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Review Article

Surface Water Pollution Source Identification and Quantification: Literature Review

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Abstract: Surface waters are important natural resources and widely used for different purpose in human life such as agriculture, industry, municipal services and so on. Using surface water at high rate led to increasing of their pollution and scarcity. This pollution is mainly human made, in some case anthropogenic. Recognizing this problem currently, water pollution source identification and quantification is an active research area. The main objective of this review is to identify different pollution factors of surface water, approaches and methods used by different researchers for identification and quantification this pollution sources. There is different pollution factors surface water such as: heavy metal, micro plastic, nutrients like Nitrogen and phosphorus, waterborne pathogenic microbes, and petroleum hydrocarbons. Different pollution identification and quantification methods were used in different literature based on objectives and scopes of the studies. This include: Inverse Methods, Bayesian Inference, an Innovative Biosensor Network, Differential Evolution (DE) optimization algorithm, Combining Differential Evolution Algorithm (DEA) and Metropolis– Hastings–Markov Chain Monte Carlo (MH–MCMC), Field Observation and Laboratory Analysis, and Multivariate Receptor Model.

Keywords: Surface Waters, Pollution Source, Identification and Quantification

1. Introduction

Water is one of the most important and very essential natural resources and fundamental for living organisms for daily basic need. Particularly Surface waters are widely used for different purpose: agriculture, industry, municipal services and so on. This is because of their availability and easy extraction [1]. Using surface water at high rate headed to highly pollution and degradation of these very important resources and their scarcity [2]. The surface water quality issue is very sensitive because of its effects on human health and aquatic eco-systems, as well as environment. Rivers are highly susceptible to pollution and attribute their role in carrying off the industrial as well as municipal wastewater and run-off from agriculture area [3]. Water quality deterioration is a major problem in developing countries. This because a huge amount of sewage is discharged into surface water without treatment [4]. Water availability and its quality concern has been growing at globally, and its demand estimated to be increase between 20 and 30% by 2050 [5].

Several studies show the inescapable future of freshwater scarcity, and both groundwater and surface waters are getting contaminated and polluted beyond repair [6]. According to Sorensen [7] analysis Cape Town, South Africa face the disastrous situation because of severe shortage of freshwater. Several other human settlements in the world, like England, USA, China, Brazil, and India are estimated to face a similar threat of water scarcity in the near future [8].

In recent years, because of different factors such as: industrial facility, rapid population growth and changes in water consumption behavior the amount of wastewater produced are highly increasing. An excess wastewater is discharged directly, or with poor treatment into surface water bodies, and results in degradation of their quality [9]. According to (UN-Water 2009) report 70% of industries in developing countries discharge their waste into water bodies without treatment.

These Pollution factors includes: heavy metals, nutrients, water-borne pathogenic microbes, micro plastic, Petroleum Hydrocarbons and so on. This pollution arises either from point sources or non-point sources. Point source pollution is pollution generated from known and identified sources, where as non-point source pollution generated from unidentified sources. The Major point-source pollution includes: landfills, septic systems, and hazardous waste sites [10]. Major non-point sources includes: leaks or spills of industrial chemicals at manufacturing facilities, pesticides runoff of salt and other chemicals from highways and roads, and fertilizers on agricultural land [9]. Non-point source pollution caused around 60% of surface water quality to be distorted [10].

Nowadays, water pollution source identification, quantification and characterization is in surface and groundwater is an active area of scientific research, and numerous approaches have been suggested to handle this problem [11]. Different method and techniques are used to identify sources of water pollution and quantify them. These includes: Simulation-optimization method, Probabilistic method, An advanced multivariate clustering method, Differential Evolution (DE) algorithm, By an innovative biosensor network, Combining differential evolution algorithm (DEA) and Metropolis– Hastings–Markov Chain Monte Carlo (MH–MCMC) Simultaneous optimization, Field Observation and Laboratory Analysis and so on.

2. Pollution Factors of Surface Water and Their Sources

Based on their source's identifiablity surface water pollution factors are classified in to two: point source pollution and non-point source pollution. Point source pollutions are pollution generated from known sources like fluent coming out from industries, research laboratory, Hospitals or health care centers, miss-designed and miss-managed land filling and waste stabilization ponds and so on. In another hand non-point sources are pollution generated from non-identifiable sources, such as urban waste, runoff from agricultural fields and etc. [12]. Both Point sources and non-point sources arise either from natural sources –such as natural corrosion, flow alterations, and benthic agitation- or anthropogenic sources –like industrial wastewater emission, sewage emission and fertilizer from agricultural field [13].

Studies conducted in different countries identified different pollution factors arise from either from point sources or non-point sources and discharged to water bodies. The following is some common pollution factors of surface water:

2.1. Heavy Metals

Heavy metal pollution in surface water is considered as a worldwide environmental problem [14]. The presence of Heavy metals in the environment at high rate and higher concentrations poses a great threat to the environment and harm human health and their discharge from various pollution sources contaminate to the water bodies negative affect organisms, as well as human welfare [15]. Due to pollution discharge to river bodie numerous rivers raised heavy metals concentration to unhealthy levels and as result threat the biodiversity of the river [6]. The number of heavy metals with higher concentrations above threshold limits of USEPA and WHO standards were higher in the developing countries and lower in the developed countries of North America and Europe [14]. Due to their extreme accumulation, toxicity and bio magnification high levels of heavy metals in surface water have evoked significant concern from the researchers, public and governments [1].

The five metals (Zn, Cd, Pb, Ni, and Cu) are the most repeatedly identified heavy metals with high concentration in the environment, which in high concentrations are considered toxic to human health and well-being as well as ecosystems [4, 16]. These five metals are trace element they need more attention because of their toxicity, non-degradability and their tendency to accumulate in biological organisms [13]. Exposure higher concentration of these trace elements threats human health such as: infectious diseases, carcinogenicity, chronic or acute chemical toxicity [14].

Higher concentration of Cadmium is mainly toxic to the kidney, specifically to the proximal tubular cells which is the main site of accumulation. Cd also causes demineralization of bone by renal dysfunction or by direct bone damage [17]. Furthermore, exposures to airborne Cd may increase the risk of lung cancer. Nickel intoxication determines respiratory dysfunction, heart disorders, reproductive effects, and respiratory cancer, dermatitis and non-cancer toxicity effects following inhalation [18]. High levels of Zink (Zn) can cause pancreatic complications; anemia and stomach pain [19]. Lead poisoning is a complex disorder affecting many organs in the body including: developing red blood cells, the kidneys, and the nervous system. Young children are most susceptible to the toxic effects of lead [18, 20]. Exposure to above threshold limits of Cupper (Cu) can lead to kidney, liver and gastrointestinal disease, anxiety, Wilson's disease and damage the immune system [21]. Human being is not only victims of these heavy metals, but also aquatic environments highly affected by frequently discharge of heavy metals into rivers [15]. These heavy metals enter the human body through different path such as skin, inhalation and the gastrointestinal tract [25].

2.1.1. Variation of Sources of Heavy Metal by Continent

Like another environmental pollutant trace element arise either from natural sources or anthropogenic sources [13]. The main pollution sources in water vary from continent to continent. According to study conducted in five continents, in Africa, the main metal sources were pesticide, fertilizer and, rock weathering, with a combined contribution more than 56.7%. In Asia, the main metal sources were manufacturing, rock weathering and mining contributing 97.1%. In Europe, the case was the same as those in the Asia, with a total combined contribution of 56.2%. In North America, the main sources were pesticide, fertilizer, manufacturing and mining with a combined contribution more than 90.4%. In South America, the main sources were fertilizer, pesticide, mining, and manufacturing contributing 93.5% of the total heavy metals [14].

2.1.2. Different Index Methods for Heavy Metal Pollution Status Assessment

Understanding the impact of heavy metal in surface water, different index methods like water quality index (WQI), heavy metal pollution index (HPI), heavy metal evaluation index (HEI), single-factor pollution index, Nemerow's pollution index and metal index (MI) have been adopted to assess the status of heavy metals contamination [22, 21]. Heavy metal pollution index (HPI) is considered, because index would be relevant to determine the quality of surface water, sediments, dissolved and suspended particles [23]. The permissible limit given by WHO for water quality standards were considered for heavy metal index value determination.

2.2. Nutrients Like Nitrogen and Phosphorus

Phosphorus (P) and Nitrogen (N) are among essential nutritional elements for life processes in water bodies. But their existence in higher concentration cause aquatic pollution [24]. The introduction of excess nutrients in water body or nutrient enrichment has number of negative impacts. One of the most common effects is what is known as eutrophication – increasing organic enrichment. Scientific literature shows that eutrophication is a widespread problem in surface water such as, lakes, rivers, coastal oceans and estuaries, caused by excessive presences of N and P [25]. The excess nutrients like Phosphorous and Nitrogen cause various problems such as loss of oxygen, toxic algal blooms, fish kills, loss of aquatic plant beds, loss of biodiversity and coral reefs and other problems on aquatic organisms and aquatic ecosystem [24]. Most of the surface water pollution is from extreme concentration of compound of chemical elements like: phosphate, sulfate, nitrate, chloride, and other pollutants [25].

Different studies shows that concentration of nitrate nitrogen (NO3_-N) of the most rivers in populated regions is exceed the healthy water quality standards suggested by the WHO (of 10 mg/L) many times. Urban human activities and agricultural activities are considered as major sources of P and N to aquatic ecosystems. The study conducted by Guo, Wang and Zhu [28] shows that about 48% of total nitrogen and 38% of total phosphorus which discharged to surface water is from agricultural land, 40% total Nitrogen and 33% of total Phosphorous from village residents, 25% of total Phosphorous and 10% of total Nitrogen from the town or city center and 4% of total Phosphorous and 2% of total Nitrogen from the poultry factory. Atmospheric deposition also considered as one source of Nitrogen [27].

2.3. Micro Plastic

Plastic particles of Small-sized with a diameter of less than 5 mm are defined as micro plastics [29]. The current period is known as the Plastic Age in human history [29]. Due to their low cost, simplicity, lightweight, and flexibility plastics have become highly demanded worldwide. But, the plastic wastes in different countries, particularly in developing countries not properly managed and most of the plastic debris is gate wayed into the water bodies. Because of this micro plastic pollution in the terrestrial and marine environment nowadays it becomes high concern of environmentalists, organizations, and governments [30]. The intake of micro plastics by aquatic organisms has been demonstrated, However the long-term effects of continuous exposures to this substances are less understood [31].

Scientific research result shows that, about 4.8 to 12.7 million tons of plastic garbage are disposed into the ocean yearly [32]. China placed in the first position in the world by producing plastic [33]. Micro plastics in the aquatic environment are mostly terrestrial origin [32]. By wind and water currents these micro plastics can be carried out to elsewhere in every corner of the world [29].

2.4. Waterborne Pathogenic Microbes

Pathogens Microbes are disease-causing microorganisms and they are a major concern for management of water resources [33]. Primary pathogens of concerns are bacteria, viruses, and protozoa, whereas helminthes and fungi are two additional pathogen groups [33]. Water-borne pathogen contamination in the water bodies and related diseases are a key water quality concern worldwide and it is a serious issue for almost all types of ambient water bodies [34]. Thes Waterborne pathogenic enters in to the water bodies from different sources, such as hospitals, research laboratory, food processing, septic tanks, untreated sewage, and various types of industries [35]. Pathogens in a water body can infect humans through skin contact or ingestion of water, contaminated fish and shellfish [38]. Human and animal feces from infected individuals are the main sources of most waterborne pathogens. These Pathogenic microbes are either transported to water bodies by overland flow and/or subsurface water flow or deposited directly into water bodies [33].

2.5. Petroleum Hydrocarbons

Environmental contamination by petroleum hydrocarbons associated with development, exploration and production operations is a common feature in oil producing countries worldwide [37]. Total petroleum hydrocarbons are a large family of numerous chemical compounds that comes originally from crude oil. They are found in the range of C_6 to C_{35} as mixture containing hundreds to thousands of hydrocarbons [38]. It is one of the main pollutants recurrently discharged into the water bodies [38]. Since the huge amount comes from petro genic and pyrogenic sources the lowermost sediments which is habitat of many aquatic organisms is recognized as reservoir of petroleum hydrocarbons in the aquatic environments and experienced high threat of bioaccumulation [39].

The toxic effect of crude oil spilled in to water body include smothering or asphyxiation of organisms in water body by oil coating, thereby lead to death [40]. Diving birds could be rendered flightiness when oiled; this leads to loss of insulating properties against cold which may lead to death [40].

3. Identification and Quantification Methods

Accurate identification of contamination sources of surface water is very important and basis for effective pollution control and feasible water management and effective groundwater pollution control [41]. Quickly identifying when, where and how much the spilled contaminant is introduced into particular water body is very for important for decision-makers to improve the management and super vision and ability for potential environmental risk [42]. In order to determine the level of the impact of each pollution sources the numbers, locations, stress periods and release histories of the unknown pollution sources need to be identified simultaneously [43]. Recognizing the importance of surface water, highly degradation and pollution of them different countries and researcher focused on surface water pollution source identification, quantification, and remediation. Different pollution identification and quantification methods were used in different literature based on objectives and scopes of the studies. These approaches include Simulation-optimization method, probabilistic method, an advanced multivariate clustering method, mathematical and classification approaches and so on. According to the mathematical characteristics, the existing identification approaches or methods can be divided into four types known as stochastic method, analytical method, optimization method and regularization method [44]. Different approaches used by different researchers are mentioned below:

3.1. Inverse Methods

The inverse method is based on the integral equation obtained from the Green's function method on the one-dimensional advection-dispersion contaminant transport equation [45]. Inverse source models keep progressing with the intention of improving identification methods with maintained implementation simplicity; and obtain the excellent estimation of sought characteristics of pollutant sources, as well as respecting all available data and information [22]. The techniques used in the inverse methods classified into three classes: simulation optimization, probabilistic and mathematical approach [45].

3.1.1. Simulation-Optimization Method

In simulation-optimization method optimization algorithms and the forward model was used in combination to solve the inverse problems [1]. The optimization method obtains the identification values of the parameters of pollution sources by minimizing the difference between the prediction values and observation values of the concentration of pollutants gives the optimization method the identification values of the parameters of pollution sources [26]. Numerical model for the transport processes and simulation of flow is externally linked to an optimization algorithm in this approach [2].

The main advantage of simulation-optimization model is its capability to linkage several optimization algorithms and different transport models. In another hand computational effort for the evaluation of the objective function and the possible convergence to a local minimum instead of a global minimum is considered as its disadvantages [45]. In addition to this the drawback of this approach is it requires high computational power [1].

3.1.2. Mathematical Approaches

In mathematical approaches inverse problems are solved in a direct way and minimize computational costs. Drawback of these method its complexity [1].

3.1.3. Probabilistic Approaches

One approaches of Probabilistic approaches Backward Probability Method (BPM). It is one of the most recommended approaches used for identification of the pollutant source location and release time. Basically this approach is developed for source identification in groundwater with an instantaneous point source, later on the method started to apply in surface water pollution source identification [1]. Cheng and Jia were among the first researchers tried identification of the source location and the release time in surface water using this model. The identification problem can be resolved in this method using two types of probability concepts known as: Backward Travel Time Probability (BTTP) and Backward Location Probability (BLP). BTTP describes the time prior to detection that the detected contaminant particle at an up gradient location, whereas BLP determines the prior location of the pollution distribution. In BTTP the information about the release time is obtained based on the assumption that the source location is known [46]. This approach was used to identify point source of sudden water pollution in rivers or any other surface water, and determine time, location and mas of pollutant introduced into the water bodies [47]. One of the significant advantages of probabilistic approach is small simulations and computations [2].

3.1.4. Simultaneous Optimization

It is an approach in which all parameters are estimated simultaneously to identify the source parameters of a spill incident. Zeunert and Meon [48] applied this approach to identify the source parameters of an instantaneous pollutant discharge in to an estuary. In this study Differential Evolution (DE) algorithm is chosen for the simultaneous identification of the source location x_s the release time t_s and the total pollutant mass M_s.

3.1.5. Genetic Algorithm Method

This method is an intelligent model established for identification of pollutant source using the basic genetic algorithm as an optimization search tool and applying an analytic solution formula of one-dimensional unsteady water quality equation [49]. This method was applied for identification of sudden water pollution incidents. Experimental assessments indicate the efficiency, effectiveness of this identification model and its ability to accurately figure out the amount of pollutants as well as positions both single pollution source and multiple pollution sources [49]. The authors (Zhang and Xin) applied this approach in identification of pollutant source of small straight rivers.

3.2. Bayesian Inference

The Bayesian method is widely applied to analyze uncertainties in hydrological models and it is among the probabilistic and geo-statistical methods [50, 51]. This method gained popularity in various fields like management science, statistics, meteorology and medicine [51]. This technique is a very communal stochastic method, which transforms emergency identification problems into the posterior estimation of unknown parameters on the basis of Bayesian inference and Markov chain Monte Carlo technique [44]. Simeonova and his Colleagues [52] studied the identification of point source release in river pollution incidents based on Bayesian inference method and genetic algorithm method. They provided a model that help decision-making during emergency responses to river pollution incidents. Ajami, Duan and Sorooshian [7] applied an integrated hydrologic Bayesian multi-model combination. It is new framework that account for the major uncertainties of hydrologic rainfall-runoff predictions explicitly. The method differentiates between the numerous sources of uncertainty such as input, parameter and model structural uncertainty.

Bayesian chemical mass balance (CMB) model also used for heavy metals source identification. Sharifi [53] applied this method for heavy metals source identification in a highly urbanized region at the vicinity of the Anacostia River in Washington, DC.

3.3. An Innovative Biosensor Network

An innovative biosensor network is one of current applied method for identification of pollution sources in surface water. The recent development of innovative sensors and ICT technologies offer novel opportunities to identify pollution sources in surface water and discover the cause of the contamination. Particularly, the availability on the wireless solutions market to connect a large on-line sensor network, coupled with the simulation software for analyzing large data in real-time, and offer opportunities to develop early-warning systems for elemental profiles of surface water protection [54]. This method also known as Early Warning Systems (EWS) and provide a crucial tool for real-time signaling of critical situations in water body or water ecosystem.

The approach performed by designing a smart integrated system able to localize one or more emission sources of contaminant. Each biosensor have tendency to detect the time of emission, magnitude, location, and lifespan of the contamination source in a reach enclosed between two biosensors. Biosensor based on a Quartz Crystal Microbalances (QCM) functionalized with antibodies through a novel immobilization technique is might be among sensor appropriate for the realization of such a smart monitoring system. Since biosensors based on QCMs are very cheap it can be installed in many sections of surface water [54].

In addition to QCM, Photonic Immobilization Technique (PIT) is simple and effective tool for this purpose. This method has been successfully verified for contaminants of environmental interest such as parathion and for toxic or undesired compounds in food [55].

3.4. Differential Evolution (DE) Optimization Algorithm

It is a new method designed for identification of multi-point sudden water pollution sources by combining Metropolis–Hastings–Markov Chain Monte Carlo (MH–MCMC) and differential evolution algorithm (DEA) based on Bayesian inference [26]. Karim, *et al* [56] verified and the accuracy and effectiveness of this method through outdoor experiments and comparison between DEA and MH–MCMC. The average absolute error of the sources' position and intensity, the average standard deviations and the relative error and obtained using the proposed method are less than those of MH–MCMC and DEA. The authors used this method for identification multi-point source of sudden pollution accidents in the surface waters.

3.5. Combining Differential Evolution Algorithm (DEA) and Metropolis– Hastings–Markov Chain Monte Carlo (MH–MCMC)

This method is new method designed by combining Metropolis–Hastings–Markov Chain Monte Carlo (MH–MCMC) and differential evolution algorithm (DEA) based on Bayesian inference for identification of multi-point sudden pollution sources in water. This method is applied Karim and his Colleagues [56]. The authors aimed identification of multi-point source of sudden water pollution accidents in surface water. The effectiveness and accuracy of this method is proved through outdoor experiments and comparison between MH–MCMC and DEA.

3.6. Field Observation, Laboratory Analysis

This method is mostly used to identify point source pollution sources. For example, Karim [56] used this method. The objective of this study is to identify the most polluted areas, describe the pollution status of Halda river of Bangladesh and find a particular reason behind it. This method not applied only for identification of pollution sources, but also for identification of polluted risky regions resulted in polluted surrounding river sections. This applied by Yan and his Colleagues [57] on the Honghe River watershed of China in which they analyze six parameters: total nitrogen (TN), nitrate nitrogen (NO3-N), ammonia nitrogen (NH3-N), nitrite nitrogen (NO2-N), total phosphorus (TP) and oxygen (DO) after field observation.

3.7. Multivariate Receptor Model

Different multivariate statistical approaches are used by different researchers for pollution source identification and quantification [58]. Multivariate statistical techniques are effectively evaluating the spatio-temporal variability in a watershed identification of the pollution sources [59]. This includes principal component analysis (PCA), cluster analysis (CA), and discriminant analysis (DA), Absolute Principle Component Score-Multiple Linear Regression (APCS-MLR) model which is combination of PCA and MLR [60].

Principal component analysis is an analytical technique by which a complex data set containing variables is transformed to a smaller set of new variables [61]. When PCA combined with MLR it is known as the Absolute Principle Component Score-Multiple Linear Regression (APCS-MLR) model [62].

Cluster analysis (CA) also known as hierarchical clustering - is a valuable method of objectively organizing a huge size data into groups on the basis of a given set of characteristics – similarities or dissimilarities [61]. Hierarchical clustering of sampling sites through cluster analysis (CA) and the identification of probable pollution sources through PCA have been broadly used and accepted [65].

Discriminant analysis (DA) is a mechanism to discriminates or classify the outcomes and valuable tool in statistics. DA as a supervised pattern recognition tool for the recognition of the most significant water quality variables responsible for spatial and temporal variability has been used more recently [63]. This method is useful method for construction of categorically dependent values from statistically classified samples. The primary objective of the PCA is to convert a high dimensionality dataset to a lower dimensionality dataset, without losing vigorous information of the data [63].

Multivariate receptor models is vital since it has the tendency to fill the gap of multivariate statistical techniques (MSTs) in quantifying pollution sources contributing to the water pollution, thus it is a very important tool that effectively quantify the pollution sources contributing to water pollution [64]. The application of different multivariate statistical techniques helps in the interpretation of complex data matrices and use full for more understanding quality of water and ecological status [55].

This multivariate Receptor Model technique applied in different countries such as in North America, South America, Asia, Europe, Africa, and accepted as successful tool in evaluating quality of river water [65]. The formula below used to identify contribution of each point source to the receiving water bodies:

$$Q_D C_D - Q_U C_U = \sum_{i=1}^{n} Li - \sum Losses + \sum insitu\ generation$$

Q_U and Q_D represent the upstream and downstream discharge respectively and expressed as m^3/d, C_D and C_U represents downstream and upstream concentrations and expressed as kg biochemical oxygen demand (BOD)/m^3. $\sum L_i$ represents the point sources contribution, estimated by the sum of the loadings imposed by each of the *n* point sources of pollution (*i* ranges from 1 to *n*). The losses and in situ generation terms used to complete the balance equation but are considered negligible in this study [66].

3.8. An Advanced Multivariate Clustering Method

This method is holistic approach for quantification and identification of pollutant sources in surface water [16]. followed this method in which they consider as holistic approach for quantification and identification of pollutant sources of a river basin. In this approach, simultaneous identification of major sources of pollution in the river along with critical pollutants and locations using an advanced hierarchical cluster and multivariate statistical analysis were identified. This technique applied to easily extract important information in large and complex water quality datasets that arise from multiple water quality parameters which collected at multiple stations in different periods; therefore this method used widely to evaluate water quality and identify potential pollution sources illuminate temporal and spatial variations of water quality; as well as identify the potential influencing factors that explain changes in water quality parameters and offers a better understanding of water quality and ecological status of the studied systems [6, 68].

4. Conclusion

Surface water is very important natural resource, but it highly degrading by different pollution factors. Most of this pollution is discharged by human. Besides, also it is arise from anthropogenic factors. To solve this problem currently, water pollution source identification and quantification is an active research area. Different method was used by different researchers and scientist. It is advisable for researcher to select appropriate method based on the object, scope and so on.

Conflict of Interest

Authors have no conflict of interest.

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