Design and Analysis of Mathematical Model for the Concentration of Pollution and River Water Quality

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Abstract
This paper primarily focuses on recent developments in mathematical models that allow for the prediction of river water pollution concentration levels. We believe that these mathematical studies would allow for better planning for the regulation of water quality. The study is an attempt by the researchers to investigate the topic of pollution. For the concentrations of the contaminant and dissolved oxygen, the model consists of two coupled reaction Advection-diffusion equations. Through simulation analysis, numerical solutions are discovered and some significant conclusions are made. When the concentration of the pollutants is involved, the Advection-Diffusion equation is characterised by the reaction component, and in this situation, the original single Advection-Diffusion equation will change into a system of equations. It goes without saying that river purity increases with increasing diffusion and coefficients..

Keywords: Mathematical model,Advection-diffusion equation, water pollution, water quality**.**

1.INTRODUCTION

One of the key components of the environment that determines the existence of life on Earth, influences the climate, and restricts the growth of civilization is water. The management of water resources necessitates ongoing evaluation of its qualitative and quantitative metrics. Water resource conservation and intelligent use are based on an accurate evaluation of the level of water contamination. Lake and dam water quality is continuously declining as a result of eutrophication-related natural processes as well as manmade factors. The modelling of changes that occur in lake waters and related changes in water quality is one of the methods used to address problems with surface water pollution [1]. The mathematical modelling of the quality of water resources has advanced quickly during the past thirty years. Many computer models have been created, and they are effectively used in many different nations today.

The modelling of changes that occur in lake waters and related changes in water quality is one of the methods used to address problems with surface water pollution. By taking into consideration changes that alter water quality parameters or changes in their intensity, such a model may be used to forecast water quality. In many nations, residential or industrial human activity-related water contamination is a serious issue. About 25 million people each year pass away as a result of water contamination. The amount of dissolved oxygen, the presence of nitrates, chlorides, and phosphates, the level of suspended solids, environmental hormones, chemical oxygen demand, such as heavy metals, and the presence of bacteria are just a few of the variables to take into account when evaluating the water quality in a river. Surface and groundwater quality deterioration can be significantly attributed to pollutants from agricultural operations [1]. The first mathematical water quality models date back to Streeter and Phelps' well-known model from 1925, which addressed the equilibrium of dissolved oxygen in rivers [5]. Eutrophication, acute and chronic toxicity, and other issues related to surface water contamination were mathematically explored by Rauch et al. [8]. In order to study the impact of aeration on the degradation of pollutants, Pimpunchat et al. [7] presented a straightforward mathematical model for river pollution. Their model consists of a pair of coupled reaction-diffusion-advection equations for the concentrations of the pollutant and dissolved oxygen. Equation of advection and diffusion. Many mathematical models on river pollution have recently been published in the literature [2], [3], [4], [9], and [10].

2. LITERATURE REVIEW

One of the essential components of the environment that controls life's existence and limits the socioeconomic development of humans is water (Stolarska & Skrzypski, 2012). Surface and subsurface water systems both overseas and domestically have a tremendous impact on daily operations. Primarily for human consumption, as well as for industrial, agricultural, recreational, and other applications. Our daily routines depend on the quantity and quality of water. FAO, 1975; FAO, 1979a; EPA (Environmental Protection Agency), 2003; and Jonnalagadda et al., 1991) is becoming increasingly difficult due to thriving agro-industries and population growth. Ecological diversity is significantly impacted by some industrial, agricultural, and human activities. In additionally, natural factors such as the quality of the water in lakes and rivers affect surface water quality. Dams are constantly degrading as a result of eutrophication-related natural processes and human-made causes (Stolarska & Skrzypski, 2012). The world's water supplies are under stress; eutrophication is a significant environmental problem. issue. High loadings of dissolved and particulate organic matter produce eutrophication. as a result of insufficient soil and water (Goshu & Aynalem, 2017), matter, and inorganic nutrients Inappropriate conservation efforts in the watershed (Teshale et al., 2002; Yitaferu, 2007); the absence of wastewater treatment methods; and wastewater disposal. Perpetual urbanisation and industrialisation, together with more people's activities, have a detrimental effect on water quality and negatively impact the aquatic ecosystem's quality. People's actions are one of the main environmental contamination variables, according to Environmental International Consultant (EIC), 2009. Agriculture methods, industrialisation, and urbanisation all significantly influence how they release a significant amount of organic and inorganic contaminants into the water and the body of water. The majority of businesses, particularly in developing countries such as Ethiopia, discharge untreated wastewater directly into the environment. Cities often have the highest pollution rates caused by insufficient waste management methods and aquatic bodies that are receiving pollutants. Sedimentation is a significant issue for lakes, rivers, and coastal regions as well as dams. According to the EEPA (Ethiopia Environmental Protection Agency), some Addis Abeba-based businesses discharged 90% of their garbage into untreated adjacent open areas and water bodies. Agricultural input discharge Domestic and industrial wastes pollute freshwater systems (fertilizers and insecticides) and harm the environment and socioeconomic values. Organic (pesticides and hydrocarbons) and inorganic contaminants are frequently found in ecosystems. (metals, phosphates, and nitrates). Eutrophication is brought on by the heightened nutrient content. This is a method of accelerating the growth of algae and other kinds of plants in the water system (Hussein et al., 2015). Eutrophication may cause the dissolved oxygen to decrease. a body of water with oxygen (X.E. Yang et al., 2008; Conley et al., 2009). Waterways are crucial. Aquatic creatures: parts of the environment that provide habitat for animals and a supply of water for human activities. However, the lack of resources is a result of the pollution discharged from several sources. Ecosystems require a consistent level of water quality to function (L. Yang et al., 2013; 2015 (Kumarasamy). When it comes to the majority of rivers and lakes in metropolitan areas in developing nations, industries dump wastewater effluents into the downstream portion. The commercial sectors are accountable for dumping 300–400 million tonnes of hazardous sludge, heavy metals, and other substances. Each year, garbage enters water sources worldwide (UNEP) (United Nations Environment Programme, 2012). River water contamination is the source of the environment's highest ecological strain. For instance, the water quality of Lake Tana, Ethiopia, has significantly declined over the years. Due to the development of aquatic pests, recent studies have shown a significant drop in fish supplies. water hyacinth in Lake Tana's vicinity to the fish hatching grounds (Solomon, 2017). The aforementioned issues are mostly caused by an imbalance between environmental and development actions. Protective measures (Teshale et al., 2002). Significant warning signs of this imbalance include: reduced fish productivity; buildup of persistent contaminants in fish species found in reservoirs as well as prolonged reservoir eutrophication periods; water hyacinth development, surface; higher operational expenses for water treatment facilities; more silt in reservoirs; and a decline in irrigation water quality. Consequently, the results of project development and, prior to implementation, related environmental effects from other activities must be taken into account. To successfully manage the environment and minimise the negative consequences of trash on the ecosystem. Continuous monitoring of environmental management, water resources, and quality and volume. The benchmark is an accurate estimate of the level of water contamination. For the management and sensible use of water resources. One of the fundamental methods. The modelling of changes in water quality is necessary to address the issue of water pollution. Mathematical modelling has advanced quickly in recent years (Stolarska & Many different models have been used up to this point (Skrzypski, 2012). Models in mathematics have been used to evaluate how wastewater flow fluctuations affect water quality (World (1998, Bank Group). Numerous mathematical models of water quality have been created and used by certain scholars to investigate the quality of water in various nations, such as Poland (Stolarska & Skrzypski, 2012), the Shenandoah River watershed in the United States (Mbongowo et al., 2019), Florida Bay, South Korea in the Ara artificial canal, and others (Carl et al., 2000). (Zhenhao & Dongil, 2013). One-dimensional water quality models have been used for water quality evaluation in a variety of water bodies. Hydrodynamic and water quality models in 1D and 2D were created. Reservoirs have been studied using mathematical models (Q. Wang et al., 2013; Kayode & Muthukrishna, 2018). The Singapore Straits and Kas Bay (Sundarambal and Pavel, 2014) (Kagan & Lale, 2015). This research is critical for water body management and planning. A brief analysis of water It has also produced high-quality models (Bai et al., 2011; Q. G. Wang et al., 2009). Among the goals of The appropriateness of the water for the planned application will be determined by a study of its quality. In terms of water quality Data on the primary and secondary water levels as well as the quality of the water has been utilised in modelling (Tri et al., 2018). Models used to study water quality use both mathematical and professional scientific terminology. Judgment, which includes models based on processes (mechanistic) and data (statistical). They are useful tools for evaluating and forecasting the movement of pollutants (Q. G. Wang et al., 2009; Bai et al., 2011, Huang et al., 2012), which detect pollution, the fate of contaminants, and their behavior. Simulating and predicting intricate processes in aquatic ecosystems (Q. G. Wang et al., 2009; Liu, 2018), understanding the temporal and geographical distribution of contaminants in the water, and stepping up decisions on how to change the quality of the water (Q. Wang et al., 2013). Models of water quality are also required for analysing and researching the environmental conditions of various water bodies. Whether beginning or boundary circumstances are altered, how the quality of the water changes (Kayode & Muthukrishna, 2018), determining future surface water quality, and carrying out environmental effect evaluation using various pollution scenarios (Q. Wang et al., 2013). The figures perform on and play a significant role in lowering the cost of labour, materials, and time for many pollution-related costs. Some mitigation scenario experiments for watersheds and watercourses have been conducted (Q. Wang et al., 2013). To replicate the quality of the water, a variety of models have been utilised. Many water systems, including rivers, streams, lakes, and reservoirs; estuaries; seas; and coastal waters, have poor water quality (Loucks & Van Beek, 2017). There have been several water quality Different model algorithms have been used to create models (Liou et al., 2003; Q. Wang et al., 2013) by several businesses and academics. But because of the many ideas and algorithms employed, the modelling outputs of various models used in the models have substantial variances. As a consequence, the When making environmental management choices, the usage of several models There is no way to link or correlate outputs with one another (Obropta et al., 2008). Assessment monitoring of pollutants is a difficult undertaking that necessitates a constant updating of models already in use and the creation of fresh water quality models. In the initial water quality investigation, Streeter and Phelps carried out modelling to replicate BOD and DO in a river system in 1925. (Chapra, 2008; Cox, 2003). The estimation and forecasting of water contamination using water quality modelling strategies for simulation in mathematics. An example of a water quality model is made up of several formulas, illustrating the physical processes that control the location and motion of contaminants in a body of water (Victoria, 2012). The concept of mathematical modelling of water quality is one of the most effective methods to gauge the current pollution load, pollution transfer, and future cause-and-effect relationship between polluting sources and water quality (Nair & Bhatia, 2017). Making better, more technically sound decisions is made possible by water quality modelling. Among the management options for water quality, effective solutions The examples are necessary to find more effective solutions to concerns with sustainable water quality in the long term. Models are also necessary to offer a foundation for economic analysis, and after that, decision-makers can use the results to evaluate a project's environmental effects and benefit-cost analysis. Water quality has been assessed and modelled using its physical features that are chemical and biological. The connections between the linked processes are Water system administrators must work to create these qualities, which must be comprehensive. a good understanding of the key elements and mechanisms influencing each region's water quality. If they are to implement proper or enhanced management of the local water supply, they are accountable for decisions (Liu, 2018). The distribution and concentrations of pollutants are affected by the contaminants' inactivation and a few dynamic processes, such as diffusion, dispersion, and advection. The water flow parameters, influent, and output of these operations are all tightly connected. entry and exit of effluent from the aquatic body, wind stress, and stratification of temperature (Liu, 2018). Consequently, to have a greater understanding of how the environment and water systems work, solid information acquired from water that is not tainted is required to make wise selections and choices. Modeling of high quality is important. Integrated water quality evaluation techniques include model-based simulation and physical observation. Agencies, resource managers, planners, scientists, engineers, and project implementers can use it. Aiding in the achievement of basin-wide, large-scale, and small-scale load reduction targets. The water system is often investigated using a variety of methods, such as theoretical studies, outdoor observations, laboratory testing, and mathematical models. Analysis in the lab and in the field. The most reliable way to obtain concrete data for a given system is through observations. This will offer a trustworthy foundation for analysis and modelling. While being noticed or quantified. Typically, data are scarce and insufficient to provide or forecast a complete picture of the actual situation in the large and complex water body. Furthermore, the information that is already accessible is low-quality data with many inaccuracies, which might prompt researchers to create a false or incorrect perception of what is actually taking place. The mathematical analysis of water quality in these situations, modelling in conjunction with observations for calibration and verification is crucial.

3. PROPOSED METHODOLOGY

The water quality model, adapted to the main stream of river, simulates the behavior and concentration distributions for different water quality parameters. The water quality module solves the following parameters, grouped according to the chemical properties:

1 Physics: Temperature, Salinity, Suspended Solids, Electic Conductivity.
2 Biochemical: Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Fecal Coliforms (FC).
3 Eutrophication: Ammonia Nitrogen (NH_3), Nitrates (NO_3) Organic Nitrogen ($N_o r$ g), Inorganic phosphorous (phosphate, PO_4), organic Phosphorous ($N_o rg$).
4 Metals: Cadmium, Chromium, Nickel, Lead, Vanadium, Zinc.
5 HAPs: Acenaphthene, Phenanthrene, Fluoranthene, Benzo (a) Anthracene, Naphthalene. The transport and transformation of the different environmental parameters was carried out by applying the Advection diffusion equation

$$\begin{aligned} \frac{\partial(RG_s(x,t))}{\partial t} &= \Phi_p \frac{\partial^2(RG_s(x,t))}{\partial x^2} - \frac{\partial(WARG_s(x,t))}{\partial x} + M \int \; G_s(x,t)dx, \\ \frac{\partial(RF_s(x,t))}{\partial t} &= \Phi_p \frac{\partial^2(RF_s(x,t))}{\partial x^2} - \frac{\partial(WARF_s(x,t))}{\partial x} + \gamma \int \; (S - F_s(x,t))dx \end{aligned} \tag{1.1}$$

With boundary conditions

$$G_s(0) = \frac{r}{Rk}; \; F_8(0) = s + \frac{r}{Rk} \tag{1.2}$$

To simplify the equations, we will consider only the steady state solutions. Where

L-Polluted length of river (15787 m)

Φ_x - dispersion coefficient of dissolved oxygen in the x direction ($\mathrm{m}^2/$ day)

Φ_p - dispersion coefficient of pollutant in the p direction ($m^2/$ day)

R - cross - section area of the river (m^2)

S - Saturated oxygen concentration(less than 5) ($\mathrm{kg/m}^2$)

γ - Mass transfer of oxygen from air to water of the river ($\mathrm{m}^2/$ day)

M - Mass transfer of solid (solute) to the water of the river ($\mathrm{m}^2/$ day)

k - Degradation rate coefficient (per Day)

$r-$ Rate of pollutant addition along the river (kg/m/day)

$w-$ Water velocity in the x - direction. (m^2)

The first equation includes the mass transferred of solid (solute) to the water (river) in $\mathrm{m}^2/$ day, and it's the concentration of pollution. The second equation is a mass balance for dissolved oxygen, with addition through the surface at a rate proportional to the degree of saturation of dissolved oxygen$(S-F)$, and consumption during the oxidation of the pollution. We can write equations (1) and (2) as:

$$\begin{aligned} \frac{\partial(RG_s(x,t))}{\partial t} &= \Phi_p \frac{\partial^2(RG_s(x,t))}{\partial x^2} - \frac{\partial(WARG_s(x,t))}{\partial x} + MG_s(x,t), \\ \frac{\partial(RF_s(x,t))}{\partial t} &= \Phi_p \frac{\partial^2(RF_s(x,t))}{\partial x^2} - \frac{\partial(WARF_s(x,t))}{\partial x} + \gamma(s - F_s(x,t)), \end{aligned} \quad (1.3)$$

For these the only variation is with the distance downstream on the river and so we write $G_s(x,t) = G_s(x)$ and $F_s(x,t) = F_s(x)$. To simplify the equations we will consider only the steady state solutions [11], [12], [13], [14]. We begin by considering the case when the dispersion can be taken to be $\Phi_x = \Phi_x = 0$. For this case the equations (4) and (5) becomes as:

$$\begin{aligned} -\frac{d(WARG_s(x,t))}{dx} + MG_s(x) &= 0 \\ -\frac{d(WARF_s(x,t))}{dx} + \gamma(S - F_s(x)) &= 0 \end{aligned} \quad (1.4)$$

with boundary conditions $G_2(0) = \frac{q}{Ak}$; $F_S(0) = S + \frac{q}{Ak}$. For this case there is no pollution upstream because of the absence of dispersion. By solving equation (6), we get:

$$\frac{d(WARG_s(x))}{dx} - MG_s(x) = 0, \quad (1.5)$$

$$WAR\frac{d(G_s(x))}{dx} - MG_s(x) = 0, \quad (1.6)$$

$$\frac{d(G_s(x))}{dx} - \frac{M}{WAR}G_s(x) = 0, \quad (1.7)$$

Then, by solving the equation (9), we can find the integral operator of this equation as:

$$\frac{d(G_s(x))}{dx} - \frac{M}{WAR}G_s(x) = 0 \quad (1.8)$$

$$\frac{d(G_s(x))}{dx} = \frac{M}{WAR}G_s(x) \quad (1.9)$$

$$\frac{d(G_s(x))}{dx} = \frac{M}{WAR}dx \quad (1.10)$$

$$\log\left(G_s(x)\right) = \int \frac{M}{WAR}dx + C, \; C = \frac{r}{Rk} \quad (1.11)$$

$$= \frac{M}{WAR}x + \frac{r}{Rk}$$

$$G_s(x) = e^{\frac{N}{WAK}x+\frac{r}{hx}} \quad (1.12)$$

$$G_s(x)e^{\int \frac{M}{WAR}dx} = \int 0e^{\int \frac{M}{WAE}dxdx} + C \quad (1.13)$$

$$G_s(x)e^{\frac{M}{WA}*} = \frac{r}{Rk}. \quad (1.14)$$

We find the pollution concentration downstream of the river $G_s(x)$, such that :

$$G_s(x) = \frac{r}{Rk}e^{\frac{-M}{WAN}x}$$

(1.15)

Which represent the pollutant concentration downstream of the river, these result tends to that the limit of these equation as:

if $x = 0$, then $G_s(x) = G_s(0) = \frac{r}{Rk}$ (1.16)

and if $x = \infty$, then $G_s(x) = G_s(\infty) = \frac{r}{Rk}e^{-\infty} = 0$ (1.17)

We believe that results are close to the truth because there is no government programming. For treatment or decreasing the high pollutant in the river. Now to find the dissolved oxygen concentration by solving equation (7), we get:

$$\frac{d(W_{AR}F_s(x))}{dx} - \gamma(S - F_s(x)) = 0,$$

$$WAR\frac{d(F_s(x))}{dx} + \gamma F_s(x) - \gamma S = 0, \quad (1.18)$$

$$\frac{d(F_s(x))}{dx} + \frac{\gamma}{WAR}F_s(x) = \frac{\gamma}{WAR}S,$$

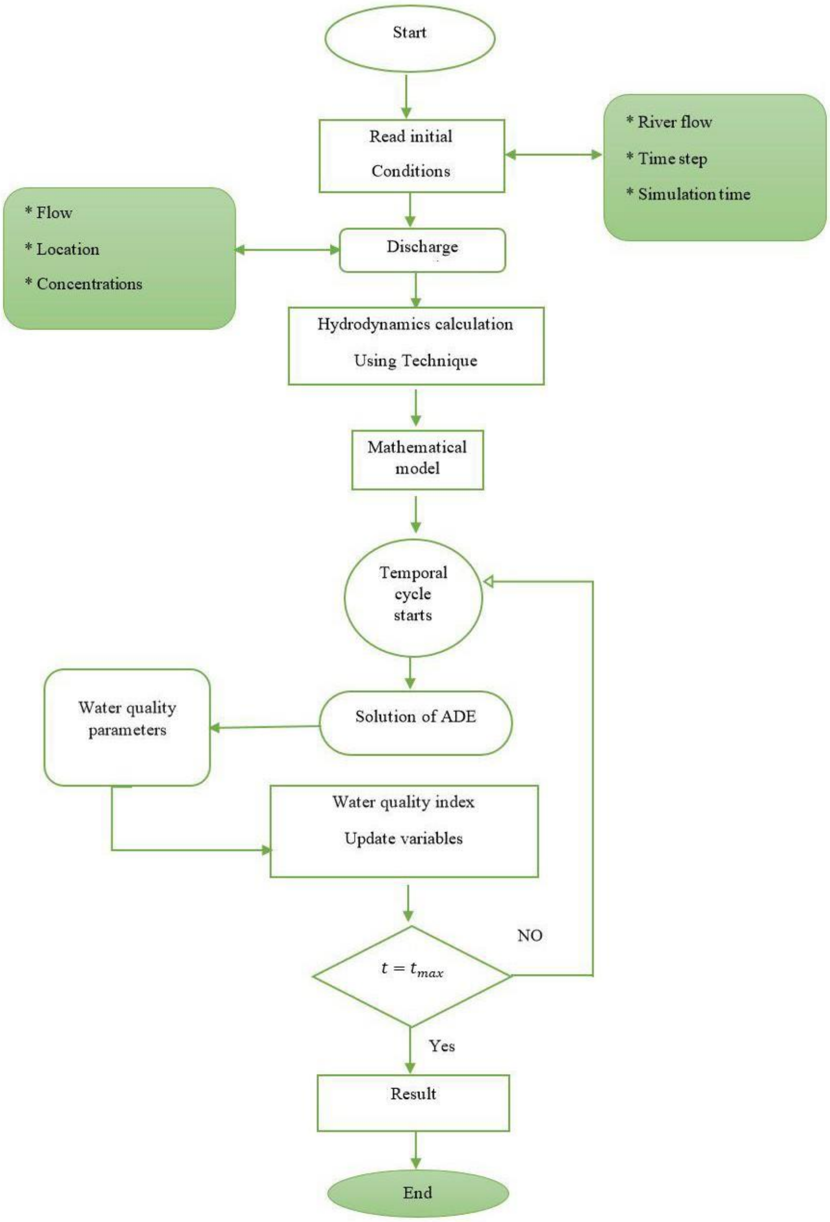

Fig. 1. Diagram of the Mathematical Model

Figure 4.1 Implementation Mechanism Comprehensive Approach

Then, by solving the equation (12), we can find the integral operator of this equation:

$$\frac{d(F_s(x))}{dx} - \frac{\gamma}{WAR}F_s(x) = 0 \tag{1.19}$$

$$\log\left(F_x(x)\right) = \int -\frac{\gamma}{WAR}dx + C,\ C = \frac{r}{Rk} = -\frac{\gamma}{WAR}x + \frac{r}{Rk} \tag{1.20}$$

$$F_s(x) = e^{-\frac{\gamma}{WAN}x + \frac{\gamma}{mk}} \tag{1.21}$$

$$F_s(x) = ve^{-\frac{\gamma}{WA\pi}x},\ v = e^{\frac{r}{RR}} \tag{1.22}$$

$$F_s(x)e^{\int\frac{\gamma}{WAR}dx} = \int \frac{\gamma S}{WAR}e^{\int\frac{y}{WAR}dx}dx +$$

$\frac{r}{Rk}$ (1.23)

$$F_s(x)e^{\frac{\gamma}{WAK}x} = \int \frac{\gamma S}{WAR} e^{\frac{\gamma}{WAK}x} dx + \frac{r}{Rk} \tag{1.24}$$

$$F_s(x) = \mathrm{S} + \frac{r}{Rk} e^{-\frac{\gamma}{WA\pi}x} \tag{1.25}$$

Which represent the dissolved oxygen concentration downstream of the river, these result tends to that the limit of these equation as:

if $x = 0$, then $F_s(x) = F_s(0) = \frac{r}{Rk}$ (1.26)

if $x = \infty$, then $F_3(x) = F_s(\infty) = S + \frac{r}{Rk} e^{-\infty} = S$ (1.27)

This means that the downstream of a river dissolved oxygen being constant and its value consistent with the saturated value of S. These mathematical results consisted of the actual results, and these results may be attributed to the controlling of adding of a pollutant that reduces the dissolved the oxygen that necessary for survival life (res Fig 1).

4. RESULT ANALYSIS

In this part, we made the assumption that a fair approximation to the river pollution model may be the advection diffusion equation. Since we assumed that the cross section of the river is uniform, we also assumed that the river is linear or one-dimensional. That refers to a cross-section of a river in one dimension with arbitrary interior locations (x=0) and (x=L). To examine the movement of contaminants, we created a computer model that solves the Advection-Diffusion equation. The model's predictions and observations of velocity direction, magnitude, and water quality metrics all match. As a result, it is believed that the established model may be put into use and used to a variety of circumstances.

5. CONCLUSION AND FUTURE WORK

The mathematical model, which relied on advection diffusion equations for the concentrations of the pollutant and dissolved oxygen, has been widely used to forecast river water quality and to give trustworthy tools for managing its quality in impacted regions. In the physical research regions, this model is used to mimic the geographical and temporal distributions of several factors linked to water quality. The decision-supporting tools for water resource management are improved by the application of mathematical models in the simulations. Numerous aspects of water quality, including dissolved oxygen level, water velocity, pollutant addition, and saturation oxygen concentration, must be measured and employed in the model. It has been shown that river purity increases with increased diffusion and reaeration coefficients.

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