

Assessment of Impact of Mining on Water Quality and it's Modelling

Amarendra Sahoo



**Department of Mining Engineering
National Institute of Technology, Rourkela**

Assessment of Impact of Mining on Water Quality and it's Modelling

*Dissertation submitted in partial fulfilment
of the requirements for the degree of*

**Master of Technology
In
Mining Engineering**

By
**Amarendra Sahoo
712MN1109**

*Based on the research carried
out under the supervision of*

**Prof. H. B. Sahu
Associate Professor**



**Department of Mining Engineering
National Institute of Technology, Rourkela**

June 2017



**Department of Mining Engineering
National Institute of Technology, Rourkela**

Certificate

This is to certify that the work done in the thesis entitled “**Assessment of Impact of Mining on Water Quality and it’s Modelling**” is a record of an original research work carried out by **Amarendra Sahoo (Roll number 712MN1109)** in National Institute of Technology, Rourkela under my guidance and supervision for the partial fulfilment for the degree of **Master of Technology in Mining Engineering**. To the best of my knowledge, neither the contents of this thesis nor any part of it has been submitted to any other institute/university for the award of any degree or diploma.

Date:
Place: NIT Rourkela

Prof. H. B. Sahu
Associate Professor
Department of Mining Engineering
NIT, Rourkela



**Department of Mining Engineering
National Institute of Technology, Rourkela**

Declaration of Originality

I, **Amarendra Sahoo**, Roll number **712MN1109**, hereby declare that this thesis entitled “**Assessment of Impact of Mining on Water Quality and it’s Modelling**” represents original work carried out by me as a post-graduate student of NIT Rourkela and to the best of my knowledge, contains no material previously published or written by another person, nor any material presented by me for the award of any other degree or diploma of NIT Rourkela or any other institution. Any contribution made to this research by others, with whom I have worked at NIT Rourkela, is explicitly acknowledged in the thesis. Works of other authors that are cited in this thesis have been acknowledged under the sections **References**. I have also submitted my original research record to the scrutiny committee for the evaluation of my research work.

I am fully aware that in case of any non-compliance detected in future, the Senate of NIT Rourkela may withdraw the degree awarded to me on the basis of the present thesis.

**Amarendra Sahoo
712MN1109**

**Department of Mining Engineering
NIT, Rourkela**



**Department of Mining Engineering
National Institute of Technology, Rourkela**

Acknowledgement

This research work is one of the most important achievements of my life which is made possible because of the constant motivation and support by many people. I express my humble appreciation and sincere thanks to all of them.

I wish to express my profound gratitude and indebtedness to Prof. H. B. Sahu, Associate Professor, Department of Mining Engineering, NIT, Rourkela; for his guidance, valuable advice and constructive criticism throughout the research work.

I am thankful to all the faculty and staff members of Department of Mining Engineering for their help and support.

I thank Mr. B. P. Sahoo, PhD Scholar, Department of Mining Engineering for his help in laboratory analysis.

I thank Mr. B. Sahoo, Asst. General Manager; and Mr. J. Maulik, Geologist; TRB Iron Ore Mines, JSPL, for their kind help in sample collection.

I thank Prof. K. K. Paul, Assistant Professor, Department of Civil Engineering, for her help in determining some of the water quality parameters using Atomic Absorption Spectrophotometer.

I thank the authors of all the research articles that have been referred in this thesis.

Finally, I would like to express my sincere respect and love to my family for their consistent encouragement in every walk of my life.

**Amarendra Sahoo
712MN1109**

**Department of Mining Engineering
NIT, Rourkela**

Abstract

Water is the most essential requirement for life. The most fundamental component of sustainable development is to ensure that the streams, rivers, lakes and oceans are not contaminated due to human activities. Water is extensively used for various mining operations, viz., wet drilling, dust suppression, ore processing, washing of heavy earth moving machinery (HEMM). Mine drainage, mine cooling, aqueous leaching and other mining processes has the potential to cause contamination of water bodies both surface and ground by discharging mine effluent and tailing seepage.

The ever increasing mining activities pose a serious threat to the water resources. The awareness towards environmental footprint of mining operations is consistently growing, but it often gets little attention. Environmental pollution is the price that we pay for our everyday use of minerals and its products. Contamination of water sources severely affects not only an individual species but the entire ecosystem and all the organisms living in the ecosystem, and also severely affect human health.

In the present work, water samples were collected from various sampling sites, followed by laboratory analysis and water quality modelling. Water sampling was done in the area surrounding TRB iron ore mine owned by Jindal Steel & Power Ltd, located in Tensa region of Sundergarh district in Odisha during October 2016. The location of sampling was so selected because of the nearness of mining site to residential areas. In recent years, the surrounding surface and ground water bodies were gradually contaminated due to the mining operations.

A total of 23 water quality parameters of the collected water samples, viz., Temperature, Conductivity, Oxidation Reduction Potential, pH, Acidity, Alkalinity, Dissolved Oxygen, Biochemical Oxygen Demand, Total Dissolved Solids, Total Hardness, Turbidity, Sulphate, Phosphate, Nitrate, Chloride, Fluoride, Sodium, Potassium, Calcium, Manganese, Iron, Copper and Nickel, were determined by laboratory analysis.

The water quality modelling was done using WA-WQI (Weighted Average - Water Quality Index) based on 11 water quality parameters, viz., pH, Conductivity, DO, TDS, Hardness, BOD, Sulphate, Chloride, Nitrate, Calcium and Iron.

Graphical modelling was done for all the determined water quality parameters in order to make the water quality analysis easily comprehensible. Graphical models of all the water quality parameters were created in QGIS (Quantum GIS) software using IDW (Inverse Distance Weighting) method, in which all the water quality parameters were interpolated and displayed for the area surrounding the sampling locations. Finally, a 3D graphical model of WA-WQI was created, represented as a DEM (Digital Elevation Model), where higher elevation indicates higher values of WA-WQI.

Based on the study of the experimental analysis data and the graphical models, it was concluded that turbidity values exceeded the permissible limit (1NTU according to IS-10500) in almost the entire study region; pH was below the permissible of 6.5 in half of the study region; iron, copper and manganese concentrations exceeded the permissible limits (0.3mg/l, 0.05mg/l and 0.1mg/l respectively) in the regions surrounding the sampling sites G1, S2 and S5; BOD value exceeded the permissible limit (5mg/l) in the regions surrounding the sampling sites G1 and S5; and nickel concentration exceeded the permissible limit (0.02mg/l) in the regions surrounding the sampling sites S5.

According to the WA-WQI ratings determined for the water samples, only G2 qualifies for excellent water quality; S1 and S3 have good water quality; G3, G4, G5 and S4 have poor water quality; and G1, S2, and S5 has very poor water quality. Although, it was inconclusive that if ground water sources are more polluted than surface water sources.

Contents

Certificate.....	i
Declaration of Originality.....	ii
Acknowledgement	iii
Abstract.....	iv
Contents	vi
List of Tables	vii
List of Figures.....	viii
1. Introduction.....	1
1.1 General	1
1.2 Impact of Mining on Water Quality	2
1.3 Effects of Polluted Water	3
1.4 Objective.....	5
2. Literature Review.....	6
3. Materials and Methods.....	11
3.1 Study Area.....	11
3.2 Sampling.....	12
3.3 Sampling Procedure.....	13
3.4 Experimental Analysis.....	16
3.5 Results of Experimental analysis.....	33
4. Water Quality Modelling	35
4.1 General	35
4.2 Weighted Arithmetic-Water Quality Index (WA-WQI)	35
4.3 Graphical Modelling.....	36
5. Discussion and Conclusion	50
5.1 Water Quality Parameters.....	50
5.2 Water Quality Index	55
5.3 Conclusion.....	59
6. References.....	60

List of Tables

Table No.	Title	Page No.
3.1	Sampling data sheet	15
3.2	Laboratory analysis data of ground water samples	33
3.3	Laboratory analysis data of surface water samples	34
4.1	Determined WA-WQI values of all sampling sites	36
5.1	WA-WQI grading	56
5.2	WA-WQI of all sampling sites	56

List of Figures

Figure No.	Title	Page No.
3.1	Google Earth imagery of the study area	11
3.2	Google Terrain view of the study area	12
3.3	Sampling Site of G1	13
3.4	Sampling Site of G2	13
3.5	Sampling Site of G3	14
3.6	Sampling Site of G4	14
3.7	Sampling Site of G5	14
3.8	Sampling Site of S1	14
3.9	Sampling Site of S2	14
3.10	Sampling Site of S3	14
3.11	Sampling Site of S4	15
3.12	Sampling Site of S5	15
3.13	Horiba Multiparameter water quality analyser (Model U52)	16
3.14	EI Deluxe Turbidity Meter 335 (Nephelometer)	17
3.15	Fisher Scientific Fluoride Ion Selective Electrode	20
3.16	Fisher Scientific Nitrate ion selective electrode	21
3.17	EI Double-Beam Spectrophotometer 2375	23
3.18	Perkin Elmer AAnalyst 200 (AAS)	25
3.19	Systronics Flame Photometer 128	26
4.1	Graphical model of Conductivity	39
4.2	Graphical model of Turbidity	39
4.3	Graphical model of TDS	40
4.4	Graphical model of pH	40
4.5	Graphical model of ORP	41
4.6	Graphical model of DO	41
4.7	Graphical model of BOD	42
4.8	Graphical model of Acidity	42
4.9	Graphical model of Alkalinity	43
4.10	Graphical model of Hardness	43

4.11	Graphical model of Sulphate	44
4.12	Graphical model of Nitrate	44
4.13	Graphical model of Chloride	45
4.14	Graphical model of Fluoride	45
4.15	Graphical model of Phosphate	46
4.16	Graphical model of Sodium	46
4.17	Graphical model of Potassium	47
4.18	Graphical model of Calcium	47
4.19	Graphical model of Iron	48
4.20	Graphical model of Nickel	48
4.21	Graphical model of Copper	49
4.22	Graphical model of Manganese	49
5.1	Turbidity	50
5.2	Conductivity	51
5.3	TDS	51
5.4	pH	52
5.5	Acidity and Alkalinity	52
5.6	DO and BOD	53
5.7	Hardness	53
5.8	Manganese and Iron	54
5.9	Copper and Nickel	55
5.10	3D model of WA-WQI (top view)	57
5.11	3D model of WA-WQI (front view)	57
5.12	3D model of WA-WQI (right side view)	58
5.13	3D model of WA-WQI (left side view)	58

1. Introduction

1.1 General

Mining is the prime source of mineral commodities and is essential for all of the humanity for development and improvement of the quality of life. Minerals are needed in almost every aspect of human development including construction of roads and buildings, generation of electricity, manufacturing of electronics and countless other goods. In addition to that, mining is also important economically as it generates enormous wealth, provides employment and provides taxes that pay for governments, promotes foreign exchange and significantly contributes to GDP of a nation. Mining promotes many associated activities including manufacturing of mining equipment, the creation of engineering and environmental services, and the development of top class universities in the fields of mining engineering, geology and metallurgy. Without mining, the human race would develop at a pace unimaginably slow. However, mining also contributes significantly towards pollution and degradation of the environment, by the clearing of large forest area, destruction of natural habitat, heavy usage and pollution of water resources, production of harmful dust and unnecessary noise. Heavy metal contamination caused due to mining activities have a severe impact on the ecosystem and especially on species that are sensitive to metals like mayflies and crustaceans(Hynes, 1960).

In mines, water is required for various mining operations, viz., wet drilling, dust suppression, ore processing, washing of heavy earth moving machinery (HEMM) in the workshop and for drinking and sanitation. In many mines, the workings also extend below the water table leading to seepage. During the rains, the run-off generated to flow into or out of the mine depending upon the topography. Sometimes, pumping of water is required to be carried out to provide a free face for working. Since the water comes in contact with a variety of pollutants, it has the potential to contaminate the nearby water bodies.

The awareness towards environmental footprint of mining operations is consistently growing, but it often gets very little attention. Environmental pollution is the price that we pay for our everyday use of minerals and its products. If preventive measures are not taken, it may result in dangerously high concentrations of radicals, including heavy metals like lead, arsenic and mercury, sulphates, fluorides, over a large area. Runoff of mere soil or rock debris is although non-toxic can also ruin the nearby plant life. Underwater tailing disposal is often considered as an environmentally friendly alternative. Mine drainage, mine cooling, aqueous leaching and other mining processes produce large amounts of contaminated water. The contaminants being in aqueous form further enhance their potential to pollute surface and ground water.

Today's modern and well-regulated mines have geologists and hydrologists for carefully monitoring any water or soil contamination that may be caused by the mining activities. In Indian mines, the DGMS enforces the mine operators to meet safety and environment standards for preventing surface and ground water contamination.

If the mining site gets polluted nevertheless, mitigation techniques are required to be performed. The five key techniques used for monitoring and controlling water flow at mining

sites are groundwater pumping system, diversion system, containment pond subsurface barrier and subsurface drainage system. In severe cases, Acid Mine Drainage (AMD) is performed, in which the mine discharges are pumped to a treatment plant to neutralise the pollutants.

1.2 Impact of Mining on Water Quality

The mining industry has provided numerous developmental benefits, but it has also caused substantial environmental pollution and degradation by the clearing of the vast forested area, destruction of natural habitat, heavy usage and pollution of water resources, production of harmful dust and unnecessary noise.

Surface mining pollutes ground and surface water occur via both direct degradation and indirect degradation. Direct degradation happens when groundwater bodies are located downgradient or downhill from the mine area. The contaminated mine drainage flows from the tailing ponds, pits and the runoff or infiltration of rainwater into the water body. Indirect degradation occurs due to blasting in the mines. The blasting creates a shockwave which causes fractures in the rock bed and also widens the pre-existing fractures making it more permeable, which result in vertical leakage of contaminated mine drainage from the ponds into the groundwater bodies.

The water present in the mines can mobilise and transport the pollutants including heavy metals, from overburden dumps and tailing ponds into surface and ground water bodies in the form of non-point source pollution. Due to mining operations, the nearby water sources have much higher concentrations of contaminants compared to other areas and also compared to the same area before the mining operations began.

1.2.1 Factors affecting the contamination of water due to mining

The extent of pollution of water due to mining is affected by the type of ore being mined, climate, hydrogeological settings, stage of mining and environmental management practices in force. These have been discussed here.

- The type of ore being mined: Ores like sulphide ores, are chemically more reactive than other ores, and are more soluble in water, which leads to higher risk of contamination of water bodies.
- Life stage of the mine: The stage in which the mine presently is, viz., under development, operating or closed affects the level of contamination of water.
- Climate: The climate of the mining area determines the water availability and usage, which in turn influence the potential for water contamination. During the wet season, the contamination is more prominent and much faster than during the dry season.
- Chemicals used for mineral processing: These chemicals usually include cyanides, strong acids and various organic compounds, which are not only highly toxic but also harder to remove by conventional water treatment methods.
- The hydrogeological setting: Hydrogeological settings significantly influence the ground water caused by mining. Usually, the shallower ground water sources like springs and wells are more susceptible towards contamination than deeper ground water sources.
- Environmental management practices: Present day environmental management practices considerably decrease the potential for water pollution by mining operations. Older and

abandoned mines usually have much higher potential for polluting water bodies because modern environmental practices and regulations were not present when the mine was started.

1.2.2 Acid Mine Drainage (AMD)

Acid Mine Drainage usually occur due to geochemical reactions when pyrites in the minerals are exposed to air and then react with oxygen and water to produce sulphuric acid, which causes iron to dissolve. The dissolved iron further oxidises to produce even more acid resulting in the further dissolution of iron generating more sulphuric acid. This acid produced is usually neutralised in nature, partially or sometimes completely, by exposure to alkaline minerals and rocks. However, in severe cases, it needs to be artificially neutralised. AMD can be neutralised using a solution of alkaline minerals like dolomite and calcite. The amount and magnitude of acid mine drainage are often exaggerated by complex biochemical reactions inside the unstable ore bodies (Caruso and Bishop, 2009).

Underground mining is usually carried out below the water table. The water is regularly pumped out to avoid flooding of the mine. When the mining is complete, and the mine is abandoned, the pumping of water stops, and the mine is flooded in a few days, which causes leaching of the rocks exposed due to mining.

In the case of surface mines, the tailing dumps, tailing ponds and overburden dumps are the principal sources of acid mine drainage.

Several species of bacteria flourish in such acidic environments and often significantly accelerate the process of decomposition and leaching. These bacteria are known as extremophiles for their ability to thrive in such in harsh environments. A particular type of extremophiles known as Acidophiles prefers lower pH environments. Particularly, the *Acidithiobacillus ferrooxidans* are the leading cause of oxidation of pyrites.

Highly acidic discharges may also be generated by copper, nickel or zinc metal mines where the ore contains sulphide. The most abundant ore of copper is chalcopyrite, which is a copper-iron-sulfide ore and often contains other sulphides, making copper mines an important source of acid mine drainage.

Usually, acid mine drainage starts to generate 2–5 years after mining operations are started. However, in some mines, it does not generate for several decades. Once the generation of acid mine drainage is started, it then may be produced for decades or even centuries. Hence, acid mine drainage is regarded a severe environmental issue caused due to mining.

1.3 Effects of Polluted Water

Contamination of water sources severely affects not only an individual species but the entire ecosystem, and all the organisms living in the ecosystem. Some of those effects are briefly described below.

1.3.1 Effects of polluted water on humans

Humans consume fresh water primarily for drinking and sanitation purposes. Contaminated water poses a significant threat to human health. Consuming polluted water causes a lot of adverse effects on human health.

Toxic metals including heavy metals like lead, mercury, cadmium, manganese and few other metals like lithium and beryllium have very well known toxic effects on human body. When water contaminated with toxic metals is consumed the toxic metals imitate the action of essential elements in the body, interfering with various key metabolic processes. Toxic metals tend to bioaccumulate in the body causing long-term effects even after brief exposure.

Mercury compounds present in drinking water cause Minamata, a neurological disease. Symptoms of Minamata include ataxia, numbness in limbs, general weakness of muscles, narrowed field of vision and damage to hearing and speech. Mercury present in waste water gets converted into extremely toxic methyl mercury by bacterial action.

Lead-contaminated drinking water interferes with many of body processes and is toxic to internal organs and tissues. Lead poisoning causes headaches, anaemia and loss of muscle power. There is no safe dosage of lead, even the smallest concentration of lead in the blood causes toxicity.

Cadmium poisoning causes Itai-Itai, a painful disease of bones and joints, causes softening of the bones and eventually kidney failure.

Consumption of arsenic polluted water causes the accumulation of arsenic in various parts of the body including skin, nails and blood causing various complications including fingernail pigmentation known as Leukonychia striata, skin lesions, drying and thickening of the skin. Arsenic being carcinogenic ultimately causes cancer.

Carcinogenic elements and compounds present in waters like asbestos, arsenic, beryllium, cadmium, benzene and chromium(IV) compounds cause many types of cancer including breast cancer, prostate cancer, lung cancer, skin cancer, leukaemia and Hodgkin's lymphoma.

Heavy metal poisoning causes hormonal problems disrupting reproductive and developmental processes, damage to the nervous system, liver and kidney, damage to the DNA. Heavy metals poisoning during pregnancy causes the unborn baby to suffer various complications after birth like slower reflexes, learning deficits, hindered or incomplete mental development causing brain damage and autism. Heavy metals also increase the chances of acquiring Alzheimer's disease, multiple sclerosis, Parkinson's disease, heart disease.

1.3.2 Effect of polluted water on animals

Acidic discharge can leach out aluminium from the soil and take it to the lakes or streams, which is toxic for fishes and other marine animals. Water contaminated with mercury can lead to several undesirable and abnormal changes in aquatic animals including hormonal imbalance causing unnatural behavioural changes, damage to tissues and organs hindering growth rate, reproductive processes. Excessive leaching of soil causes nutrient pollution in the water ecosystems causing overgrowth of toxic algae, which are consumed by seabirds, fishes, turtles, dolphins and other aquatic animals. Some toxic algae tend to choke the gills of fishes.

Mercury contamination can drastically escalate the susceptibility towards diseases and hinder the reproductive process by altering the metabolism of fishes, making unsuitable for consumption by humans or other organisms in the ecosystem. Persistent organic pollutants (POPs) causes various deformities in marine species causing a decline in population and biodiversity.

Pollutants such as lead and cadmium disturb the ecological food chain by a phenomenon known as bioaccumulation, causing a build-up of toxins up in the food chain.

1.3.3 Effect of polluted water on plants and trees

Acid mine drainage contains sulphuric acid which damages the leaves and bark of the trees and also damages fine root hairs of smaller plants causing disruption in the absorption of soil nutrients.

Contamination drastically reduces the solubility of carbon dioxide in water disrupting photosynthesis in aquatic plants. Plants also need many nutrients like calcium and magnesium for their growth, iron for the formation of Chlorophyll (pigment required for photosynthesis), and potassium for the transport of water. Acidic water increases the solubility of these nutrients causing them to leach out of the soil, causing a deficiency of these nutrients which hampers the plant growth rate and makes the plants more susceptible to drought and diseases.

Phytotoxicity occurs when the plants absorb toxic elements. It causes poor growth rate, dead spots on leaves and dead seedlings. It also starts a chain of bioaccumulation along the food chain as herbivores eat the phytotoxic plant, and carnivores in turn eat them. The level of accumulation of toxins increases as they move up in the food chain.

1.4 Objective

The primary objective of this study is to assess the environmental impact of mining on water quality and its modelling. The specific objectives are mentioned below.

- Determination of surface and ground water quality of a mining area.
- Determination of harmful contaminants present in water.
- Assessment of environmental and health impact.
- Designing of a graphical model of water quality.

2. Literature Review

Rosner and van Schalkwyk (2000) showed that in recent years gold mining in South Africa had produced a significant amount of tailings, which were dumped in huge piles which were poorly managed. Significant volumes of seepage were released into the soil and water bodies causing substantial degradation. The tailings were only partially removed leaving behind considerable footprints posing a severe threat of further pollution. They investigated footprints of 7 such reclaimed sites. They found that the top-soil was dangerously acidic. Phytotoxic elements including Cobalt, Nickel and Zinc had diminished rehabilitation by limiting the functioning of the soil. The soil also had concentrations of trace elements much higher than the surrounding soils, which buffer minerals to deplete and successive acidification. They suggested that proper soil management techniques were needed to stop further contamination of topsoil and water sources which would allow safe future land use.

Bordalo et al. (2001) analysed pH, DO, temperature, turbidity, TSS, ammonia, faecal coliforms, Biochemical Oxygen Demand, Chemical Oxygen Demand, phosphate, conductivity and heavy metals present in the Bang Pakong River in eastern Thailand. They found that the mean WQI was as low as 41%, and quality declined considerably during the dry seasons. The prime reason for variation between every season was the difference between locations along the gradient, while monthly variability corresponds as low as 20% of the variations. This seasonal result showed that Bang Pakong river was only suitable for the species of fish that are tolerant and it should not be utilised for drinking purposes during the dry season. However, the quality was improved in the wet season, so that the river water may be utilised for drinking, although after proper treatment only. Better water quality in the central portion of the river allows several uses at increased cost.

Niyogi et al. (2002) proposed a hypothesis relating the biodiversity, community biomass, and ecosystem to the stress gradient. According to that hypothesis, biodiversity had a low threshold of reaction toward the stress gradient, while biomass was stable under high stress. Their hypothesis was evaluated on the primary producers present in the downstream of the mine drainage in the Rocky Mountains, Colorado. The drainage exerted a chemical stress resulting in lower pH and higher dissolved metals, and physical stress including accumulation of metal oxides. They showed that the biomass was satisfactorily healthy in downstream with only chemical stress. However, it drastically decreased when physical stress was added. Locations, where there was an accumulation of aluminium oxide, was present had hardly any algal biomass. The biomass showed 65% variation caused by the accumulation of oxides of aluminium and lower pH. The chemical stress largely resulted in trends consistent with the hypothesis in their ecosystem model. However, the physical stresses showed inconsistent results.

Sadashivaiah et al. (2008) analysed the water quality of the groundwater in Tumkur Taluk in Karnataka. Groundwater samples were collected, and various physiochemical analysis was carried out. They considered 12 parameters for calculating Water quality index, viz., hardness, pH, calcium, magnesium, chlorides, nitrate, bicarbonates, sulphates, total dissolved solids, iron, manganese, and fluoride. WQI values were found to be in the range between 89.2 and

660.5. Their work showed that the groundwater in that area required proper treatment before consumption.

Najah et al. (2009) evaluated water quality of the river Johor in Malaysia and discussed measures to develop a better water resources management plan. They found that classical process-based modelling technique may provide a comparatively accurate prediction of water quality parameters. However, the models would require extensive data and also require many other data that are usually undetermined. Modern approaches like Artificial Intelligence methods had proven their capabilities for applications in modelling and simulating several physiochemical processes in the water resources.

Singkran et al. (2010) studied various parameters viz., DO, BOD, nitrates, phosphorus, TSS and faecal coliform bacteria and used them to assess the water quality of the rivers in the northeastern region of Thailand viz., Lam Chi, Lam Seaw, Loei, Nam Oon and Lam Pao. The average observed values of those water quality parameters of every river over a period of five years from 2003 to 2007 were used to calculate their water quality index for the dry and wet season. The results showed that the water quality of almost all sampling locations was good. They were of the opinion that the water quality index of Loei and Lam Chi would degrade over the next five years if suitable measures are not taken to reduce the pollutants those rivers.

Ochieng et al. (2010) studied the effect of acid mine drainage (AMD) generated coal and gold mines in South Africa. They showed that the mine drainage waters were highly acidic and should not be released into the ground and surface water bodies. Heavy water treatment was required to neutralise the high acid level of the mine drainage water. The quality of water of Klip River, Blesbokspruit site and Wonderfontein stream was below the quality standards because of acid mine drainage. The main purpose of their study was to promote awareness towards environmental threat posed by acid mine drainage.

Kar et al. (2010) analysed various chemical, physical and microbiological parameters of the water in the river Mahanadi near Hirakud, Orissa. They evaluated the suitability of water for different purposes over four different seasons viz., monsoon, post-monsoon, winter and pre-monsoon. They collected water samples from four different locations viz., Hirakud dam reservoir, upstream, downstream and middle stream of the river. The samples were analysed for 18 physicochemical parameters. Pearson's correlation coefficients were calculated to show correlations between various parameters. The Water Quality Index of the samples were calculated using National Sanitation Foundation - Water Quality Index and were found to be in the range 26.52 to 32.97. They concluded that the quality was poor. Hence proper treatment is needed.

Liu et al. (2011) observed that mine water discharge and significant usage of fresh water posed a serious threat to the environment and proposed an approach to improve the management of water quality systematically. They suggested that mining industry should practice the use of multiple sources of water supply and recycling of used water. However, implementing such water quality management approach may reduce the efficiency of various mining operations. They proposed that the water should flow simultaneously to the processing unit, mine workings and tailings, and the used water should be cleaned and then sent back to the blender, whereas

the water saved from the processing unit should flow straight to the blender without any treatment.

Sahu et al. (2011) observed that the groundwater bodies near mines were heavily polluted with heavy metals, acidity, alkalinity and microbes. They evaluated the water quality index (WQI) of urban areas near the mining sites for establishing corrective actions. They proposed an effective methodology viz., ANFIS(Adaptive Neuro-Fuzzy Inference System) to predict the water quality. The parameters that were used to assess water quality were correlated, which made the evaluation indiscriminate. They used principle component analysis to determine the most dominant parameter that affects the water quality. An effective rule base and optimal distribution were constructed of the member function using the hybrid learning algorithms of ANFIS.

Akkaraboyina and Raju (2012) studied DO, pH, TDS, conductivity, alkalinity, hardness, magnesium and calcium for calculating WQI of the water of Godavari river at the Rajahmundry monitoring station. They discussed the variations of Water Quality Index from season to season during the study period of three years, from 2009 to 2012 and a three-year future period from 2012 to 2015. The WQI values of Godavari river ranged from good to excellent. High predicted values of WQI for the future period indicated that the water quality of Godavari river would remain in good condition.

Jordaan (2012) showed that the growing Oil Sands processing in Alberta, Canada has not only polluted the surrounding soil and natural water bodies, but it has also released a significant amount of greenhouse gas. Also, the oil sand processing was consuming a large amount of water taken from surface water sources. He also showed that the expanding oil sands operations were taking up ever increasing the amount of water. This large withdrawal of water and the increased levels of Polycyclic Aromatic Compounds(PAC) affected the population of fish by decreasing the level of oxygen accessible to fish. He also showed that the concentrations of heavy metals, viz., copper, cadmium, mercury, lead, nickel, zinc and silver exceeded the water quality standards in Canada.

Mahapatra et al. (2012) applied an empirical approach for the classification of waters based on ten water quality parameters. They applied the Q-mode principal component analysis to categorise the water samples into four classes considering ten water quality parameters, viz., pH, DO, turbidity, TDS, hardness, calcium (Ca^{2+}), chloride (Cl^-), BOD, iron (Fe^{2+}), sulphate (SO_4^{2-}). This classification was supposed to help the field engineers for taking remedial actions in advance to prevent the groundwater contamination. The proposed non-parametric technique efficiently evaluated the water quality index to classify water quality. This model can also be applied to estimate water quality on-line. However, the accuracy of their model would directly depend on the judicious selection of parameters.

Arman et al. (2013) studied the water quality of the river Melana in Johor, Malaysia to get the comparative results through conventional physical and chemical analysis, and biological monitoring. They determined the biological indicator based on macrobenthos due to Biological Water Quality Index (BWQI). The resulting BWQI and WQI results suggested that the level of pollution of Melana river was classified as Class III. They showed that even though they

used different methods of analysis, the results acquired for both rivers were consistent. They also suggested that the same approach can be applied to any other river.

Hoseinzadeh et al. (2014) analysed the water quality of the river Aydughmush using National Sanitation Foundation Water Quality Index (NSF-WQI), Forestry Water Quality Index (F-WQI), and River Pollution Index (RPI), by evaluating various parameters, viz., DO, temperature difference, BOD, faecal coliform bacteria, turbidity, TDS, pH, phosphate in addition to 22 other parameters. They monitored parameters of eight different locations for 12 months. The RPI was found to be in the range of 1 to 3.25 indicating that water quality of Aydughmush River was in the “Negligibly polluted” category, whereas NSF-WQI was in the range 55.83 to 72.51 suggesting the quality to be in “Medium” category. The results of NSF-WQI and F-WQI were consistent with each other, but RPI index indicated a different conclusion.

Aikins et al. (2015) worked on physicochemical quality of ground and surface waters from Bibiani, Ghana determined whether physical, chemical and trace metal contamination of water sources as a result of mining or geochemical and biochemical processes within the environment. Levels of trace metals, viz., Arsenic, Iron, Manganese, and Copper, physical parameters, viz., pH, TDS, electrical conductivity and temperature and chemical parameters, viz., alkalinity, hardness, phosphate and cyanide in water bodies were determined. However, most of them had levels safe for human consumption.

Al Obaidy et al. (2016) studied and assessed the WQI based on Weighted Arithmetic Index to evaluate the water quality of the Tigris River for drinking. Water quality deterioration in surface water was the effect of human activities because of the rapid industrialisation. Tigris River is of vital significance in the assessment of surface water quality as industrial, agricultural and municipal wastes and surface runoffs were getting mixed with river stream and the nearby water bodies thereby degrading the water quality. The Water Quality Index was calculated based on the concentration of eleven parameters viz., pH, TDS, Hardness, Calcium, Magnesium, Chloride, Turbidity, Nitrite, Nitrate, sulphate and Zinc. The calculation of WQI showed that the water quality of Tigris river could be rated as very poor and unsuitable conditions at winter and summer, respectively.

Gaonkar et al. (2016) suggested that the open cast mining imposes significant effects on the environment including degradation of the quality of water sources, mainly due to deliberate violation of environmental regulations, widespread usage of unscientific methods, and flawed mining and dumping practices. They also suggested that the study of quality of water in the areas surrounding the mines is essential for analysing the potential effects on the environment and taking suitable preventive and remedial measures. They studied sample collected from 18 surface water sites at the end of the rainy season. Their results implied that the iron content of all the samples exceeded the permissible guideline value defined by World Health Organization (WHO) indicating flawed mining practices to be the prime cause of water pollution.

Bora and Goswami (2016) conducted a study to analyse the seasonal variations in the water quality of the river Kolong through WQI. The WQI values indicated very poor and unacceptable water quality of almost all samples from along the river Kolong. The water quality was found to be worst during the wet season with a mean WQI of 122.47, whereas, the

dry season had a mean WQI value of 85.73. The sampling locations that were found to be most polluted are Hatimura site and Nagaon Townsite.

Essalhi et al. (2016) suggested that the violation of environmental regulations causes harmful effects on the surrounding environment of the mining area. They studied the mining areas near the Little Atlas mountain ranges in Morocco. They showed four key adverse impacts, viz., the effect on the natural beauty, safety, human health and the rate of recovery. The prime cause of which was found to be over-exploitation of the ore deposits without employing any geological preparation and application of non-adaptive exploitation techniques. They suggested that to reduce these effects proper geological studies and explorations must be conducted for the region, and modern and environmentally friendly mining techniques, viz., like cut-and-fill mining and sublevel stoping methods, should be employed.

Singh (2016) computed the Canadian Council of Ministers of the Environment-Water Quality Index (CCME-WQI) to assess the overall water quality scenario in the limestone mining area of Meghalaya. The CCME WQI value ranges between 0 to 100 indicating poor to excellent water quality and has been widely used by the researchers for quality assessment. Data of pH, EC, turbidity, total alkalinity, total hardness, calcium, magnesium, sulphate, chloride and BOD from 5 sampling sites near limestone mining and cement plants in East Jaintia Hills, Meghalaya were used to compute the CCME WQI. The CCME WQI values indicated that water quality is varying from marginal to good categories in the limestone mining area. However, water samples collected from cement plant areas revealed CCME WQI 33.34 (Station 4) and 30.34 (Station 5) exhibiting the poor quality of water which can be attributed to elevated levels of EC, turbidity, sulphate, total hardness, and calcium. The activities at cement plants were found having more impact on water quality deterioration than the limestone mining.

Madzin et al. (2016) assessed the concentration of heavy metals in the soil of the area near iron ore mines, viz., active Kuala Lipis Mine and abandoned Bukit Ibam Mine in Pahang, Malaysia. The water bodies were also evaluated for various physicochemical parameters for determining the WQI. Soil and water samples were collected from four different sites. The physicochemical parameters used for assessing WQI were DO, pH, BOD, COD, TSS, and ammoniacal nitrogen. They showed that most of the sites in the area were mostly clean or slightly contaminated. However, the heavy metal analysis of water revealed that manganese and aluminium concentrations in all locations were above permissible limits for treated and untreated water quality standards set by the Ministry of Health, Malaysia. However, the heavy metal concentrations in soils turned out to be below the permissible values with exceptions being for arsenic, zinc, copper and lead.

3. Materials and Methods

3.1 Study Area

For the present study the area nearby TRB iron ore mine owned by Jindal Steel & Power Ltd was selected. The area is located in Tensa region in Sundergarh district of Odisha, bound by latitude N21°51' and N21°59'; longitude E85°9' and E85°17', which comes in the central part of Bonai-Keonjhar Iron Ore belt in Koira Sub-division of Sundargarh district. The presence of active iron ore mines at Tensa and Kalta, active manganese mines in Kusumdih, Orahori and Dengura in the Jamda-Koira Valley makes it a potential site for pollution caused by mines.

The location of the area of study was selected because of the nearness of mining site to residential areas. In the recent years, the nearby surface and ground water bodies were gradually getting contaminated due to the mining operations. This area has primarily tropical climate. The summer season spans from mid-March to the end of June, with high temperatures reaching up to 40°C. However, due to being situated at higher altitude, the summer is never too hot. The rainy season starts with the arrival of monsoon by the end of June and continues till the end of September. The annual precipitation is about 150cm. The winter season spans from November to February.

The Google Earth imagery of the study area has been presented in Figure 3.1 and the Google Terrain view has been presented in Figure 3.2.



Figure 3.1: Google Earth imagery of the study area

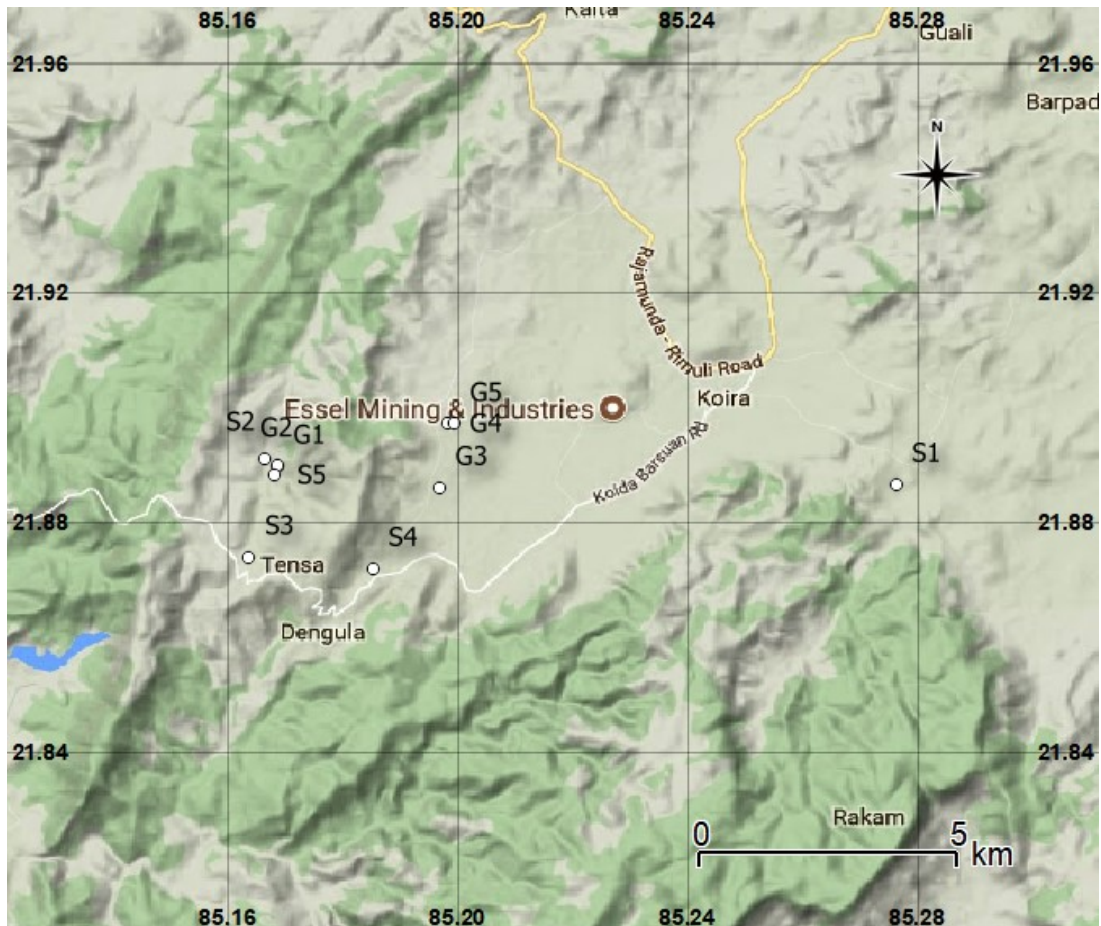


Figure 3.2: Google Terrain view of the study area

3.2 Sampling

Sampling is the process of collecting samples from a large population, depending upon the analysis to be done it can be random sampling or systematic sampling. There are two major types of sampling, viz., Grab sampling and Composite sampling. The sample collection in this work is of the type Grab sampling. The purpose of sampling is to collect representative samples such that the concentration of all its components would be identical or near identical to the concentrations of the sample source, and also the sample should be handled such that there is no considerable alteration in the composition of the sample until the laboratory analysis is done. The sample volume must be sufficient enough to carry out all the experimentations easily.

3.2.1 General guidelines for sampling

For performing sampling in a proper systematic process, certain guidelines must be followed. Those guidelines are mentioned below.

- All sampling containers must be clean and free from contamination.
- Sample containers are rinsing with the sample before filling with samples.
- A small air gap should be left in the sampling bottle after filling to allow mixing of the sample before the laboratory analysis.

- When performing composite sampling the samples collected over a period, or from different sampling locations, or from the same site but different depths; mixed to get a representative composite sample.
- Sampling data sheet must be maintained in an organised manner.
- Special precautions are to be taken obtaining samples containing trace metals and organic compounds as they are present in very low concentrations. Their concentrations can get partially or completely lost, or altered without proper handling and preservation.
- When sampling for toxic metals, it is advised to wear disposable safety gloves while sampling, so that those toxic metals are not absorbed into the hands of the person performing the sampling.

3.3 Sampling Procedure

Water sampling was done by following the sampling procedure in an orderly fashion. The sample containers were cleaned before the sampling. The sample containers were rinsed three times with sample water before filling. To allow the mixing of the sample at the time of laboratory analysis, the sampling bottles were left with small air gaps. Sampling location code, location, date, time, GPS coordinates, sampling type, weather were noted down on the field data sheet. Sampling was done from surface water bodies from about 30cm below the water surface, and from tube wells after running the tube well for about 5 minutes. Samples were collected in 1 litre PET (polyethylene terephthalate) sampling bottles. The location of the sampling points have been presented in Figure 3.1, and the photographic view of the sampling locations have been presented in the Figures 3.3 to 3.12.



Figure 3.3: Sampling site of G1



Figure 3.4: Sampling site of G2



Figure 3.5: Sampling site of G3



Figure 3.6: Sampling site of G4



Figure 3.7: Sampling site of G5



Figure 3.8: Sampling site of S1



Figure 3.9: Sampling site of S2



Figure 3.10: Sampling site of S3



Figure 3.11: Sampling site of S4



Figure 3.12: Sampling site of S5

The locations from which the samples are collected has been presented in Table 3.1.’

Table 3.1: Sampling data sheet

Sl. No.	Sample Code	Source Type	Sampling Location
1	G1	Ground	RO Input of Water treatment unit (Behind Guest House)
2	G2	Ground	RO Output of Water treatment unit (Behind Guest House)
3	G3	Ground	Tap Water (Borewell), Raikela Village
4	G4	Ground	Tube well, Bandhal Village
5	G5	Ground	Tap Water (Borewell), Bandhal Village
6	S1	Surface	Tehrei Nalah (10km from origin point)
7	S2	Surface	Samiji Nalah (After Mine discharge is mixed into the stream)
8	S3	Surface	Samiji Nalah (Origin point)
9	S4	Surface	Karo Nalah (Origin Point)
10	S5	Surface	Mine discharge pond

3.4 Experimental Analysis

Various physiochemical parameters were determined in the laboratory by the following methodology:

3.4.1 Determination of various physiochemical parameters using Horiba multiparameter water quality analyser

The Horiba multiparameter water quality analyser (Model U-52) can be used to measure and log data of up to nine parameters. By deploying the probe directly into the water body, it can perform on-site monitoring of both surface and ground water.



Figure 3.13: Horiba multiparameter water quality analyser (Model U52)

Apparatus Required

- Horiba multiparameter water quality analyser (Model U52)
- Wash Bottle
- Beaker

Chemicals Required

- Distilled Water

Procedure:

- It was checked that if each sensor and sensor guard is mounted properly.
- Single Measurement mode was selected in the menu.
- The sensor probe was submerged in the sample. It was then gently shaken in the sample for removing any air bubbles on the sensors.
- *Meas* key was pressed when the displayed measurement values became stable.
- *Enter* key was pressed to save the displayed measurement values.
- *Esc* key was pressed to close the operation.

3.4.2 Determination of Turbidity using Nephelometer

Turbidity is the measure of the cloudiness of any liquid or solution caused due to the presence of insoluble solid particles that are suspended in the fluid medium and partially obstructs the transmittance of light through the solution. A nephelometer is an instrument which quantitatively measures the turbidity of a water sample.

Principle

EI Deluxe Turbidity Meter 335 (Nephelometer) measures turbidity by using source light beam and a sensor fixed at 90° to the direction of the source light beam. Turbidity is measured based on the intensity of the light scattered by the sample in the cuvettes. First, the instrument is calibrated by using known standard suspensions then the turbidity of the sample is thus calculated by comparison with the standard suspension.



Figure 3.14: EI Deluxe Turbidity Meter 335 (Nephelometer)

Apparatus Required:

- Nephelometer
- Cuvettes
- Volumetric flasks
- Funnel
- Wash Bottle
- Tissue Paper

Chemicals Required:

- Standard Hexamethylene tetramine solution
- Standard Hydrazine sulphate solution
- Standard 4000 NTU Solution
- Distilled water

Procedure:

- Standard suspensions were filled into the cuvette up to the horizontal mark, the outer surface of the cuvette was wiped gently with a tissue paper to remove drops from the surface.
- The cuvette was then placed in the nephelometer such that the vertical mark on the cuvette coincided with the mark in the nephelometer and the cover was shut.
- The instrument was then calibrated using the calibration knob.
- After calibration was done, sample water was filled into the cuvette up to the horizontal mark, the outer surface of the cuvette was wiped gently with a tissue paper to remove drops from the surface.
- The cuvette was then placed in the nephelometer such that the vertical mark on the cuvette coincided with the mark in the nephelometer and the cover was shut.
- The reading in the nephelometer was noted down after a stable reading was reached.

3.4.3 Determination of Sulphate by Turbidimetric method

Sulphates occur in nature in many minerals, like gypsum, epsomite, and barite. Sulphates are often present in natural bodies of water in concentrations ranging from less than ten to several hundred ppm which contributes to the mineral content of drinking water. In fact, sulphates are the second most common anion found in seawater. Acid Mine Drainage(AMD) often contributes a considerable amount of sulphates via oxidation of pyrite.

Principle

The turbidimetric method for the measurement of sulphates is based on the precipitation of barium sulphate into a colloidal suspension in the presence of a HCL, NaCl and glycerine.



UV-visible spectrophotometer is employed to measure the absorbance of the light beam of 420nm wavelength by barium sulphate present in the colloidal suspension. The concentration of sulphate ions present in the solution is calculated by comparing the absorbance reading with the standard calibration curve.

Apparatus Required

- UV-Visible spectrometer
- Cuvettes
- Beaker
- Volumetric flask
- Wash bottle
- Tissue paper

Chemicals Required

- Sodium Chloride
- Barium chloride
- Sodium sulphate
- Distilled water

Procedure

- A Blank solution was filled into the cuvette and was placed inside the chamber of the spectrometer.
- Blank button was pressed.
- The standard solutions were filled in the cuvettes, were placed inside the chamber.
- Start button was pressed, and the absorbance readings were noted down.
- Then the sample solutions were filled in the cuvettes, were placed inside the chamber.
- Start button was pressed, and the absorbance readings were noted down.

Calculation

A standard calibration curve was plotted, and the following equation was evaluated using that curve.

$$Y = mX + C$$

where,

Y = absorbance reading

m = slope of the curve

X = concentration of sulphate in ppm

C = intercept on the Y-axis

3.4.4 Determination of Fluoride using Ion Selective Electrode

Ion selective electrode (ISE) is a transducer based instrument that shows the presence of a specific ion in a solution in the form of electrical signal (Bakker and Qin, 2006).

Principle

According to the Nernst equation, the voltage is proportional to the logarithm of the activity of the ion. The higher the voltage from the ISE, higher is the concentration of the ion.

Apparatus Required

- Fisher Scientific Fluoride Ion Selective Electrode
- Fisher Scientific ISE meter
- Wash Bottle
- Beakers

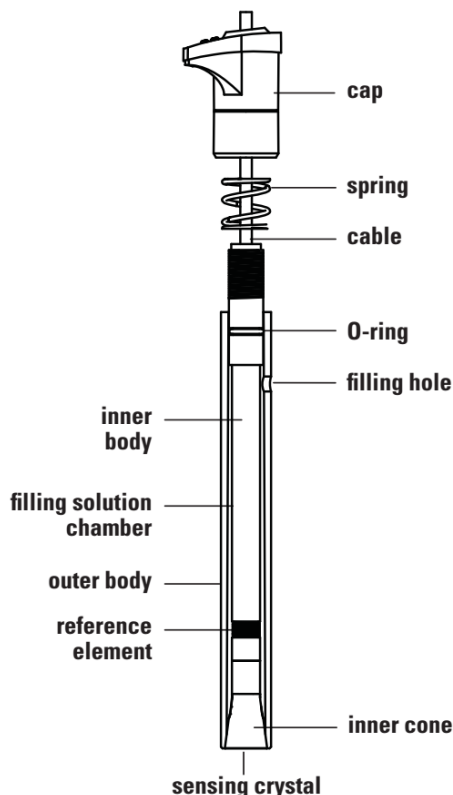


Figure 3.15: Fisher Scientific Fluoride Ion Selective Electrode

Chemicals Required

- Electrode filling solution
- Distilled Water
- TISAB III
- Fluoride standards

Procedure

- Standards of 0.5ppm, 1ppm, 1.5ppm and 2ppm were prepared by diluting the 100ppm standard solution.
- 1ml of TISAB III was added to every 5ml of standard or sample and then stirred at a uniform rate.
- All the standards and samples were allowed to come to the same temperature so that precise measurement could be taken.
- The electrode was rinsed with distilled water before and after every measurement.
- The filling hole cover was removed during measurements to get a constant flow of filling solution.
- Calibration was done by first immersing the electrode in the standard solution, and the value was set in the digital ISE meter.

- The electrode was then immersed in the sample and then was shaken gently to remove any air bubbles stuck on the sensing surface of the electrode.
- The readings were noted down.

3.4.5 Determination of Nitrate using Ion Selective Electrode

Nitrate Ion Selective Electrode is a liquid membrane combination type ISE used for the determination of nitrate in a solution. It has a PVC polymer membrane consisting of an organic ion exchanger. It produces a potential change because of the exchange of nitrate ions between the PVC membrane and the solution. The sensing electrode is held inside a rigid polyetherimide (PEI) frame.

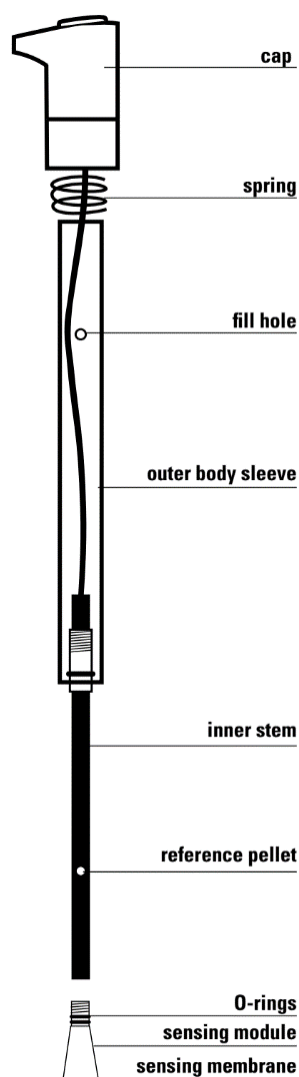


Figure 3.16: Fisher Scientific Nitrate ion selective electrode

Principle

According to the Nernst equation, the voltage is proportional to the logarithm of the activity of the ion. The higher the voltage from the ISE, higher is the concentration of the ion (Bard and Faulkner, 2001).

Apparatus Required

- Fisher Scientific ISE meter
- Nitrate Ion selective electrode
- Double Junction Reference Electrode

Reagents Required

- Nitrate filling solution
- Distilled water
- Nitrate Standards

Procedure

- Standards of 0.5ppm, 1ppm, 1.5ppm and 2ppm were prepared by diluting the 100ppm standard solution.
- All the standards and samples were allowed to come to the same temperature so that precise measurement could be taken.
- The electrode was rinsed with distilled water before and after every measurement.
- The filling hole cover was removed during measurements to get a constant flow of filling solution.
- Calibration was done by first immersing the electrode in the standard solutions and setting the value in the digital ISE meter.
- The electrode was then immersed in the sample and then was shaken gently to remove any air bubbles stuck on the sensing surface of the electrode.
- The readings were noted down.

3.4.6 Determination of Phosphate by Stannous Chloride method

Industrial waste water and sewage are the major sources of phosphate contamination in water bodies. The presence of high concentrations of phosphate may promote the growth of many harmful microbes. Although the presence of phosphate in surface water bodies causes many problems, its presence is essential for the biological degradation of waste water.

Principle:

For phosphate analysis, phosphorous in any form is first converted to orthophosphate by acid hydrolysis. Under acidic conditions, ortho-phosphate reacts with ammonium molybdate to form molybdo-phosphoric acid, which is again converted to molybdenum blue by reacting with stannous chloride dissolved in glycerine. The blue colour formed is then measured in a UV-visible spectrophotometer (EI Double-Beam Spectrophotometer 2375) at 690 nm. The concentration of phosphates in the solution is calculated by comparing the absorbance reading with the standard calibration curve.



Figure 3.17: EI Double-Beam Spectrophotometer 2375

Apparatus Required:

- UV-Visible Spectrophotometer
- Glass cuvette.
- Wash bottle
- Beakers

Reagents Required:

- Standard phosphate solution
- Ammonium molybdate reagent
- Strong acid (concentrated H_2SO_4 + 4ml HNO_3)
- Sodium hydroxide reagent (6N)
- Phenolphthalein indicator
- Stannous chloride
- Glycerol

Procedure:

- Calibration was done by plotting absorbance vs. concentration curve using blank and standard phosphate solution.
- 100mL of the sample was taken in a conical flask, and a drop of phenolphthalein indicator was added. Red colouration forms, sulphuric acid was added dropwise remove the red colour.
- 1ml of Ammonium molybdate solution was added to the flask and shaken for a few seconds.
- 2 drops of stannous chloride reagent was added and left for 15 minutes for the blue colour to develop
- After formation of colour, the solution is then put inside spectrometer for colorimetry.

3.4.7 Determination of Chloride by Argentometric Method

Principle

The chloride content in water is determined by titration with silver nitrate. The AgNO_3 reacts with chloride ions producing a precipitation of silver chloride (AgCl) stochastically. Immediately after that, silver chromate is formed causing a red colouration. The red colour indicates the end of titration.

Apparatus Required

- Burette
- Burette stand
- Pipette
- Conical flask
- Beaker
- Wash bottle

Chemicals Required

- Standard silver nitrate solution (0.0282 N)
- Phenolphthalein Indicator
- Standard Sodium Chloride Solution
- Potassium Chromate Indicator
- Distilled water

Procedure

- The burette was rinsed with silver nitrate solution before starting the titration.
- The burette was filled with silver nitrate solution(0.0282 N).
- 20 mL of the sample was taken in a conical flask.
- 1 mL of potassium chromate indicator was added to obtain a light yellow colour.
- The sample was titrated with silver nitrate solution until the yellow colour changes to red.
- The volume of silver nitrate used was noted down.
- The above procedure was repeated three times to get concordant values.

3.4.8 Determination of Iron, Copper, Manganese and Nickel by Atomic Absorption Spectroscopy (AAS)

Atomic absorption spectroscopy (AAS) is a spectral analysis technique for determining various elements quantitatively. This method is used for the determination of the concentration of the element, making use of the absorption of radiation by free atoms in the gaseous state. It can be used for determining more than 60 elements in a sample (Koirtyohann, 1991).

Principle

This is a controlled flame test, and the intensity of the flame is manipulated by electronic circuitry. It requires standard solutions with known concentration of the element for calibration based on Beer-Lambert Law. The electrons in the atoms jump to an excited state when introduced to the flame, by absorbing a fixed amount of energy via radiation of a fixed wavelength. This wavelength is unique every particular element and is known as its characteristic wavelength. Every element responds to a fixed wavelength only, and the intensity of the light absorbed and gives the concentration of the element in the sample.



Figure 3.18: Perkin Elmer AAnalyst 200 (AAS)

Apparatus Required:

- Atomic Absorption Spectrophotometer
- Beaker
- Volumetric flask for keeping standards

Chemicals Required:

- Standard solution of Iron (1000mg/l)
- Standard solution of Copper (1000mg/l)
- Standard solution of Manganese (1000mg/l)
- Standard solution of Nickel (1000mg/l)
- Distilled water

Procedure:

- Standards of 1, 2, 3, 4 and 5mg/l were created by diluting the 1000mg/l stock solution for Iron, Copper, Manganese and Nickel.
- The AAS was turned on and was allowed to warm up for about 5 minutes.
- Distilled water was aspirated for 2 minutes to clear the system.
- Lamp for Fe element was installed.

- The element Fe was selected in the setup menu.
- Fe Standard solutions were aspirated into AAS for calibration.
- Sample solutions were aspirated for Fe, and the readings were recorded.
- Again distilled water was aspirated for 2 minutes to clear the system.
- Lamp for Cu element was installed.
- The element Cu was selected in the setup menu.
- Cu Standard solutions were aspirated into AAS for calibration.
- Sample solutions were aspirated for Cu, and the readings were recorded.
- Again distilled water was aspirated for 2 minutes to clear the system.
- Lamp for Mn element was installed.
- The element Mn was selected in the setup menu.
- Mn Standard solutions were aspirated into AAS for calibration.
- Sample solutions were aspirated for Mn, and the readings were recorded.
- Again distilled water was aspirated for 2 minutes to clear the system.
- Lamp for Ni element was installed.
- The element Ni was selected in the setup menu.
- Ni Standard solutions were aspirated into AAS for calibration.
- Sample solutions were aspirated for Ni, and the readings were recorded.
- Again distilled water was aspirated for 2 minutes to clear the system.

3.4.9 Determination of Sodium, Potassium and Calcium using Flame Photometer

Systronics Flame photometer 128 is microcontroller based instrument is used determine concentrations of metals, viz., sodium, potassium and calcium, in a single aspiration. It has a 4 line 20 character LCD display. It has an air compressor with built-in air filter and regulator. It can perform both linear and non-linear curve fitting in a fully automated fashion for calibration.



Figure 3.19: Systronics Flame Photometer 128

Principle:

This is a controlled flame test, and the intensity of the flame is manipulated by electronic circuitry. It requires standard solutions with known concentration of the element for the calibration based on Beer-Lambert Law. The electrons in the atoms jump to an excited state when introduced to the flame, by absorbing a fixed amount of energy via radiation of a fixed wavelength. This wavelength is unique every particular element and is known as its characteristic wavelength. Every element responds to a fixed wavelength only, and the intensity of the light absorbed and gives the concentration of the element in the sample.

Apparatus Required:

- Flame Photometer
- Pipette
- Volumetric Flask
- Beaker
- Wash bottle

Reagents Required:

- Standard solution of Sodium (1000mg/l)
- Standard solution of Potassium (1000mg/l)
- Standard solution of Calcium (1000mg/l)
- Distilled water

Procedure:

- Standards of 10, 20, 30, 40 and 50mg/l were created by diluting the 1000mg/l stock solution for Sodium, Potassium and Calcium.
- Flame photometer was turned on and allowed to warm up for 5 minutes.
- Distilled water was aspirated for 2 minutes to clear the system.
- The detection of elements Na, Ca and K was enabled in the setup menu.
- Distilled water was aspirated to set the zero.
- Standard solutions for Na, Ca and K were aspirated respectively into the flame photometer.
- Sample solutions were aspirated on by one.
- Distilled water was aspirated for a few seconds between every two sample aspiration to clear the system.
- The displayed readings for all three elements were recorded.
- Again distilled water was aspirated for at 2 minutes to clear the system.
- Flame photometer was then shut down.

3.4.10 Determination of Acidity

The acidity is the quantitative ability of water to react and neutralise strong base. Higher acidity severely affects marine life by lowering the pH. Water with high acidity is unsuitable for use in construction for mixing of concrete due to its corrosive nature. High acidity water is also unsuitable for human consumption. Wastewater discharge from mines with high mineral acidity needs to be neutralised before being biologically treated or discharged into water bodies.

Principle

The hydrolysis of solutes produces hydrogen ions (H^+) which are then reacted with standard alkali (NaOH) solution. The phenolphthalein indicator changes colour at about pH 8.3 at 25°C indicating the stoichiometric neutralisation of carbonic acid into bicarbonate. The volumes of alkali solution used in neutralisation give the acidity of the solution.

Apparatus Required

- Pipette
- Beaker
- Burette
- 500ml conical flask
- Wash Bottle
- Measuring cylinders

Reagent Required

- Sodium Hydroxide
- Phenolphthalein
- Methyl Orange
- Ethyl alcohol
- Distilled Water

Procedure

- The burette was rinsed with sodium hydroxide solution (0.02N), and the solution was discarded.
- The burette was filled with sodium hydroxide solution (0.02N), and the burette was fixed to the stand.
- 100ml of the sample was taken in a conical flask.
- 2-3 drops of methyl orange indicator were added to the sample.
- Colour of the solutions changed to orange.
- The sample was titrated with sodium hydroxide solution (0.02N) until orange colouration disappeared.

- The volume consumed for titration was noted down.
- 2-3 drops of phenolphthalein indicator were added to the conical flask.
- Titration was continued until a faint pink coloration appeared.
- The total volume consumed for titration was noted down.
- The process was repeated 3 times to concordant readings.

3.4.11 Determination of Alkalinity

Alkalinity is the quantitative measure of the capacity of water to neutralise strong acid. This property of water exists by virtue of the presence of carbonate, bicarbonate and hydroxyl ions in the water. Carbonate ion primarily comes from calcium carbonate or limestone into the natural water bodies. Hence, water coming in contact with limestone will have higher concentrations of carbonate ions and hence will have higher hardness and alkalinity levels.

Principle

The alkalinity of water can be determined by titration of water against sulphuric acid of known strength, pH and volume. OH^- ions are dissociated from H_2O molecules based on the chemical composition of the water sample. In order to neutralise the OH^- ions it is titrated with sulphuric acid. The volume of the sulphuric acid consumed at the end of the titration is used for the calculation of the alkalinity. Phenolphthalein indicator is added to the sample before titration causing pink coloration in the sample. When the pink colour disappears, the titration end, meaning that all the OH^- ions are neutralised.

Apparatus Required

- Burette
- Burette stand
- Pipette
- 250 mL measuring cylinders
- Conical flasks
- Wash bottle
- Beakers

Chemicals Required

- Sulphuric Acid Solution (0.02N)
- Phenolphthalein Indicator
- Mixed Indicator
- Distilled Water

Procedure

- The burette was rinsed with sulphuric acid solution (0.02N), and the solution was discarded.
- The burette was filled with sulphuric acid solution (0.02N) and adjusted to zero.
- The burette was then fixed to the stand.
- 100 mL of sample was measured using a volumetric cylinder and was poured into the conical flask.
- 2-3 few drops of phenolphthalein indicator were added to the sample. The colour changed to light pink.
- The sample was then titrated with sulphuric acid solution (0.02N) until pink colouration was disappeared. The volume consumed was noted down.
- 2-3 drops of mixed indicator were then added to the conical flask. The colour changed to blue.
- The titration was continued until its colour turns red. The total volume of sulphuric acid solution consumed during titration was noted down.
- The entire process was repeated 3 times for concordant readings.

3.4.12 Determination of Total Hardness by EDTA Titration Method:

Total hardness of water is the measure of the total concentration of calcium and magnesium ions present in the water in the form of carbonates and bicarbonates. Water with higher mineral content have higher total hardness.

Principle:

The sample is taken in a conical flask and buffered to pH 10.1 by adding ammonia buffer. Erichrome Black-T indicator is added to the sample solution which changes the colour to wine red. The solution is then titrated with EDTA. EDTA form complexes with calcium and magnesium ions. When all the calcium and magnesium ions have formed complex with EDTA, the colour of the solution will turn blue indicating the end of titration.

Apparatus Required:

- Burette
- Burette stand
- Pipette
- Conical flasks
- 250 mL volumetric cylinders
- Volumetric flasks
- Wash Bottle
- Beaker

Chemicals Required:

- Ammonia buffer solution
- Standard EDTA Solution
- Erichrome Black T
- Distilled water

Procedure:

- 20mL of the sample was pipetted into a conical flask.
- 2mL of ammonia buffer solution was added to the sample to change the pH to in between 9 and 10.
- Few drops of Erichrome Black-T indicator was added to it, and the colour of the sample changed to wine red.
- The burette was rinsed with EDTA solution and the rinsed out solution was discarded.
- The burette was filled with EDTA solution and was adjusted to zero.
- The burette was then fixed to the stand.
- The sample was then titrated with EDTA solution until a blue colour appeared.
- The burette reading was noted down.
- The entire process was repeated 3 times for concordant readings.

3.4.13 Determination of Biochemical Oxygen Demand

Biochemical Oxygen Demand (BOD) of water is defined as the amount of oxygen that is required for the biological decomposition of organic matter dissolved in it, under standard experimental conditions at a constant temperature for a fixed time.

Principle:

The initial Dissolved Oxygen (DO) is determined then the samples are filled in airtight bottles and kept at 20°C for 5 days inside BOD incubator at a specific temperature for 5 days. The biochemical oxygen demand hence obtained is called BOD₅. After five days of incubation, the final DO is determined. BOD is then calculated by the difference between the initial and the final DO.

Apparatus Required:

- BOD Incubator
- Burette
- Burette stand
- BOD bottles with glass stoppers
- Conical flasks
- Pipette

- 250 mL volumetric cylinders
- Wash bottle

Chemicals Required:

- Distilled water

Procedure:

- Four BOD bottles were taken, 2 for blank and 2 for samples.
- 10 mL of sample was added to each BOD bottle, and the remaining space was filled with the distilled water dilute the sample 1:30.
- 2 BOD bottles were filled completely with blank (distilled water).
- The glass stopper was placed immediately over the BOD bottles.
- One BOD bottle containing sample solution and one containing blank were kept in the BOD incubator for 5 days at 20°C.
- Remaining two bottles were analysed immediately.
- 2mL of manganese sulphate solution was added to the BOD bottle by inserting a pipette just below the surface of the liquid.
- It was allowed to settle for some time and to react with oxygen completely.
- It was shaken thoroughly by turning it upside down after the floc has settled to the bottom.
- 2 mL of concentrated sulfuric acid was added using a pipette.
- The stopper was attached, and the bottle was shaken properly.
- The burette was rinsed with sodium thiosulphate solution, and the rinsed solution was discarded.
- The burette was filled with sodium thiosulphate solution and was fixed to the stand.
- 200 mL of the solution was measured out from the bottle and was transferred to a conical flask.
- The solution was titrated against sodium thiosulphate solution until yellow colour disappeared.
- 1 mL of starch solution was added, and titration was continued until the blue colour disappeared.
- The volume of solution used in the titration was noted down, which gave the DO in mg/L.
- The process was repeated 3 times for concordant readings.
- The bottles were taken out from the BOD incubator after 5 days and were analysed for DO by following the above steps.
- 2mL of manganese sulphate solution was added to the BOD bottle by inserting the pipette just below the surface of the liquid.
- Brownish orange floc appeared in the sample, indicating the presence of oxygen.

3.5 Results of Experimental analysis

Table 3.2: Laboratory analysis data of ground water samples

Sl.No.	Parameter Type	Parameter	G1	G2	G3	G4	G5	Permissible Limit (IS-10500)
1	Physical	Temperature (°C)	26.66	26.58	27.38	27.84	27.69	–
2		Conductivity (µS/cm)	349	25	57	91	101	400
3		TDS (mg/L)	227	17	37	59	66	2000
4		Turbidity (NTU)	1.2	0.2	1.1	297	8.6	5
5	Chemical	Hardness (mg/l)	167	19	69	181	72	600
6		ORP (mV)	215	219	220	30	91	–
7		pH	7.27	6.53	5.36	5.95	5.5	6.5-8.5
8		Acidity (mg/l)	48.3	9.43	57.74	160.8	78.48	–
9		Alkalinity (mg/l)	30.37	8.87	67.32	138.31	32.69	600
10		DO (mg/L)	9.84	8.64	10.41	8.27	10.35	5
11		BOD (mg/l)	5.27	1.54	1.76	2.77	2.43	5
12		Sulphate (ppm)	4.49	3.76	3.86	4.95	3.95	400
13		Phosphate (ppm)	1.18	0.02	0.23	0.59	0.65	–
14		Nitrate (ppm)	12.31	0.7	8.61	4.97	5.81	45
15		Cl (ppm)	8.52	2.84	5.68	5.68	2.84	1000
16	F (ppm)	0.07	0.0073	0.017	0.023	0.016	1.5	
17	Metal	Na (ppm)	7.97	0.82	2.43	1.98	2.65	–
18		K (ppm)	1.32	0.37	1.99	1.09	1.42	–
19		Ca (ppm)	25.53	2.34	0.21	3.53	7.14	200
20		Mn (ppm)	0.15	0.02	0.04	0.05	0.07	0.3
21		Fe (ppm)	0.35	0.08	0.24	0.27	0.17	0.3
22		Cu (ppm)	0.1	0	0	0	0	1.5
23		Ni (ppm)	0.01	0	0.01	0	0	0.02

Table 3.3: Laboratory analysis data of Surface water samples

Sl.No.	Parameter Type	Parameter	S1	S2	S3	S4	S5	Permissible Limit (IS-10500)
1	Physical	Temperature (°C)	27.77	26.84	27.71	27.58	26.4	–
2		Conductivity (µS/cm)	51	73	59	25	54	400
3		TDS (mg/L)	32	47	38	16	37	2000
4		Turbidity (NTU)	3.1	86.7	10.1	24.9	116.7	5
5	Chemical	Hardness (mg/l)	29	117	37	57	135	600
6		ORP (mV)	115	185	144	207	197	–
7		pH	7.31	7.01	6.27	5.32	6.77	6.5-8.5
8		Acidity (mg/l)	19.93	20.31	11.63	64.87	45.75	–
9		Alkalinity (mg/l)	30.33	34.98	26.73	27.45	49.2	600
10		DO (mg/L)	5.98	10.77	6.24	6.78	7.26	5
11		BOD (mg/l)	2.65	4.94	1.67	2.89	5.72	5
12		Sulphate (ppm)	4.04	3.77	4.22	3.67	3.86	400
13		Phosphate (ppm)	0.47	0.82	0.37	0.43	1.04	–
14		Nitrate (ppm)	2.26	6.39	15.67	3.78	11.79	45
15		Cl (ppm)	2.84	7.1	7.1	2.84	5.68	1000
16		F (ppm)	0.025	0.02	0.018	0.012	0.031	1.5
17	Metal	Na (ppm)	3.98	4.12	2.23	2.54	4.92	–
18		K (ppm)	1.29	2.89	1.21	1.82	3.87	–
19		Ca (ppm)	7.65	11.43	8.45	6.84	17.32	200
20		Mn (ppm)	0.06	0.13	0.06	0.05	0.16	0.3
21		Fe (ppm)	0.16	0.38	0.14	0.21	0.31	0.3
22		Cu (ppm)	0	0.08	0	0	0.11	1.5
23		Ni (ppm)	0	0	0	0	0.04	0.02

4. Water Quality Modelling

4.1 General

Water quality modelling includes the classification based on mathematical formulations and the prediction of water quality using simulation techniques (EPA, 1985). Water quality model usually consists of a compilation of mathematical formulations signifying physical processes for the determination of the position, momentum and levels of contaminants in the water bodies. Water quality models are also used for demonstrating various specific mechanisms of the hydro-geological system including seepage and surface runoff. Some models can also address hydrogeological transportation in estuaries lakes and streams.

Water Quality Index (WQI) expresses the overall water quality in terms of mathematical figure, considering various water quality parameters (Yogendra and Puttaiah, 2008), whose primary objective is the conversion of complex water quality data into easily understandable information for the general public. There are several WQI Models present, each having different mathematical formulations and take various water quality parameters as input. Each water quality index has its classification system based on the numeric value of WQI it generates. Water quality index provides a much simpler explanation of water quality, giving the general public a basic idea about the quality of water in the area.

Water quality modelling is also useful in circumstances where monitoring is not feasible (Loucks and van Beek, 2005). Integrated modelling and monitoring system can give better estimation than any individual system given the same total cost of the system. For instance, regression analysis which correlates the concentration of pollutant with more easily measurable parameters like runoff can also be applied to extend the monitoring.

Bayesian framework models can also be used for determining the probability distributions of degradation which may help on direct monitoring and may also reduce the amount of monitoring data required for taking listing decisions any given level of reliability. Modelling could also be utilised for predicting the water quality based on conditions created by various water quality management strategies.

4.2 Weighted Arithmetic-Water Quality Index (WA-WQI)

Weighted Arithmetic-Water Quality Index (WA-WQI) classifies the water quality based on the level of purity of water, using the most commonly analysed water quality parameters, viz., pH, dissolved oxygen, biochemical oxygen demand, conductivity, total dissolved solids, total hardness, chloride, nitrate, and sulphate. Scientists have widely used the method for classifying water quality. The WA-WQI (Brown, 1972) can be calculated by using the following expression:

$$WQI = \Sigma Q_i W_i / \Sigma W_i$$

Q_i (quality rating scale) can be calculated for each parameter by using the following expression:

$$Q_i = 100 \times \left[\frac{(V_i - V_0)}{(S_0 - V_0)} \right]$$

where,

V_i is determined concentration of i th parameter in the analysed water.

V_0 is the ideal value of i th parameter and

$$V_0 = \begin{cases} 7, & \text{for pH} \\ 14.6, & \text{for DO} \\ 0, & \text{for all other parameters} \end{cases}$$

S_0 is the standard permissible value of i th parameter

W_i is the weightage for i th parameter, and is calculated from the following expression:

$$W_i = \left(\frac{K}{S_i} \right)$$

where,

K is the proportionality constant, and is calculated from the following expression:

$$K = \left(\frac{1}{\sum(1/S_i)} \right)$$

The Weighted Average – Water Quality Index for all the samples have been presented in Table 5.1.

Table 4.1: Determined WA-WQI values of all sampling sites

Sampling site	G1	G2	G3	G4	G5	S1	S2	S3	S4	S5
WQI	87.8	24.4	67.9	72.8	51.8	43.2	92.3	41.5	63.7	79.8

4.3 Graphical Modelling

A graphical model is a model represented in a visual form, showing information in a graphical way, allowing easier comprehension of much more complex underlying data. The graphical modelling of all the parameters and Water Quality index was done in QGIS (Quantum GIS) software by using Inverse Distance Weighting (IDW) method of interpolation. The output of the graphical modelling came out as images (Figure 4.1 to 4.22) showing concentrations/values of different parameters as different shades of the colour spectrum (Single band Pseudo-colour) with respect to their corresponding coordinates. In these images, the red colour indicates higher value, blue colour indicates lower value, and green and yellow colour indicates moderate values. The detailed procedure of graphical modelling has been described as follows.

4.3.1 Inverse Distance Weighting (IDW) Interpolation

Inverse Distance Weighting (Shephard, 1968) is a deterministic technique used for multivariate interpolation with a predetermined set of points. The values of the known points with their weighted averages are used to estimate the values at unknown points.

The estimated value of any unknown point u is given by the following expression:

$$u(x) : x \rightarrow R, x \in D \subset R$$

where D is the study region

The set of N known data points can be expressed as ordered pairs.

$$[(x_1, u_1), (x_2, u_2), (x_3, u_3), \dots, (x_N, u_N)]$$

The function $(u(x_i) = u_i)$ must be continuous and differentiable. Standard form of expression to interpolate unknown values u_x at any given point x considering the N known data points $u_i = u(x_i)$ for $i = 1, 2, \dots, N$ is given by the following function:

$$u(x) \begin{cases} \frac{\sum_{i=1}^N w_i(x) \times u_i}{\sum_{i=1}^N w_i(x)}, & \text{for } d(x, x_i) \neq 0, \text{ for all } i \\ u_i(x), & \text{for } d(x, x_i) = 0, \text{ for some } i \end{cases}$$

$$w_i(x) = \frac{1}{d(x, x_i)^p}$$

where w_i is the weighting function where x is the unknown point to be interpolated point, x_i is a known data point, N is the total number of known data points, d is the distance the points x_i and x, and p is a positive whole number known as power parameter.

The weight (w_i) is inversely proportional to the p^{th} power of the distance $d(x, x_i)$, meaning that the weightage decrease with increase in distance and higher value of p makes the distance to impose more impact on the interpolated values. For 2-D, the power parameter $p \leq 2$ will make the value to be interpolated predominantly by the far away points. With the density of the known sample points ρ and neighbourhood points between the distances R and r_0 , the total weightage will be:

$$\sum_j w_j \approx \int_{r_0}^R \frac{2\pi r \rho}{r^p} dr = 2\pi \rho \int_{r_0}^R r^{1-p} dr$$

which diverges at $R \rightarrow \infty$ and $p \leq 2$. The choice of value for p can be made by considering the degree of smoothness required for the interpolation of unknown values, density and the level of scattering of the known data points, and the maximum distance which any single data will have an influence on the interpolated points. This method is a result of minimising function related to the measure of variations among the ordered pairs of interpolating points $\{x, u\}$ and i ordered pairs of the interpolated points $\{x_i, u_i\}$, is given by the following expression:

$$\phi(x, u) = \left(\sum_{i=0}^N \frac{(u - u_i)^2}{d(x, x_i)^p} \right)^{\frac{1}{p}}$$

can be determined from the following minimising expression:

$$\frac{\partial \phi(x, y)}{\partial u} = 0$$

This technique can be easily extended to more dimensional spaces, and in fact, it is a generalised form of the Lagrange approximation of multidimensional spaces.

4.3.2 Procedure of graphical modelling

QGIS (Quantum GIS) is an open source, cross-platform GIS (Geographic Information System) that is used for viewing, manipulating and analysing geospatial data in addition to importing, exporting and composing geographical maps. It can be utilised for both raster and vector data analysis. QGIS supports various formats, viz., shapefiles, geodatabases, coverages, MapInfo, dxf, PostGIS. QGIS also supports plugins based on Python and C++ in order to extend its abilities.

QGIS was used in this work for the graphical modelling. The graphical model was created by using the Inverse Distance Weighting (IDW) interpolation method. First, the laboratory analysis data of the water samples with all the water quality parameters was the input into a CSV file using Microsoft Excel, then a layer of Google terrain was added, raster interpolation was performed on the data using IDW method, a 3D model was then created using the QGIS3threejs plugin.

4.3.3 Graphical modelling result

The graphical modelling was done in QGIS using the data from laboratory analysis. IDW (Inverse Distance Weighting) was used as the Interpolation method.

Figure 4.1 to 4.22 show the result of graphical modelling. The colours in the images represent the concentration/value of each parameter. The red colour indicates higher value, blue colour indicates lower value, and green and yellow colour indicates moderate values.

Physical parameters

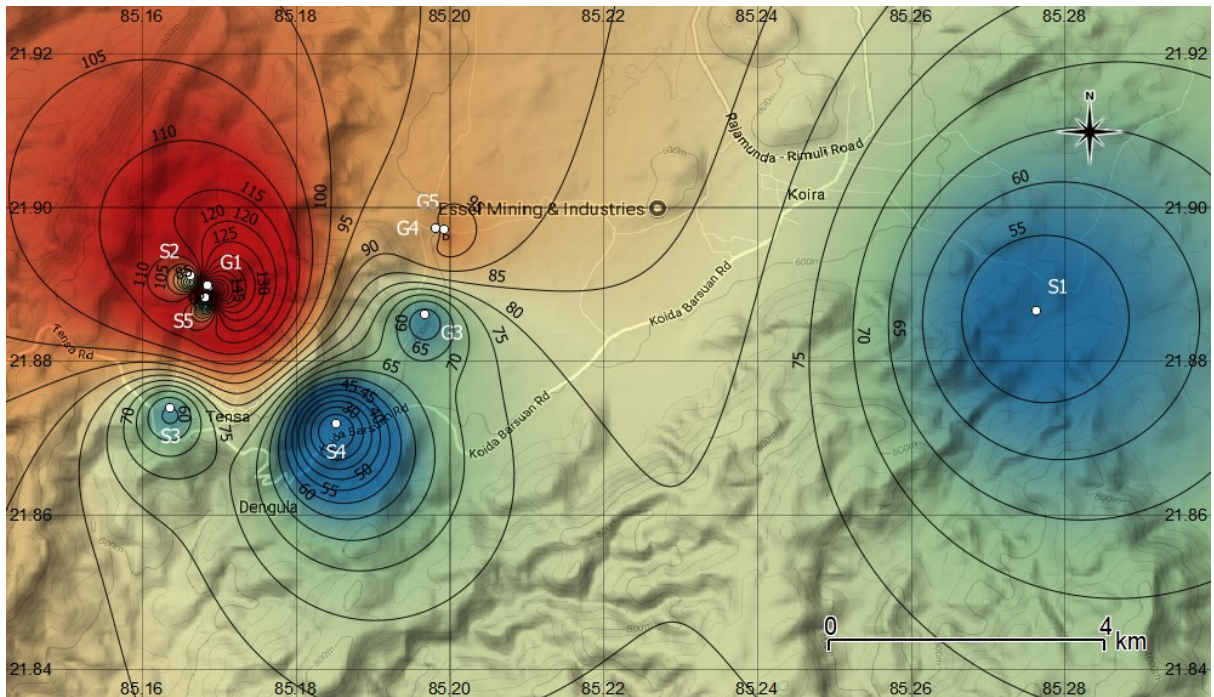


Figure 4.1: Graphical modelling of Conductivity

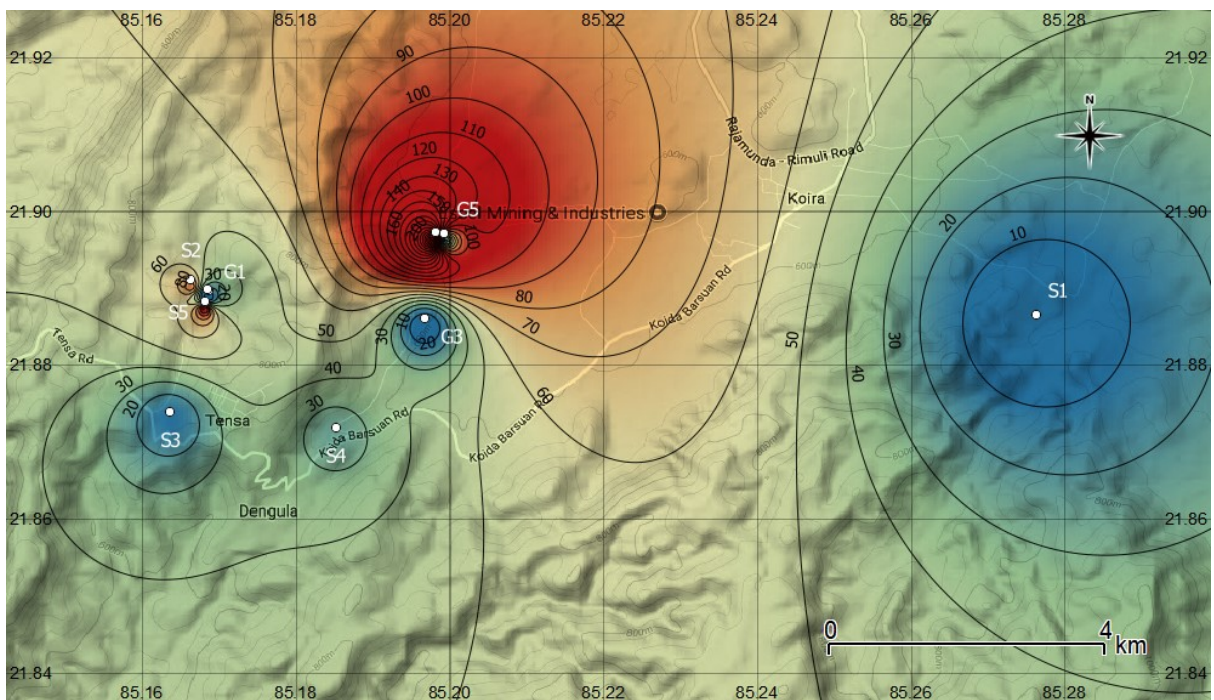


Figure 4.2: Graphical modelling of Turbidity

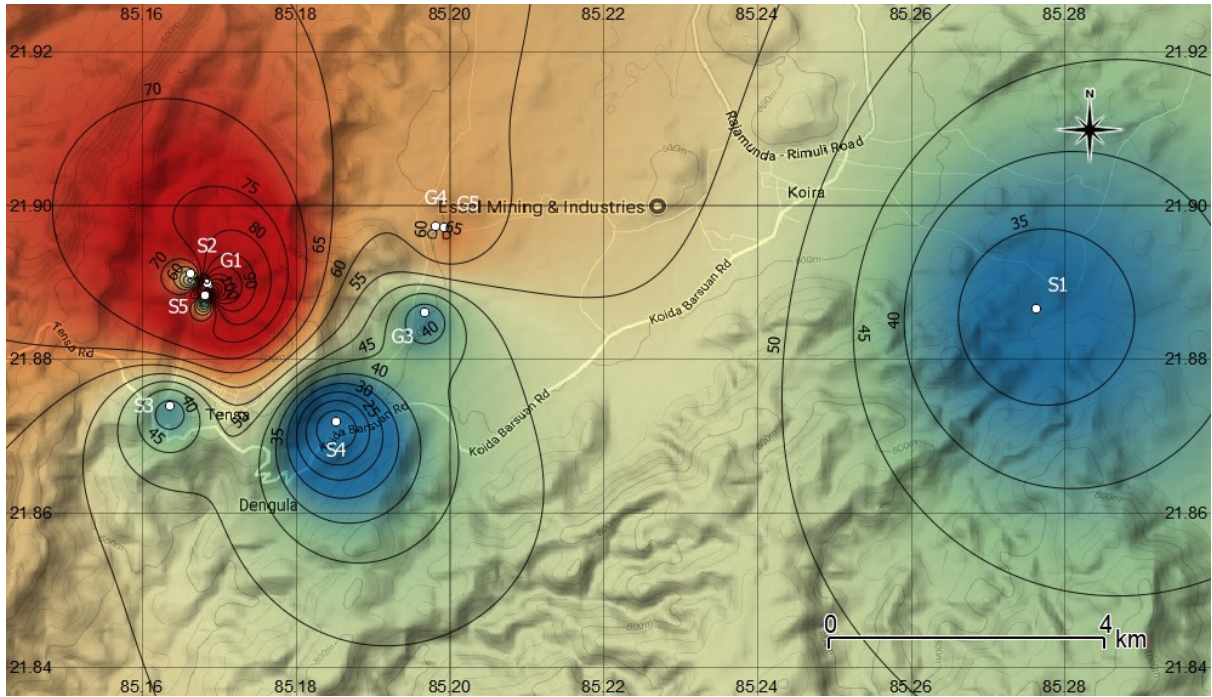


Figure 4.3: Graphical modelling of TDS

Chemical parameters

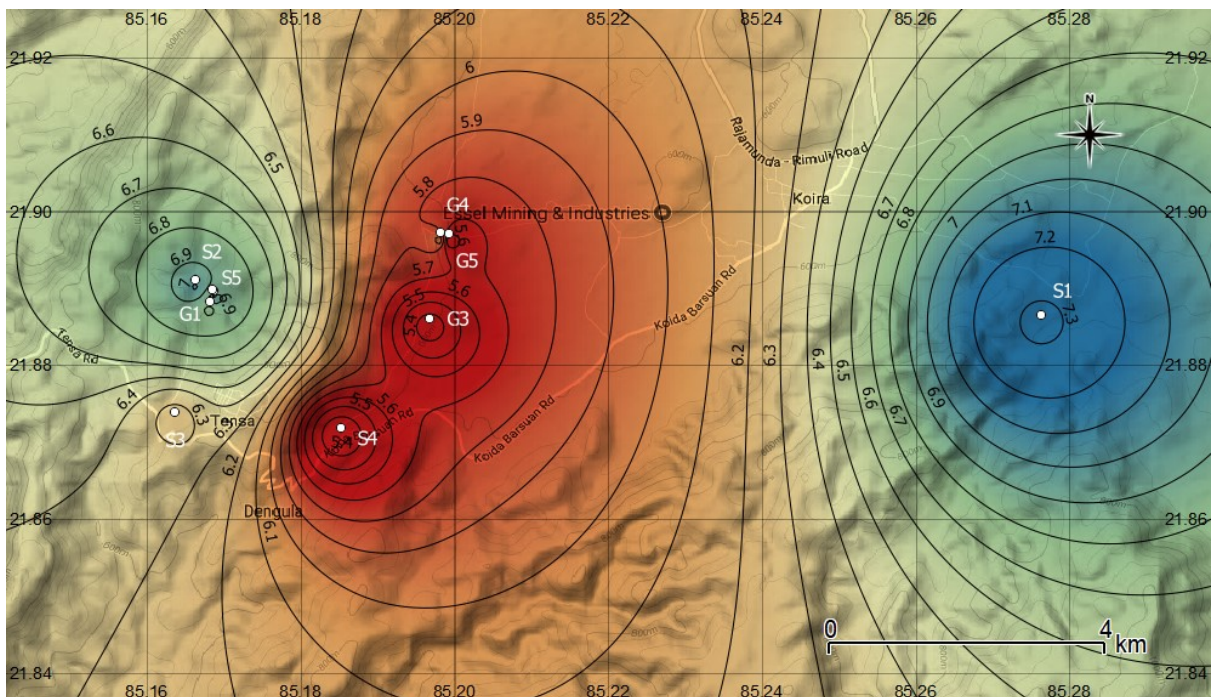


Figure 4.4: Graphical modelling of pH

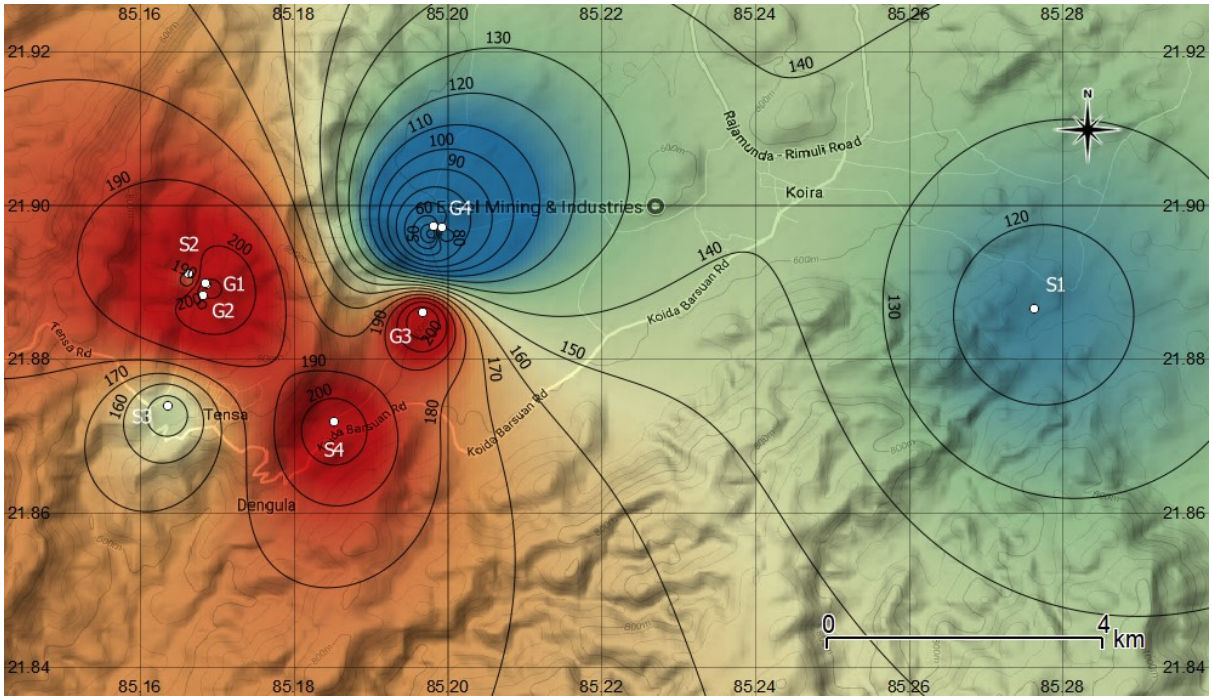


Figure 4.5: Graphical modelling of ORP

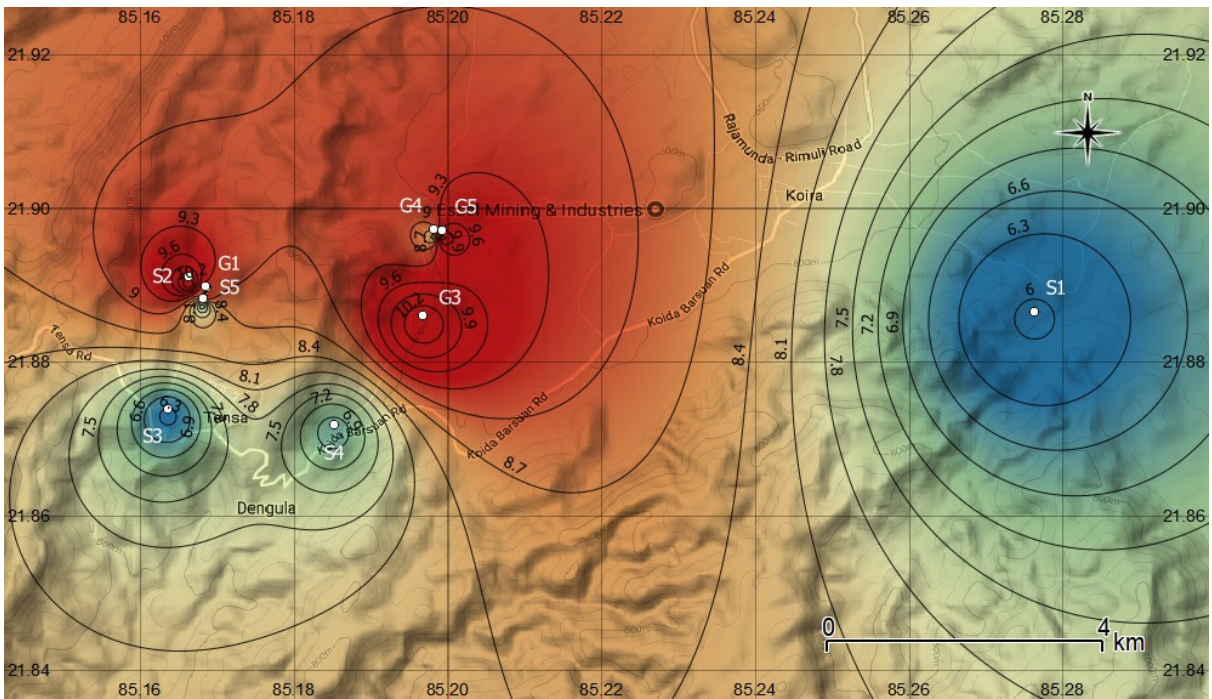


Figure 4.6: Graphical modelling of DO

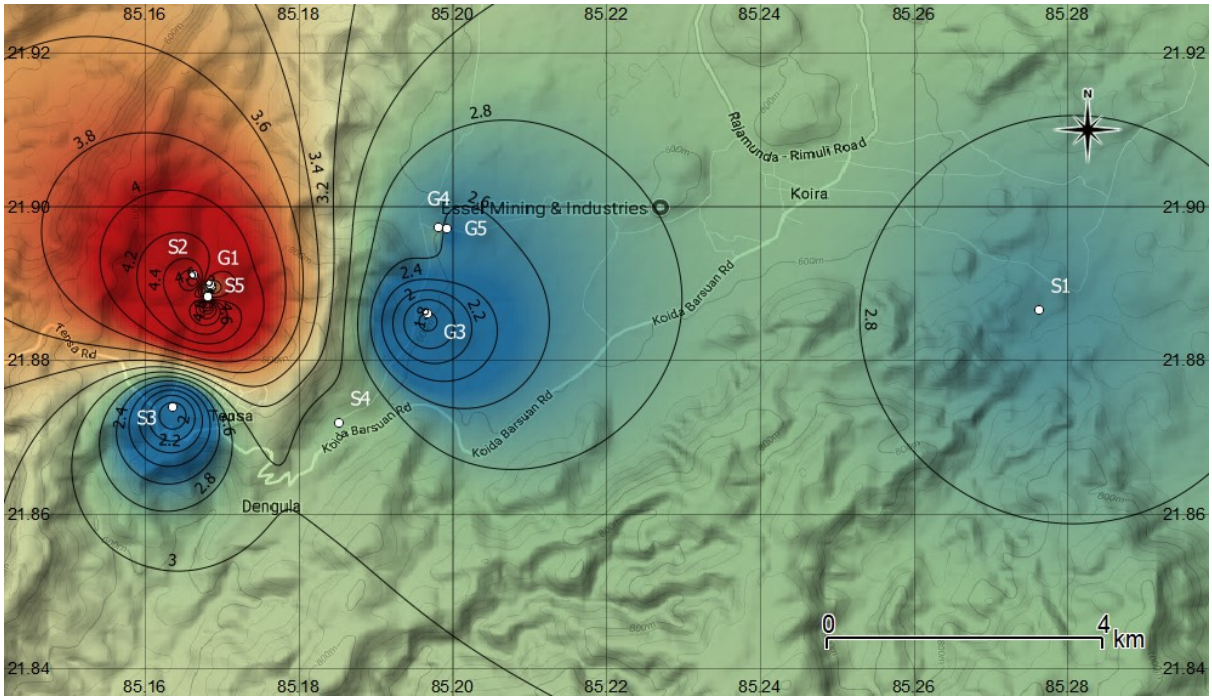


Figure 4.7: Graphical modelling of BOD

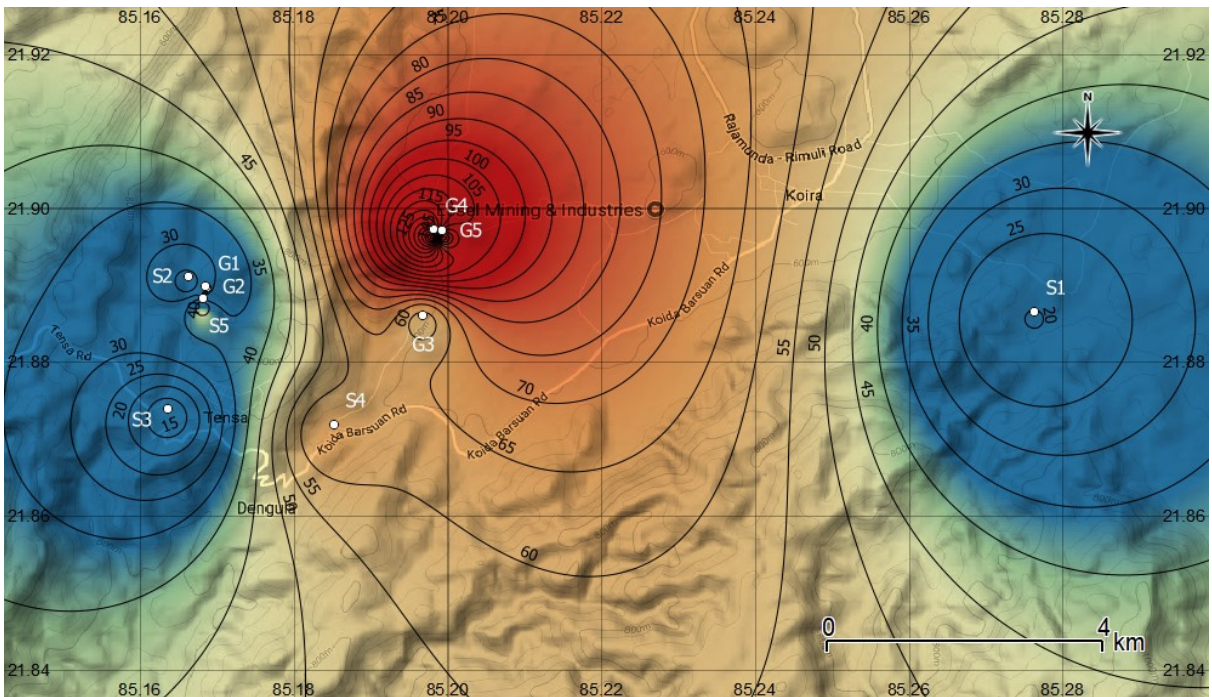


Figure 4.8: Graphical modelling of Acidity

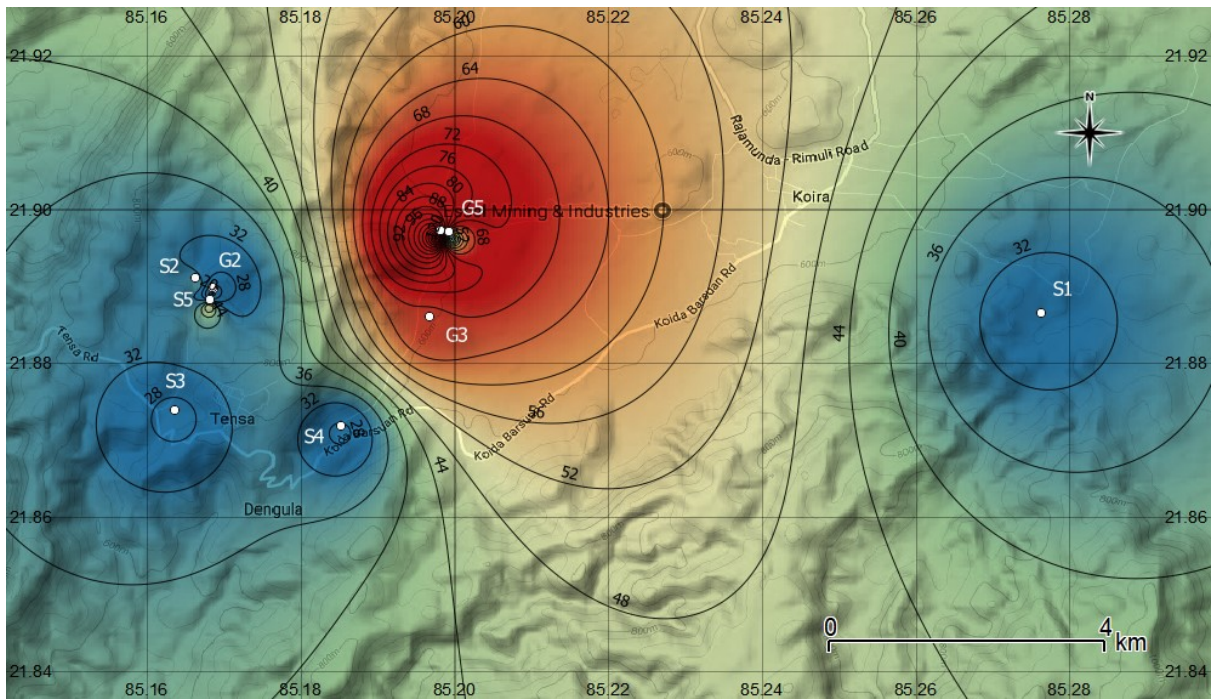


Figure 4.9: Graphical modelling of Alkalinity

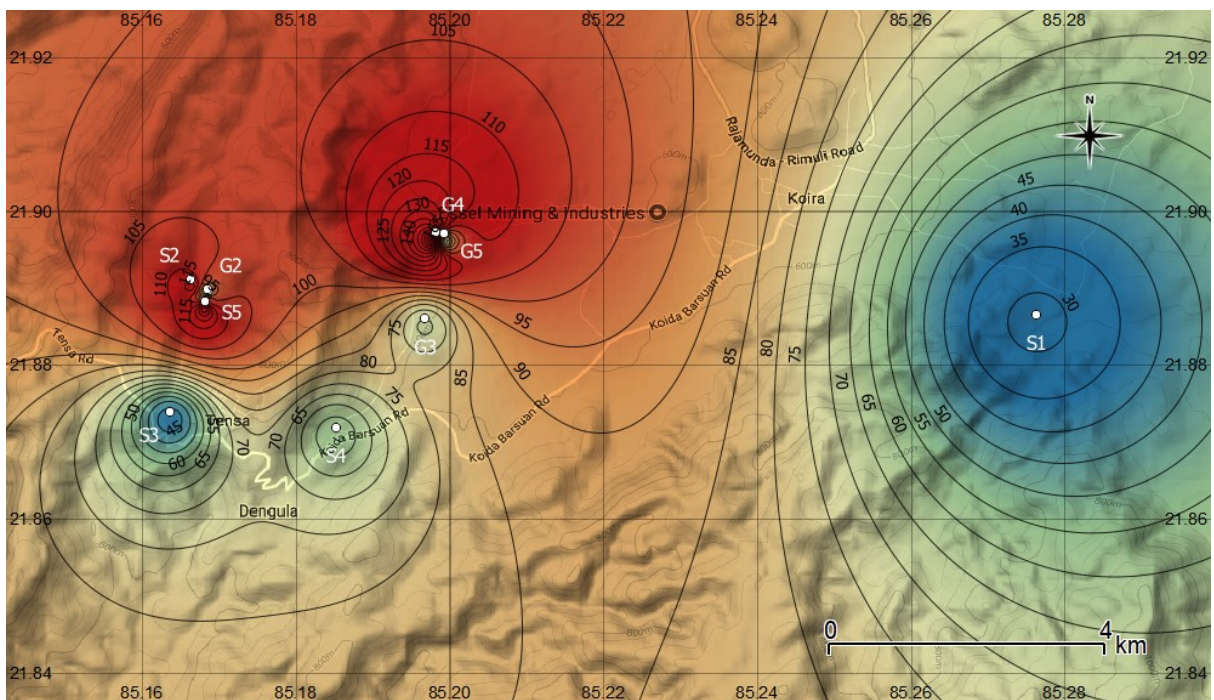


Figure 4.10: Graphical modelling of Hardness

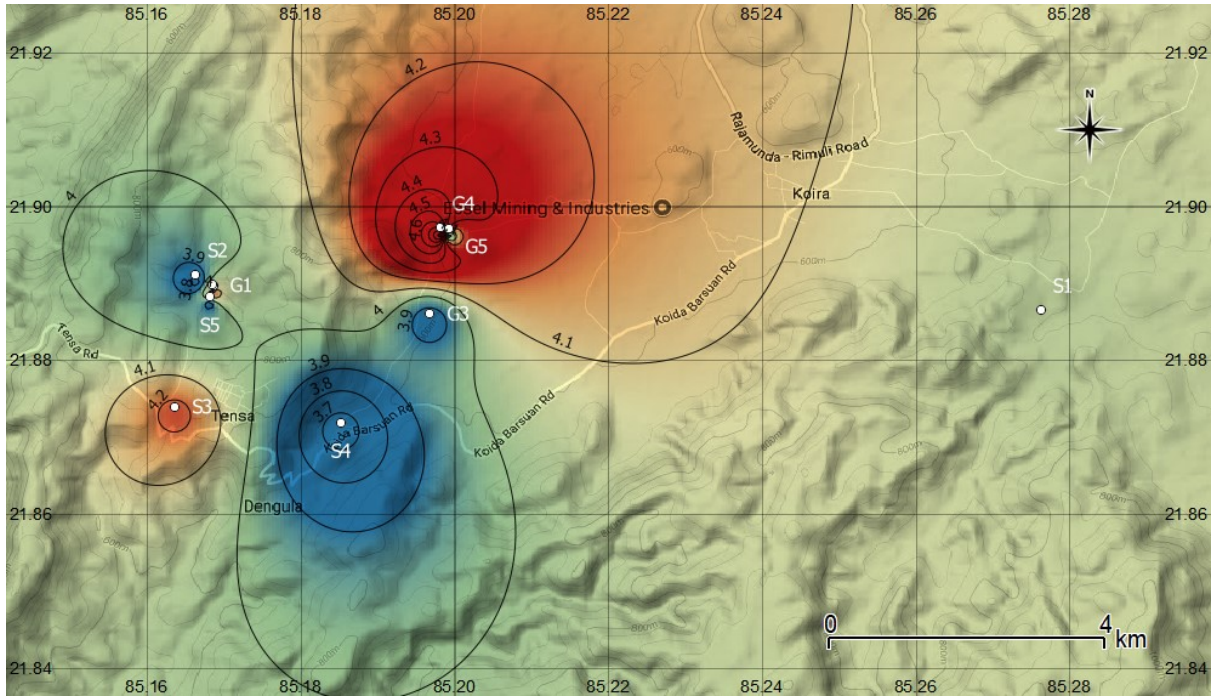


Figure 4.11: Graphical modelling of Sulphate

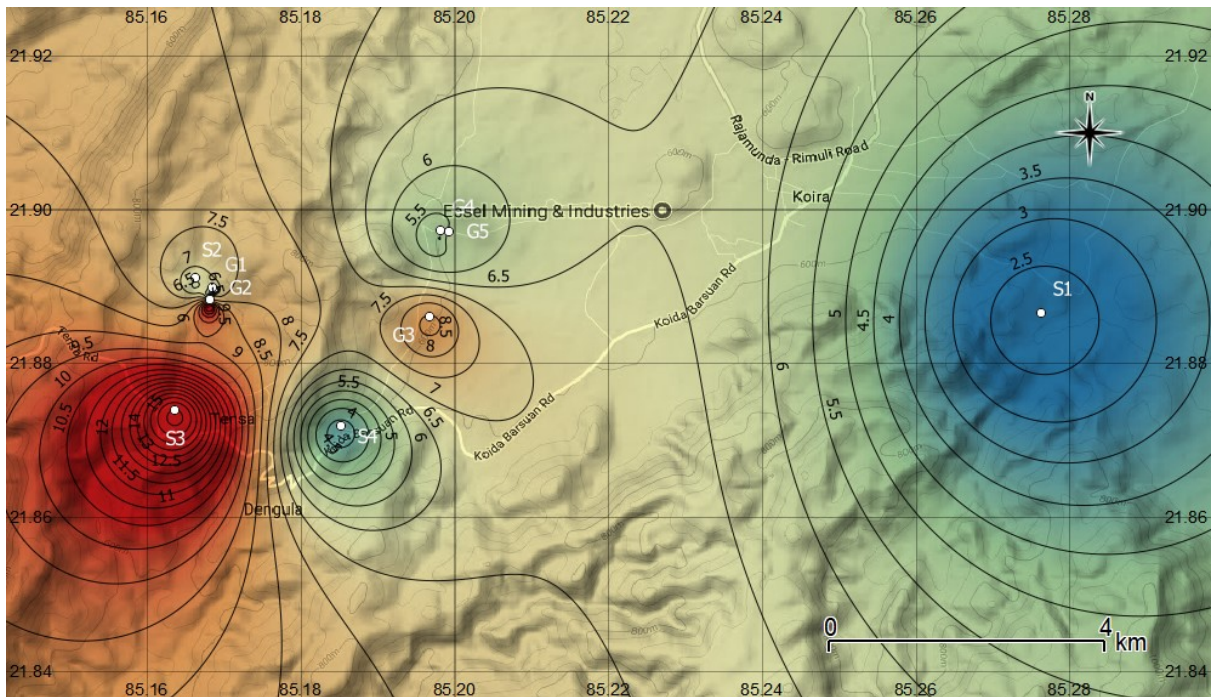


Figure 4.12: Graphical modelling of Nitrate

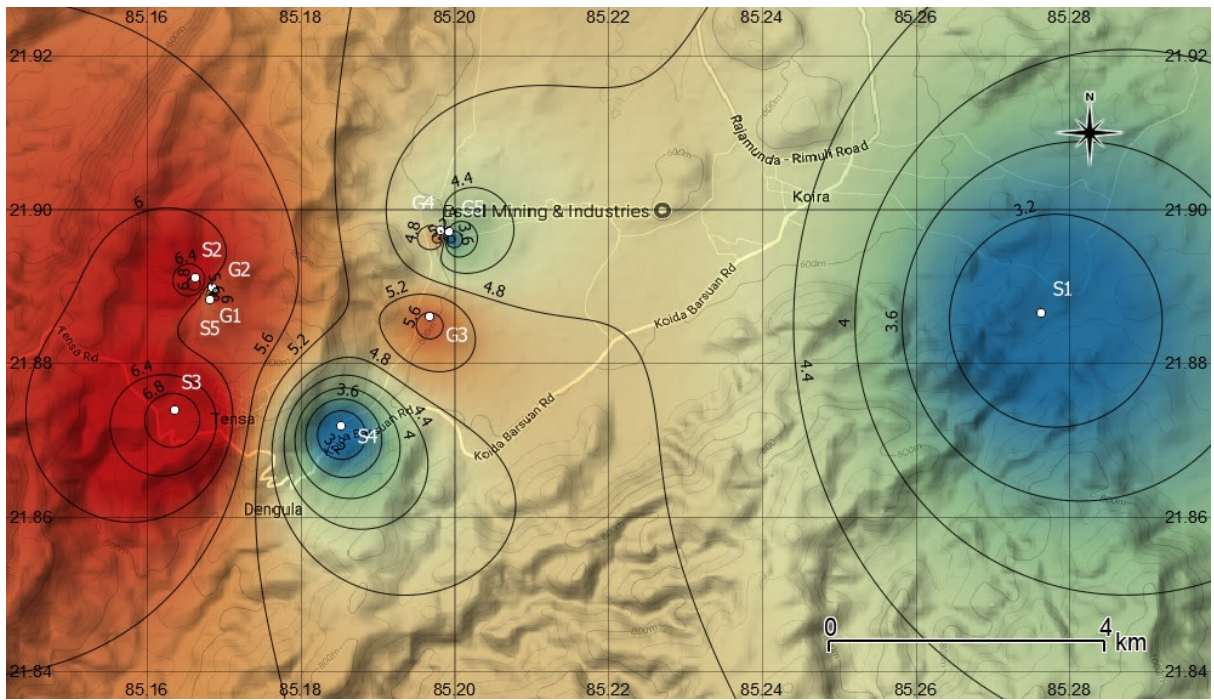


Figure 4.13: Graphical modelling of Chloride

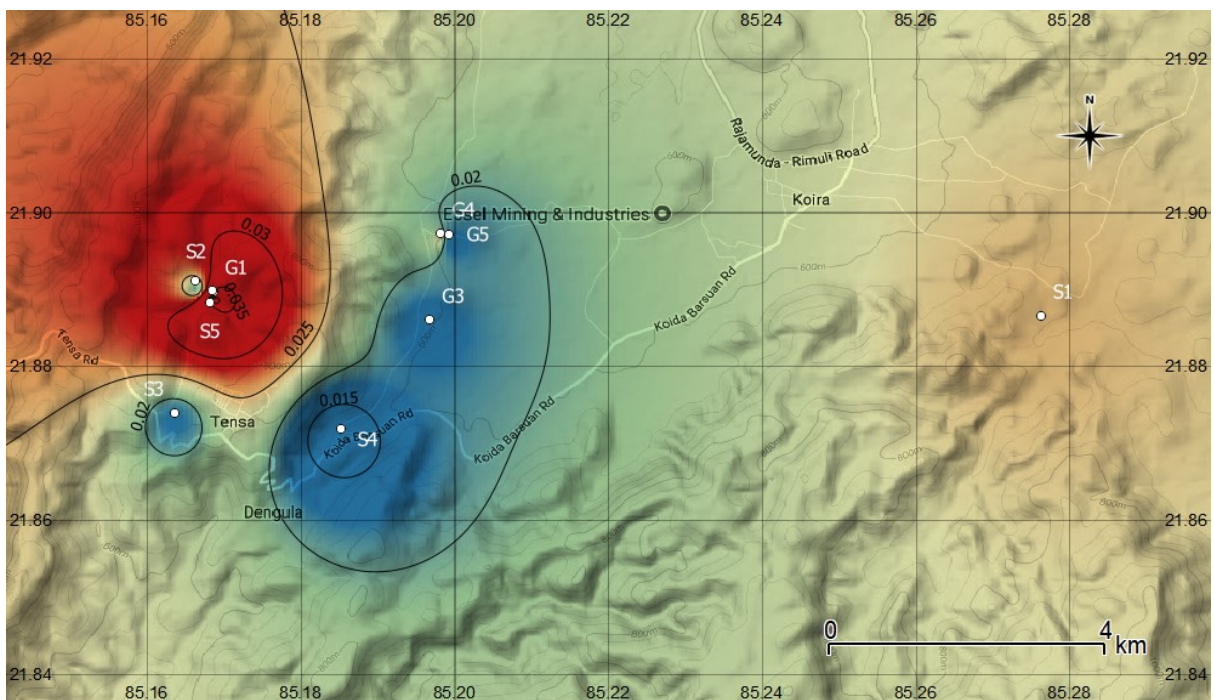


Figure 4.14: Graphical modelling of Fluoride

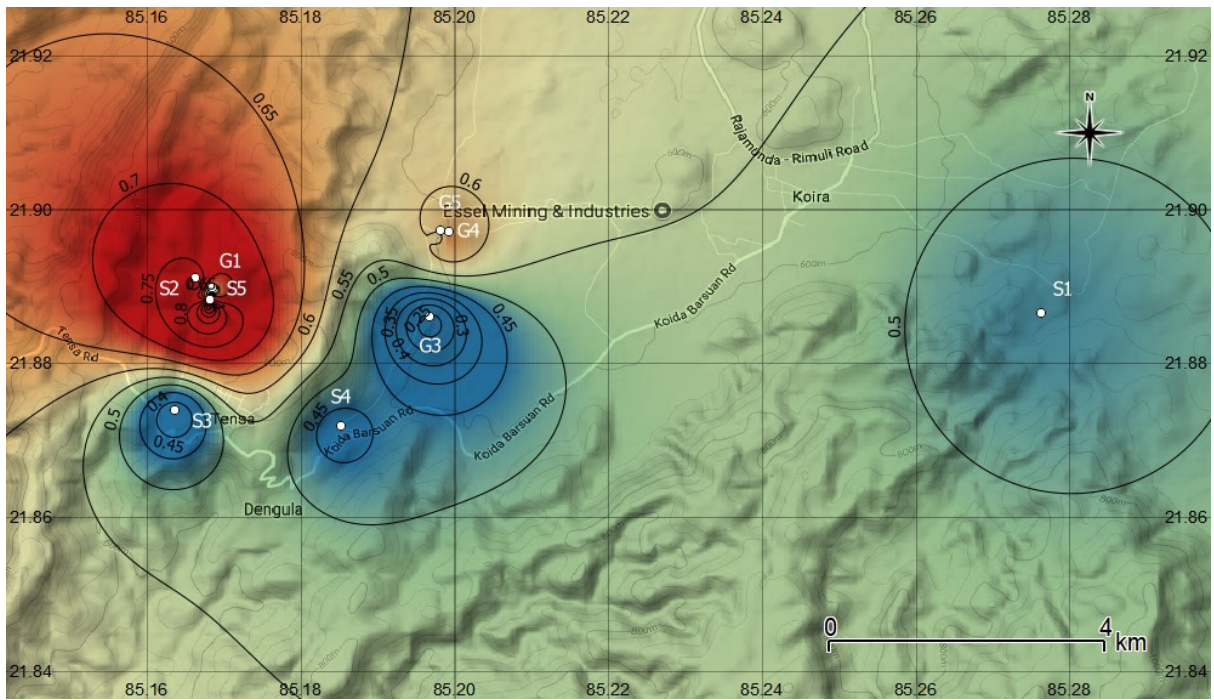


Figure 4.15: Graphical modelling of Phosphate

Metals

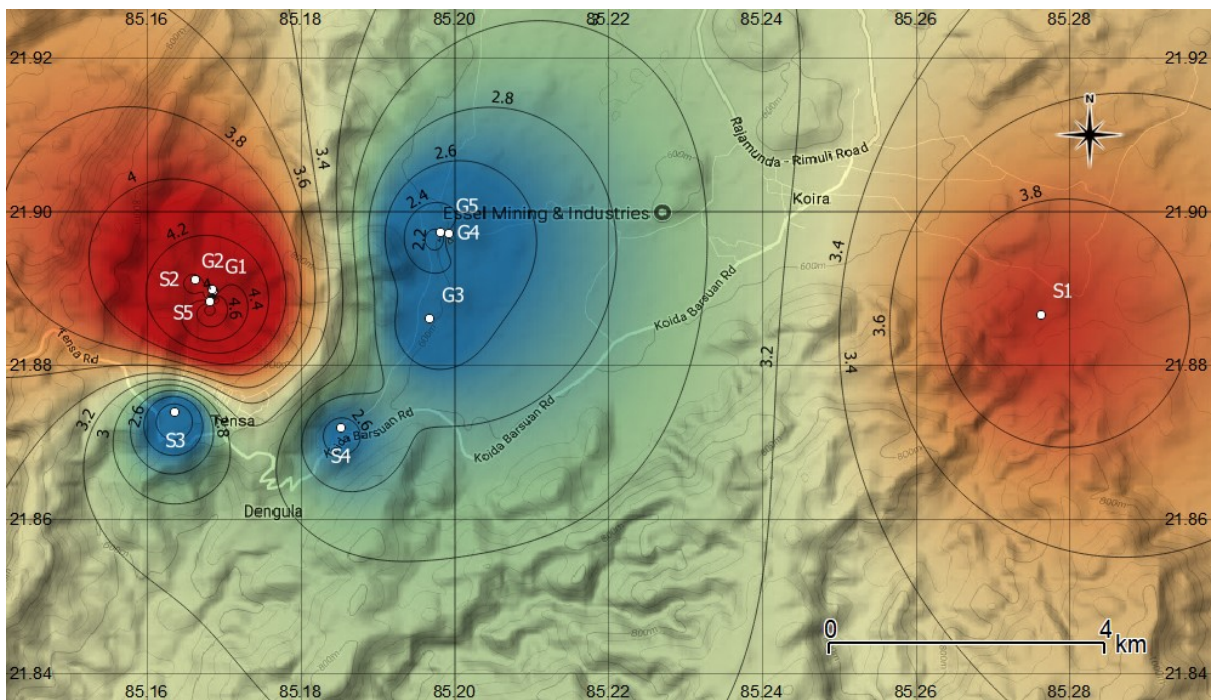


Figure 4.16: Graphical modelling of Sodium

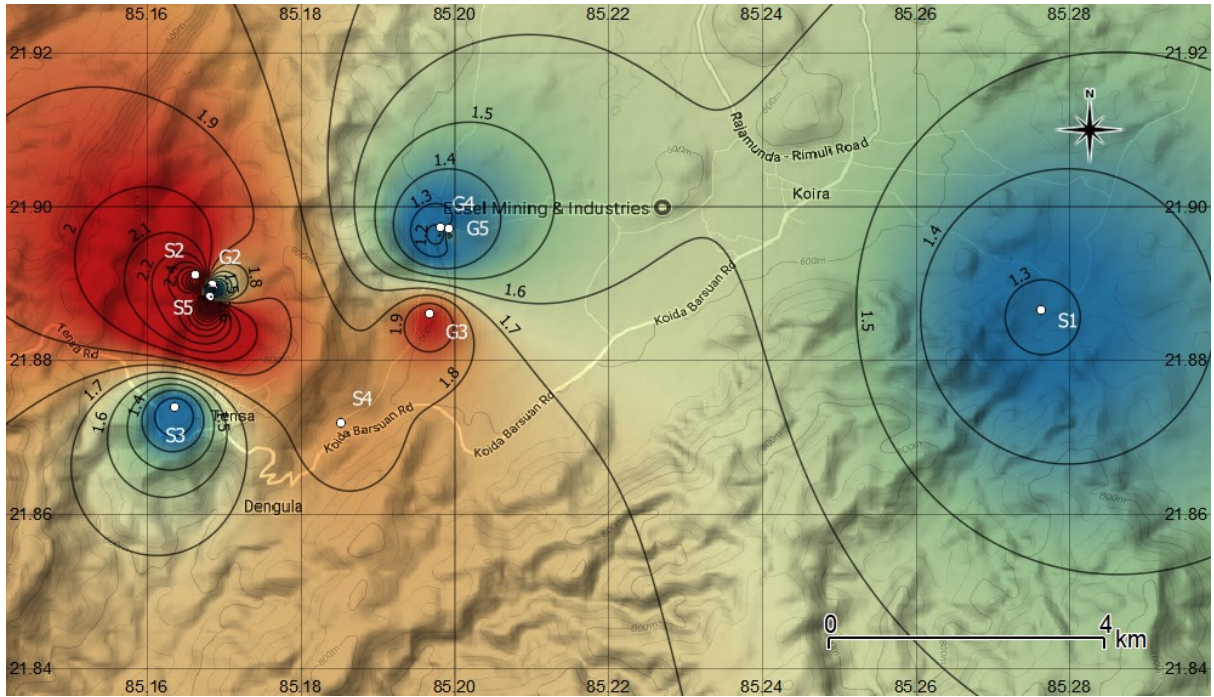


Figure 4.17: Graphical modelling of Potassium

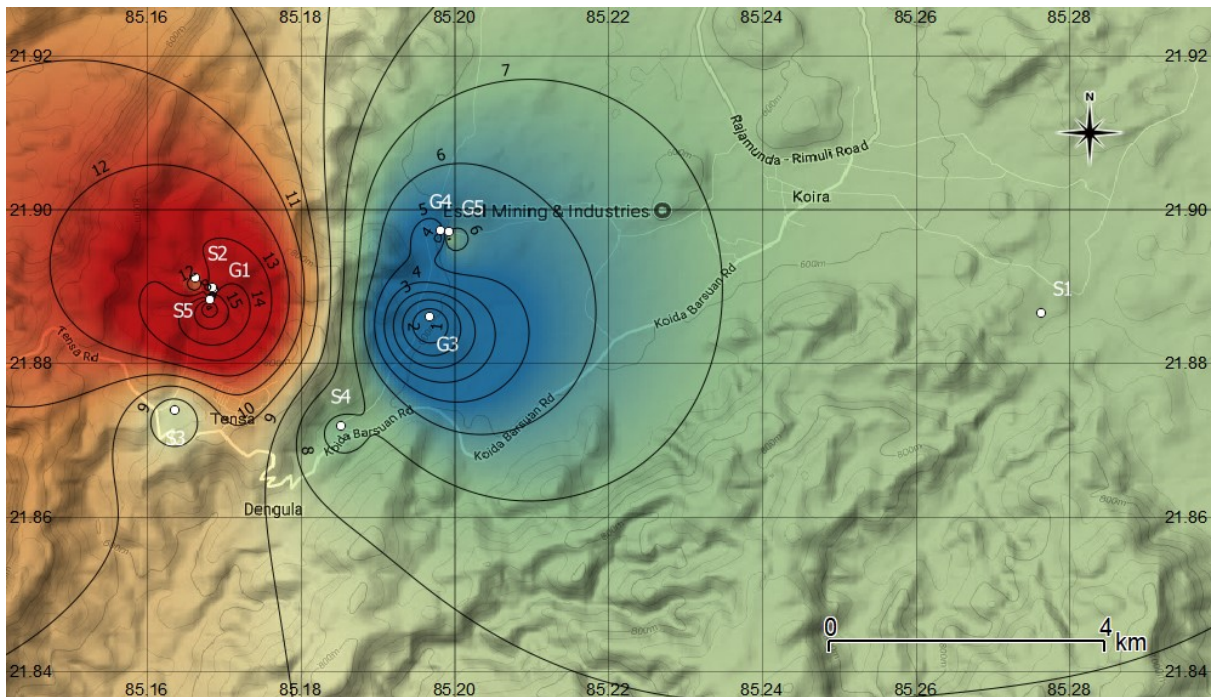


Figure 4.18: Graphical modelling of Calcium

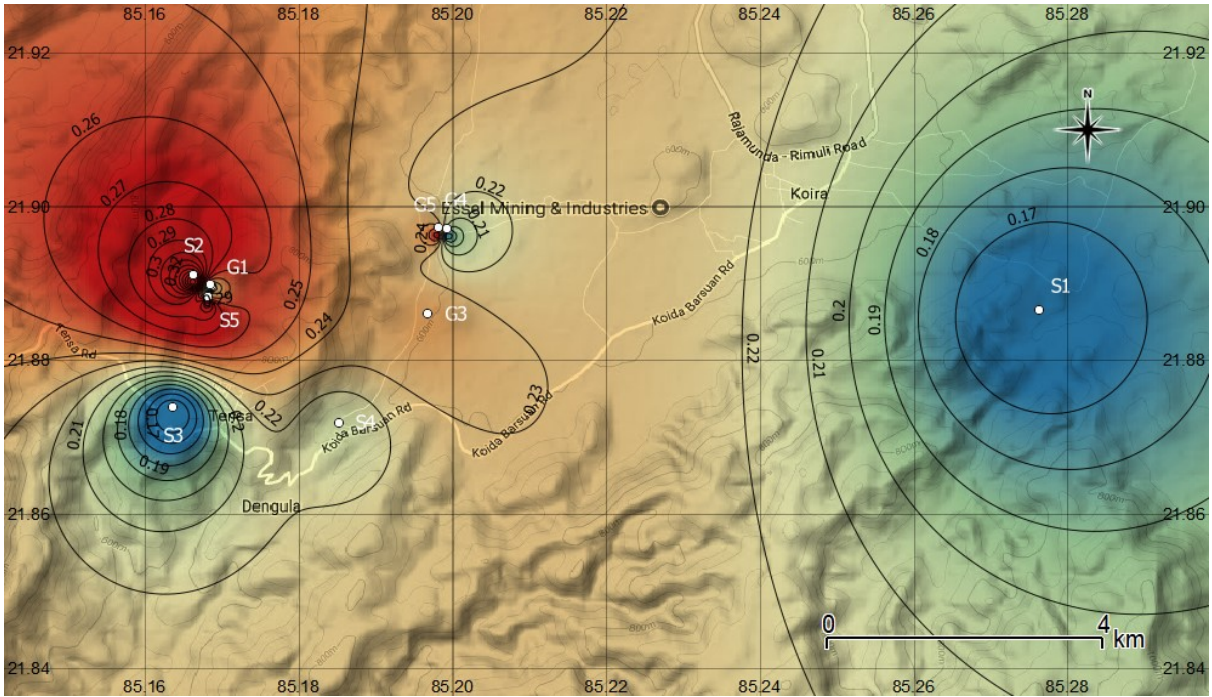


Figure 4.19: Graphical modelling of Iron

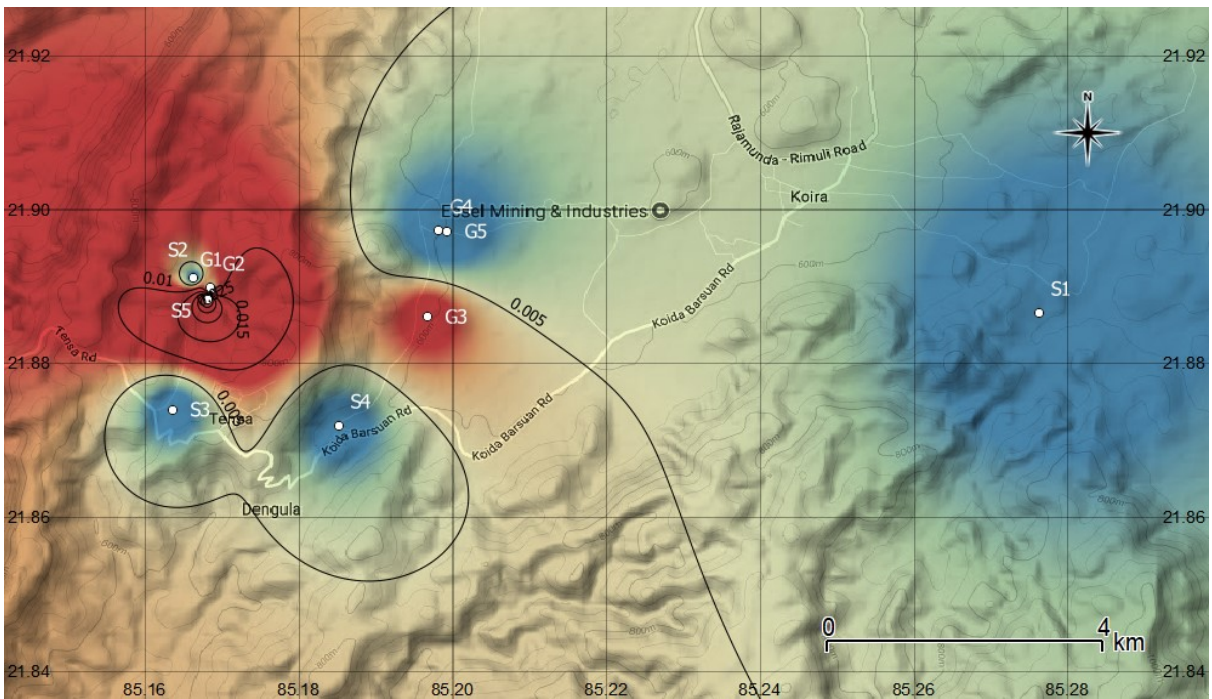


Figure 4.20: Graphical modelling of Nickel

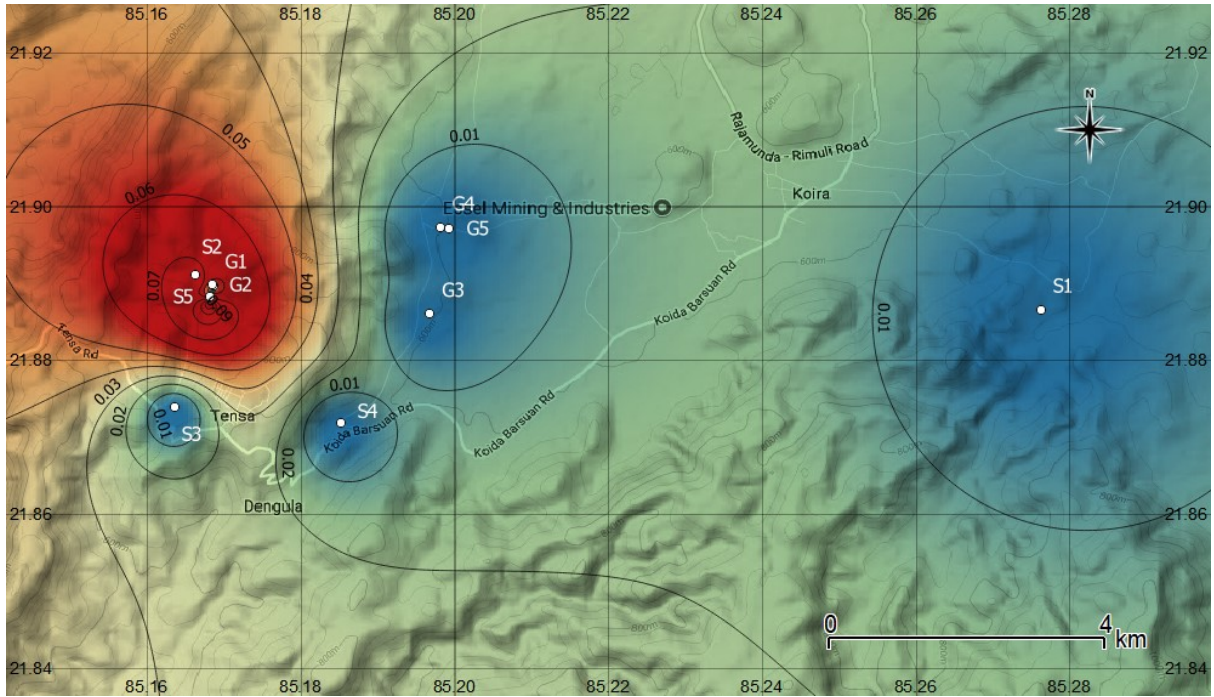


Figure 4.21: Graphical modelling of Copper

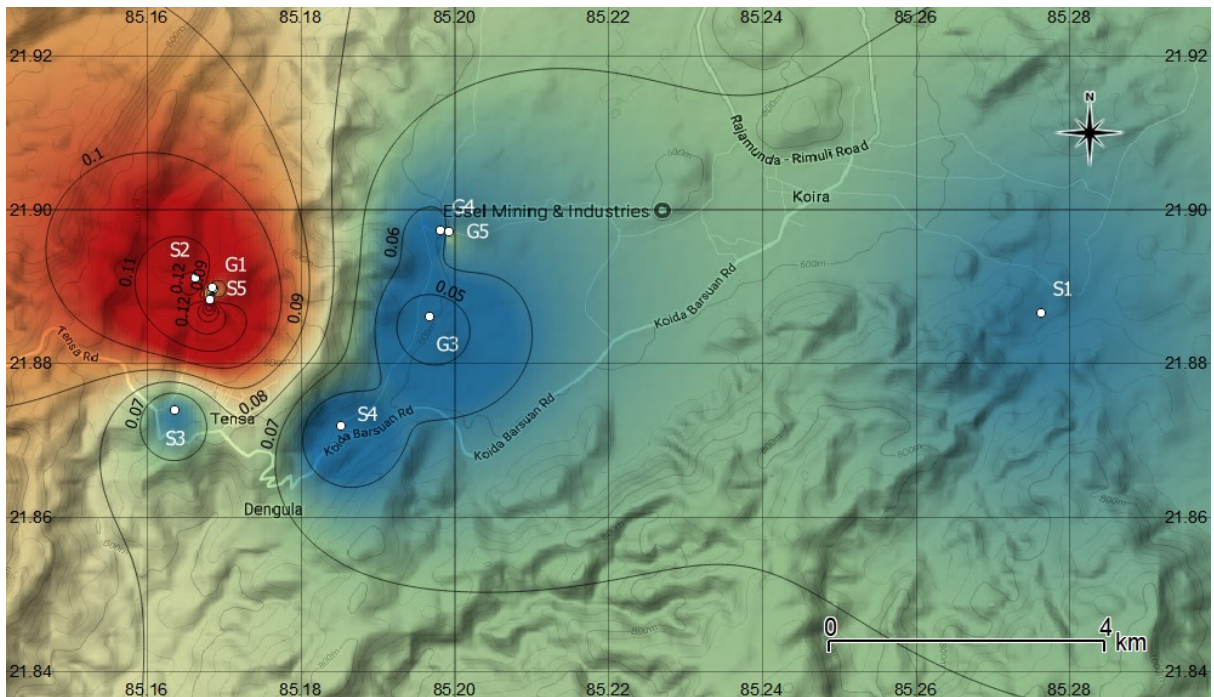


Figure 4.22: Graphical modelling of Manganese

5. Discussion and Conclusion

5.1 Water Quality Parameters

Most of the Iron deposits in our country occur in hilly terrain and in forest areas. Being closer to the surface, iron ore is mined by the opencast method of mining. Therefore, it is expected that it might have a significant environmental footprint on the nearby locality. Keeping this mind this study was envisaged to assess the impact of iron ore mining on the water quality in the nearby regions and also to carry out its modeling. In order to carry out this study, surface and ground water samples were collected from 10 locations, and 23 water quality parameters were determined in the laboratory following standard procedure.

5.1.1 Physical Parameters

The physical parameters with their corresponding determined values and permissible limits have been presented in Figure 5.1 to Figure 5.3.

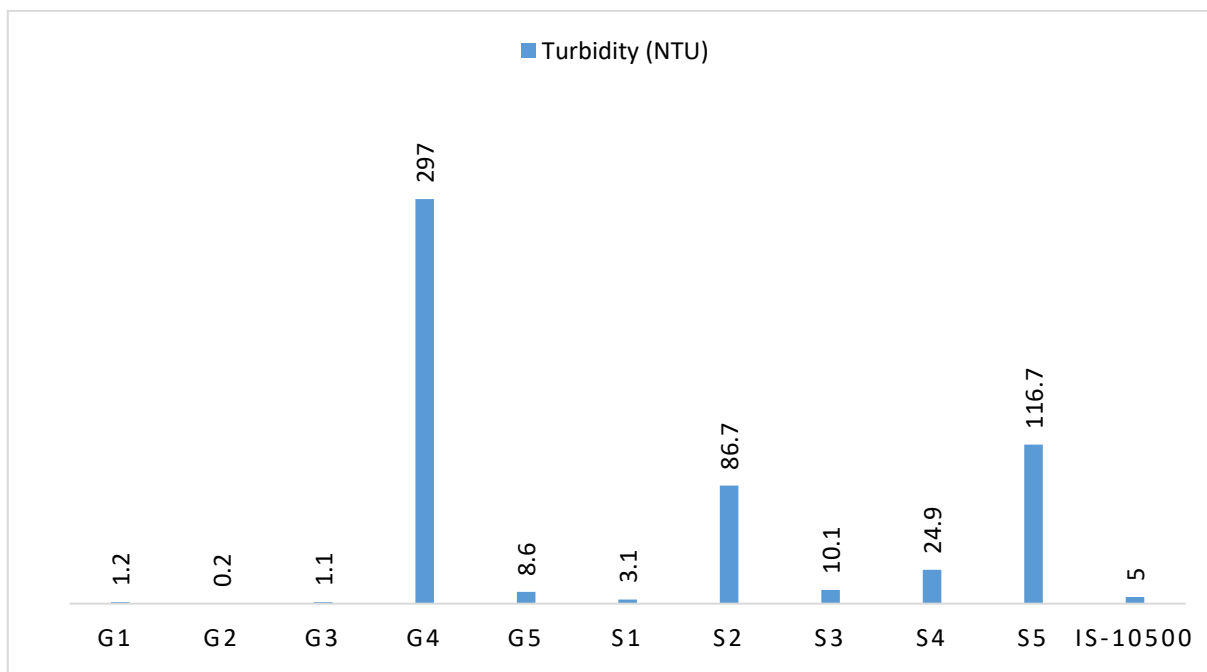


Figure 5.1: Turbidity

It may be observed from Figure 5.1, Table 3.2 and Table 3.3 that the turbidity values are below the permissible limit for all sampling locations except G4, G5, S2, S3, S4 and S5.

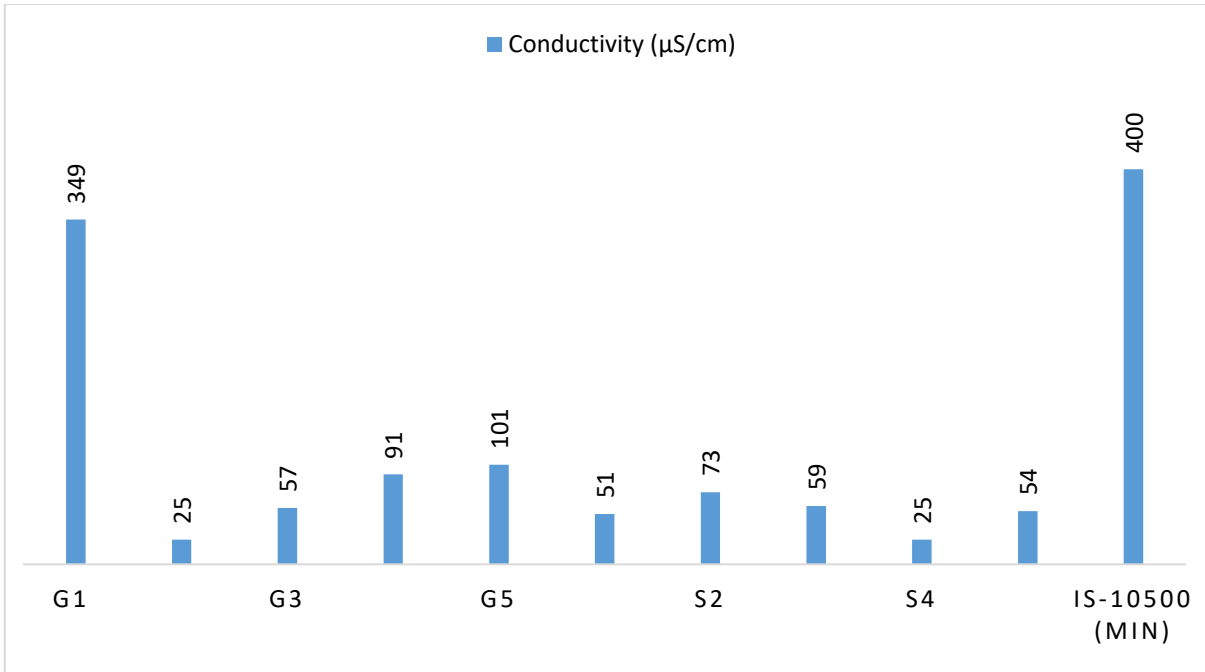


Figure 5.2: Conductivity

It may be observed from Figure 5.2, Table 3.2 and Table 3.3 that the conductivity values are below the permissible limit for all sampling locations.

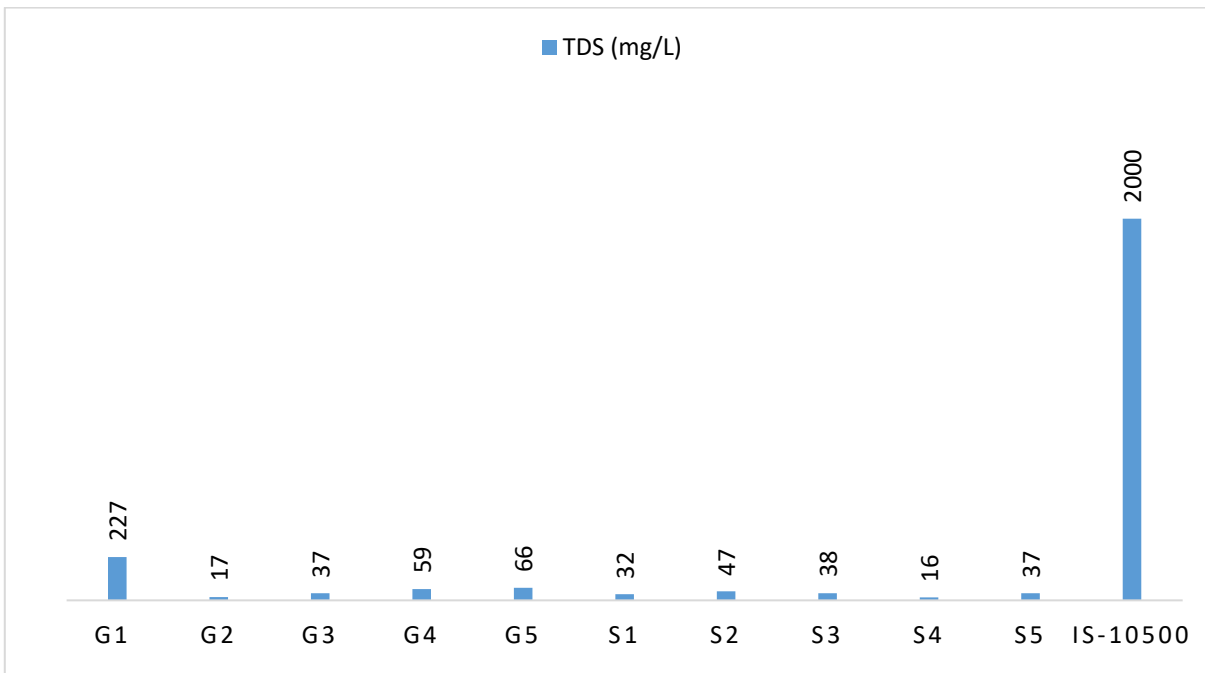


Figure 5.3: TDS

It may be observed from Figure 5.3, Table 3.2 and Table 3.3 that the TDS values are below the permissible limit for all sampling locations.

5.1.2 Chemical Parameters

The chemical parameters with their corresponding determined values and permissible limits have been presented in Figure 5.4 to Figure 5.7.

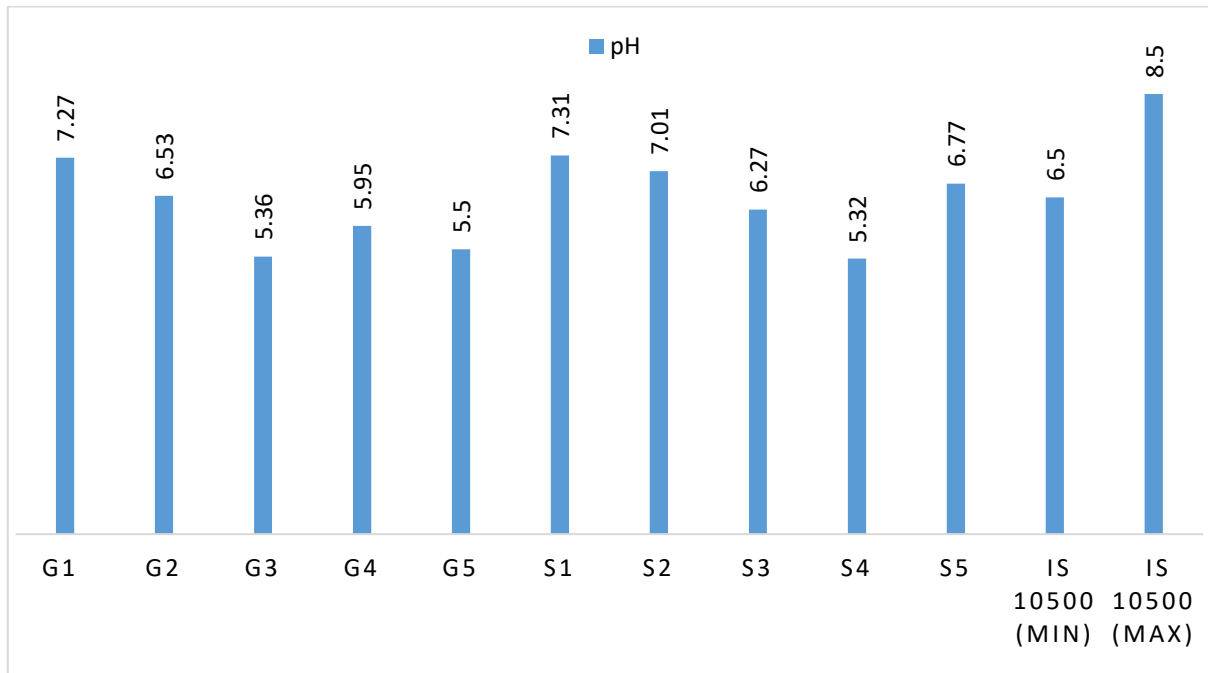


Figure 5.4: pH

It may be observed from Figure 5.4, Table 3.2 and Table 3.3 that the pH values are within the permissible range for all sampling locations except for G3, G4, G5, S3 and S4.

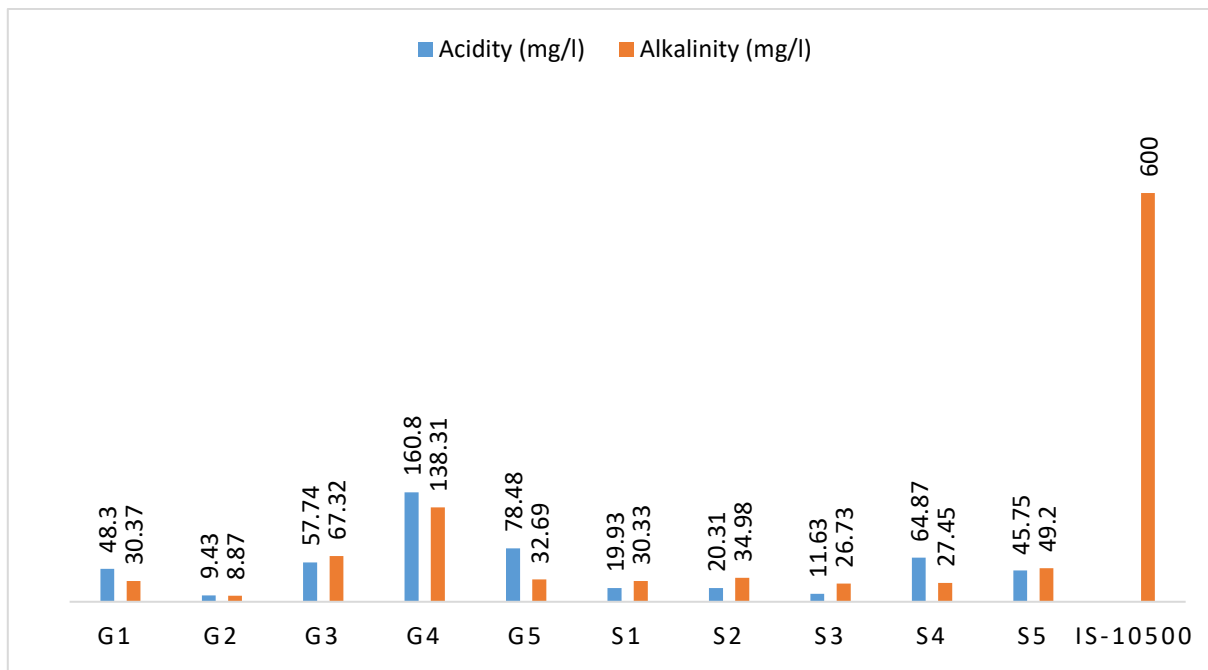


Figure 5.5: Acidity and Alkalinity

There is no permissible limit for acidity in IS-10500, although higher acidity value may cause harm to aquatic life. It may be observed from Figure 5.5, Table 3.2 and Table 3.3 that the

acidity is moderately high for sampling locations G4 and G5, and is low for the remaining sampling locations. It may be observed from Figure 5.5, Table 3.2 and Table 3.3 that the Alkalinity values are within the permissible limit for all sampling locations.

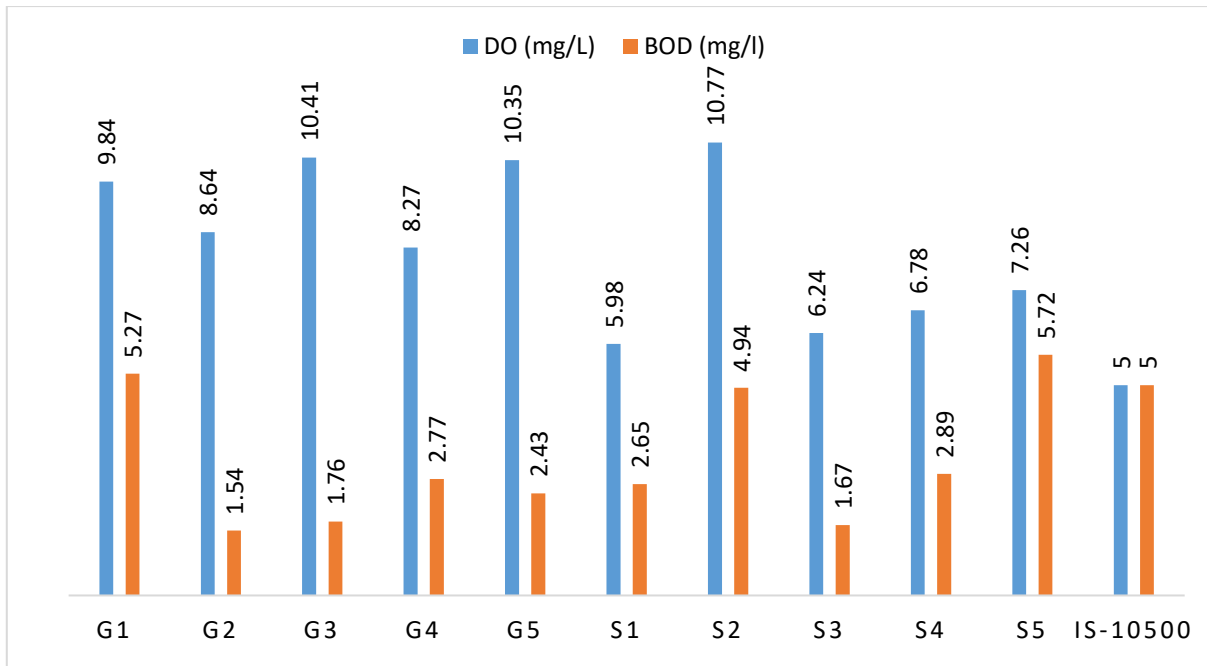


Figure 5.6: DO and BOD

It may be observed from Figure 5.6, Table 3.2 and Table 3.3 that the DO values are above the minimum recommended value for all sampling locations.

It may be observed from Figure 5.6, Table 3.2 and Table 3.3 that the BOD values are below the permissible limit for all sampling locations except G1 and S5.

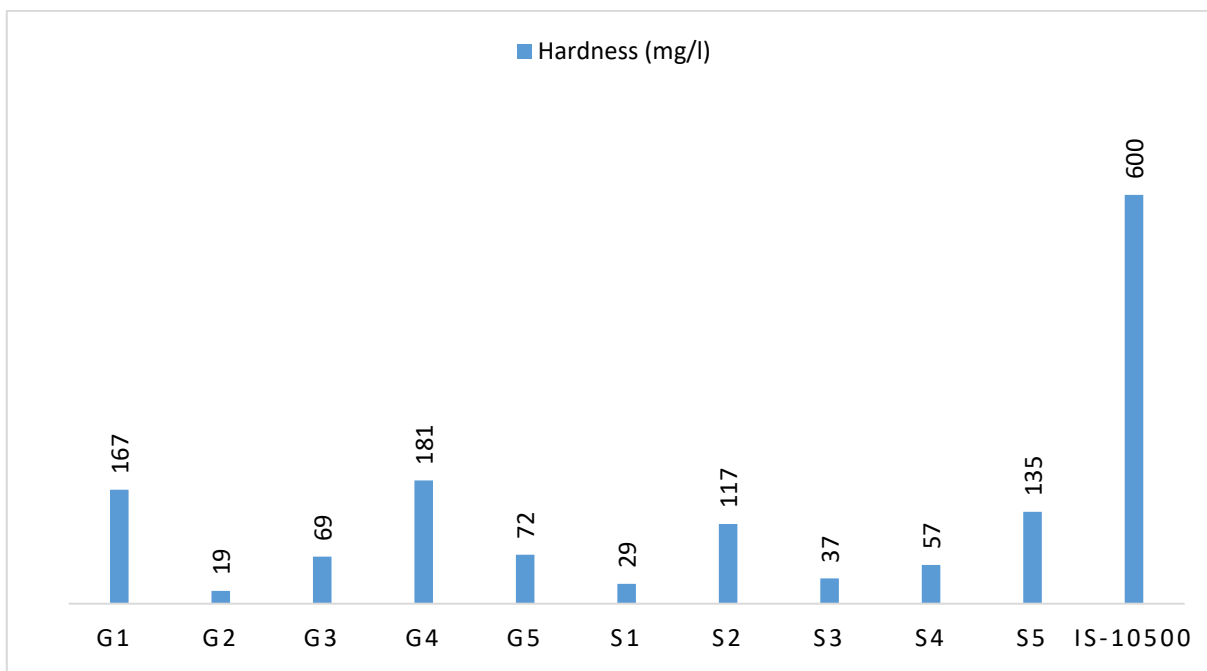


Figure 5.7: Hardness

It may be observed from Figure 5.7, Table 3.2 and Table 3.3 that the Hardness values are below the permissible limit for all sampling locations.

5.1.3 Metals

Metallic parameters with their corresponding determined values and permissible limits have been presented in Figure 5.8 and Figure 5.9.

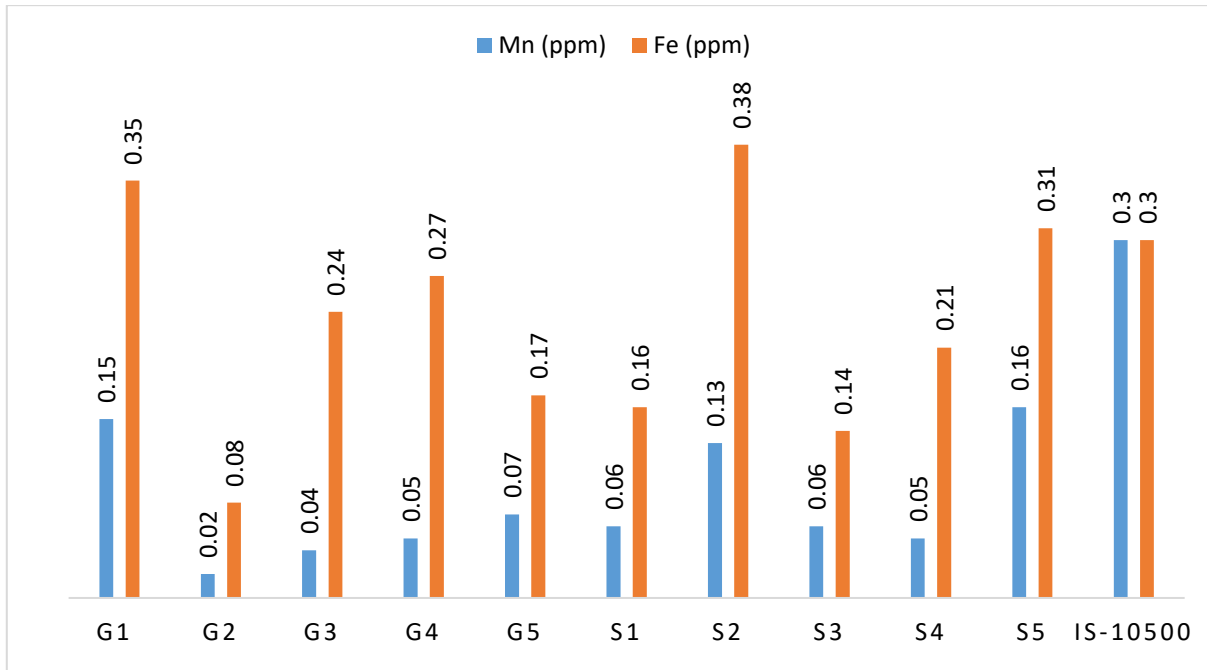


Figure 5.8: Manganese and Iron

It may be observed from Figure 5.8, Table 3.2 and Table 3.3 that the manganese concentration values are below the permissible limit for all sampling locations.

It may be observed from Figure 5.8, Table 3.2 and Table 3.3 that the iron concentration values are below the permissible limit for all sampling locations except G1, S2 and S5.

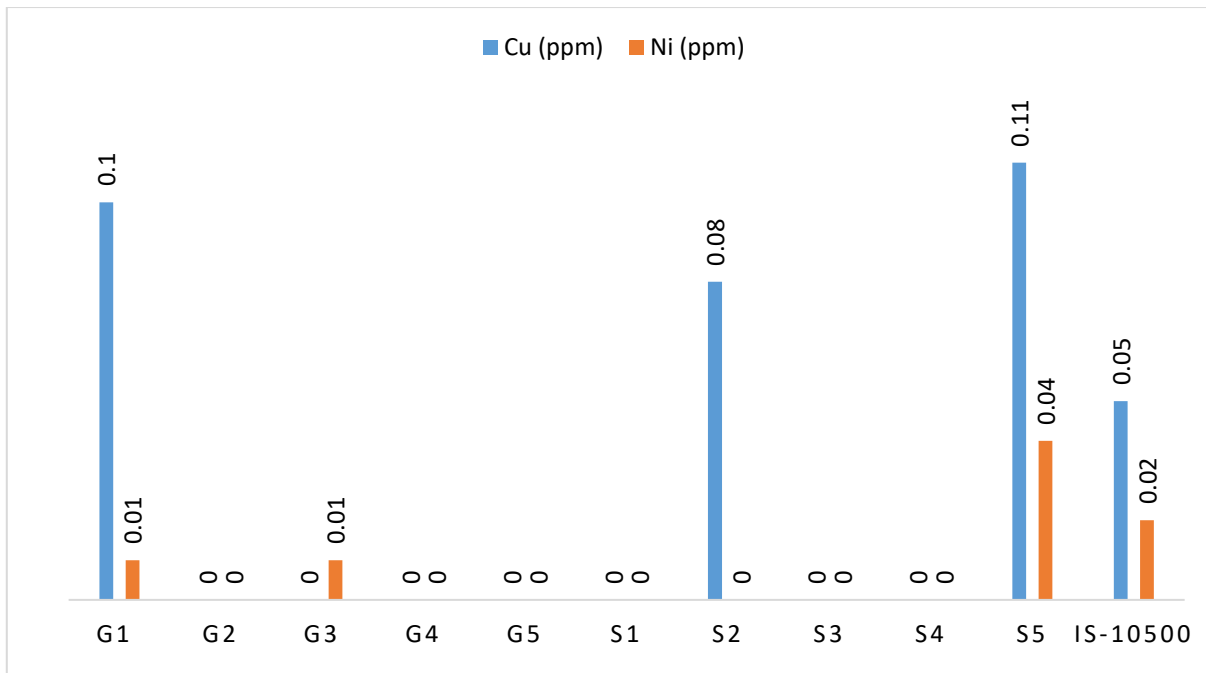


Figure 5.9: Copper and Nickel

It may be observed from Figure 5.9, Table 3.2 and Table 3.3 that the copper concentration values are below the permissible limit for all sampling locations except G1, S2 and S5.

It may be observed from Figure 5.9, Table 3.2 and Table 3.3 that the nickel concentration values are below the permissible limit for all sampling locations except S5.

5.2 Water Quality Index

Water quality index (WQI) is a valuable and unique rating to depict the overall water quality status in a single term which is helpful for the assessment of status of the location, and the public and legislative decision makers to adopt appropriate measures. The common Weighted arithmetic water quality index (WA-WQI) method is the most widely used method, which classifies the water quality according to the degree of purity by using the most commonly measured water quality variables.

The rating of water quality according to this index is given in Table 5.1 in the current work, the water quality modelling was done using WA-WQI (Weighted Average - Water Quality Index) based on 11 water quality parameters, viz., pH, Conductivity, DO, TDS, Hardness, BOD, Sulphate, Chloride, Nitrate, Calcium and Iron; and the result has been presented in Table 5.2.

Table 5.1: WA-WQI grading

WA-WQI Value	Rating of Water Quality	Grading
0-25	Excellent water quality	A
25-50	Good water quality	B
50-75	Poor water quality	C
75-100	Very Poor Water Quality	D
>100	Unsuitable for drinking purpose	E

Table 5.2: WA-WQI of all sampling sites

Sampling site	WA-WQI	Remarks
G1	87.8	Very Poor Water Quality
G2	24.4	Excellent water quality
G3	67.9	Poor water quality
G4	72.8	Poor water quality
G5	51.8	Poor water quality
S1	43.2	Good water quality
S2	92.3	Very Poor Water Quality
S3	41.5	Good water quality
S4	63.7	Poor water quality
S5	79.8	Very Poor Water Quality

In order to have a better depiction, 3D graphical modelling of WA-WQI was done in QGIS (Quantum GIS) software using IDW (Inverse Distance Weighting) method. This has been represented as Digital Elevation Model (DEM), where higher elevation indicates higher values of WA-WQI (Figure 5.10 to Figure 5.13).

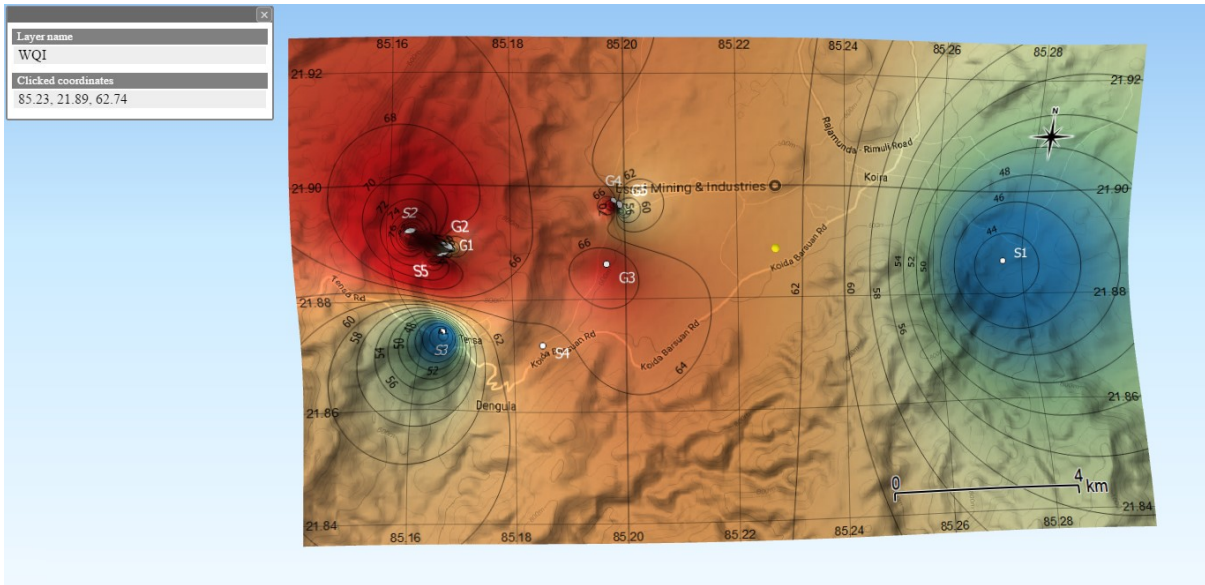


Figure 5.10: 3D model of WA-WQI (top view)

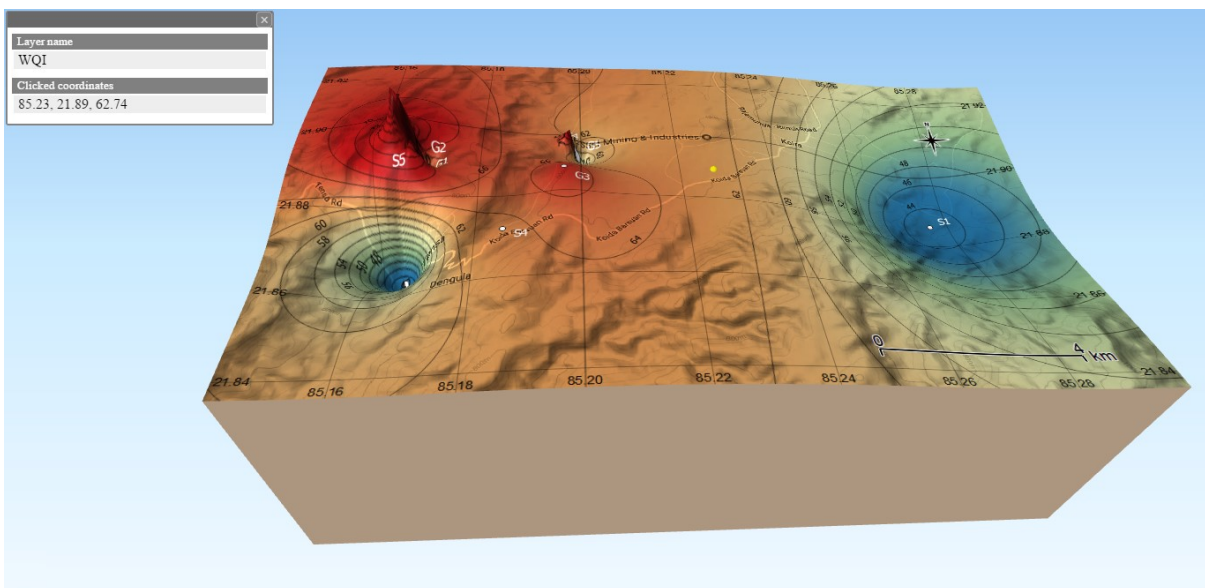


Figure 5.11: 3D model of WA-WQI (front view)

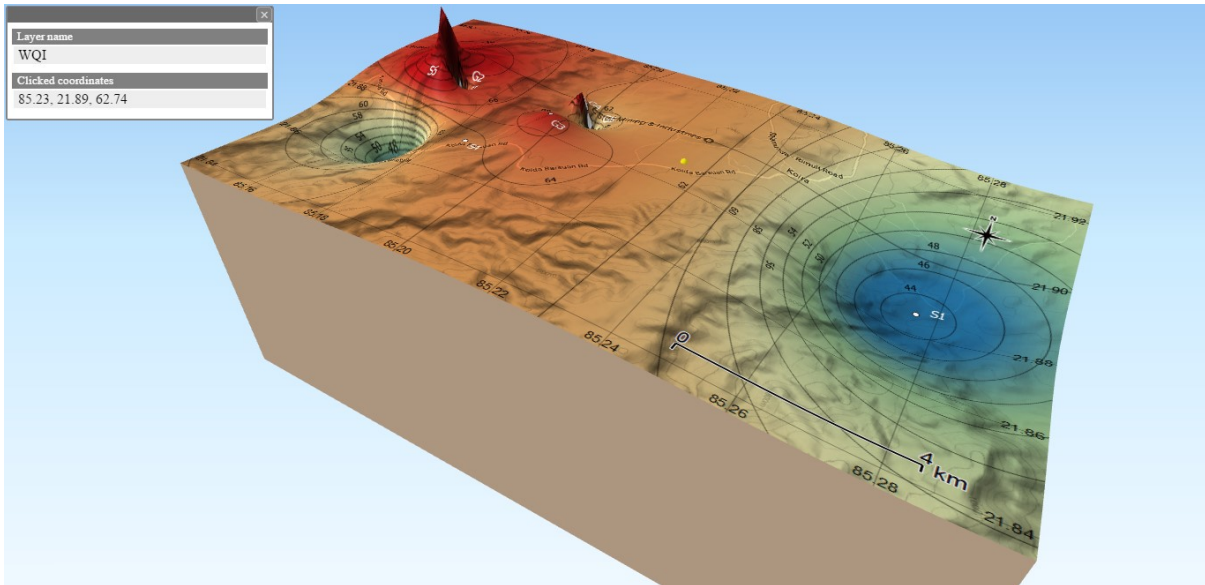


Figure 5.12: 3D model of WA-WQI (right side view)

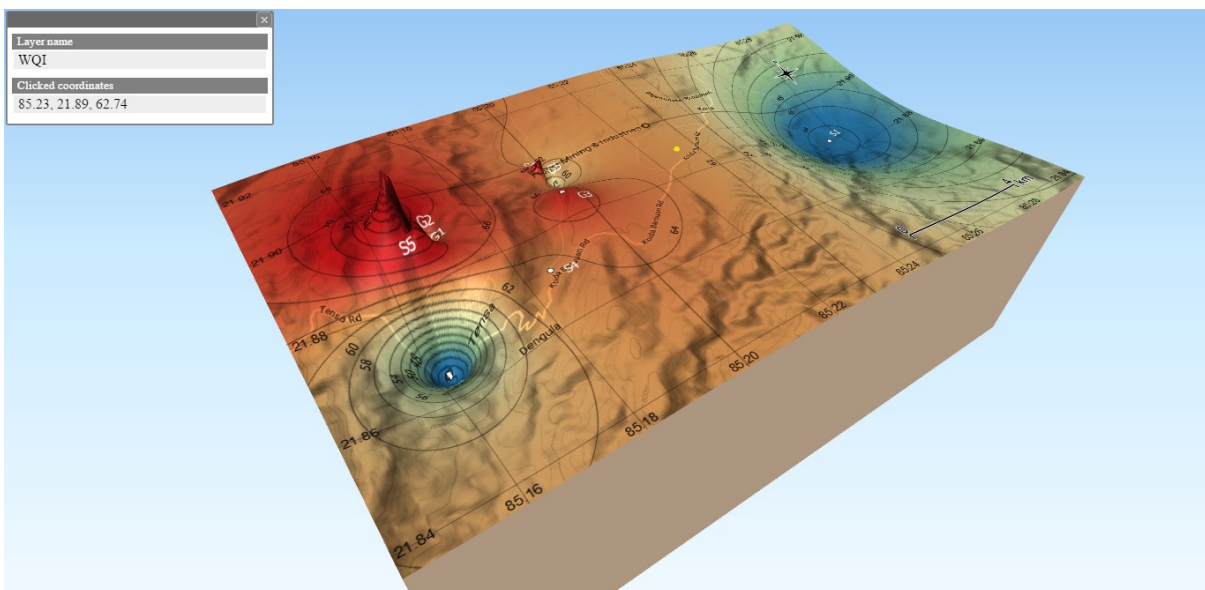


Figure 5.13: 3D model of WA-WQI (left side view)

The surface water bodies in the study area are getting contaminated due to the direct discharge of mine effluents into them, whereas, the ground water bodies are getting contaminated mainly due to the mixing of mine drainage caused due to the seepage through the fractures in the bedrock (Younger and Wolkersdorfer, 2004) that are caused by blasting and use of heavy earth moving machinery (HEMM).

pH is the influencing parameter for poor quality for G3, G4, G5, S3 and S4; turbidity is affecting the water quality of all the samples except G2; and metals, viz., iron, copper, manganese and nickel are the cause of very poor water quality of G1, S2, and S5. Fortunately, water from the most polluted sampling locations, viz., G1, S2 and S5, are not used for drinking purpose; although G2, G3, G4 and G5 are used for drinking purpose, out of which G3, G4 and

G5 have poor water quality. Water from S1, S3 and S4 are used for agricultural purpose and are also essential for surrounding ecosystems.

For the removal of turbidity Electro-Coagulation (EC) techniques can be used which have been proven to be very efficient for the removal of turbidity and TSS with efficiencies of 98% and 99% respectively (Sadeddin et al, 2011). Lime neutralisation (Aubé and Zinck, 2003) is very effective for neutralising the low pH of water; and can be applied to G3, G4, G5, S3 and S4. Removal of heavy metals from water can be efficiently done (for sampling sites G1, S2 and S5) by using Ion Exchange Membrane method (Praveen et al, 2013). Although Ion Exchange Membrane method is very cost effective for treatment of drinking water, it can be costly to use for treating a large amount of water for other purposes like agriculture and pisciculture.

5.3 Conclusion

In the present work, water sampling was done in the area surrounding TRB iron ore mine owned by Jindal Steel & Power Ltd, located in Tensa region of Sundergarh district in Odisha during October 2016. The location of sampling was so selected because of the nearness of mining site to residential areas. In recent years, the surrounding surface and ground water bodies were gradually contaminated due to the mining operations.

Based on the study of the experimental analysis data and the graphical models, it was concluded that turbidity values exceeded the permissible limit (1NTU according to IS-10500) in almost the entire study region; pH was below the permissible of 6.5 in half of the study region; iron, copper and manganese concentrations exceeded the permissible limits (0.3mg/l, 0.05mg/l, 0.1mg/l respectively according to IS-10500) in the regions surrounding the sampling sites G1, S2 and S5; BOD value exceeded the permissible limit (5mg/l according to IS-10500) in the regions surrounding the sampling sites G1 and S5; and nickel concentration exceeded the permissible limit (0.02mg/l according to IS-10500) in the regions surrounding the sampling sites S5.

It is evident from Table 5.2 that only the water sample from G2 qualifies for excellent water quality; whereas S1 and S3 have good water quality; G3, G4, G5 and S4 have poor water quality; and G1, S2, and S5 have very poor water quality. Although, it was inconclusive that if ground water sources are more polluted than surface water sources.

6. References

- Aikins, S., Asante, G. F. N., and Voegborlo, R. B., 2010, “Physico-Chemical Quality of Water in the Gold Mining areas of Bibiani, Ghana”, *International Journal of Innovative Science, Engineering & Technology*, 2(1), pp. 229-238.
- Akkaraboyina, M.K., and Raju, B.S.N., 2012, “Time Series Forecasting of Water Quality of River Godavari”, *Journal of Mechanical and Civil Engineering*, 1(3), pp. 39-44.
- Al Obaidy, A.H.M.J., and Awad, E., 2016, “Impact of Medical City and Al-Rasheed Power Plant Effluents on the Water Quality Index Value of Tigris River at Baghdad City”, *Engineering and Technology Journal*, 34(A), pp. 716-722.
- APHA, AWWA, and WEF, 1998, “Standard Methods for the Examination of Water and Wastewater”, 20th Ed., Washington DC, USA.
- Arman, N. Z., Said, M. I. M., Salmiati, S., Azman, S., and Hussin, M. H. M., 2013, “Comparison Between Water Quality Index (WQI) And Biological Water Quality Index (BWQI) For Water Quality Assessment: Case Study of Melana River, Johor”, *The Malaysian Journal of Analytical Sciences*, 17(2), pp. 224 – 229.
- Aubé, B., Zinck, J., 2003, “Lime Treatment of Acid Mine Drainage in Canada”, *Proceedings of Brazil-Canada Seminar on Mine Rehabilitation*, Florianópolis, Brazil.
- Bakker E., and Qin, Y., 2006, “Electrochemical Sensors”, *Analytical Chemistry*, 78(12) pp. 3965-3984.
- Bard, A. J., and Faulkner, L., 2001, “Electrochemical Methods: Fundamentals and Applications”, 2nd Ed., *John Wiley and Sons, New York*.
- Bora, M., and Goswami, D.C., 2016, “Water quality assessment in terms of water quality index (WQI): case study of the Kolong River, Assam, India”, *Applied Water Science*, pp. 1-11.
- Bordalo, A., Nilsumranchit, A.W., and Chalermwat, K., 2001, “Water quality and uses of the Bangpakong River (Eastern Thailand)”, *Water Research*, 23(35), pp. 3635-3642.
- Brown, R. M., McClelland, N. J., Deininger, R. A. and O’Connor, M. F., 1972 “A Water Quality Index-Crossing the Psychological Barrier”, *Proceedings of International Conference on Water Pollution Research, Jerusalem*, 6, pp. 787-797.
- Caruso, B. S., and Bishop, M., 2009, “Seasonal and spatial variation of metal loads from natural flows in the upper Tenmile Creek Watershed, Montana”, *Mine Water and the Environment*, 28(3), pp.166–181
- Essalhi, A., Essalhi, M., and Toummite, A., 2016, “Environmental Impact of Mining Exploitation: A Case Study of Some Mines of Barite in the Eastern Anti-Atlas of Morocco”, *Journal of Environmental Protection*, 7, pp. 1473-1482.
- Gaonkar, G. V., Gudagur, J. T., and Lakkundi, T. K., 2016, “Impact of Mining on Surface Water Quality in the western part of Sandur Schist belt, Karnataka, India – A preliminary investigation”, *International Journal of Advanced Research*, 4(10), pp. 1475-1482.

- Hoseinzadeh, E., Khorsandi, H., Wei, C., and Alipour, M., 2014, "Evaluation of Aydughmush River water quality using the National Sanitation Foundation Water Quality Index (NSFWQI), River Pollution Index (RPI), and Forestry Water Quality Index (FWQI)", *Desalination and water treatment*, 54(11), pp. 2994-3002.
- Hynes, H. B., 1960, "The Biology of Polluted Waters", *Liverpool University Press, Liverpool*.
- Indian Standards (IS-10500), "Drinking Water – Specification", Bureau of Indian Standards, 2nd Revision, New Delhi.
- Jordaan, M. S., 2012, "Land and water impacts of oil sands production in Alberta", *Environment Science and Technology*, 46(7), pp. 3611–3617.
- Kar, P. K., Pani, K. R., Pattanayak, S. K., and Sahu, S. K., 2010, "Seasonal variation in physicochemical and microbiological parameters of Mahanadi river water in and around Hirakud, Orissa (India)", *The Escosan*, 4(4), pp. 263-271.
- Koirtiyohann, S. R., 1991, "A History Of Atomic Absorption Spectrometry", *Analytical Chemistry*, 63(21), pp. 1024A-1031A.
- Liu, W., Moran, C. J., and Vink, S., 2011, "Quantitative risk-based approach for improving water quality management in mining", *Environmental Science & Technology*, 45(17), pp. 7459-7464.
- Loucks, D. P., van Beek, E., 2005, "Water Resources Systems Planning and Management: An Introduction to Methods, Models and Applications", *UNESCO, Paris*, Chap. 10.
- Madzin, Z., Kusin, F. M., Yusof, F. M., and Muhammad, S. N., 2016, "Assessment of water quality index and heavy metal contamination in active and abandoned iron ore mining sites in Pahang, Malaysia", *Proceedings of MATEC Web Conferences*.
- Mahapatra, S.S., Sahu, M., Patel, R.K., and Panda, B.N., 2012, "Prediction of Water Quality Using Principal Component Analysis", *Water Quality, Exposure and Health*, 4, pp. 93-104.
- Najah, A., Elshafie, A., Karima, O.A., and Jaffar, O., 2009, "Prediction of Johor river water quality parameters using artificial neural networks", *European Journal of Science Research*, pp. 422-435.
- Niyogi, D. K., Lewis, W. M., and McKnight, D. M., 2002, "Effects of Stress from Mine Drainage on Diversity, Biomass, and Function of Primary Producers in Mountain Streams", *Ecosystems*, 5(6), pp. 554–567.
- Ochieng, G. M., Seanego, E. S., and Nkwonta, O. I., 2010 "Impacts of mining on water resources in South Africa: A review", *Scientific Research and Essays*, 5(22), pp. 3351-3357.
- Praveen, A., Kumar, R., Kumar, P., Kumar, R., 2013, "Removal of Heavy Metal from Drinking Water Supplies through the Ion Exchange Membrane- A Review", *IOSR Journal of Applied Physics*, 3(2), pp. 25-39.
- Rosner, T., and van Schalkwyk, A., 2000, "The environmental impact of gold mine tailings footprints in the Johannesburg region, South Africa", *Engineering Geology and the Environment*, 59(2), pp. 137–148.

- Sadashivaiah, C., Ramakrishnaiah, C.R., and Ranganna, G., 2008, "Hydrochemical Analysis and Evaluation of groundwater quality in Tumkur Taluk, Karnataka state, India", *International Journal of Environmental Research and Public Health*, 5(3), pp. 158-164.
- Sadeddin, K., Naser, A., Firas, A., 2011, "Removal of Turbidity and Suspended Solids by Electro-Coagulation to improve feed water quality of Reverse Osmosis plant", *Desalination*, 268(1-3), pp. 204-207.
- Sahu, M., Mahapatra, S.S., Sahu, H.B., and Patel, R.K., 2011, "Prediction of Water Quality Index Using Neuro-Fuzzy Inference System", *Water Quality, Exposure and Health*, 3, pp. 175-191.
- Shepard, D., 1968, "A two-dimensional interpolation function for irregularly-spaced data", *Proceedings of the 1968 ACM National Conference*, pp. 517-524.
- Singh, O.P., 2016, "Application of CCME Water Quality Index in evaluating the water quality", *The Ecoscan*, 10, pp. 149-154.
- Singkran, N., Yenpiem, A., and Sasitorn, P., 2010, "Determining Water Conditions in the Northeastern Rivers of Thailand Using Time Series and Water Quality Index Models", *Journal of Sustainable Energy and Environment*, 1, pp. 47-48.
- US EPA, 1985, "Rates, Constants and Kinetics Formulations in Surface Water Quality Modeling" 2nd Ed., Athens, GA, USA.
- Wijnen, B., Anzalone, G. C., and Pearce, J. M., 2014, "Open-source mobile water quality testing platform", *Journal of Water, Sanitation and Hygiene for Development*, 4(3), pp. 532-537.
- Yogendra, K., Puttaiah, E. T., 2008, "Determination of Water Quality Index and Suitability of an Urban Waterbody in Shimoga Town, Karnataka", *Proceedings of Taal2007: The 12th World Lake Conference*, pp. 342-346.
- Younger, P. L., and Wolkersdorfer, C., 2004, "Mining Impacts on the Fresh Water Environment: Technical and Managerial Guidelines for Catchment Scale Management", *Mine Water and the Environment*, 23, pp. S2-S80.