



Modelling of pH/Conductivity in the Transportation of Solute Contaminants in Surface Water through the Life of a Mine

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ABSTRACT

Demand for water quality is uncontained because of the rising population growth. It is impossible to overstate the stress caused by human activity since every person requires their own space to thrive and does not care about others. The majority of water pollution is caused by mining, primarily by the release of sulfate ions ($\text{SO}_4^{2-}(\text{aq})$) and toxic ferrous iron ($\text{Fe}^{2+}(\text{aq})$) into the environment, which results in acid mine drainage (AMD). This research proposed a Model of pH and conductivity of surface water as a transport medium of solutes during mining activities with an enhanced Wireless Based Sensor Probe for real-time monitoring using the Internet of Things (IoT) and smartphones. Baseline data was established, and samples were collected at 100m intervals from the mine to the river. The sampling program was tailored to the target mineralization and ground conditions, where all data interpretation and collation will be available on a cloud server and Android smartphone. The result of the laboratory and field data collected in real-time will finally validate the model.

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INTRODUCTION

Over the years, water quality has become increasingly important, owing to the increased demand of the growing population. Anthropogenic activities including mining, industry, agriculture, and the release of household and industrial wastewater have contaminated the majority of water resources, placing some pressure on the supply side (Camden-Smith et al., 2015). Most water pollution in South Africa is caused by mining, primarily from abandoned mines that have continuously released pollutants into surface and groundwater over the years (Tutu, 2012).

There has been widespread concern over organic pollutants, such as contaminants of emergent concern (CECs), in aquatic habitats. To ensure that people will always have access to clean drinking water and that the environment will be developed sustainably, efforts must be made to understand the distribution and movement of the many types of CECs found in the aquatic environment (Pietrzak, 2021). Complex

mathematical models are now employed to simulate the flow of organic contaminants in the soil-water system, thanks to developments in software (Kumar & Singh, 2019). These models can be used to compute transport parameter values via inversion and simulate the movement of contaminants. The results of a literature review of software available for simulating the movement of organic contaminants in groundwater are compiled in this article (Ijort & Year, 2021).

Assessing water quality indicators is a critical component of integrated water resource management, given that drinkable water is vital for global health and sustainable development (Ngene et al., 2021). A coupled MODFLOW and MT3DMS (Mass Transport 3-dimension multi-species) model was used in the current study to detect the process of groundwater pollution from drains when fresh water is affected and the contamination level exceeds acceptable limits. This made it possible to combine two water supply systems: groundwater and surface water (polluted drains and canals) (Abd-Elaty et al., 2019).

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Majority of streams impacted by coal mine drainage have significant concentrations of iron and sulfate and are acidic (pH 2.5 to 6.0) (Chen et al., 2021). Often precipitating as a fine floc, ferric hydroxide can damage aquatic life and cover stream bottoms. AMD can extract harmful metals from rocks and soil, including copper, aluminum, and zinc (Daniel A.Vallero, 2006).

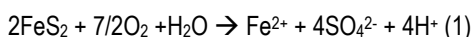
Geochemical modeling is still a reliable technique for reducing the issue of acid AMD because it provides a better understanding of contaminants and aids in decision-making. Therefore, these studies seek to suggest suitable remediation plans for contaminated water, project possible environmental effects of contaminants, and perform general risk assessments.

Acid Mine Drainage and Its Impact

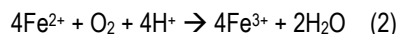
Naturally occurring acid mine drainage (AMD) is produced when hard rock mines containing pyrite are exposed to the atmosphere or other oxidizing environments. Iron, sulfate, and other metals are present in this acidic water, which has a pH of less than five. The corrosive water released into the environment by mining operations is another name for AMD. It also expedites the deterioration of minerals containing sulfides. Bacteria found in nature have the ability to hasten AMD development (John et al., 2017).

Pyritic minerals are invariably exposed to oxygen and water during coal mining. The spaces caused by the mining process expose these materials in deep mines (Amrclearinghouse.Org ::::AMD Basics - PYRITE REACTIONS:::, n.d.). Moreover, they come to the surface with the coal as spoils. The gangue materials are subsequently separated from the coal and are usually stacked into sizable areas known as culm banks, gob piles, boney piles, and slate dumps.

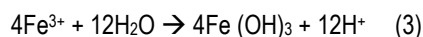
A well-researched phenomenon, acid mine drainage (AMD), is the primary issue in abandoned mining sites, including coal and gold mines. The oxidation of sulphide to sulphate and ferrous ions is the first of AMD's four sub-reactions (Camden-Smith et al., 2015).



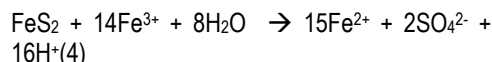
The resulting ferrous iron oxidizes when it is added to surface water systems that absorb it. This process depends on pH and oxygen in an acidic environment (pH<3) and proceeds slowly [4].



The acidophilic bacteria *Thiobacillus ferrooxidans* catalyzes this process. This reaction's slow rate makes it the process that ultimately determines the rate at which acid is generated. When radiating acidity (H^+) comes into touch with minerals like calcite (CaCO_3), it can undergo under-neutralizing processes that raise pH and prolong concentrations of Fe^{2+} and SO_4^{2-} (Santelli et al., 2001). When the ferric hydroxide ($\text{Fe}(\text{OH})_3$) that was produced in process 2 precipitates as ferric ion (Fe^{3+}), further acidity is released:



Iron hydroxide transforms into goethite (FeOOH), a common iron (III) oxide, by losing a water molecule and going through structural reorganization. The fourth step is the oxidation of excess pyrite by ferric ions, Fe:



Both industrialized and developing nations mine, which increases government revenue and raises living conditions by creating jobs (C. Nhantumbo et al., 2018). It is expensive to restore rivers and ecosystems damaged by AMD, and programs to monitor water quality are frequently absent from underdeveloped nations, making it difficult to determine how mining has affected local water supplies (Anwar et al., 2015). Human and financial resources restrict the ability to enhance existing water quality monitoring programs. To anticipate changes in water quality, indirect techniques like modeling provide an alternative. This makes it possible to allocate resources for water quality monitoring programs as efficiently as possible (C. M. C. Nhantumbo et

al., 2015). Several models, including Streeter-Phelps, QUAL, WASP, QUASAR, MIKE, BASIN, EFDC, OTIS, and PHREEQ C, have been created over time to replicate the processes that control the quality of the water in surface waters (Burigato Costa et al., 2019).

The water quality index (WQI) shows from a study that it is valuable and unique to depict the overall water quality status in a single term. To have an appropriate use, WQI is helpful for the selection (Dohare et al., 2014).

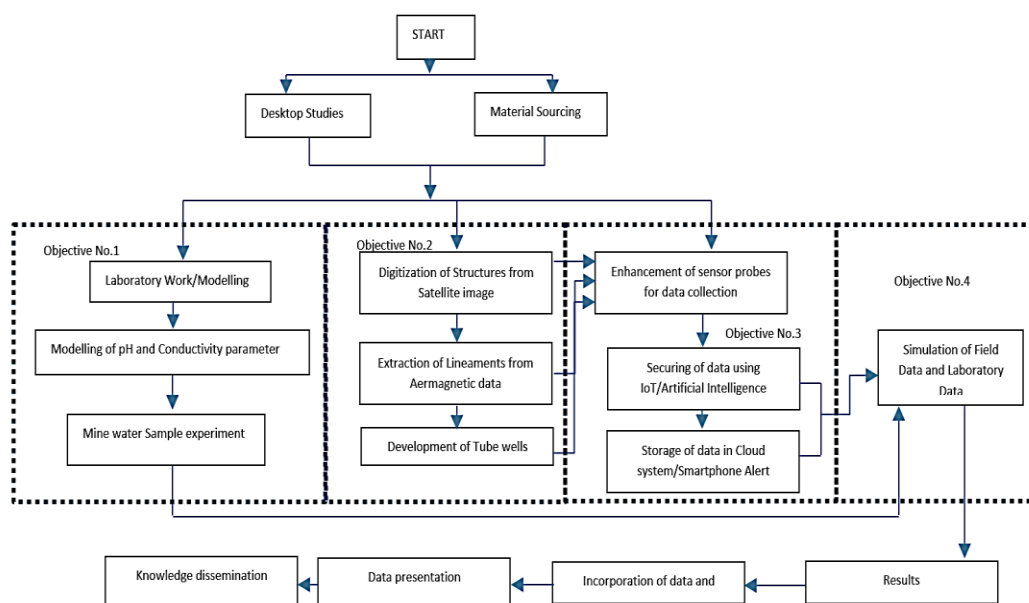
MATERIALS AND METHOD

Objective 1: To analyze quantitative results of laboratory modelling of pH/conductivity of collected water samples from existing mines.

Objective 2: To develop a quantitative correlation between the structural network and groundwater flow direction of the mine site and environs.

Objective 3: To enhance a monitoring Wireless Based Sensor Probe for real-time monitoring of pH and Electrical Conductivity of mine effluents in Maiganga Coal Mine, Akko Local Government Area of Gombe State, Nigeria, using the Internet of Things (IoT) and smartphone.

Objective 4: To verify and simulate laboratory data with real-time data from the sensors for corroboration.



Modelling of Transport of Solute

The spatial and temporal variations at their boundaries are frequently oversimplified in models that simulate water flow in unsaturated zones. Similarly, regional groundwater-flow models streamline vadose-zone operations and necessitate the external calculation of groundwater recharge from the vadose zone through other streamlined processes. As a result, "large-scale" or coupled systems must be created

to address the regional spatial interaction between the two water zones (Dohare et al., 2014). The three-dimensional, finite-difference groundwater flow model that was simulated was done using Anasys 16.2 Workbench. This integration allows the Fluid Flow (Fluent) model to generate simulated recharge fluxes at the groundwater table's lower boundary. These fluxes act as inputs, or the upper-boundary condition, for the mode.

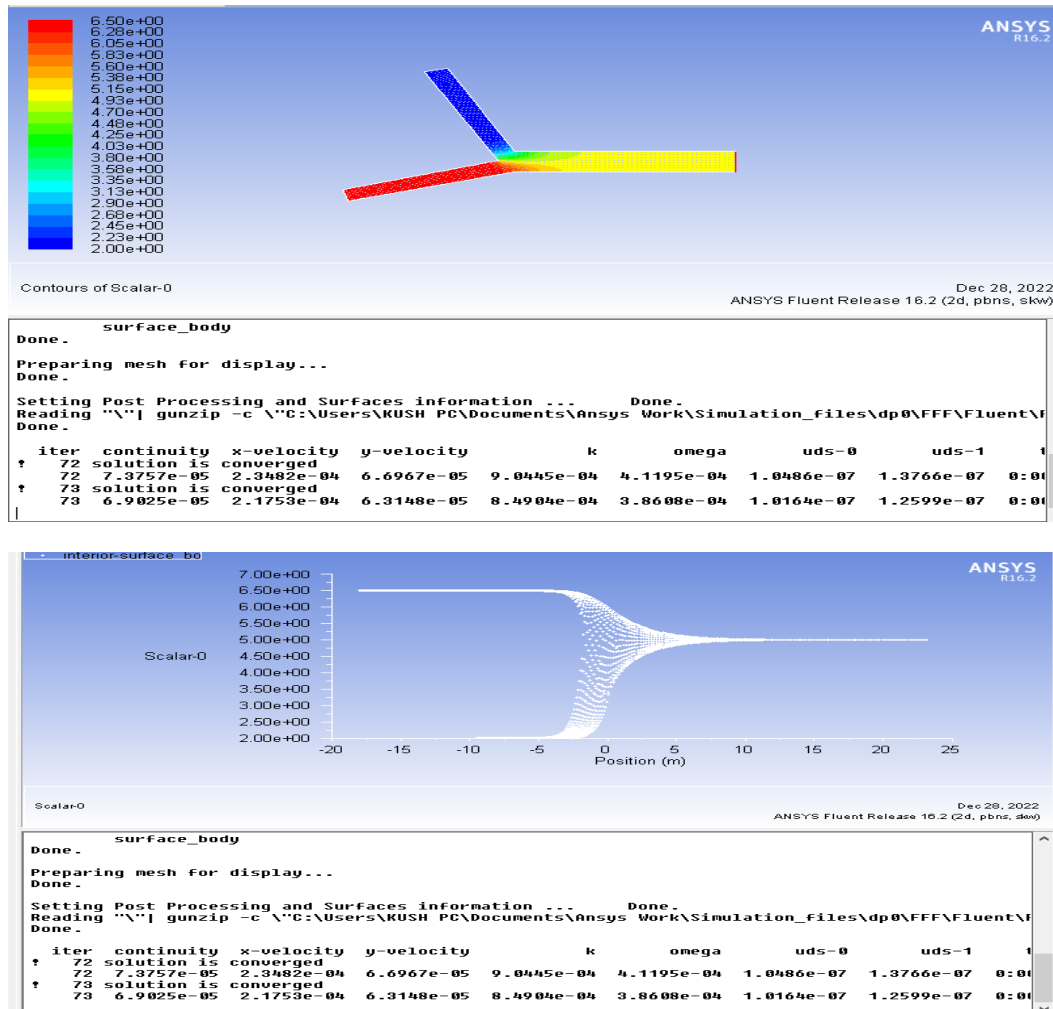
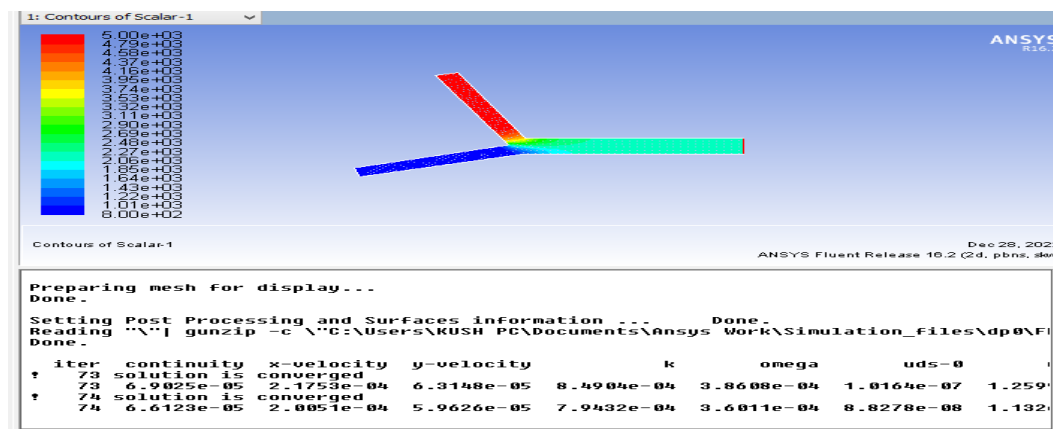


Figure 2: Simulation of water for pH from the mine in Maiganga Coal Mine, Gombe, Nigeria



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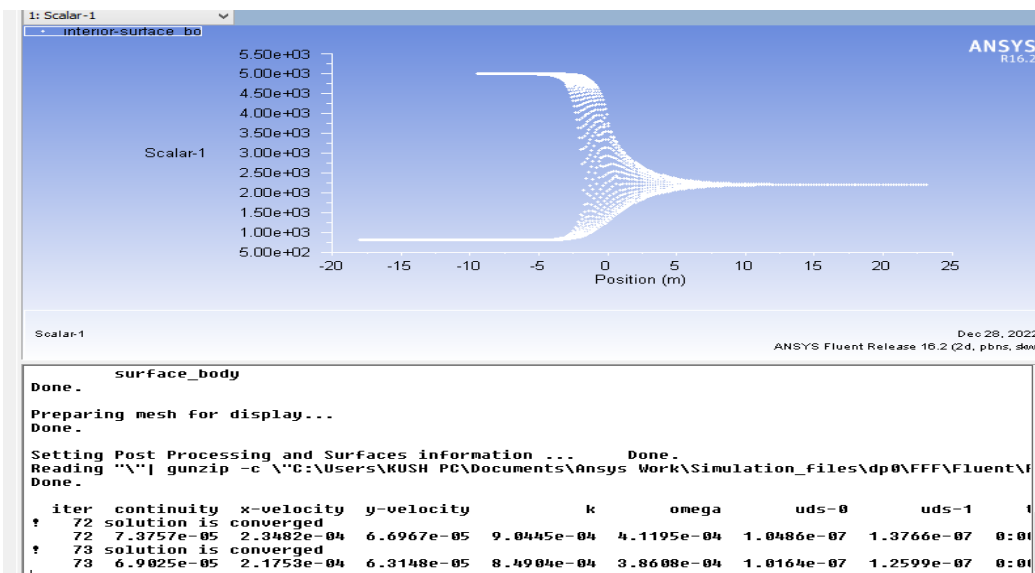


Figure 3: Simulation of water for EC from the mine in Maiganga Coal Mine, Gombe, Nigeria

Many opportunities for further development in modelling applications are promising. pH and EC embed much information with low-cost technology applications, potential site-specific applications, and solute-specific need to 'train' the algorithm pH and EC sensors: the application is durable. However, maintenance is still required because the EC signal is easily clouded by point sources (road salting and sewage discharge) (Novák & Hlaváčková, 2019).

Structural Impact on Transport of Solute

The impact of topography on groundwater flows and water table depths throughout the contiguous United States (CONUS) was examined by Condon et al. (Condon & Maxwell, 2015). They discovered that groundwater tables are frequently thought of as muted copies of topography. Kosovo (Kodešová et al., 2009) found that different soil types have varied soil structures, and that horizons significantly impact how contaminants move through soils and water flows through them. While the experiment's structural modifications impacted solute transport and water flow, the dual-permeability and two-site sorption models could closely match the experimental data (Li et al., 2016).

This work used the groundwater flow model and calibrated analytical solutions to estimate pollutant concentration and variation trends. Contaminants will migrate and agglomerate in the flow direction toward the wellhead as long as pumping is continued (Meyer et al., 2019). The concentration and range of pollution increase, as does the flow rate. Below is a figure showing the correlation between satellite images and aeromagnetic data.



Figure 4a: Satellite image showing surface structures (Black Lines) mostly flowing south ward towards the river.

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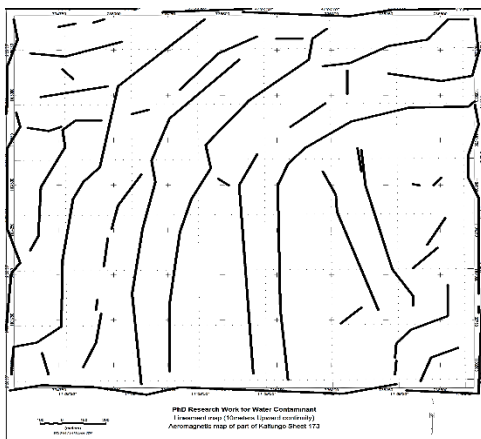


Figure 4b: Structures measure at about 10m near

Design of Wireless-Based Sensor Probe for Real-Time Monitoring

Ahmed critically evaluates recent developments in chemical sensor-based real-time

water quality monitoring. He focused on the systems purportedly tested online using real water samples and their viability for extended usage. The assessment demonstrates that numerous challenges remain in developing a single sensing strategy that would meet the needs of various scenarios. The most effective systems use chemical sensing as their foundation.

Ahmed et al. (Ahmed et al., 2020) Conduct a thorough analysis of WSN-based and conventional laboratory water quality monitoring systems. On the other hand, its second portion recommended an IoT-WQMS for residential water. The coordination module, data processing and analysis module, storage and core analytics module, and sensor module make up the system's four primary modules. Although the authors state that four sensors were employed, the sensor for TSS is missing from the graphic since the sensing module only shows pH, turbidity, and temperature (Figure 5).

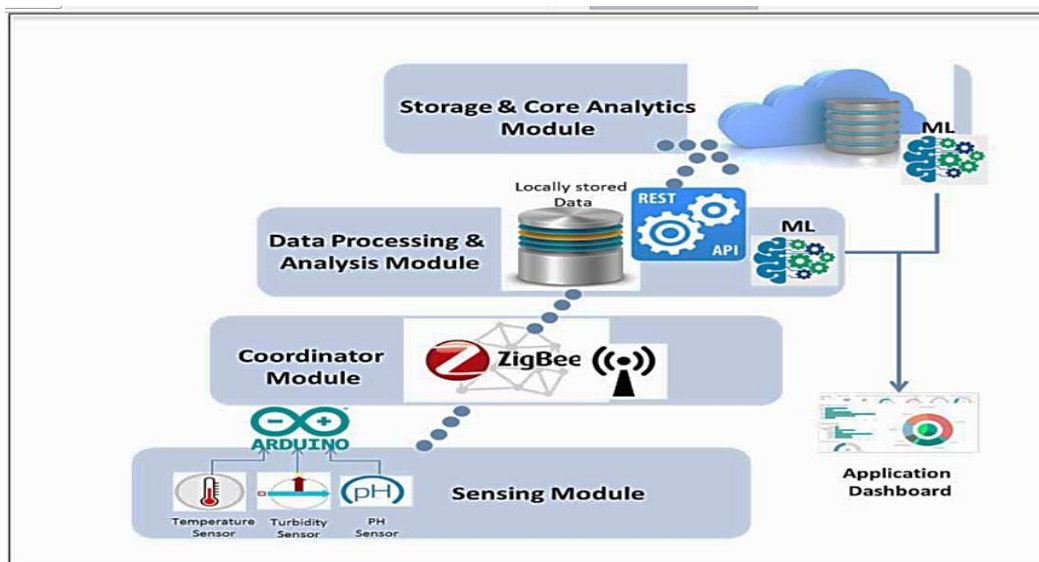


Figure 5: The suggested Water Quality Monitoring and Detection System (WQDMS)(Vijai & Sivakumar, 2016).

Table 1 thoroughly explains and evaluates a number of research studies on the Internet of Things, machine learning, and manual laboratory analysis. The parameters of the research technique used by the researchers for the topic, the research paper's limitations, the

dataset used, the water quality metrics employed, the findings, and the hardware used in the suggested solution have all been taken into consideration when comparing the research papers.

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Table 1: A comparison of different research papers about the detection of water quality (Shafi et al., 2018)

No.	Authors	Methodology	Limitations	Dataset	Parameters	Results	Hardware
1	(Mining Exploration Sampling Mining Exploration Analysis SRK, n.d.)	LS-SVM estimation of BOD5 and COD	It is not practicable for an IoT system to use nine WQPs.	200 datasets from the River Karoun	EC, pH, turbidity, Ca ²⁺ , Na ⁺ , Mg ²⁺ , NO ⁻² , NO ⁻³ , PO ³⁻⁴ .	RMSECOD = 4.461 and RMSEBOD5 = 5.463	N/A
2	(Najafzadeh et al., 2019)	Using MT, EPR, and GET to estimate BOD, COD, and DO	Its application for IoT systems is cumbersome because it still requires nine parameters, even if it is unquestionably a superior option to empirical computations.	Dataset of River Karoun, Iran	EC, pH, turbidity, Ca ²⁺ , Na ⁺ , Mg ²⁺ , NO ⁻² , NO ⁻³ , PO ³⁻⁴ .	RMSECOD= 4.997, RMSEDO= 4.728, and RMSEBOD = 5.388	N/A
3	(Najafzadeh et al., 2018)	Sensor monitoring with DNN, NN, SVM, and KNN water quality classification	solely distinguishes between two categories for water quality: excellent and poor. No usage of the standard WQI has occurred.	667 sample datasets gathered from PCRWR for analysis	temperature , pH, turbidity,	Precision: DNN 93% SVM 91% 86% NN, 76% kNN	Parameter sensors, LCD, and ATMega328
4	(Shafi et al., 2018)	Sensor and cloud infrastructure monitoring	Did not anticipating it, just monitoring	N/A	pH, turbidity, water level, and conductivity	N/A	Sensors and controller for the TI CC3200
5	(Geetha & Gouthami, 2016)	General assessment of Pakistan's provinces' water quality	Just manual analysis in the lab	manually collected samples throughout Pakistan	E. coli, fecal coliform, and total coliform	Elevated total coliform brought on by sewage	N/A

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No.	Authors	Methodology	Limitations	Dataset	Parameters	Results	Hardware
6	(Daud et al., 2017)	Monitoring water quality with sensors and SOAP web services	Just for observation only, no forecast	N/A	pH, dissolved oxygen, and temperature	N/A	ZigBee transceivers, Arduino modules, and parameter sensors
7	(Molina et al., 2022)	Aqua farmers can be informed of contamination with a real-time monitoring system and a mobile application.	Merely offers observation; does not analyze data for patterns	N/A	Temperature, pH, DO, ammonia, salt, nitrate, and carbonates	N/A	Raspberry Pi 3 with a sensor node, solar panel, and built-in Wi-Fi module
8	(Sita et al., 2017)	Xively IoT platform, web services, adaptive sampling methodology, and adaptive sampling of water are used to monitor the quality of the water.	This study only provides sampling-based monitoring; it does not give real-time water quality monitoring. Not a forecasting study	N/A	N/A	N/A	Xively IoT platform and ARM-Cortex M3 CPU comprise the Neonode wireless sensor platform. Automatic sampler (ISCO 3700, capable of holding 24 bottles)
9	(Wong & Kerkez, 2016)	Fuzzy systems and artificial neural networks (ANNs)	Suggests a general-purpose IoT system devoid of any data and outcomes	N/A	Temperature, conductivity, pH, nitrates, chlorine, ORP, and turbidity	N/A	Connectivity and sensors: Bluetooth, 3G, and ZigBee

Futures and Directions of novel AMD Monitoring

Recall that pH is regarded as a chemical component of wastewater, much like electrical conductivity (EC), which means it has a definite

impact on the wastewater treatment process. You can use a chemical or biological treatment procedure, but this measurement works both ways (Massima Mouele et al., 2021). The characteristics above necessitate real-time

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monitoring of mine water to ensure the appropriate administration of pH and EC control measures. Larger industrial or water treatment facilities that demand higher standards of quality and dependability need to be constantly monitored. Maintaining the ideal water chemistry for aquatic and human life requires precise pH and EC levels management. It will take ongoing online monitoring with automated instrumentation to achieve the necessary level of precision (Essamlali et al., 2024).

To ensure continuous effective system monitoring, tube wells along the groundwater/surface water flow direction will have pH and EC sensor probes installed. These probes are based on digitized structures from aeromagnetic data/satellite images (Figures 4a and b) for monitoring the geological units. After installation, the pH and conductivity probes will be calibrated by the World Health Organization's legal limit to convey information over a wireless system network using IoT/Artificial Intelligence and Storage of data in a system/Smartphone Alert (Usman et al., 2019).

A thorough evaluation of laboratory and WSN-based water quality monitoring systems will be conducted as part of this study. For mine water, on the other hand, the second phase will consist of an IoT-WQMS that has five main modules: (i) coordinator; (ii) sensing; (iii) storage and core analytics; (iv) data processing and analysis; and (v) modeling of field and laboratory data. Authorities can use decision-support tool when awarding new mining permits, and various enterprises that generate toxic wastewater can use it to control the amount of their industrial effluent released into the environment.

CONCLUSION

A data collection and sampling program was created to reduce the possibility of obtaining skewed or non-representative samples. The laboratory model will be verified by analyzing the model's output and taking into account the buffer effect of carbonic acid in water as well as values using laboratory data. The simulation's data indicates that contaminants from the mine will inevitably flow into the river before their

concentration changes, putting anyone exiting the mine along the flowline to the river in danger. The mine site and its surroundings are structurally controlled, presenting a surface and groundwater pollution risk. Even though this research is still in its early stages, its completion will involve using smartphones and the Internet of Things (IoT) to track the flow of contaminants and solutes during a mine's planning process from start to finish. Additionally, a model will be provided based on flow, pH, and electrical conductivity data from the Mine and its tributaries—which could be altered by solute transport.

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