.00459		[65]
Cr	0–0.00978	0.05	[29]
	0.010–0.020		[56]
	0.0054–0.012		[63]
	0.005–0.175		[64]
	0.000297–0.00103		[65]
Cu	0.0008–0.00487	2.0	[29]
	0.03–0.07		[56]
	0.005–0.0323		[63]
	0.005–0.058		[64]
	0.00128–0.0825		[65]
Hg	0.11 x 10^{-3} – 0.18 x 10^{-3}	0.006	[56]
Pb	0.07 x 10^{-3} – 0.24 x 10^{-3}	0.01	[29]
	0.021–0.075		[64]
	0.039 x 10^{-3} – 0.522 x 10^{-3}		[65]
Σ 11 OCPs	2x10^{-6} - 245x10^{-6}; 12x 10^{-6} - 154x 10^{-6}	–	[17]
Σ 13 OCPs	4.07 x 10^{-6} – 30.1 x 10^{-6}		[30]
Σ 16 OCPs	0.45 x 10^{-6} - 6.98 x 10^{-6}		[47]
PCBs	39x 10^{-6} - 161 x 10^{-6}	–	[17]
	2.28 x 10^{-6} – 10 x 10^{-6}		[47]
PAHs	0–72.38 x 10^{-3}	–	[16]
Σ 16 PAHs	464 x 10^{-6} - 992 x 10^{-6}		[48]
PFOA	10 x10^{-6} – 42 x10^{-6}	–	[49]
	4.2 x10^{-6} – 130 x10^{-6}	–	[18]
PFOS	1.2 x10^{-6} – 4.4 x10^{-6}		[49]
	1.1 x10^{-6} – 11.12 x10^{-3}		[18]
FPASs	1.3 x10^{-6} –15.9 x10^{-6}		[50]
Σ 76 PhACs	13.022 x 10^{-3}		[51][a]
	12.028 x 10^{-3}		[51][b]
	1.702 x 10^{-3}		[51][c]
	0.759 x 10^{-3}		[51][d]
Σ 9 PhACs	ND - 2.64 x 10^{-3}		[68]
Σ 40 PhACs	0.17–19.1 x 10^{-3}		[69]
Coliform (MPN/100ml)	0.014–920	0	[58]
	2.13 x 10^4–6.38 x 10^4		[67]
E.Coli CFU/100ml	5 x 10^3–2.5 x 10^4	0	[67]

ND: None detection; PhACs: pharmaceutically active compounds.
[7] Siriri River basin – Brazil [8]; Burío River – Costa Rica [16]; Diep River – South Africa [17]; Brahmaputra and Hooghly rivers – India [18]; Llobregat River – Spain [27]; Kuantan, Belat, and Galing rivers – Malaysia [29]; Maotiao River Basin – China [30]; Rivers in Jiuxi Valley, China [31]; Setikhola watershed – Nepal [47]; Volturno River – Southern Italy [48]; Euphrates River – Iraq [49];

Rivers – Osaka – Japan [50]; Ganges River – India [55]; Geum River – Korea [56]; Shuangji River – China [58]; Pucang river – Indonesia [64]; Aji-Chay River – Iran [65]; Voghji River – Armenia [63]; Four rivers in Mokopan – Limpopo Province – South Africa [67] 12 main rivers – Ecuador [51];[a] Llobregat River – Spain [51];[b] Ebro River – Spain [51];[c] Guadalquivir River – Spain [51];[d] Júcar River – Spain [68]; Yamuna River – India [69]; Pearl River – China.

interpretation of water quality datasets [36,37]. Moreover, machine learning (ML) algorithms such as artificial neural network (ANN), support vector machine (SVM), decision tree (DT), naive Bayes, k-nearest neighbor (KNN), and random forest (RF) are used for analyzing complex water quality datasets to acquire information from possible patterns [39]. However, the application of ML to analyzing key factors affecting river water quality is still limited.

Water quality index. The concept of the Water Quality Index (WQI) was proposed by Horton (1965) [70]. Brown et al. (1970) applied the Delphi technique to generate the water quality index for the US National Sanitation Fund (NSF – WQI) [71]. However, this approach is not objective because of the consultation of a panel of experts for rating parameters. Many indexes, such as the Oregon Water Quality Index (OWQI), British Columbia Water Quality Index (BCWQI), and Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI) were developed to improve the final calculation of WQI [72–74]. In recent studies, principle component analysis has been used to find significant parameters and weights that are input into the final calculation of the water quality index. In fact, PCA helps objectively define the relative weights for each water quality parameter, resulting in more reliable results [75,76]. In addition, the index of biodegradability was generated by dividing BOD_5 by COD. The BOD_5/COD ratio of 0.4 indicated a high degree of degradability; 0.2–0.4 showed a low level of degradability; and 0.2 revealed a low degree of degradability [55,77]. This high index can show more degradable matter in the river, but not clarifying sources or factors affecting [55]. Heavy metal Pollution Indexes (HPI and modified-HPI) are used to assess water quality based on the concentration of heavy metals by calculating the weighted arithmetic sum of water quality parameters. Also, the Heavy metal Evaluation Index (HEI) is used to explain the levels of heavy metals and trace elements with regard to water quality. The HEI index is divided into three categories: low heavy metal (<10), moderate heavy metal (10–20), and high heavy metal (>20) [63,78]. However, This approach can not identify the pollution sources or factors affecting water quality, and its results only illustrate the pollution levels of river water.

Statistical analysis. Statistical methods such as Pearson's or Spearman's correlation, MLR, CA, and PCA has been applied to interpret complex water quality datasets in many studies [75,79,80]. To illustrate the degree of dependence of one variable on the others, Pearson's or Spearman's correlation analysis is often employed. Water quality parameters are evaluated for correlation depending on the coefficient values. The correlation coefficient values range from $+1$ to -1, a zero value means no correlation, $+1$ and -1 values show a perfect relationship at a significant level of $p < 0.05$. Correlation coefficient values of $r > 0.7$ have strong correlations, whereas r values between 0.5 and 0.7 are defined as having moderate levels of correlation. In recent studies, this technique has been applied to analyze the degree of correlations between water quality parameters in a negative or positive way [8,34,55,75]. Multiple linear regression (MLR) analysis has been applied to create simple MLR models, which can identify some important factors affecting water quality paramters. For instance, a simple MLR model has been generated based on water quality variables and land use variables. Therefore, MLR models for parameters have established based on important land use types [26]. CA is applied to classify the objects into clusters based on their similarity or difference. The Euclidean distance indicates if two samples are comparable; the "distance" can be defined as the "difference" between the two values. The sum of the squares of the analysis of variance is used to calculate the distance between two groups, and then a dendrogram is generated to illustrate clustering [8,56,75]. By applying CA, the sampling sites in rivers were clustered based on their physico-chemical characteristics, and the clusters often have similarity in land use patterns or/and spatial distribution (upper, middle and bottom of catchments), or/and the presence of point pollution sources. The results are often linked to land use types and the population levels of sampling locations [8,75,81]. PCA can be used to decrease the number of variables and explain the same amount of variance with fewer variables (principal components). PCA aims to clarify the correlation between the observations regarding the unmeasured underlying components. The primary factors that affect water quality in river basins were determined. The Kaiser-Meyer-Olkin (>0.5) and Barlett's sphericity tests ($p < 0.05$) were used to determine whether the data were appropriate before running the PCA [8,56]. PCA was used to identify the key parameters and pollution sources affecting the variation in river water quality. The key parameters in each principle components (PC) help predict pollution sources and factors [7,8]. For example, the results from PCA were found strong positive loadings on EC, TDS, and strong negative loading on DO in PC1 (26% of the total variance). This component was affected by most of agriculture activities, which mainly contribute to the increases in the levels of EC and TDS and decreased in DO levels. While nitrate and nitrogen had strong positive loadings in PC2 (20% of the total variance) that can be associated with the nutrient parcel of water pollution (domestic sewage and fertilizers). The results from another study showed that COD, TP, Cu and volatile phenols have strong positive loadings in the first PC (29% of the total variance). These results and spatial distribution characteristics revealed that emissions can be related to the presence of industrial activities (paper manufacturing, coking, chemical products manufacturing, and metal products).

Application of machine learning or/and remote sensing in water quality assessment. In machine learning, a subfield of artificial intelligence, algorithms are applied to analyze complex datasets and search for possible patterns in order to acquire new information. In contrast to conventional models, machine learning models can efficiently solve more complex nonlinear issues. Supervised and unsupervised learning are two main classes of machine learning technologies. Using labeled training datasets, supervised learning derives predictive functions, while unsupervised learning is typically used to deal with unlabeled data and recognize patterns based on unlabeled training datasets. Supervised learning algorithms such as linear regression, artificial neural network (ANN), support vector machine (SVM), decision tree (DT), naive Bayes, k-nearest neighbor (KNN), and random forest (RF). For example, the study applied the Bayesian network and ANN to estimate the optimum population ranges of each watershed from the probability distribution table of the population node. The findings showed that TC, and BOD had a strong positive correlation with the population, while DO was negatively correlated with the population [39].

The combination of multiple methods has proven to be effective in identifying factors and pollution soucres. The remote sensing method has been used for image classification, which can provide percentages or areas of land use types. Those results are often input data in correlation analysis [82] and multiple linear regression analysis [26]. Moreover, some machine learning algorithms can be applied to image classification. For instance, the systematic remote sensing monitoring method and Mixed Kernel ELM with Particle Swarm Optimization (PSO-M-K-ELM) were applied to analyze the spatio-temporal variation rules of non-point sources surrounding the drinking water source area in the Huangpu River, Shanghai. The findings illustrated that COD was the predominant non-point source pollutant, while TP contributed the least in the study area. The continuously increasing areas of building land were the main source of COD emissions in the period 1989–2019 [41].

3.2. Land-use, land cover and land management

Land use and water quality**.** Previous research has revealed that land use is one of the dominant factors determining variations in water quality [3,42,83]. Increased urban and industrial land can be linked to decreased infiltration, increased runoff, and the transport of contaminants from the catchment to waterbodies. This could lead to the deterioration of water quality in rivers [26]. The concentration of pollutants in river water was influenced by a number of human activities that are linked to urban land, including the discharge of domestic and industrial sewage, the application of fertilizers and pesticides, surface runoff, and other non-point pollution sources [26]. By analyzing the correlation between land use types and water quality parameters, the results showed that residential land had a positive relationship with the nutrients (NO_3^-N, and PO_4^-P), suspended solids, and organic pollutants (BOD_5, and COD) in the Medlock River, Uniter Kingdom [28]. This is consistent with the results of the study in the Mitidja Watershed in Algeria. Settlement land had a positive correlation with the parameters BOD_5, COD, NH_4–N, PO_4^-P, and SS, and the regression analysis showed that settlement land can be a good predictor for these water quality parameters. In the case of industrial land, the study in Hooghly River, India, illustrated that industrial and port activities along the river were responsible for the elevated concentration of PCBs [17]. The sampling site in the industrial zone had much higher levels of PAHs than the figures in the other two sites [16].

Agricultural activities can be linked to the amount of nutrients, pesticide residues, and other organic pollutants entering rivers through surface runoff or irrigation, leading to the deterioration of water quality. The results from the analysis of Spearman Rank correlation showed that intesification activities on agricultural land have a strong positive correlation with nitrate and phosphorus concentrations and bacterial coliforms [42]. This is consistent with the results from PCA in the case study of the Opak Sub-Watershed, Indonesia. The levels of nitrate, nitrit, amonia, and DO were significantly correlated with cultivation and livestock activities on agricultural land in the third and fifth principal components. Nitrate and phosphate could be released from the application of fertilizers through runoff or irrigation, causing an increase in nutrients [83]. However, the relationship between agricultural activities and water quality can be uncertain due to the simultaneous impact of urban land, agricultural land, forest land, and other types of land use on each of the water quality parameters [26]. In general, agriculture activities are still a major source of water contamination, which was confirmed in previous studies [7,8,26]. With the selection of water sampling sites with different land-use characteristics, the study showed that organic and biological contaminants are associated with agricultural activities and urban sewage, which predominate in the Siriri River watershed in Brazil. By analyzing PCA, the agricultural activities in PC1 components can explain 26% of the variance of the river water quality in the catchment. PC1 had significant positive loadings on EC and TDS and a strong negative loading on DO. Additionally, strong positive loadings were determined on NO_3^- and TN, while there was a moderate negative loading on temperature, explained by the PC2 component (made up 20% of the total variance), which can be related to domestic waste and the application of fertilizers on crops [7]. At the buffer scale, agricultural land had a positive correlation with the levels of DO and conductivity in Setikhola, Nepal [31]. Lastly, the occurrence of OCPs and other pesticide residues has been found to be linked agricultural land. However, the case studies have not analyzed the correlation between land use types and pesticide residues [17,30,87].

In the case of forest land, most studies suggest that its importance lies in reducing soil erosion and intercepting solid contaminants. Therefore, the enhancement of forest protection and afforestation is important for improving water quality in river basins [88,89]. The case study in the Medlock River, United Kingdom, showed that urban green and woodland had a positive correlation with DO levels and a negative correlation with nutrients and conductivity through the analysis of the correlation between land use areas and water quality values [28]. Similarly, forest landcover positively correlated with the levels of DO in the Setikhola watershed, Central Nepal [31]. In addition, the case study in Chao and Bai Rivers in China applied multiple linear regression, redundancy analysis, and remote sensing to evaluate landscape influences on water quality in buffer zones. At the buffer scale, the results concluded that landscape factors in the buffer zone significantly affect the water quality variation, and landscape in the 100-m buffer zones has the most significant impact on river water quality. While agricultural land and grassland in buffer zone had a significant and positive correlation with TN, and NO_3^-, forest land was negatively correlated with water quality indicators [85]. Similarly, the study in the Guadalupe Dam Watershed, Mexico, also revealed that forest land in buffer zones had a positive impact on the protection of water quality [84]. Recent studies showed the importance of a buffer zone along the river, which could improve river water quality [84,90]. Therefore, measures such as rehabilitation and protection of the buffer zone should be considered when implementing river water management actions. A summary of previous studies demonstrated that agricultural land and built-up land are the leading causes of the degradation of water quality, while vegetation cover, forestland, and grassland may improve water quality in river basins [7,8,91].

Urbanization and water quality**.** Population growth and rapid urbanization have affected many aspects of life [1]. To meet the demand of population growth, the combustion of fossil fuels in industrial activities or the demand for crude oil and petroleum products has been increasing, which are the main sources of PAHs entering waterbodies [16]. The use of household chemicals, carpets, degradation products, fire-fighting foams, and sewage sludge disposal could release PFASs into the environment, which could reach the waterbodies under favorable conditions [18]. When assessing the impact of urbanization on river water quality, Kim et al. (2016) applied a simple linear regression to analyze the relationships between the percentages of impervious areas and water quality parameters. The percentage of impervious area was positively correlated with some physical and chemical parameters such as BOD_5, COD, TOC, and TP [44]. The results from the correlation analysis showed that the increase in population has a significant impact on water quality parameters. The population had a positive correlation with the five parameters (BOD_5, COD, fecal coliforms, toxicity, and TSS) in Alto the Atoyac Basin, Puebla, Mexico. The explanation suggested that population growth resulted in a higher demand for the production and consumption of goods and services. As a result, a higher amount of waste and wastewater could be generated, leading to disturbance of the ecosystem as well as the aquatic environment [6]. The nutrients (TN, TP, NH_4–N and PO_4–P) and microbial load (fecal maker, pathogen) in highly urbanized areas were found to be much higher than those in medium and low urbanized areas [43]. Similarly, another study in Suzhou, China, revealed that water quality was worst in high urban areas, followed by medium urban areas and rural areas [92].

3.3. Climate condition and atmospheric deposition

Seasonal variation in water quality**.** Seasonal variation in precipitation, runoff, and undergound flow could directly affect river flow, resulting in a change in pollutant concentrations in river water. In a certain climate condition, temperatures could be higher in the dry season than in the rainy season, and water flow is low, leading to less disturbance and dilution. By comparing the analytical results during different seasons, the seasonal variations in river water quality can be explained. For instance, with the presence of wastewater discharge from residential areas, agricultural and industrial activities, the concentrations of TN, TP, TS, and BOD_5 in the dry season were higher. In addition, the levels of DO and turbidity were higher due to high dilution in the wet season [7,8]. Through analyzing ANOVA and the Turkey test, the findings showed that the mean concentrations of COD, TSS, and TP were higher during the summer than in other seasons due to the high flow of river water, while the figure for BOD_5 was higher during the spring due to the low flow of river water. In addition, the results from regression models illustrated that TSS is a good predictor for river water quality. TN and TP levels are determinants of the levels of algal chlorophyll-a in the

Geum River. The river water quality was poor to very poor in the summer (rainny season) [55]. Remote sensing and statistical analysis (Spearman correlation and simple linear regression analysis) have been used to clarify land use types and parameters. Another study showed that the levels of nutrients (TN, TP, NO_3–N, and NH_4–N) were higher in the rainy season, and these levels changed significantly according to the season. Built-up areas had a more significant correlation with NO_3–N concentration in the rainy season than in the dry season because of the increased non-point pollution sources from surface runoff instead of only point sources in the dry season. The findings also indicated a high correlation between river flow and nitrate concentrations [82]. In addition, these phenomena could be enhanced by favorable terrain and geology conditions (steeper slope, well-drain soil, and low vegetation cover) for surface runoff reaching rivers [11,45,82].

Climate change, extreme weather events and water quality**.** The main problems facing water management in river basins include water pollution, the effects of climate change, and water shortages. Climate change can significantly affect runoff and river basin sediment loads. Recent studies on the effects of climate change on water quality have emphasized nutrient loads and sediment transport [93–96]. Based on data collected during droughts (1976, 1991 and 2003), simple linear regression was used to establish the relationship between DO levels and the temperature of river water, and the levels of dicharge and chlorine during the period of 2001–2005. The results showed that a reduction in DO levels was related to the increase in temperature, and an increase in chlorine concentrations depended on the levels of decreasing discharge [97]. Similarly, increased temperatures in some European rivers could lead to decreased DO concentrations and pH [97,98]. Droughts could also affect water quality because of high water temperatures, long residence times, and high nutrient concentrations, which facilitate the development of algae blooms. Increased nutrient levels during droughts may be related to a decrease in the dilution capacity of waterbodies [10]. Floods can affect the increase in flow volume, which could bring excessive organic or inorganic matter and sedimentation to river water during this period. By applying WQI calculation and Pearson correlation, the study in Muar River, Malaysia, during the flood events indicated that high levels of suspended solids cause an increase in NO_3–N levels and a decline in pH values, resulting in a deterioration in river water quality [99]. In general, climate-related variables such as water temperature and (extreme) river flows can influence surface water quality [97]. Land-use change should be carefully planned and controlled because of its potential impact on river water quality. For instance, new developments must not be approved in flood-prone areas that can increase the risk of flooding [99]. During drought periods, point sources should be controlled due to low flow and high temperatures, which cause seveve deterioration of river water quality [98].

Atmospheric deposition. Nutrients, heavy metals, and persistent organic pollutants in the atmosphere entering surface water could be transported through wet and dry deposition [11,100]. Atmospheric precipitation is one of the main pathways for delivering pesticides, PCBs, and other persistent organic pollutants, and higher rainfall may facilitate the process by which these substances are transported from the atmosphere to waterbodies [17,30]. Through this mechanism, air pollution can have a considerable influence on the quality of river water. In particular, some heavy metals (Pb and Cd) could reach surface water through atmospheric deposition in Czechia [101]. Another case study in the Ganga River, India, the nutrients and heavy metals in surface runoff that act as a means of pollutant transport to rivers, strongly correlate with these concentrations in atmospheric deposition input [102].

3.4. *Catchment geology, topography and hydrology*

The amounts of nutrient and salt sources in catchments are influenced by the chemical properties of the soils and rocks. The mobilization of constituents in catchments may be impacted by soil and rock erodibility, and soil sorption capacity. Surface and subsurface runoff containing phosphorus, nitrogen, and salts can reach waterbodies, and these processes depend on the drainage capacity of the soils [11]. Phosphorus concentration is strongly correlated to soil texture, and clayey soils, for example, have high erodibility [103]. Sedimentary and igneous rocks are major sources of phosphorus, released through weathering and hydrological transport [45].

Topographic setting significantly affects the mechanism of pollutants transport to waterbodies, and determines how runoff flows into surface water or infiltrates into subsurface or groundwater [2]. The characteristics of a waterbody could also impact the transport and attenuation of pollutants within a catchment. Stream flow moves in one or more channels with different widths and depths. This process is affected by factors such as topography, geology, the magnitude of streamflows, climatic factors, and groundwater discharge [2]. The study of Liu et al. (2021) used the factors of natural catchment characteristics (topography and geology) and anthropogenic factors (land use) to model their impacts on water quality. The results from the multi-model inference showed that catchment elevation significantly affects NH_4 and dissolved organic nitrogen with a negative correlation, while dissolved organic phosphorus is negatively correlated to slope [45]. Moreover, the presence of lakes, wetlands, and dams could result in lower concentrations of sediments, nutrients, and salts downstream of rivers, which could be related to low levels of phosphorus in the case study [103].

4. Key factors affecting river water quality in urban and rural areas

The expansion of residential and industrial land is a popular trend in urban areas, and this phenomenon has considerable impacts on environmental aspects. In the case of land use fators, the study in Medlock River, Great Manchester, United Kingdom, revealed that DO levels had a negative relationship with residental, and industrial land, and a positive relationship with urban green and woodland. Nutrient concentrations (PO_4–P and NO_3–N) correlated negatively with urban green areas and positively with impervious areas [28]. Similarly, while DO levels decreased, BOD_5 and TP concentrations increased due to wastewater discharges from residential areas and industrial zones (urban land) in the middle of the river basin Burío River in Costa Rica [8]. The decrease in DO levels was due to microbial activity that can degrade organic matter in river water [8,92]. Another study of water pollution levels in three rivers in Malaysia showed that the water quality of the Galing river in urban areas was the worst due to poor wastewater treatment, with the highest average levels of COD, TP, and total inorganic nitrogen (TIN) [27]. Urbanization processes have been found to significantly affect the aquatic environment. Urbanization factors such as impervious areas and dense population density or population growth are often analyzed to find relationships with river water quality parameters. For example, population growth was considered the main determinant of the deterioration of river water quality in the Atoyac River in Puebla, Mexico [6]. The aquatic environment is often disturbed by receiving waste and wastewater from domestic and industrial lands. Urban areas with the presence of industrial activities (petroleum refinery companies and incomplete combustion) were found to be related to the occurrence of PAHs in river water [16,86]. High levels of PCB were detected in river sections flowing through industrial zones because of the combustion of coal and industrial waste [17]. The occurrence of emerging pollutants such as PFASs, and PhACs has been confirmed in recent years. For instance, anthropogenic direct sources such as waste water and leaching from poorly disposed solid waste could be the main sources of PFAS [50]. PhACs were found in the Yamuna River, India, because treated and partially untreated domestic and industrial effluents entered river water [68]. In general, Table 2 shows that land use/cover (urban and industrial land) often have negative impacts on water quality parameters such as COD, BOD_5, TN, TP, and microbiological parameters in urban rivers. This means that the increase in urban and industrial land often results in increases in these pollutant concentrations. Noticably, emerging and

Table 2
The correlation between land-use/Land cover and water quality parameters.

Parameters	Forest/wood land	Urban green/vegetation	Residential or urban areas	Industrial/commercial areas	Agriculture land	References
DO	+	+		–		[28]
		+	–		–	[26]
	+				+	[31]
Conductivity	–	–	+	+		[28]
					+	[31]
	–		+			[84]
NO_3^-N		–	+			[28]
		–	+		+	[26]
					+	[85]
	–		+			[84]
PO_4^-P		–	+			[28]
		–	+		+	[26]
TSS			+			[28]
		–	+		+	[26]
	–		+			[84]
COD		–	+		+	[26]
			+	+		[27]
			+	+		[6]
BOD_5		–	+		+	[26]
			+	+		[6]
PAHs				+		[16]
						[86]
PCBs				+		[17]
OCPs					+	
OCPs		–			+	[30]
Pesticides[a]					+	[87]

(–): Negative correlation/relationship; (+): Positive correlation/relationship.

[a] Cadusafos, Butachlor, Pendimethalin, Fenpropimorph, Malathion, Pyrimethanil.

persistent organic pollutants such as PAHs, PCBs, PFASs, and PhACs have been detected in many urban rivers due to waste and wastewater from domestic and industrial activities.

In rural areas, land use types such as agricultural land, forest land, and vegetation cover are often dominant, which has been confirmed to affect the variations in river water quality in previous research [29,31,104,105]. The case study in the Maotiao River Basin, China, illustrated that The levels of river water quality gradually decreased from upstream to downstream. The negative relationship between water quality and forest land indicated that river water quality was significantly influenced by topography, landscapes, and soil thickness. Heavy metals, TN, TP, and BOD_5 were key parameters in the variations in river water quality [29]. Similarly, land use factors were the main determinants of river water quality in Kuantan, Malaysia. The levels of NO_3^- in the Kuantan River in rural areas were higher than those of Galing River in urban areas due to domestic wastewater. Since high levels of DO facilitated microorganisms and nitrification reactions, which decomposed organic compounds into NH_3 and NH_4^+, and then NH_4^+ was oxidized into NO_3^- via the nitrification process [27]. In Burío River, Costa Rica, agriculture activities are dominant in the upstream, which could release nitrate content through runoff or irrigation containing the residues of fertilizers. The levels of turbidity, TS, TP, and BOD in upstream areas were lower than those in the middle and downstream of the river (urban areas) [8]. The study in the Siriri River basin, Brasil, indicated that agriculture land, and catchment topology (slope), and hydrology (in the wet period) are key factors that significantly affect river water quality [7]. At the buffer scale, forest land has a positive correlation to DO, while agriculture land has a significant positive correlation with conductivity and DO levels. In addition, catchment characteristics (steeper slope, cooler water temperature, and forest land) greatly contribute to higher turbulence instream, leading to an increase in DO levels, while the levels of conductivity were higher in bigger tributaries than in smaller ones due to receiving more ions from bedrock and soil surface [31]. Notably, pesticides residues have been found in river water, which could pose a threat to human and animal health [106]. For instance, the past or current local use of pesticides on agricultural land in Juixi Valley, China, was found to be the main source of OCP concentrations in river water that were higher in autumn (dry season) than in spring (wet season) due to the effect of high dilution [30]. Similarly, the study in Thamirabarani River, India, found that the main source of OCPs was farmland runoff from the extensive cultivation of tea and rubber plantations in the hilly terrain region [107].

Table 3 shows the key factors that could affect water quality parameters in urban and rural areas. Identifying key factors depends on the characteristics of each case study, such as climate regions, catchment characteristics, and land use/cover. In general, land use or cover is one of the key factors that defines the levels of river water quality in urban and rural areas. Since each land use type has some characteristics that are related to some pollution sources affecting river water. In urban areas, factors related to urbanization (impervious areas and population growth), and land use (residential and industrial land) are the determinants of the dynamics of river water quality. Point sources (domestic and industrial wastewater) are often found to be the main cause of river water pollution. However, land use (agriculture land), catchment geology, topology, and hydrology, and climate conditions (seasonal variations) significantly affect river water quality in rural areas.

5. Conclusion

Identifying the key factors and pollution sources of deteriorating river water quality is essential for managing river basins towards sustainable water management. Natural and anthropogenic factors are affecting river water quality, and pollution levels are becoming severely in many river basins around the world. This could have negative impacts on animal, human, and ecosystem health. Land use (residential and industrial land) and urbanization factors (population growth and impermeable areas) are the key factors significantly affecting river water in urban areas, while agriculture land, forest land or vegetation, climate conditions, and catchment conditions (geology, topography, and hydrology) are the key determinants of river water quality in rural rivers. Noticeably, the concentrations of some emerging and persistent organic pollutants such as OCPs, PCBs, PAHs, and PFASs were detected in river water and treated water, so it is necessary to introduce regulations and monitoring programs in rivers. In addition, key factors affecting the

Table 3
Possible main sources and affected water quality parameters in urban and rural area.

Rivers	Rural areas/low density of residential areas			Urban areas			References
	Sections of River basin	Key factors/sources	Parameters	Sections of River basin	Key factors	Parameters	
Maotiao River Basin – China	Upstream	- Land use (Agriculture and forest land) - Climate condition (rainy season) - Catchment geology and topography.	N, P, BOD_5, heavy metals	Middle-stream	- Land use (urban land far from the river) - Climate condition (dry season).	None or minor impact	[29]
Setikhola watershed – Nepal	Upstream	Land use (Agricultural and Forest land) Catchment geology and topography (slope, soil and rock types). - Climate condition - Catchment hydrology (Lakes)	DO,EC	Downstream	None or minor impact (Dense urban land with a small area)	None or minor impact	[31]
Kuantan river, Belat river, and Galing river – Malaysia	Upstream and middle-stream of Kuantan and Belat rivers	Land use (Forest land)	DO, Nitrate	Galing river Downstream of Kuantan and Belat river	Land use (residential land) Urbanization (Centralized sewer system, Household wastewater)	COD, TP, NH_4–N.	[27]
Burío River, Costa Rica	Upstream	Land use (Agriculture land)	Nitrate	Middle and Downstream	Land use (Residential and industrial land)	DO,BOD_5,TP, TSS,Faecal Coliform	[8]
Siriri River basin, Brazil	Upstream and Middle-stream	Land use (Agriculture and Forest land) Catchment topology (Slope) Climate condition (seasonal variation)	TN	Downstream	Land use (Residential and Agriculture land) Climate condition (seasonal variation)	DO, TN,TP, Coliform, Turbidity	[7]
Alto Atoyac Basin in Puebla, Mexico				Whole basin	Urbanization (population growth)	BOD_5, COD, and TSS	[6]
Sabarmati River, Gujarat, India	Upstream	Land use (vegetation and forest land)	DO, BOD, COD, Coliform	Downtream	Land use/cover (Residential and industrial land)	DO, BOD_5, COD, Coliform	[92]
Jiuxi Valley – China		Land use (Agriculure land)	OCPs				[30]
Thamirabarani river – India	Upstream	Land use (Agriculture land) Catchment topology (Slope)	OCPs				[107]
Medlock River – Great Manchester – UK				Whole basin	Land use Urbanization (imperious areas)	DO, PO_4–P, NO_3–N, SS	[28]
Ganges River – India				Whole basin	Land use (residential and industrial land) Urbanization (population density)	PFASs (PFHxA, PFHpA, PFOA)	[50]
Yamuna River – India				Middle and downstrem	Land use (residential and indutrial land)	PhACs	[68]
Brahmaputra and Hooghly rivers – India				Downstream	Land use (Industrial land) Atmospheric deposition	PCBs	[17]
Diep River in South Africa				Downstream	Land use (Industrial land) Atmospheric deposition	PAHs	[16]

occurrence and transport of emerging and persistent organic pollutants should be further studied to help prevent these substances from entering river water. This review provides an overview of key factors, sources, and parameters affecting water quality and the differences between urban and rural areas. This helps managers and policymakers make wise decisions in river basin management.

Human and animal rights and informed consent

This article does not contain any studies with human or animal subjects performed by any of the authors.

Declaration of competing interest

The Authors have no interests to declare. There are no conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

Data availability

Data will be made available on request.

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