MAMDANI FUZZY INFERENCE SYSTEM FOR CLASSIFICATION OF GROUNDWATER AND SOIL QUALITIES IN SELECTED AUTOMOBILE WORKSHOP PREMISES, OMU ARAN, KWARA STATE, NIGERIA.

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DECLARATION

I, Praise Oladapo EJIGBOYE, an M.Eng student in the ***Department of Civil Engineering***, Landmark University, Omu-Aran, hereby declare that this thesis entitled *"**MAMDANI FUZZY INFERENCE SYSTEM FOR CLASSIFICATION OF GROUNDWATER AND SOIL QUALITIES IN SELECTED AUTOMOBILE WORKSHOP PREMISES, OMU ARAN, KWARA STATE, NIGERIA**"*, submitted by me is based on my original work. Any material(s) obtained from other sources or work done by any other persons or institutions have been duly acknowledged.

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CERTIFICATION

This is to certify that this thesis has been read and approved as meeting the requirements of the Department of Civil Engineering, Landmark University, Omu-Aran, Nigeria, for the Award of M.Eng (Civil Engineering).

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ABSTRACT

Major activities in automobile workshops involve the release of toxic substances into the surrounding soil and water, which could pose adverse impact on human health. Little has been documented on the application of Mamdani Fuzzy Inference System (MFIS) to classify the impact of automobile workshop activities on the surrounding soil where effluents are disposed off indiscriminately. Therefore, the aim of this study is to classify ground water quality in automobile workshop premises where effluent are not properly managed using Mamdani Fuzzy Inference System in Omu Aran, Kwara State, Nigeria.

Forty eight groundwater and soil samples were obtained from six hand-dug wells and surrounding soils from five selected location points near automobile workshops and one control point in Omu Aran from October 2020 to January 2021. Physico-chemical and heavy metals parameters were determined in the groundwater and soil sample using standard APHA methods. MFIS was used for the classification of ground water quality. Different linguistic variables were generated using a triangular membership function for five MFIS model with the implementation of 170 number of rules and fuzzy model was classified into five groups: excellent, good, poor, very poor and non-suitable. The result of the proposed model was compared with the output obtained using deterministic method (WAWQI). Data analyses were carried out by descriptive statistic and ANOVA at $\alpha_{0.05}$.

The mean value of parameters in the groundwater samples collected ranged from 5.39 ± 0.33 to 6.17 ± 0.75 for pH and 2.58 ± 0.35 mg/L to 4.66 ± 0.17 mg/L for D.O.. Chloride had values of 34.5 ± 3.87 to 56.75 ± 27.76 mg/L, 0.14 ± 0.02 mg/L to 0.89 ± 0.14 mg/L for phosphate and magnesium had values of 0.99 ± 0.16 mg/L to 12.15 ± 1.16 mg/L respectively. All heavy metals (Pb, Fe, Cd, Cr, As) were significantly different from control and above permissible limits. The mean value of parameters in the soil samples collected around study wells ranged from 6.17 ± 0.75 to 5.39 ± 0.33 for pH and from 47.83 ± 15.46 to 135.3 ± 16.09 for electrical conductivity. Phosphate value ranged from 0.230 ± 0.122 mg/kg to 0.674 ± 0.134 mg/kg, 0.875 ± 0.250 mg/kg to 9.850 ± 1.344 mg/kg for magnesium and 0.024 ± 0.013 to 0.8041 mg/kg ± 0.013 mg/kg for Sodium. All heavy metal ions concentration were above the standard permissible limits and were significantly different from control. Based on the result obtained from MFIS model, 83.4% of groundwater samples in the study area fall in the ‘poor’ water category while 16.6% were in the ‘good’ water category. There was a strong positive correlation between deterministic method (WAWQI) and proposed model (FWQI) (r = 0.998).

The groundwater within the vicinity of auto mechanic repair activities areas in Omu-Aran has been greatly impacted negatively. It is recommended that prompt action should be taken to ensure that local trees with phytoaccumulation potentials are planted in and around mechanic villages to serve as trap for these heavy metals and help to reduce the migration of contaminants in soils and underground water. Furthermore, proper waste disposal facility such as impervious layer for collection and waste management practises should be put in place in the automobile workshops. In addition, routine assessment and further monitoring of the concentration of heavy metal.

Keywords: Heavy metals, automobile workshops, groundwater, Fuzzy water quality index.

DEDICATION

I dedicate this dissertation to the Almighty God who alone deserves all thanks and appreciation.

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LIST OF ABBREVIATIONS

APHA	American Public Health Association
ANOVA	Analysis of Variance
As	Arsenic (As)
FAAS	Flame Atomic Absorption Spectroscopy
Ca	Calcium
Cd	Cadmium
CKDu	Chronic kidney Diseases with unknown etiology
Cl	Chlorine
Cr	Chromium
Cu	Copper
D.O	Dissolved oxygen
EC	Electrical Conductivity
Fe	Iron
FCE	Fuzzy comprehensive evaluation
FIS	Fuzzy Inference system
FWQI	Fuzzy water quality index
GUI	Graphical User Interface tools
K.	Proportionality constant
K	Potassium
MDG7c	Millennium Development Goal 7c
MFIS	Mamdani Fuzzy Inference System
Mg	Magnesium

n	number of parameters
Na	Sodium
Pb	Lead
pH	Potential of Hydrogen
Qi	Quality rating of the ith parameter
Si	Standard permissible limit in water for the ith parameter
SO_4	Sulphate
SSSA	Soil Science Society of America
SON	Standard Organization of Nigeria
TDS	Total Dissolved Solids
WAWQI	Weight Arithmetic Water Quality Index
WHO	World Health Organization
Wi,	Weight used by each unit parameter
WQI	Water Quality Index

CHAPTER ONE

INTRODUCTION

1.1 Background of the Information

Water resources have been one of the most utilized natural systems since the beginning of time and it is used for municipal, industrial and agricultural activities (Woke and Bolaji, 2015). In most developing countries, the current situation of uneven distribution of social amenities in major cities has created numerous challenges for infrastructure efficiency and effectiveness. This seriously affects the distribution of pipe-borne water and consequently makes groundwater an alternate supply of water for household, industry or farming operations (Aladejana and Talabi, 2013). The quality of water and soil affect the quality of life because water is one of the necessities of life employed by man for consumption and directly or indirectly influenced by the quality of soil via operations such as percolation (Steffan *et al*., 2018). However, though water is of great importance to man, polluted water can also serve as a medium to transmit pathogens and parasites that are harmful to human health (Cabral, 2010). Unintended urbanization, unrestricted exploration guidelines, and inappropriate disposal of solid and liquid wastes all contribute to the seepage of hazardous substances into the groundwater resources (Ojekunle *et al.*, 2020). Contamination of the soil, water, and atmosphere is caused by industrial and anthropogenic activities, aggravating the severity of environmental problems (Alirzayeva *et al*., 2006). Decision-makers and renowned researchers generally realize that polluted water and air can have harmful health implications; however, the effects of such polluted soil on our health are considered less significant (Payá and Peláez, 2017).

Human activities such as construction, agriculture, waste disposal and mechanical activities contribute to the release of these chemicals (contaminants) in the soil and water which accumulate with time and increase in concentration (Arinze *et al.,* 2015). Several automobile mechanical operations have become a hub for the release of heavy metals into the groundwater and soil including charging of batteries, engine lubrication, welding and soldering, repair of engine and gearbox, panel beating, electrical work, polishing, automobile bodywork, combustion process and painting (Pam *et al.,* 2013). They require the use of oil, electrode and other substances that can contaminate soil and water (Ololade, 2014). Oil includes oxidants, sediments, liquids and metallic fragments produced from wear of equipment, used batteries, organic and inorganic chemicals used in oil additives and metals (E.E.A., 2007). These substances contain heavy metals and hydrocarbon in high concentration which pose serious danger to the environment. Generally, they contain an extensive range of toxic compounds which are not only heavy and stick but can build up and persist in the environment for years (Jhanani and Joseph, 2011). Oil pollution threatens public health, degrades drinking water, ruins natural resources and disrupts the economy (U.S.E.P.A, 1999).

During repair or maintenance operations at mechanical workshop, operators often discard waste materials such as petroleum products on the ground surface triggering an increase in pollution levels of the soil, water, and the atmosphere (Nwachukwu *et al.*, 2013). A wide range of mechanical workshops utilizes petroleum products such as motor oil, fuel oil, diesel and kerosene. These products are toxic and tend to harden or modify the soil's composition, which can influence the physicochemical and microbial properties of the contaminated soil (Aqeel *et al.*, 2014). During precipitation, theses toxic substances in the soil may be transmitted by infiltration or discharged into underground or surface water (Sasakova *et al.,* 2018).

Groundwater analysis is greatly emphasized in evaluating the quality of groundwater and thus determining its use (Semiromi *et. al.*, 2011). Assessment of groundwater quality and its degradation have been studied significantly by many researchers (Selvakumar *et al.* 2017; Chandrasekar *et al.* 2014; Aryafar *et al.* 2013; Nasr, et al., 2012; Dahiya, *et al.*, 2007). Based on the preceding research findings, the fuzzy logic was proven to be a practical technique for the analysis of water quality (Hosseini-Moghari *et al.,* 2015; Nasiri *et al.* 2007; Chang et al. 2001; Lu *et al.* 1999). The fuzzy inference evaluation method can be applied to assess the physicochemical and heavy metal characteristic and quality of ground water for comprehensive evaluation.

Fuzzy logic is excellent because of its capacity to incorporate human thinking and expertise in the indices, and to manage non-linear, unpredictable, ambiguous and subjective information efficiently. Fuzzy logic is efficient for reporting assessment results in a linguistic term for easy comprehension by the populace (McKone and Deshpande, 2005;).

Therefore, due to the increasing operations of automobile mechanic workshops and their uncontrolled disposal of used oil into the surroundings, it is imperative to determine water quality parameters level for acceptable water quality is based on the standard limit of classification by diverse regulatory bodies and experts perception from the field of drinking water quality using Fuzzy synthetic evaluation model.

1.2 Problem Statement

Accidental or intentional releases or discharges of gas, gasoline, solvents, grease, and lubricants on the land and the environment occur in mechanic shops (Oloruntoba and Ogunbunmi, 2020). The spilled materials at the mechanical automobile workshops in developing countries are not effectively monitored for proper disposal (Ololade, 2014). These substances remain in the environment and eventually find their ways into human body (U.S.E.P.A., 2015). The contaminants can be transported from the soil into major water bodies, most especially ground water that is sourced for drinking (Pérez-Lucas *et al.*, 2019). These can result in severe disorders, diseases such as cancer and eventually death of man because ground water is the major source of water in Nigeria due to affordability and accessibility (Oloruntoba, and Ogunbunmi, 2020). The presence of contaminants in the soil such as heavy metals, pose serious side effects for soil dwelling organisms and can change the physiochemical characteristics that hinder plants growth (Gupta and Gupta, 1998). Furthermore, decision on use of appropriate water quality methods is a major problem because of various uncertainties such as complex environmental problems (Nasr *et al.*, 2012).

1.3 Justification

Several researches on soil and water pollution from various human activities have been carried out while little has been done on automobile workshop impact on surrounding soil and water quality in Omu-Aran and its environs. Studies on use of Mamdani fuzzy inference system to classify groundwater and soil qualities impacted by activities in automobile workshops in Omu-Aran have never been carried out. Due to lack of information on the influence of automobile mechanical workshop activities on quality of soil and water in Omu Aran, the quality of water and soil in automobile workshop vicinity, there is need for effective monitoring to avoid bioaccumulation which on the long run affects the health of mankind. This study intends to make available the necessary information about these water and soil quality parameters.

1.4 Significance of study

Groundwater in many areas of Nigeria is one of the most important water sources available and it is essential for survival (Essien and Abasifreke, 2014). Many communities rely on hand-dug wells to gain access to groundwater (Okoro, 2015). Due to accessibility and affordability, groundwater should be secured and preserved from all sources of pollution and contamination that can cause health problems for enhancement of proper environmental management (Ibe *et al.*, 2020). Ground water quality preservation and monitoring is also one of the objectives of Sustainable Development Goals (SDG) 4 and 6.

1.5 Aim

The aim of this study was to classify ground water and soil qualities in selected automobile workshop premises using Mamdani Fuzzy Inference System in Omu Aran, Nigeria.

1.6 Specific objectives

The specific objectives of the study are to:

i. assess the effects of automobile repair workshop activities on the physiochemical properties and heavy metals concentration in groundwater.
ii. assess the effects of automobile repair workshop activities on the physiochemical properties and heavy metals concentration parameters of soil.
iii. classify water quality model using Mamdani Fuzzy water quality index.

1.7 Expected Outcome

This study will use Mamdani fuzzy-logic-inference system to make available the necessary information about soil and water quality distribution in Omu-Aran using wastes spilled or discharged from automobile repair workshops as potential sources of pollution, which informs inhabitants of their level of exposure to these contaminants.

1.8 Limitations of Study

This study was confined to assessment of soil and water pollution resulting from waste disposed from automobile repair workshops within Omu-Aran using Mamdani Fuzzy Inference System to assess groundwater quality.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

Water is a basic need, essential for life, and a sufficient (adequate, secure, and accessible) supply must be available to everyone, therefore, improving access to clean drinking water will result in substantial health benefits and every effort should be taken to ensure the safest drinking water quality possible (W.H.O., 2008). About 97.5 percent of the earth's water is ocean and saline groundwater, which is unsafe for human use without extensive treatment. The remaining 2.5 percent of the earth's water that has a low salinity is fresh water (Rajagopal *et al.*, 2016). According to Rajagopal *et al.*(2016), only a fraction of 1% of all water on the earth is available for human use. While progress in percentage of population using improved drinking water has been made, quite a large number of people still lack supply of quality water. Poor hygiene affects quality water.

Human activities such as automobile workshop activities contribute to deterioration of water quality. Deliberate and accidental release of toxic substances in automobile mechanical workshops exposes surrounding soil and ground water to contaminants, having adverse impacts on human health. Waterborne diseases is one of the prominent causes of death in developing countries around the world. Access to safe water therefore means water-related diseases are reduced (Dinka, 2018).

Water Quality Index (WQI) is an essential and fundamental rating that shows the overall quality of the water within a single term which helps to choose a treatment technique fit to meet the intended use (Tyagi *et al.,* 2013). WQI can reduce the majority of the information into one value in a simplified and logical way to express the data (Semiromi, *et. al.,* 2011). However, there are many uncertainties is one of the problems facing decisions on water quality employing techniques. (Nasr *et al.,* 2012).

In various research, Fuzzy comprehensive evaluation methods procedures were employed effectively (Dahiya *et al.,* 2007, Nasr *et al.,* 2012). Fuzzy logic (FL) was first introduced by Zadeh in 1965. Gharibi *et al.,* (2012) have outlined the efforts made to develop water quality indicators that are centered on.

One of the most significant problems for successful management of resources is to recognize the periodic and cumulative impacts on water quality by human activities and volumes along the hydrological pathways. Downstream users can experience a deterioration of water quality in a catchment zone. Everyone is affected by the effects of any human activity (Peters, 2000).

2.2 Background of Water Resources in Nigeria

Nigeria's water supplies are large and have irregular distribution throughout the different hydrological areas. The Niger Delta and tropical rainforest areas receive the most precipitation with annual rainfall of about eight months. The Savannah region is the next with precipitation of about 1000 mm-1250 mm of rain per year, with the amount of rain declining northward. The Sahel in the northeastern region, receives only about 750 mm of rain per year, with some years receiving as little as 500 mm. In these northern zones, Rainfall can last for 3-4 months and in the dry seasons shallow wells usually shrink due to inadequate recharge (Idu, 2015).

Water resources are the most abundant and rapidly developing of Nigeria's diverse natural resources. The exploitation of water resources is a serious concern and an obstacle for the nation due to the absence of a good policy of early growth and substantial investment. This is now being given significant consideration by the River Basin Development Authorities, which were established to manage the resource (Ojiako, 2009). After the establishment of the 11-river basin development authorities, the Federal Ministry of Water Resources has spent billions of Naira on various water projects. The Ministries established by State Governments for water resources have great influence on Water Resources Management around the country, often with financial and technical assistance from the Federal Ministry of Water Resources and donor agencies such as the United Nations Educational and Cultural Organization, United Nations Children's Fund, and others. The private sector recently has developed water resources in particular through corporate and public sector partnerships for the development and administration of drinking water (Ezeabasili, 2014).

2.3 Soil

2.3.1 Definition

Soil is essential to quality of life because it provides food, fibre, heat, clean water, and regulates greenhouse gas emissions (Zhang, 2019). Soil is typically considered as the fine earth covering the surface of the ground by break down of parent materials or the deposition of mineral matter carried by water, wind, or ice (Stephen, 2012). Soil is the base of all terrestrial ecosystems and has a wide range of bacteria, archeological species, fungus, insects and other invertebrates. The soil species serve as food or nutrients to organisms that live above and below ground surface. Soils can also serve as buffer and filters to produce freshwater in ecosystems (Aislabie *et. al.*, 2013).

2.3.2 Soil Quality

Soil quality is defined by the Soil Science Society of America (SSSA) as a soil's capacity to function within ecological boundaries in order to preserve biological production, conserve environmental sustainability, and improve plant and animal health" (SSSA, 1997). Soil quality is often regarded as a dynamic trait that is difficult to define because it is influenced by several variables such as land use, soil conservation activities, and ecosystem and environmental experiences. However, soil quality must be clearly defined in order to preserve and sustain our soils in an acceptable condition for future generations (Bucher, 2002). Soil quality is becoming increasingly critical in terms of conservation, wellbeing, good agricultural practices, and agroecosystem sustainability (Martinez-Salgado, 2010). Salinity, heavy metals, presence of sodium, excessive water, compaction, acidification and loss of nutrients and organic matter can cause soil degradation (Karlen, 2008). Soil contamination endangers people's health all over the world.

Heavy metals pollution of soils such as cadmium, copper, chromium, lead, nickel, and zinc in terrestrial ecosystem has been identified as a key environmental health issue (Okunola *et al.*, 2020). This is because of the non-biodegradable nature of heavy metals and can build up in plant, animal and later in the human food chain which can lead to a serious health challenge (Kimumwe, 2015).

Soil quality indicators can be assessed by the physio-chemical and microbial parameters of the soil (Priyono, 2017).

2.3.2.1 Soil Quality Indicators

Soil quality changes can be determined using indicators that comprise of physio-chemical and microbial state and properties, therefore quality indices, including diverse indicators, have to be provided for soil quality determination (Martinez-Salgado, 2010)**.** All indicators of soil quality are directly relevant to existing and future soil policy (Rickson, 2013).

Physical Properties

The Physical indicators relate to particle arrangement and porosity, with impacts on root development, plant emergence speed and water infiltration. The Physical soil quality index relating to the process of soil, land function, and delivery of ecosystem goods and services have been identified (Rickson, 2013). The physical soil quality indicators are: pH, Electrical Conductivity (EC), Oil and Grease e.t.c.

Chemical Properties

The following are soil chemical indicators: pH, electrical conductivity (EC), oil and grease, phosphorus availability, sulphate, sodium, magnesium, calcium, potassium and other contaminants present such as organic compounds, heavy metals, radioactive compounds, etc. These indicators identify the availability of nutrients, water for plant and other organisms, dispersion of pollutants and existence of soil-plant organisms (Martinez-Salgado, 2010).

Studies have shown that the most frequently used soil chemical indicators for assessment are: pH, electrical conductivity, available phosphorus and potassium, total nitrogen and cation exchange capacity (Bünemann *et al*., 2018).

Microbial properties

Biological indicators encompass measurements of the operations of micro and macro-organisms. Density or population of earthworms, nematodes, termites, ants and microbial biomass may be utilized as indicators because of a function they play in soil development and management; nutrient cycling and specific land fertility (Anderson, 2013).

2.3.3 Soil Pollution

Pollution of heavy metals in the natural environment is a global challenge, as these metals cannot be destroyed and the vast majority have harmful effects on living beings when allowable concentration thresholds are exceeded (Mmolawa, 2011). Emissions from rapid industrialized regions, mine waste materials, disposal of heavy metal residues and leaded pets, fertilizer application on lands, animal manure, sewage dust, pesticides, irrigation of wastewater, coal combustion residuals, waste of petrochemicals and deposition of atmospheric waste could contaminate soils by the accumulation of heavy metal and metalloids (Khan, 2008). Soil pollution from activities such as urbanisation, industrialisation, the use of chemical pesticides and fertilizers has rapidly contaminated both water and air. Man is exposed to polluted soil by means of heavy metal transfer from contaminated soil to plants (Reddy, 2017). Heavy metals are an undefined set of hazardous inorganic, and most typically encountered in contaminated areas are mercury, copper, arsenic, nickel, zinc, chromium, cadmium and lead (Okieimen, 2011). The environmental pollution by these metals has led to an increased concern for environmentally and global public health in recent years (Paul, 2012).

2.3.4 Human Exposure to Soil Contaminants

Under normal circumstances, humans are always exposed to the natural levels of trace elements, which can be regulated by the body. However, exposure to excessive amounts of toxic metals accumulated in human tissues and consequently in the brain, may cause severe behavioural and neurological disorders, which includes depression, increased irritability, anxiety, sleeplessness, hallucination, memory loss, aggressiveness and many other diseases disorders (Okieimen, 2011).

2.4 Water

Water is a universal solvent enriched with a wide range of spectrum of diverse elements in a gaseous, solid, and liquid form, thus its chemical composition varies significantly. Natural water is one of the most important substances for the maintenance of life. An ancient Greek philosopher Thales, Miletus 2,600 years ago, describe water as a primary source of everything (Khublaryan, 2009).

2.4.1 Groundwater

Groundwater supplies a significant amount of water in the main cities of Africa for domestic, agricultural, recreational and industrial uses. Therefore, the adequacy of both quality and quantity of ground water services is important for socio-economic sustainability in the region (Majolagbe *et al*., 2016). Groundwater may also be described as water in confined or unconfined aquifer, water characterized by water elements (Magesh, 2013).

2.4.2 Significance of Groundwater

Statistics reveals that as much as 60 percent of Nigerians consume groundwater for domestic purposes (Omole, 2013). Groundwater sources help to reduce the world population that cannot access clean water and improved sanitation, which is the primary aim of the Millennium Development Goal 7c (MDG7c) (Omole, 2013).

2.4.3 Pollution of water

Industrial waste has become a significant cause of ground water pollution by leaching contaminants into the groundwater. Most heavy metals in industrial waste such as lead , iron, cadmium, copper, zinc, nickel, manganese, cobalt, cadmium and chromium have concentrations significantly higher than acceptable limit set for drinking water by World Health Organization (W.H.O.) and Standard Organization of Nigeria (S.O.N.) (Oluyemi *et al.*, 2009).

2.4.4 Ground Water Quality

Previous research have revealed that the quality of urban groundwater in Nigeria is significantly affected by the geological and geochemical aspects of the environment, rate of urbanization, industrialisation, wastewater, heavy metal, the contamination of bacteria and seasonal effects (Ocheri, 2014). In many cities, a significant percentage of the population depend on dug wells as drinking water source, a low quality of drinking water with health implications (Yusuf, 2007). The maintenance of water quality at an acceptable level is therefore an essential condition for the use of water resources successfully (Soladoye, 2014).

Water quality expresses the suitability of water for different applications or processes. Any individual application should have specified physical, chemical or biological water characteristics criteria, for instance limitations on the concentrations of hazardous chemicals for drinking water usage or restrictions on pH values and water temperature for water sustaining invertebrate (Bartram and Ballance, 1996).

Routine monitoring allows assessment of water quality according to water quality standards and to eventually identify uses for a specific waterbody. Water reserved as groundwater comes from surface water, which slowly infiltrates into the soil and takes a long time to store in groundwater reservoir. Data on groundwater quality provide essential input into historical geology for charging, discharging and storing (Babiker, 2017).

2.5 Activities of Automobile Mechanics and their Effect on Soil and Water

Studies have shown that different contaminants such as heavy metals, oil and grease can accumulate to extremely high concentrations in the soil due to carefree handling of petroleum products in the course of repair or maintenance operations in Automobile mechanical workshop. These contaminants percolate into the groundwater zone constituting a health hazard to the environment as well as people that consume the water. The soil quality is compromised and affects the groundwater because of infiltration during the rainy season. This upsets not only humans, which depend on such water; it deteriorates the soil fauna equally. Most heavy metals analysed and the level of concentration are not able to sustain soil animal's life (Oloruntoba and Ogunbunmi, 2020).

2.5.1 Heavy Metals

Trace elements and heavy metals in the soil have serious consequences for soil organisms (Gupta, 1998). Auto-mechanic site is rapidly polluted with increased amounts of Heavy metals originating from indiscriminate dumping of spent crankcase engine oil (Anegbe, 2016). These heavy metals include: arsenic, zinc, manganese, copper, chromium and lead.

2.6 Water Quality Assessment and Classification

Water quality can be understood as the intrinsic capacity of a water body to respond to the use external agents make of it so a balance with the ecosystem is obtained, satisfying some water quality standards. The steady availability of sophisticated analytical instruments for water potability assessment and monitoring could be far-reaching for residents of rural areas (Oladipo *et al.*, 2019). To define a standard for portable water, various agencies, World Health Organization (WHO), Bureau of Indian Standards (BIS) and Indian Council of Medical Research (ICMR), ISI (1983) and Indian Standard Specification for Drinking Water (1983) have developed standards (W.H.O. 2004; BIS 1991) (Selvaraj *et al.*, 2020). However, these standards also have limitations. Various other indexes were also developed for the surface and groundwater quality monitoring such as water quality index (WQI) by Backman *et al.,* (1998) to assess the groundwater pollution in Finland and Slovakia. The limitations of WQIs demonstrate the need to develop techniques and more advanced assessment methods which enable the analyst to include and interpret qualitative and quantitative information. The methods based on Artificial Intelligence (AI) can combine the advantages of the traditional methods with the advantages provided by the AI

(González *et al.,* 2012). Introduced by Zadeh (1965), Fuzzy logic is another low cost and effective method for water quality evaluation. It is potentially an excellent tool because it employs both qualitative and quantitative models to simulate intricate systems under uncertain and imprecise conditions.

2.6.1 Fuzzy Neural Network

Fuzzy comprehensive evaluation (FCE) is a quantitative scientific evaluation method, proposed by LA. Zadeh, a U.S. expert in control theory (Cheng and Tao, 2010). The fuzzy logic implemented in the water resource problems minimize the risk effects and offer specific values (Meidani and Araghinejad 2014). The Mamdani-based fuzzy system is highly recommended for multiple inputs and single output system because of the Sugeno-based fuzzy inference system that functions only for multiple inputs and multiple outputs (Rout *et al.*, 2018). The use of fuzzy comprehensive technique for evaluation incorporates the evaluation theory and approach that is based on the comparative rigorous mathematical model, a fuzzy degree of assessment and a thorough calculation of health degree. Therefore, the merit and disadvantage of water quality can be examined visually. The FCE principle process involves defining the evaluation factor (via U={U1,U2,U3,…Um}) set and grading level (via V={V1,V2,V3,…Vn})set of the assessed objects.

2.7 Review of past work using Mandani Fuzzy Inference System

The past research work conducted using Mandani Fuzzy Inference System is shown in the Table 2.1 below:

Table 2.1: Review of past work on Mandani Fuzzy Inference System.

Author	Title	Conclusion
Dewanti and Abadi, 2019	Fuzzy Logic Application as A Tool for Classifying water quality status in Gajahhwong River, Yogyakarta, Indonesia	The Mandani fuzzy logic technique can be used as a replacement for the Environment Agency's manual computations.
Nasr *et al.*, 2012	Analysis of Groundwater Quality using Mamdani Fuzzy	The proposed fuzzy model has produced more reliable result for

	Inference System (MFIS) in Yazd Province, Iran.	groundwater irrigation classification.
Sedeno-Diaz and Lopez, 2016	Fuzzy Logic as a Tool for Assessment of Water Quality for reservoir: A regional perspective (Lerma River basin, Mexico)	The study concludes that Fuzzy Logic and Fuzzy Inference System is an effective water quality assessment tool in water bodies.
Oladipo *et. al.*, 2021	Comparison between Fuzzy Logic and Water quality index methods: A Case study of Ikare community, Southwestern Nigeria.	The study shows that the Fuzzy logic is preferable than WQI methods because FL gives the measured values and WQ Standards equal consideration.

The studies in table 2.1 shows that Mamdani fuzzy inference system has been used for water quality assessment and classification of surface water and groundwater in different part of the world with non point source pollution. However, MFIS has not been used to classify water quality of point source pollution especially Automobile workshop premises.

CHAPTER THREE

METHODOLOGY

3.1 Study Area

3.1.1 Site Location

Omu Aran is the administrative headquarter of Irepodun local government area located in North-central Kwara state, Nigeria as shown in Figure 3.1. Omu Aran a section of Kwara forms part of north central Nigeria. It has a land size covering an area of 73.7 km^2 and a human population of 148,610 by 2006 census (N.P.C, 2006). The specific location of sampling points was conducted in the field study, using gps location and altitude as shown in Table 3.1.

3.2 Research Design Layout

3.2.1 Preliminary Survey

To determine the properties (location, altitude and nature) of the wells, a reconnaissance survey was carried out on the proposed study area. ArcGIS was used to illustrate the result.

3.2.2 Sampling Method and Criteria for Mechanic Workshops

Five mechanic workshop locations were purposefully selected in Omu-Aran. Hand dug wells in automobile mechanical workshops where samples were collected are shown in Plate 3.1.The Sampling locations selected were: Secretariat, Bikgate, Water works, Oroago Garage big uncle and G.R.A. The five mechanic workshops were selected using the following criteria:

i. absence of other industries within the area.

ii. presence of hand dug wells as shown in plate 3.1.

Survey shows the potential pollution source (Automobile workshop) is in close proximity to the sampling points and a control point.

A residential area where industries and mechanic activities were absent served as control.

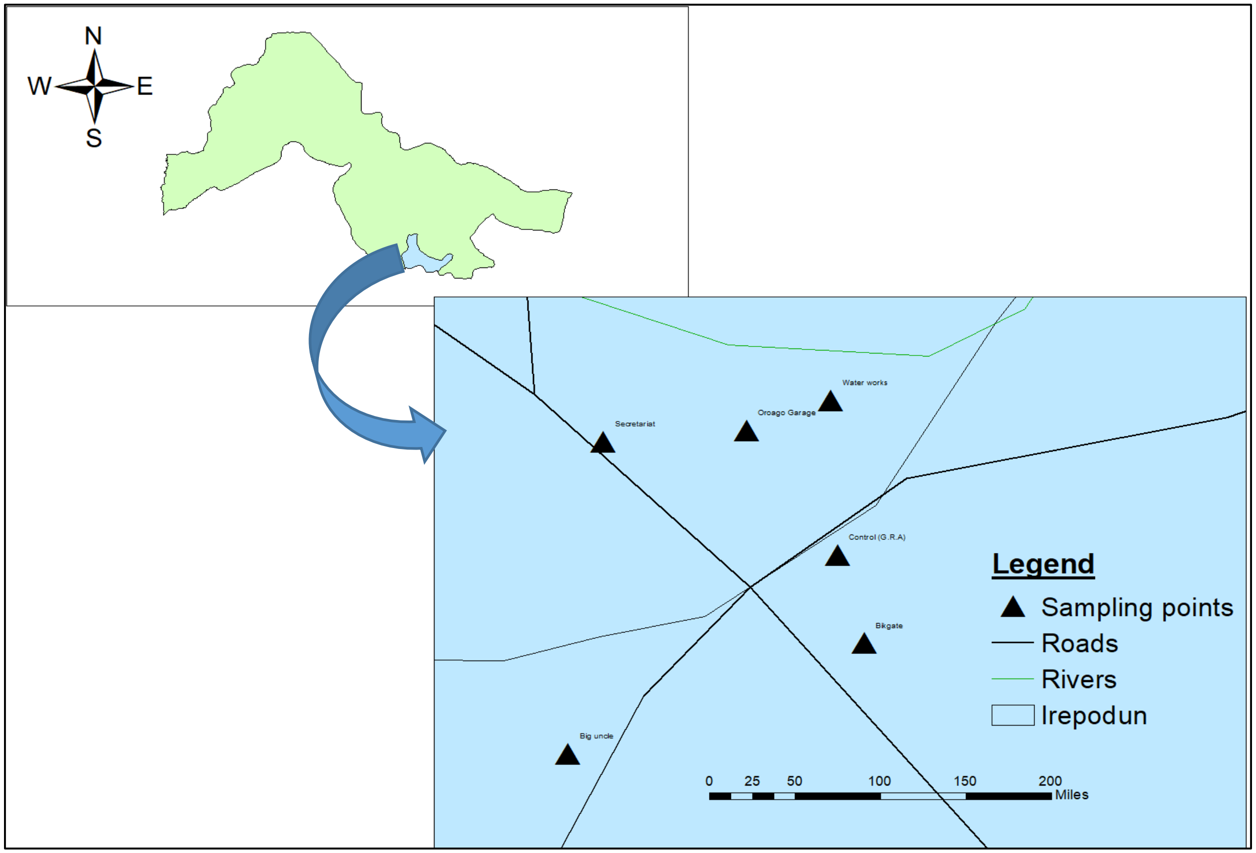

Figure 3.1: Map of the North-Central Kwara state.

Table 3.1: Results of survey on sampling points in the study area.

S/N	Location	Latitude	Longitude	Altitude	Land Use	Site description
1	Bikgate	8.133507	5.111817	528	Residential	Opposite Bikgate hotel and suite.
2	Water works	8.146333	5.110095	525	Residential	Adjacent to the water works office.
3	Oroago Garage	8.144758	5.105858	540	Commercial	Situated at the centre Oroago Garage.
4	Secretariat	8.144158	5.098618	543	Residential	Adjacent to Irepodun secretariat office.
5	Big uncle	8.127655	5.09683	538	Residential	Opposite Big uncle filling station.
6	Control (G.R.A)	8.138170	5.110450	530	Residential	Close to government residential area

Plate 3.1: Some of the Hand dug wells sampled.

3.3 Samples Collection

3.3.1 Groundwater Samples

Ground water samples were collected from 5 separate hand dug wells around the workshops across the city using 750mL pet bottles twice every month for a period of 4 months as shown in Plate 3.2. All sampling bottles were washed and rinsed with distilled water as a quality control measure prior to collection of the water samples and labelled properly at the point of collection. A total of two water samples each were collected by adopting the method described by Elemile *et al*., (2019) using grab method as a representative of the well water from the month of October 2020 to January 2021. The samples were kept in iced packed cooler and transported to the laboratory for analyses.

Plate 3.2: Water samples collected in prewashed bottles.

3.3.2 Soil Samples

Grab samples of top (0-30 cm) were collected from the five different locations where the hand dug wells are situated using a soil auger, four times every month for a period of 4 months. These samples were representative of top soils within each workshop. Soil samples were collected at the 6 selected Automobile workshop locations in airtight polythene bags and stored in the laboratory when not in use. The properties (position and altitude) of each well and soil sampling point relative to the potential source of pollution (automobile workshop) within proximity were evaluated.

3.3.3 Determination of Physio-chemical parameters

Analysis includes investigating physicochemical parameters for both soil and water samples. The parameters analysed were selected based on the need for water quality assessment and time schedule constraints. This was done according to the American Public

Health Association (APHA) Standard Method. Physio-chemical parameters determined included;

I. pH using pH meter model PHS – 3C

II. Dissolved oxygen using Smart D.O meter model mw600

III. Electrical Conductivity (EC) using a multi parameter tester model DZS – 706

IV. Total Dissolved Solids (TDS) using a multi parameter tester model DZS – 706

V. Oil and Grease using partition-gravimetric method

VI. Temperature using a standard thermometer

VII. Phosphate, chlorine and sulphate were determined using the multi parameter photometer.

VIII. Sodium, calcium and magnesium using Jen Way flame photometer as shown in Plate 3.3.

Plate 3.3: Flame photometer apparatus used to analysis Na, Mg Concentration.

3.3.4 Determination of Heavy metals (Water Samples)

Determination of Heavy metals parameters comprising iron, arsenic, cadmium, chromium and Lead were carried out in the environmental laboratory using Flame Atomic Absorption Spectrometer. Strict preservation guidelines were followed to ensure that no further reaction takes place after sample were collected. This was done according to the American Public Health Association (APHA) Standard Method.

3.3.5 Digestion of Soil Sample for Heavy Metal Determination

The USEPA Method 3005A acid digestion procedure was adopted to prepare the soil samples for analysis by Flame Atomic Absorption Spectroscopy (FAAS). Filtration process during acid digestion of soil samples using 1 mole of Hydrochloric acid is shown in Plate 3.4. Analytical procedures were carried out on each sample which includes investigating heavy metal parameters such as lead (Pb), iron (Fe), cadmium (Cd), chromium (Cr), copper (Cu) and arsenic (As). The parameters analysed were selected based on the need of soil quality assessment and time schedule constraints. Strict preservation guidelines were followed to ensure that no further reaction took place after samples were collected.

Plate 3.4: Filtration process during acid digestion of soil samples.

3.4 Development of Water Quality Index

Weight Arithmetic Water Quality Index (WAWQI) were used to obtain a single value from multiple test results and a scale was used to rate the quality of water as described by Tyagi *et al*., (2013). The WAWQI was determined as follows:

$$WQI = \sum WiQi \Big/ \sum Wi \qquad (3.1)$$

$$Wi = K/Si \tag{3.2}$$

$$K = \frac{1}{\sum_{i=1}^{n}\frac{1}{Si}} \tag{3.3}$$

where K and Si are the proportionality constant and the standard permissible limit in water for the ith parameter, respectively. Wi, is the weight used by each unit parameter; Qi describes the quality rating of the ith parameter; n, the number of parameters considered; Qi is calculated as follows;

$$Qi = 100 * \left[\frac{Vn-Vio}{Si-Vio}\right] \tag{3.4}$$

3.5 Data Preparation and Input Selection for Fuzzy Logic

It is important to normalize factors for water quality in order to avoid greater numbers within a uniform range and to scale data within the same range. There are many methods for statistical normalisation for example, Z-score, min-max, median, sigmoid, and statistical normalization column (Jayalakshmi and Santhakumaran, 2011). This study normalizes all input data with min-max normalization method. It is also necessary to evaluate whether the variables are related while modelling WQI of water samples from hand dug wells.

3.6 WQI Model Using Fuzzy Inference System

Fuzzy tool in Mathlab software version R2018a was used for modelling work. System Specification for operating the Mathlab program in this study: Hp Elite book folio 9470m with 8gb ram and 4ghz processor speed. Mamdani fuzzy inference system (MFIS) was used to step up the models in order to use best possible input combination to classify WQI with good accuracy. The model compares selected water quality parameters with W.H.O standard limits. The fuzzy output results of each model such as FIS1, FIS2, FIS3, FIS4 and FWQI are classified into excellent, good, poor, very poor and useless. The input network structure consists of the original raw data with significant selected variables. One target output (WQI) was examined. The network frame structure of MFIS model is shown in Figure 3.2.

The fuzzy inference system was developed using the Graphical User Interface tools (GUI).

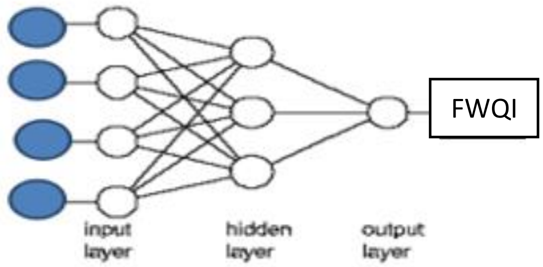

Figure 3.2: Network structure of a MFIS model.

The GUI comprises of FIS editor, membership function editor, rule editor, rule viewer and surface viewer (Payal *et al.*, 2013).

i. Fuzzy Inference System (FIS) editor – used to allocate the numbers and names of each input and output variables.
ii. Membership function editor – used for selection of the membership function shapes assign to each variable.
iii. Rule editor – to input set of rules that defines the network of the system.
iv. Rule viewer – it shows fuzzy inference diagram, i.e Active rules or influence of each membership function on the result obtained.
v. Surface viewer – it shows interdependency of output on the input variables.

Based on available data sets and expert assessment, a total of 170 rules were created for the creation of the fuzzy model. The number of rules in this model relies on the number of input parameters and membership functions as shown in Tables 3.1, 3.2, 3.3 and 3.4.

Table 3.2: Fuzzy range and terms for input parameters.

Input Parameters	**Terms**				
	Unacceptable	Acceptable	Desirable	Acceptable	Unacceptable
pH	0, 6.5	6, 6.75, 7.5	6.5, 7.5, 8.5	7.5, 8.25, 9	8.5, 14
D.O	0, 5	5, 10, 14.5	14.5, 20		
TDS	1200, 2000	200, 1600	0, 800		
EC	1200, 2000	200, 1600	0, 800		
Oil & Grease	30, 60	20, 30, 40	0, 30		
Cl	750, 1000	200, 500, 800	0, 250		
So	200, 300	50, 150, 250	0, 100		
Na	800, 1000	150, 500, 850	0, 200		
K	10, 20	4, 10, 16	0, 10		
Mg	60, 120	20, 60, 100	0, 60		
Ca	75, 200	55, 75, 100	0, 75		
As	0.01, 0.1	0.008, 0.009, 0.01	0, 0.01		
Cd	0.003, 0.05	0.001, 0.002, 0.003	0, 0.003		
Cr	0.05, 0.2	0.03, 0.04, 0.05	0, 0.05		
Fe	0.05, 0.3	0.03, 0.04, 0.05	0, 0.05		

Table 3.3: Some sample rules designed for FIS 1 on the basis of expert assessment for the input parameters.

Group 1		
Rule No.	Antecedent Part	Consequent Part
R1	If Ph = Desirable and Tds = Desirable and Ec = Desirable and D.O = Acceptable	Then Fis1 = Excellent
R2	If Ph = Unacceptable And Tds = Acceptable and Ec = Accptable and D.O = Unacceptable	Then Fis1 = Very Poor
R3	If Ph = Acceptable and Tds = Desirable and Ec = Desirable and D.O = Acceptable	Then Fis1 = Good
R4	If Ph = Acceptable and Tds = Acceptable and Ec = Desirable and D.O = Unacceptable	Then Fis1 = Poor
R5	If Ph = Desirable and Tds = Desirable and Ec = Desirable and D.O = Acceptable	Then Fis1 = Very Poor
R6	If Ph = Desirable and Tds = Desirable and Ec = Desirable and D.O = Desirable	Then Fis1 = Excellent
R7	If Ph = Unacceptable and Tds = Unacceptable and Ec = Acceptable and D.O = Acceptable	Then Fis1 = Poor
R8	If Ph = Acceptable and Tds = Acceptable and Ec = Acceptable and D.O = Desirable	Then Fis1 = Good
R9	If Ph = Acceptable and Tds = Acceptable and Ec = Unacceptable and D.O = Unacceptable	Then Fis1 = Poor
R10	If Ph = Unacceptable and Tds = Unacceptable And Ec = Unacceptable and D.O = Acceptable	Then Fis1 = Poor

Table 3.4: Some sample rules designed for FIS 2 on the basis of expert assessment for the input parameters.

Group 2		
Rule No.	Antecedent Part	Consequent Part
R1	If Oil&Grease =Desirable and Cl =Desirable and So4 =Desirable and Na =Desirable	Then Fis2 = Excellent
R2	If Oil&Grease = Acceptable and Cl =Desirable and So4 = Unacceptable and Na = Acceptable	Then Fis2 = Good
R3	If Oil&Grease = Unacceptable and Cl =Desirable and So4 = Unacceptable and Na =Desirable	Then Fis2 = Poor
R4	If Oil&Grease = Acceptable and Cl = Acceptable and So4 = Acceptable and Na = Acceptable	Then Fis2 = Good
R5	If Oil&Grease = Acceptable and Cl =Desirable and So4 =Desirable and Na =Desirable	Then Fis2 = Good
R6	If Oil&Grease = Unacceptable and Cl = Unacceptable and So4 =Desirable and Na = Acceptable	Then Fis2 = Poor
R7	If Oil&Grease = Acceptable and Cl = Unacceptable and So4 = Unacceptable and Na = Unacceptable	Then Fis2 = Very Poor
R8	If Oil&Grease =Desirable and Cl = Acceptable and So4 = Acceptable and Na = Acceptable	Then Fis2 = Good
R9	If Oil&Grease = Unacceptable and Cl = Unacceptable and So4 = Unacceptable and Na = Unacceptable	Then Fis2 = Very Poor
R10	If Oil&Grease =Desirable and Cl =Desirable and So4 = Unacceptable and Na = Unacceptable	Then Fis2 = Poor

Table 3.5: Some sample rules for FIS 3 on the basis of expert assessment for the input parameters.

Group 3		
Rule No.	Antecedent Part	Consequent Part
R1	If K = Desirable and Mg = Desirable and Ca = Desirable	Then Fis3 = Excellent
R2	If K = Acceptable and Mg = Unacceptable and Ca = Unacceptable	Then Fis3 = Very Poor
R3	If K = Unacceptable and Mg = Acceptable and Ca = Unacceptable	Then Fis3 = Very Poor
R4	If K = Acceptable and Mg = Acceptable and Ca = Acceptable	Then Fis3 = Good
R5	If K = Unacceptable and Mg = Unacceptable and Ca = Unacceptable	Then Fis3 = Very Poor
R6	If K = Acceptable and Mg = Desirable and Ca = Acceptable	Then Fis3 = Good
R7	If K = Desirable and Mg = Acceptable and Ca = Acceptable	Then Fis3 = Good
R8	If K = Unacceptable and Mg = Acceptable and Ca = Unacceptable	Then Fis3 = Very Poor
R9	If K = Acceptable and Mg = Acceptable and Ca = Unacceptable	Then Fis3 = Good
R10	If K = Acceptable and Mg = Desirable and Ca = Acceptable	Then Fis3 = Good

Table 3.6: Some sample rules for FIS 4 on the basis of expert assessment for the input parameters.

Group 4		
Rule No.	Antecedent Part	Consequent Part
R1	If As = Acceptable and Cd = Desirable and Cr = Desirable and Fe = Acceptable	Then Fis4 = Excellent
R2	If As = Desirable and Cd = Unacceptable and Cr = Unacceptable and Fe = Desirable	Then Fis4 = Useless
R3	If As = Acceptable and Cd = Desirable and Cr = Desirable and Fe = Acceptable	Then Fis4 = Good
R4	If As = Acceptable and Cd = Unacceptable and Cr = Acceptable and Fe = Unacceptable	Then Fis4 = Very Poor
R5	If As = Acceptable and Cd = Acceptable and Cr = Desirable and Fe = Desirable	Then Fis4 = Good
R6	If As = Unacceptable and Cd = Acceptable and Cr = Unacceptable and Fe = Acceptable	Then Fis4 = Very Poor
R7	If As = Unacceptable and Cd = Unacceptable and Cr = Unacceptable and Fe = Acceptable	Then Fis4 = Very Poor
R8	If As = Acceptable and Cd = Acceptable and Cr = Acceptable and Fe = Acceptable	Then Fis4 = Good
R9	If As = Acceptable and Cd = Acceptable and Cr = Unacceptable and Fe = Desirable	Then Fis4 = Poor
R10	If As = Unacceptable and Cd = Desirable and Cr = Acceptable and Fe = Unacceptable	Then Fis4 = Very Poor

3.7 Data Analysis

To establish a relationship between water and soil quality at sampling points and pollution parameters, descriptive analyses were used to interpret the data and determine the mean and standard deviation for each input parameter. The relationship between the Physio-chemical Parameters of groundwater across the locations, Concentrations of heavy metals in groundwater, soil and controls were established using analysis of variance (ANOVA). Mandani Fuzzy Inference System and WAWQI were used to classify the quality of groundwater samples. Correlation analysis, analysis of variance (ANOVA) ($P<0.05$) as applicable were carried out using IBM SPSS V.22 software.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Assessment of Water Quality

4.1.1 Physio-chemical parameters

Water samples from the study area were collected from ground water sources in hand dug wells. They were analysed for various physiochemical parameters such as pH, Electrical Conductivity (EC), Dissolved Oxygen (DO), Total Dissolved Solids (TDS), Dissolved Oxygen (DO), Oil and Grease, Sulphite, Chlorine, Sodium, Magnesium, Calcium and Potassium as shown in Table 4.1.

4.1.1.1 pH

The values of the pH ranged between 5.39 ± 0.33 and 6.17 ± 0.75, which falls below acceptable range of WHO. The pH value of control (6.92 ± 0.34) is significantly different from values obtained in other locations. These shows that water samples at all sampling points are acidic. The recorded pH values across the sampling locations were slightly higher than that reported by previous studies (Ashraf *et al.*, 2020). The pH of water is a significant factor, which influences geochemical reactions that take place within groundwater. Water becomes corrosive at low pH values which is of particular importance as past literature has shown that apart from organoleptic concerns, it could lead to water pollution since it can intensify leaching of metal from pipes such as copper and lead (Sorlini *et al.*, 2013).

4.1.1.2 Total Dissolved Solids (TDS)

The TDS values obtained for all sampling points varied from 24.81 ± 9.65 to 73.2 ± 7.75 mg/L. The control has TDS value slightly lower than other sampling points, however, only Secretariat is significantly different from control. Non-plastered walls that allow entry of runoff during precipitation may cause this. The result all fall within the WHO guideline values of 500 mg/L.

According to Sojobi, (2016), the groundwater in the study area can be characterized as freshwater (TDS <1000mg/L). Water becomes undrinkable at a high level of TDS which may even corrode storage containers used.

Table 4.1: Descriptive statistics for groundwater physicochemical properties.

Parameters	Units	Bikgate	Water works	Oroago garage	Secretariat	Big uncle	Control	WHO
pH		6.17 ± 0.75^{b}	5.87 ± 0.13^{bc}	5.39 ± 0.33^{c}	5.56 ± 0.45^{bc}	5.92 ± 0.47^{bc}	6.92 ± 0.34^{a}	6.5-8.5
TDS	**mg/L**	26.84 ± 3.05^{a}	24.81 ± 9.65^{a}	27.4 ± 2.06^{a}	73.2 ± 7.75^{b}	32.48 ± 1.23^{a}	25 ± 4.31^{a}	500
EC	**µs/cm**	50.33 ± 6.38^{ab}	47.83 ± 15.46^{ab}	50.91 ± 4.96^{ab}	135.3 ± 16.09^{c}	60.6 ± 3.61^{b}	38.4 ± 6.24^{a}	1000
DO	**mg/L**	2.58 ± 0.35^{a}	2.98 ± 0.17^{a}	4.15 ± 0.129^{b}	3.53 ± 0.08	4.66 ± 0.17^{b}	6.85 ± 0.56^{c}	5
Oil and Grease	**mg/L**	0.41 ± 0.03^{b}	0.41 ± 0.05^{b}	0.04 ± 0.01^{a}	4.58 ± 0.43^{c}	0.57 ± 0.07^{b}	__	0.05
PO_3	**mg/L**	0.14 ± 0.08^{a}	0.71 ± 0.05^{b}	0.89 ± 0.14^{b}	0.35 ± 0.26^{a}	0.14 ± 0.02^{a}	0.12 ± 0.01^{a}	5
SO_3	**mg/L**	13.89 ± 2.34^{b}	13.36 ± 1.79^{b}	11.01 ± 0.87^{b}	9.43 ± 1.36^{a}	12.18 ± 1.87^{b}	10.21 ± 3.21^{a}	100
Cl	**mg/L**	48 ± 26.72^{c}	46.5 ± 8.35^{bc}	34.5 ± 3.87^{b}	56.75 ± 27.76^{c}	36.25 ± 13.92^{b}	24.38 ± 4.57^{a}	250
Mg	**mg/L**	1.11 ± 0.117^{b}	0.99 ± 0.16^{a}	2.92 ± 0.13^{b}	12.15 ± 1.16^{c}	1.58 ± 0.018^{b}	0.31 ± 0.23^{a}	150
Na	**mg/L**	0.03 ± 0.01^{a}	0.01 ± 0^{a}	0.06 ± 0.01^{a}	0.11 ± 0.03^{ab}	0.04 ± 0.01^{a}	0.26 ± 0.13^{b}	250
Ca	**mg/L**	5.73 ± 0.63^{b}	8.95 ± 2.87^{b}	6.68 ± 0.71^{b}	5.4 ± 0.52^{b}	6.08 ± 1.23^{b}	16.46 ± 3.85^{a}	75
K	**mg/L**	0.10 ± 0.07^{a}	0.12 ± 0.02^{a}	0.21 ± 0.03^{b}	0.29 ± 0.08^{b}	0.27 ± 0.03^{b}	0.32 ± 0.13^{b}	20

Results are expressed as mean of duplicates ± SD and as compared on same row followed by different superscripts (a-d) show significant difference ($P<0.05$) using duncan's test by (ANOVA)

4.1.1.3 Electrical Conductivity

The electrical conductivity values observed ranged from 47.83 ± 15.46 and 135.3 ± 16.09 µs/cm for all sampling points while control has a value of 38.4 ± 6.24 µs/cm. All values were found to be relatively low and within the WHO permissible standard limits (1000 µs/cm) for conductivity, although the well water at Secretariat has a significantly higher value than other sampling points including control. This is a measure of ability of a medium (water) to transmit electric current (Opara *et al*, 2020). Water intake, with values over time beyond the allowable limits, will have severe impacts on human health since it can affect the endocrine functions and induce complete brain damage (Conteh *et al.,* 2020).

4.1.1.4 Dissolved Oxygen (D.O)

The value for DO ranged between 2.58 ± 0.35 and 4.66 ± 0.17 mg/L with the highest value recorded at Big Uncle Station. The DO values are significantly different across sampling sites and this dissimilarity could be a result of the presence and action of microorganisms and strong oxidizing substances. Result obtained failed to meet both minimum WHO requirements (5mg/L) and SON standard (7.5 mg/L) indicating slight degree of pollution by organic matter (Elemile *et al*., 2019).

4.1.1.5 Oil and Grease

The concentration of oil and grease in the groundwater samples measured ranged from 0.04 ± 0.01 to 4.58 ± 0.43 with an average value of 1.2 ± 1.75 mg/L. The measured values of oil and grease in the five sampling points falls above the permissible limit (0.05 mg/L) except at Oroago garage. The presence of oil and grease may be attributed to the activities of oil operators, household consumption and automobile shop within the study area, such that an unavoidable amount of hydrocarbon was released into the ground water (Oloruntoba and Ogunbunmi, 2020).

4.1.1.6 Phosphate

The value for Phosphate ranged between 0.14 ± 0.02 and 0.89 ± 0.14 mg/L with mean value of 0.45 ± 0.34 mg/L. All phosphate values fall within the W.H.O permissible limits (5 mg/L). The phosphate value of control (0.12 ± 0.01 mg/L) is lower than values of sample points. Groundwater samples from Oroago garage have the highest value of phosphate concentration, this may be caused by presence of car wash facility in the automobile mechanic workshop. The presence of phosphate in water could result to eutrophication. Phosphates are prevalent in car wash detergents and can promote excessive algae growth in reservoirs (Mohamed *et al.,* 2014).

4.1.1.7 Sulphate

The value for the sulphate ranged between 9.43 ± 1.36 and 13.89 ± 2.34 mg/L with the water samples from Bik gate having the maximum value of 13.89 ± 2.34 mg/L. Although, there is no standard sulphate value established for human health, however, W.H.O suggest that any amount over acceptable level (100 mg/L) be considered non-hygienic (Conteh *et al.,* 2020).

4.1.1.8 Chloride

The value for the chloride ranged between 34.5 ± 3.87 and 56.75 ± 27.76 mg/L. The mean value of control is (24.38 ± 4.57 mg/L) although the concentration fall within the WHO allowable limits of 250 mg/L; the observed chloride levels of the control wells and other sampling locations were significantly different. Although chloride ions with low concentration are safe, well water with high chloride ion concentrations can distort plant growth when used for gardening or irrigation and might have an unpleasant taste of drinking if water is consumed (W.H.O, 2004).

4.1.1.9 Sodium

The value for sodium ranged between 0.01 ± 0 and 0.11 ± 0.03 mg/L. The values fall within the WHO allowable limits of 50 mg/L. High salt values have been observed to influence the taste of water at concentrations exceeding 200 mg/litre (W.H.O, 1997). However, sodium concentration in the water samples are negligible.

4.1.1.10 Calcium

The value for the calcium in all groundwater sample ranged between 5.4 ± 0.52 and 8.95 ± 2.87 mg/L. The WHO allowable levels of 75 mg/L were not exceeded, although samples were significantly lower than the value from the control (16.46 ± 3.85 mg/L). In a study carried out by Phungula, (2016), it was observed that calcium increases in water samples with low alkalinity. Although there are no limits for calcium and magnesium in the guidelines, these are important variables because they contribute to the hardness of the water (Phungula, 2016).

4.1.1.11 Potassium

The potassium ranged between 0.10 ± 0.07 and 0.29 ± 0.08 mg/L. The measured values of potassium fall within the allowable limits of 20 mg/L. The effect of the high potassium levels is that the water might be undrinkable and it can also lead to eutrophication.

4.1.2 Determination of Heavy metals in water samples

The Heavy metal parameters include Lead (Pb), Iron (Fe), Cadmium (Cd), Chromium (Cr), Copper (Cu), Arsenic (Ar) and Zinc (Zn). The summary of heavy metal levels across the locations are presented in Table 4.2.

4.1.2.1 Lead (Pb)

The observed lead values ranged from 0.048 ± 0.012 to 0.105 ± 0.009 mg/L. The values are beyond the acceptable WHO standard limits of 0.015 mg/L. The lead levels in the control wells is significantly different from other sampling locations. Lead accumulates and increases over a period of time in the blood vessels and bones. It may reach man’s body system through water consumption, food and air intake (Nazir *et al.*, 2015). As well as being carcinogenic, lead also affects the exposed person's core neurological system. It could also distort physical and mental growth in children and could disrupt children’s' care and learning skills (Omole *et al.*, 2018).

4.1.2.2 Iron (Fe)

The concentration of iron ranged from 0.130 ± 0.008 to 0.269 ± 0.005 mg/L. The values are beyond the acceptable WHO standard limits of 0.05 mg/L. Iron reaches the ground water from the surrounding rocks that penetrate the groundwater. The iron levels differed significantly between the control wells and other sampling points. It is regarded as an essential trace metal but in high quantities it is toxic and harms human health.

It has also been reported as a possible carcinogen of cancer in man (Oloruntoba and Ogunbunmi, 2020).

4.1.2.3 Cadmium (Cd)

The concentration of cadmium for all groundwater samples ranged from 0.011 ± 0.004 to 0.115 ± 0.002 mg/L. The irregularities in distribution of the metal may be attributed to either human activities in these different locations or the sediments composition.

Table 4.2: Descriptive statistics for heavy metals properties in Groundwater.

Parameters	Unit	Bikgate	Water works	Oroago garage	Secretariat	Big uncle	Control	W.H.O
Pb	**mg/L**	0.048 ± 0.012^{a}	0.078 ± 0.017^{a}	0.056 ± 0.009^{a}	0.105 ± 0.009^{c}	0.085 ± 0.006^{ab}	0.00 ± 0.00^{c}	0.01
Fe	**mg/L**	0.207 ± 0.015^{b}	0.130 ± 0.008^{ab}	0.144 ± 0.013^{ab}	0.188 ± 0.021^{b}	0.269 ± 0.005^{b}	0.050 ± 0.004^{a}	0.3
Cd	**mg/L**	0.011 ± 0.004^{ab}	0.018 ± 0.002^{b}	0.037 ± 0.007^{b}	0.022 ± 0.007^{b}	0.017 ± 0.004^{b}	0.003 ± 0.001^{a}	0.003
Cr	**mg/L**	0.068 ± 0.014^{b}	0.095 ± 0.008^{b}	0.112 ± 0.006^{b}	0.069 ± 0.08^{b}	0.115 ± 0.002^{b}	0.00 ± 0.00^{c}	0.05
As	**mg/L**	0.014 ± 0.003^{ab}	0.027 ± 0.004^{b}	0.016 ± 0.004^{ab}	0.082 ± 0.015^{b}	0.064 ± 0.005^{b}	0.004 ± 0.003^{a}	0.01

Results are expressed as mean of duplicates ± SD and as compared on same row followed by different superscripts (a-d) show significant difference ($P<0.05$) using duncan's test by (ANOVA)

It enters the groundwater through weathering and erosion of soils and bedrocks or direct deposal from industrial activities. Cadmium builds up in the kidney, where it damages filtering mechanism, it causes diarrhoea, bone fracture, reproductive failure and infertility, damage to the central nervous system, damage to the immune system, psychological disorder and cancer development.

4.1.2.4 Chromium (Cr)

The chromium value for all groundwater samples ranged from 0.068 ± 0.014 to 0.112 ± 0.006 to mg/L. The concentration falls beyond the acceptable WHO standard limits of 0.05 mg/L. The concentration of the chromium in the sampling locations is significantly different from control well. Ground water contamination from chromium may be caused by exposure to chromate waste disposal products. Chromium's detrimental impacts on humans are mostly related to its oxidized state. Chromium intake may cause liver necrosis and membrane ulcers as well as dermatitis if it contacts the skin (Ololade, 2014).

4.1.2.5 Arsenic (As)

The concentration of arsenic ranged from 0.08 ± 0.002 to 0.015 ± 0.004 mg/L. Although the arsenic values for all samples were within the WHO allowable limits of 0.01 mg/L, they are significantly different from the control well. Arsenic is one of the metals known to be highly injurious to human health particularly if they exist in high proportion. Arsenic was also found in all the water samples analysed in abnormal proportions. Long-term human exposure to Arsenic in drinking water result in by higher risk of skin, lungs, bladder and kidney cancer, as well as other skin change such as changes in hyperkeratosis and pigmentation (Abernathy *et al.*, 2017).

4.2 Assessment of Soil properties

4.2.1 Physio-chemical parameters

Soil samples collected from sampling points were analysed for various physiochemical parameters such as pH, Electrical Conductivity (EC), Oil and Grease, Sulphate, Chlorine, Sodium, Magnesium, Calcium and Potassium as shown in Tables 4.3.

Table 4.3: Descriptive statistics for soil physicochemical properties.

Parameters	Units	Bikgate	Water works	Oroago garage	Secretariat	Big uncle	Control
pH		7.478 ± 0.274^{bc}	6.428 ± 0.224^{a}	7.240 ± 0.345^{ab}	6.378 ± 0.226^{a}	6.328 ± 0.374^{a}	7.650 ± 0.512^{c}
EC	**µs/cm**	50.333 ± 6.38^{ab}	102.88 ± 20.102^{bc}	59.483 ± 12.917^{b}	125.425 ± 6.394^{bc}	153.300 ± 41.417^{c}	41.90 ± 2.000^{a}
K	**mg/kg**	0.187 ± 0.065^{a}	0.240 ± 0.089^{a}	0.570 ± 0.099^{ab}	0.618 ± 0.274^{ab}	0.330 ± 0.034^{a}	0.718 ± 0.130^{b}
PO_3	**mg/kg**	0.513 ± 0.099^{ab}	0.495 ± 0.363^{a}	0.674 ± 0.134^{ab}	0.320 ± 0.055^{a}	0.230 ± 0.122^{a}	2.40 ± 0.12^{c}
SO_3	**mg/kg**	25.12 ± 5.31^{a}	43.59 ± 7.95^{c}	38.21 ± 3.85^{b}	41.34 ± 4.45^{c}	33.26 ± 3.72^{ab}	36.21 ± 5.32^{ab}
Mg	**mg/kg**	1.067 ± 0.306^{ab}	0.875 ± 0.250^{ab}	6.750 ± 4.864^{c}	9.850 ± 1.344^{c}	2.150 ± 0.196^{ab}	0.31 ± 0.23^{a}
Na	**mg/kg**	0.038 ± 0.013^{a}	0.030 ± 0.018^{a}	0.8041 ± 0.013^{b}	0.024 ± 0.013^{a}	0.092 ± 0.106^{ab}	0.57 ± 0.35^{b}
Ca	**mg/kg**	3.700 ± 0.173^{a}	8.550 ± 1.323^{ab}	7.475 ± 0.714^{ab}	5.100 ± 0.849^{ab}	4.525 ± 0.472^{a}	16.46 ± 3.85^{c}

Results are expressed as mean of duplicates ± SD and as compared on same row followed by different superscripts (a-d) show significant difference (P<0.05) using duncan's test by (ANOVA)

4.2.1.1 pH

pH is one of the most significant factors for soil quality assessment. It shows the soil acidity, neutrality and alkalinity (Wang, 2000). The values of pH level in soil ranged from 6.378 ± 0.226 to 7.478 ± 0.274 which is lower compared to the control (7.650 ± 0.512). The presence of plant nutrients depends on the pH level of the soil, as soil pH value can be considered a replaceable cation saturation index. Acidic soil indicates the availability of nutrients such as iron (Fe), zinc (Zn), Copper (Cu), manganese (Mn) etc. The potassium (K), phosphorus (PO4), iron (Fe) and other nutrients content in alkaline and calcareous soils is low, therefore fertilizers with these components are needed for the soil. Soil pH plays a major role in determining soil fertility.

4.2.1.2 Electrical Conductivity (EC)

The results revealed that the mean values of electrical conductivity ranged from 50.333 ± 6.38 µs/cm to 153.300 ± 41.417 µs/cm for the samples and 41.90 ± 2.00 µs/cm is the mean value of control sample. The recorded EC values for control was significantly lower compared to other samples. The observed increase in conductivity of the soils could be ascribed to low cation exchange capacity of the control soil and variations rates for the formation of metallic salts and organic matter compounds (Duru, et al., 2017).

4.2.1.4 Potassium

The potassium value for the soil samples ranged between 0.187 ± 0.065 mg/kg and 0.618 ± 0.274 mg/kg. The results varied significantly from each other and considerably lower than observed value for control (0.718 ± 0.130 mg/L). The high values of sulphate can be attributed to increased automobile repair activities. It has been reported that low potassium concentration will affects plants growth, development and crop production especially when it is below necessary value.

4.2.1.5 Phosphate

The mean value of phosphate ranges between 0.230 ± 0.122 to 0.674 ± 0.134 mg/kg. The phosphate values in the sampling locations varied significantly from each other. The values were lower than the values of control well (2.40 ± 0.12 mg/kg). If the level of phosphate in the soil is lower than required content, plant growth might result in underdevelopment (Patil, *et al.,* 2014).

4.2.1.6 Calcium

The calcium values for the soil samples ranges from 3.700 ± 0.173 and 8.550 ± 1.323 mg/kg while the measured value for control is 16.46 ± 3.85 mg/kg. The values were lower than the values of control well. This variation can be directly related to leaching losses, low content of rock parent, and the share of clay minerals.

4.2.1.7 Magnesium

The magnesium values obtained for all sampling points varied between 0.875 ± 0.250 and 9.850 ± 1.344 mg/kg. The values were higher than the values control well of 0.31 ± 0.23 mg/kg, although there were significant differences in the results. Magnesium is harmless at lower concentrations but if it goes beyond the standard limits, it is harmful.

4.2.1.8 Sodium

The sodium concentration in the samples ranges from 0.024 ± 0.013 to 0.8041 ± 0.013 mg/kg, with a mean concentration of 3.54±0.71 mg/kg. The Sodium concentration in all the sample soils, significantly different from the control soil 0.69 ± 0.21 mg/kg at $p < 0.05$ except oroago garage. The level of Sodium in sample soil is significantly lower than the concentrations of control.

4.2.1.9 Sulphate

The sulphate values for the soil samples ranges from 25.12 ± 5.31 and 41.34 ± 4.4 mg/kg. The values were lower than the measured value for control (36.21 ± 5.32 mg/kg). Sulphur-bearing minerals are common in most sedimentary rocks. Gypsum (calcium sulphate) is dissolved in the process of weathering and sulphide minerals partly oxidized which results in a soluble form of sulphate that is supplied by water (Patil, *et al.*, 2014).

4.2.2 Determination of Heavy metals in Soil samples

The heavy metal parameters include lead (Pb), iron (Fe), cadmium (Cd), chromium (Cr), copper (Cu) and arsenic (As). The summary of heavy metal levels across the locations are presented in Table 4.4

Table 4.4: Descriptive statistics for soil heavy metals properties.

Parameters	Units	Bikgate (HW1)	Water works (HW2)	Oroago garage (HW3)	Secretariat (HW4)	Big uncle (HW5)	Control
Pb	**mg/kg**	0.276 ± 0.004^b	0.178 ± 0.001^b	0.212 ± 0.001^b	0.279 ± 0.004^b	0.313 ± 0.004^b	0.025 ± 0.021^a
Fe	**mg/kg**	120.375 ± 0.081^c	90.715 ± 0.038^b	115.278 ± 0.040^c	131.838 ± 0.050^c	178.582 ± 0.089^c	50.23 ± 0.421^a
Cd	**mg/kg**	0.106 ± 0.002^c	0.078 ± 0.004	0.115 ± 0.007^c	0.084 ± 0.003^b	0.154 ± 0.004^c	0.003 ± 0.001^a
Cr	**mg/kg**	0.337 ± 0.004^c	0.279 ± 0.005^b	0.305 ± 0.003^c	0.246 ± 0.002^b	0.429 ± 0.002^c	0.051 ± 0.015^a
As	**mg/kg**	0.111 ± 0.004^b	0.091 ± 0.002^b	0.102 ± 0.004^b	0.087 ± 0.002^b	0.012 ± 0.004^a	0.01 ± 0.023^a

Results are expressed as mean of duplicates ± SD and as compared on same row followed by different superscripts (a-d) show significant difference ($P<0.05$) using duncan's test by (ANOVA).

4.2.2.1 Lead (Pb)

High concentration of lead was found in all samples from the sampling points in the mechanical workshops. The lead values ranged from 0.178 ± 0.001 to 0.313 ± 0.004 mg/kg. In control soil, the mean concentration of Pb was 0.025 ± 0.021 mg/kg. The concentration of Pb in the contaminated soil was significantly higher than that of the control soil, at $p < 0.05$.

4.2.2.1 Iron (Fe)

Iron has the highest concentration among the identified heavy metals as expected and it was discovered at all mechanical workshop sites. The concentration of iron ranged from 90.688 ± 0.03 to 178.358 ± 0.08 mg/kg. The mean concentration was 127.36 ± 30.48 mg/kg. The mean concentration of Fe in the sample and control (50.23 ± 0.421 mg/kg) soil samples was significantly different at $p< 0.05$, indicating the influence motor oil on automobile workshop soil. The mean Fe concentration has also been found to be quite high compared to Cd, Cr, As and Pb concentrations (Sadick *et. al.*, 2015).

4.2.2.1 Cadmium (Cd)

The cadmium concentration ranged from 0.075 ± 0.003 mg/kg to 0.115 ± 0.002 mg/kg while the mean cadmium concentration in the soil samples was 0.107 ± 0.03 mg/kg. The cadmium level of the sample (0.107±0.03 mg/kg) and the control soil concentration (0.003±0.001mg/kg) was significantly different. The concentration of cadmium from this study was considerably lower than similar study carried out by Ololade, (2014).

4.2.2.1 Chromium (Cr)

The chromium concentration ranged from 0.244 ± 0.002 to 0.43 ± 0.001 mg/kg was detected in all the soil samples examined. The mean chromium concentration in the soil was 0.319 ± 0.07 mg/kg. The chromium levels in the contaminated soil (0.319 ± 0.07 mg/kg) and control soil (0.23 ± 0.01 mg/kg) were not significantly different. The chromium concentration from this study was higher than that reported by (Sadick, *et. al.*, 2015).

4.3.2.1 Arsenic

The range of the arsenic concentration in the contaminated soil was 0.012 ± 0.004 to 0.111 ± 0.004 mg/kg, with a mean value of 0.102 ± 0.031 mg/kg. There is significant difference between arsenic concentration in the sample soil and that of the control soil 0.01 ± 0.023 mg/kg at $p < 0.05$ except at Big Uncle location.

4.3 Water Quality Index

The Water Quality Index (WQI) values for groundwater samples in the study area ranged from 108.18 to 184.07. About 83% of samples falls above the permissible WQI limit of 100 that shows the water is not fit for drinking purposes as seen in Table 4.5. As indicated by the WQI, 16.6% of samples in the study area fall below WQI of 100. Most samples from within the vicinity of mechanical workshop fall in the 'poor' water category while all samples from control fall in the excellent or good categories. Therefore, the entire study area can be considered as a vulnerable area for water quality related issues. Chronic kidney diseases with unknown etiology (CKDu) is a major health issue associated with poor water quality (Wickramarathna *et al*., 2017).

Table 4.5: WAWQI range and classification for drinking purposes.

S- NO.	Range	WAWQI Classes	No of Samples	% of samples
1	< 50	Good	4	16.6
2	101-300	Poor	20	83.4

4.4 Fuzzy Water Quality Index (FWQI)

The FWQI values obtained for all station is within the range of Excellent and very poor with a maximum value of 198 and minimum value of 30, similar to WQI result for each location. FWQI shows that 83.4% of groundwater samples in the study area fall in the 'poor' water category, 8.3% falls under 'good' category while 8.3% were in the 'excellent' water category as shown in Table 4.6. The fuzzy representation of physiochemical parameters model, FIS1, FIS2, FIS 3 and heavy metal concentration model, FIS 4, are responsible for poor state of the water quality due to result above 100 as shown in Appendix V. The pH values and D.O are relatively above moderate standard, including heavy metal concentration found in the water samples. The fuzzy representation of trace metals, FIS3, is within the desirable range.

The possible estimated value of the first fuzzy model (FIS1) is 43.8, according to the fuzzy inference based system of FIS1, if the mean concentration of chemical parameters pH, TDS and EC are 7.51, 1e+03 and1e+03, respectively as shown in appendix X.

Table 4.6: FWQI range and classification for drinking purposes

S- NO.	Range	FWQI Classes	No of Samples	% of samples
1	< 50	Excellent	2	8.3
2	51-100	Good	2	8.3
3	101 – 200	Poor	20	83.4
4	201 – 300	Very Poor	nil	0
5	> 300	Not suitable	nil	0

The fuzzy representation of FIS2, which indicates that if an average concentration of oil and grease, Cl, SO_4, Na were 30, 500, 150 and 500 mg/l, respectively; the possible value of FIS2 was estimated to be 75 as shown in XI. In addition, the fuzzy rule base system for FIS3, which suggest that if an average concentration of K, Mg and Ca were 10, 60 and 100 mg/l, respectively; the possible value of FIS3 is 150 as shown in Appendix XII. Appendix XIII shows that the average concentration of arsenic, cadmium, chromium and iron was 0.15, 0.5, 4.5 and 0.05 mg/l, respectively; the possible FIS4 result is estimated to be 266.

4.5 Relationship between FWQI and WAWQI of Groundwater Samples

WQI and FWQI indicates 83.4% of groundwater samples in the sampling location fall in the ‘poor’ water category while 16.6% were in the ‘poor’ water category. The output of FWQI has a strong positive correlation with the WQI result and (r^2 = 0.998) as shown in Table 4.7. Thus, showing that removing some factors from the FWQI development did not reduce the accuracy of water quality classification.

Table 4.7: Correlation between WQI and FWQI

Association	Correlation	Level of Significance
WQI – FWQI	0.998**	0.000

** Correlation is significant at the 0.01 level (2-tailed)

The validation results for each location are been shown in Figures 4.1, 4.2, 4.3, 4.4, 4.5, 4.6; The fuzzy WQI for predicting groundwater quality is compared with the WQI observed. The model validation indicates that the FWQI outputs are consistent with the deterministic technique.

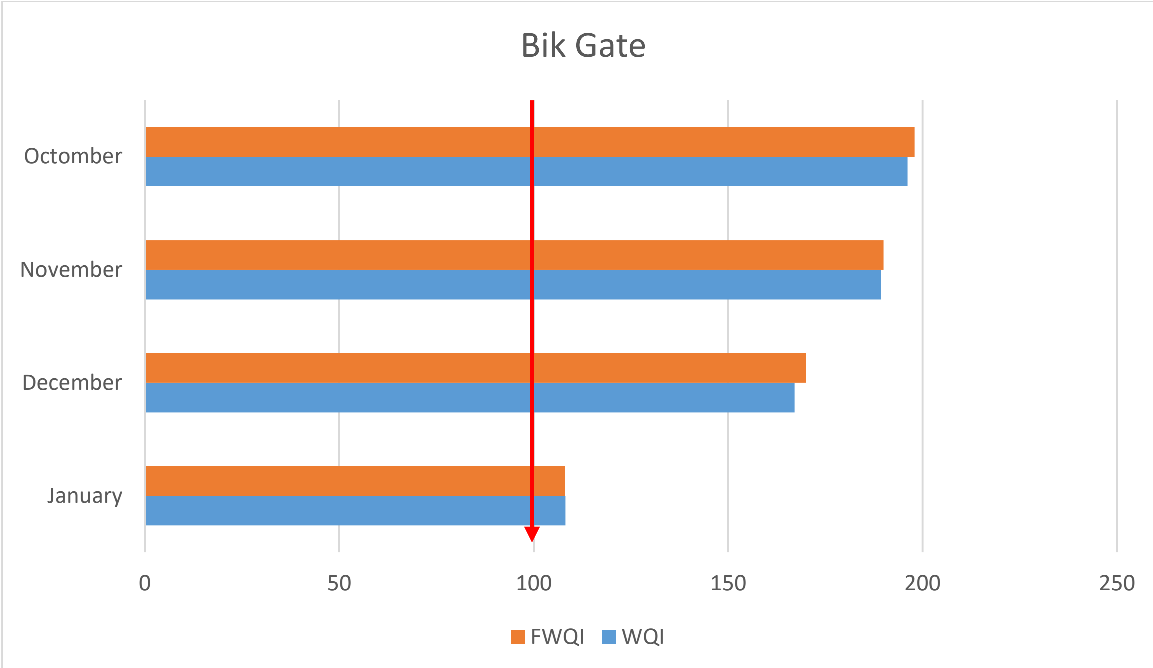

Figure 4.1: Validating the model at Bik gate.

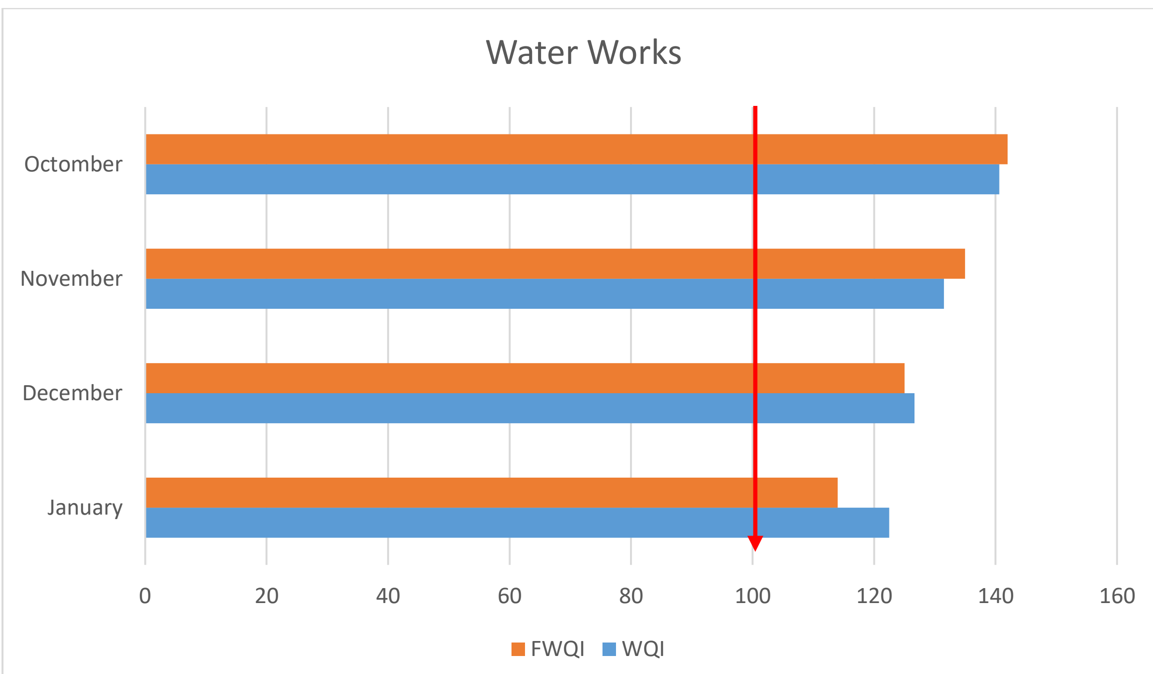

Figure 4.2: Validating the model at Water works.

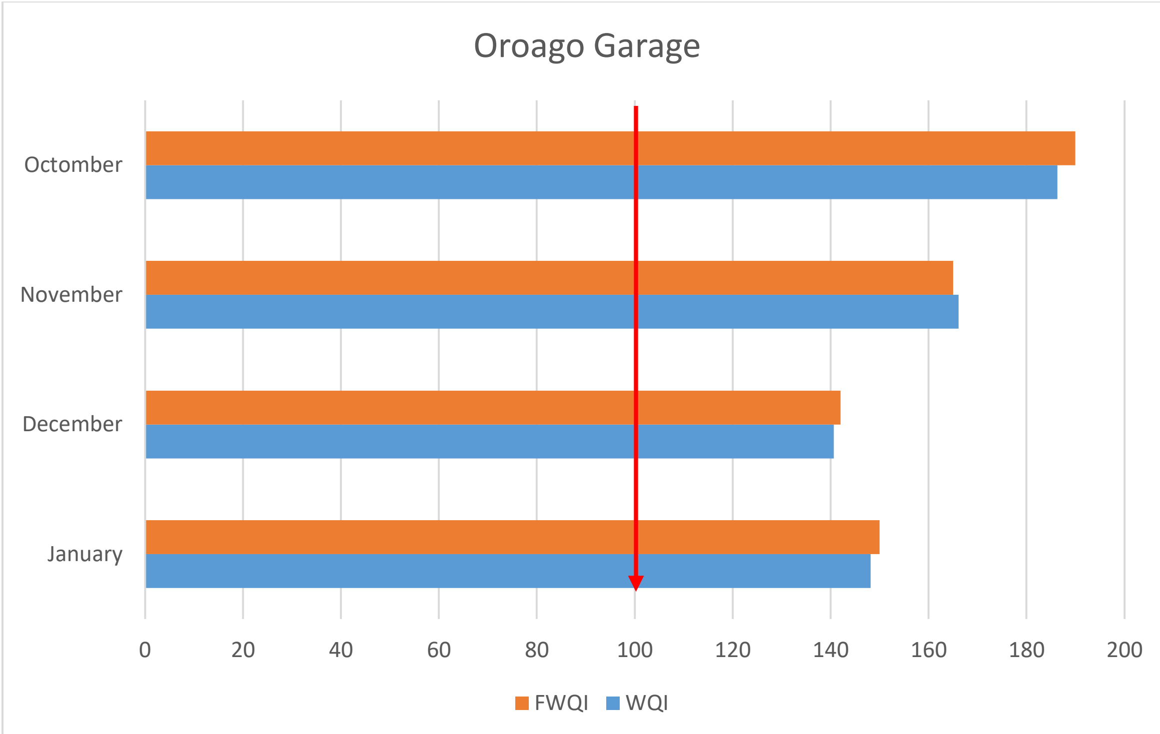

Figure 4.3: Validating the model at Oroago Garage.

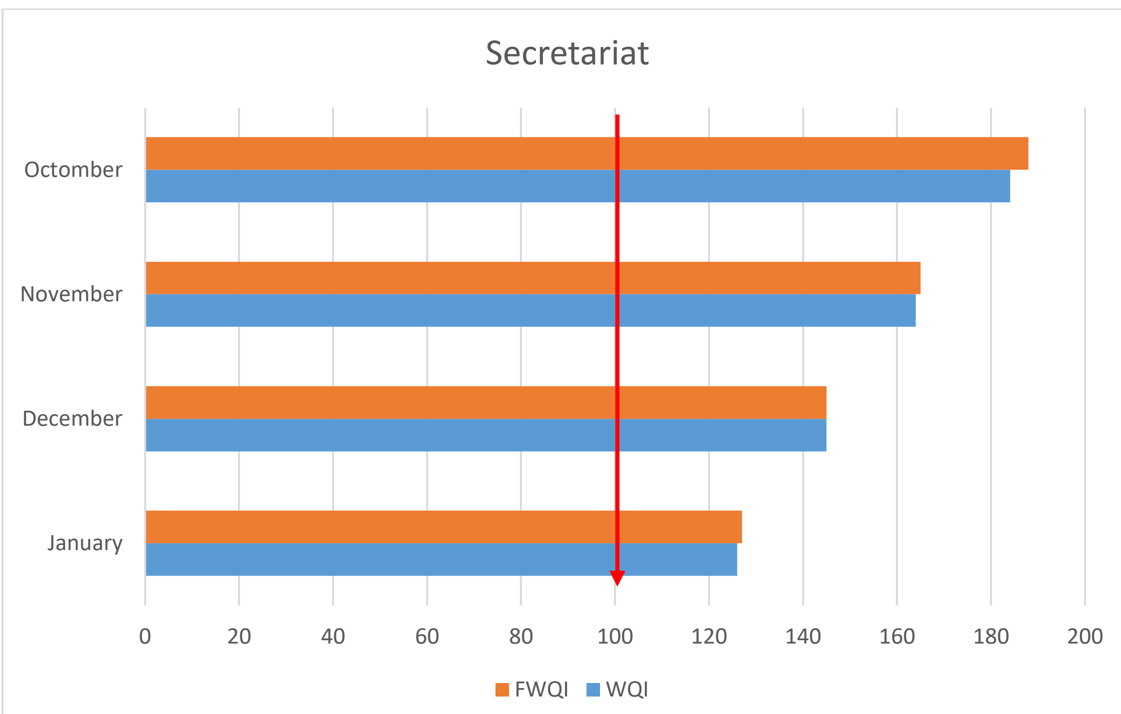

Figure 4.4: Validating the model at Secretariat.

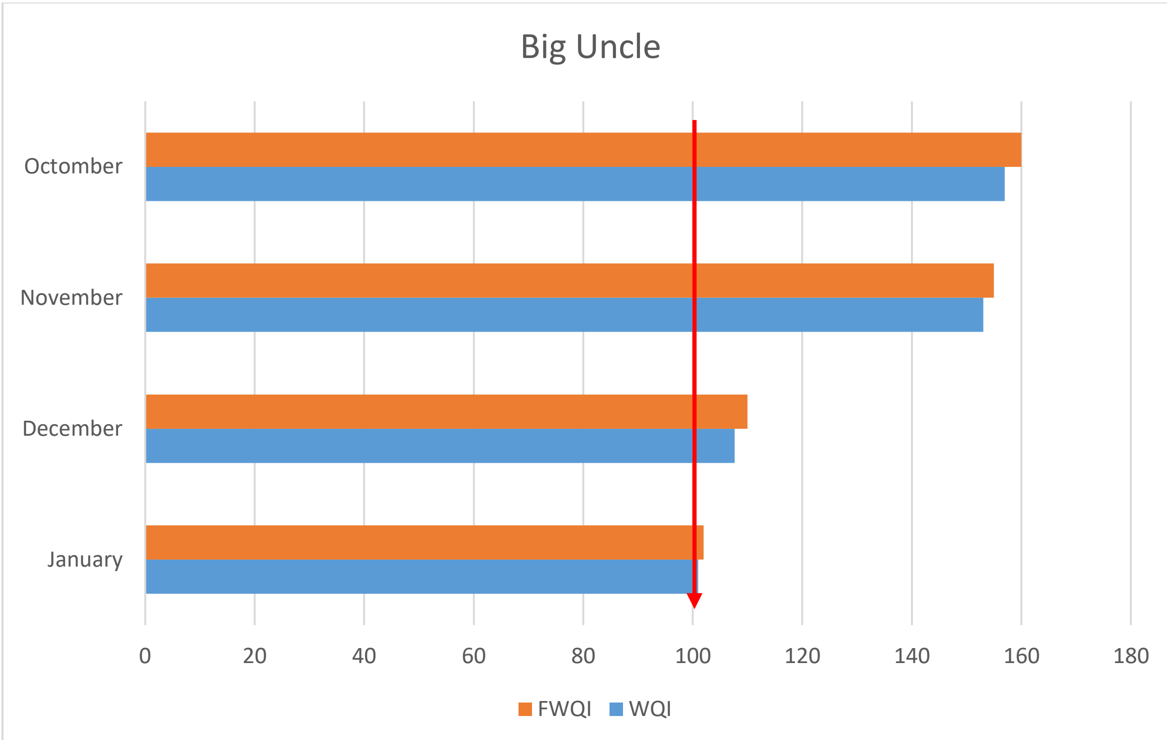

Figure 4.5: Validating the model at Big Uncle.

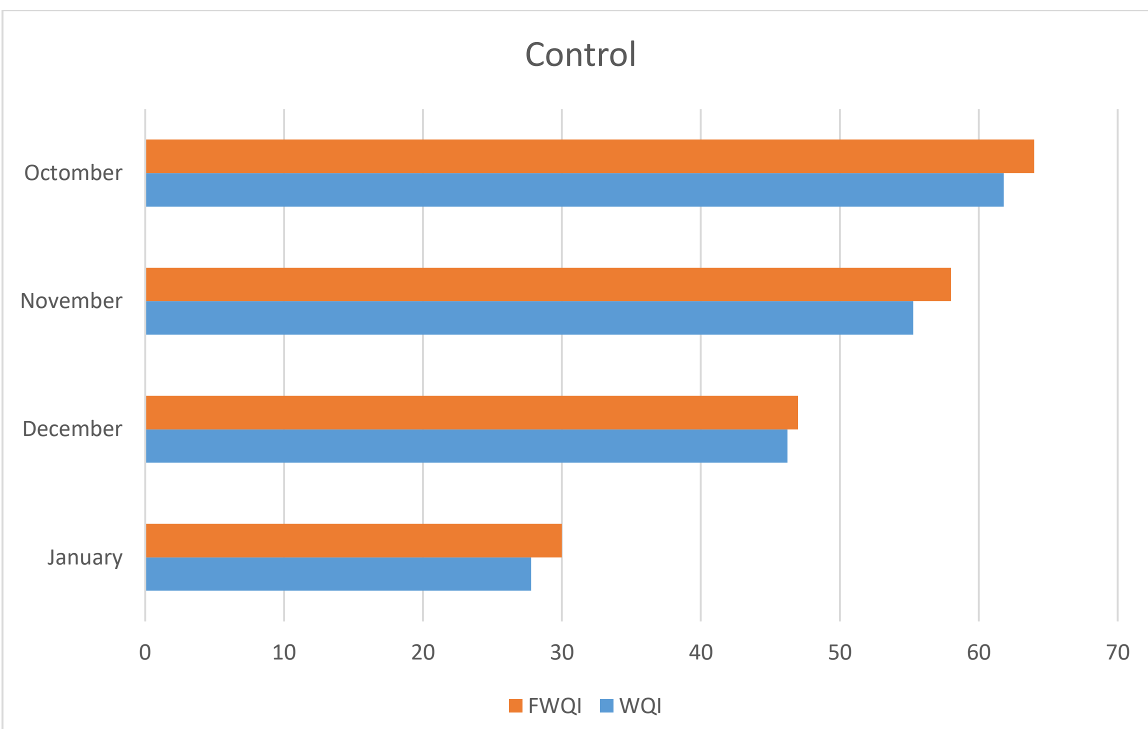

Figure 4.6: Validating the model at Control.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The classification of ground water quality in automobile workshop using Mamdani Fuzzy based Inference System in Omu-Aran, Nigeria was carried out. At the end of the study, the following conclusions were drawn:

1. Activities in the auto mechanic workshops affect the surrounding groundwater sources especially the heavy metal parameters.
2. The physiochemical parameters are within standard for good water quality except pH value and D.O.
3. The groundwater pH indicates that the water samples was slightly acidic which correlate with soil value for groundwater sources except Oroago Garage and Bikgate area.
4. Geo accumulation of heavy metals (Pb, Fe, Cr, Cd and As) is present in soil samples, as soil samples are significantly higher compared to control samples.
5. Mandani Fuzzy based Inference System classification indicate all sampling locations except control falls under the poor category, hence it is not suitable for drinking purposes.
6. As regards Water Quality Index Assessment (WAWQIA) classification reveals significant pollution occurs in all locations except the control.
7. There was a strong positive correlation between WQI and FWQI ($r^2 = 0.998$) for all locations except the control.

5.2 Recommendation

From the discoveries and observations during the course of the research, the following are recommended:

1. Proper waste disposal facility such as impervious layer for collection and waste management practises should be put in place in the automobile workshops.
2. Prompt efforts should therefore be made to ensure that local trees with bioaccumulation potentials are planted in and around mechanic villages to serve as

trap for these heavy metals and help to reduce the migration of contaminants in soils and underground water.

3. Routine assessment and further monitoring of the concentration of heavy metal and organic compounds by the appropriate regulatory agencies within the area should be carried out to ascertain its pollution status and thus adverse effects on biological systems, as there is a tendency of increase of concentration over time.
4. In future, the quick, green, easy, and innovative technique to extract or adsorb the heavy metals ions from groundwater or other environmental water samples may be studied. In addition, all stakeholders should make concerted efforts.
5. Further research can carried out on assessment of hydrocarbon concentration which is associated with automobile workshop activities, in the study area.
6. Government, in collaboration with the ministries of health and environment to establish legislative authorities on waste disposal management, regulation and control and educate the workshops owners on the hazards of their indiscriminate waste disposal within the area.

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APPENDIX I – Data for Ground water Physiochemical Parameters

Sampling points	Month	pH	TDS (mg/L)	EC (uS/cm)	D.O (mg/L)	Oil & grease (mg/L)	PO (mg/L)	SO (mg/L)	Cl (mg/L)	Na (mg/L)	Mg (mg/L)	Ca (mg/L)	K (mg/L)
Bikgate	October	7.17	28.75	41.90	2.10	0.45	0.04	10.80	60.00	0.02	1.260	4.90	0.01
	November	5.70	29.60	54.33	2.80	0.40	0.19	15.35	54.00	0.03	1.030	6.13	0.15
	December	5.49	26.20	56.10	2.90	0.38	0.22	16.00	69.00	0.03	1.000	6.30	0.17
	January	6.33	13.10	49.00	2.50	0.40	0.09	13.40	9.00	0.02	1.130	5.60	0.08
Water Works	October	6.00	22.65	32.00	2.80	0.50	0.76	15.20	49.00	0.01	.860	11.20	0.10
	November	5.93	36.30	41.00	2.90	0.42	0.73	14.15	42.00	0.01	.860	11.20	0.11
	December	5.70	27.20	68.20	3.20	0.35	0.64	11.00	57.00	0.01	1.200	5.20	0.14
	January	5.85	28.20	50.10	3.00	0.38	0.70	13.10	38.00	0.01	1.030	8.20	0.12
Oroago Garage	October	5.26	25.00	52.80	4.10	0.05	0.84	10.67	39.00	0.05	2.910	6.95	0.22
	November	5.78	29.80	45.15	4.30	0.03	1.06	12.03	33.00	0.07	2.930	5.85	0.18
	December	5.01	26.60	56.70	4.00	0.03	0.73	10.00	30.00	0.05	2.900	7.50	0.25
	January	5.52	76.20	49.00	4.20	0.04	0.95	11.35	36.00	0.06	2.920	6.40	0.20
Secretariat	October	5.33	64.20	141.50	3.56	5.20	0.25	9.95	67.50	0.10	11.700	5.20	0.26
	November	5.93	82.20	116.60	3.44	4.50	0.65	7.85	24.50	0.14	13.500	6.00	0.38
	December	5.03	70.20	154.00	3.62	4.24	0.05	11.00	89.00	0.08	10.800	4.80	0.20
	January	5.93	32.95	129.10	3.50	4.36	0.45	8.90	46.00	0.12	12.600	5.60	0.32
Big uncle	October	5.74	31.05	62.00	4.90	0.63	0.13	11.45	51.00	0.04	1.590	6.55	0.26
	November	6.47	33.90	56.40	4.64	0.61	0.16	14.35	41.50	0.06	1.560	4.65	0.31
	December	5.37	32.00	64.80	4.60	0.55	0.11	10.00	34.50	0.03	1.600	7.50	0.23
	January	6.10	22.60	59.20	4.50	0.48	0.14	12.90	18.00	0.05	1.570	5.60	0.28
Control	October	6.75	25.00	39.00	6.60	0.00	2.12	12.56	24.00	0.28	0.300	16.80	0.30
	November	6.90	29.00	38.21	6.95	0.00	2.45	11.24	26.50	0.27	0.330	14.50	0.25
	December	7.05	23.50	38.50	6.72	0.00	2.36	8.50	23.50	0.24	0.300	18.55	0.32
	January	6.98	28.75	38.80	6.90	0.00	2.58	7.83	27.00	0.25	0.310	14.00	0.45

APPENDIX II – Data for Ground water Heavy Metal Parameters

Sampling points	Month	Pb	Fe	Cd	Cr	As
Bikgate	October	.050	.210	.010	.060	.010
	November	.050	.200	.010	.070	.020
	December	.050	.202	.010	.072	.016
	January	.050	.206	.012	.068	.015
Water Works	October	.070	.140	.010	.090	.030
	November	.070	.140	.010	.100	.030
	December	.071	.130	.019	.098	.028
	January	.070	.134	.015	.096	.027
Oroago Garage	October	.050	.150	.040	.120	.010
	November	.060	.140	.030	.110	.020
	December	.058	.151	.037	.116	.014
	January	.057	.146	.035	.114	.017
Secretariat	October	.110	.190	.020	.070	.080
	November	.100	.180	.030	.060	.080
	December	.106	.186	.022	.070	.085
	January	.104	.185	.025	.066	.082
Big uncle	October	.090	.270	.020	.120	.070
	November	.090	.270	.020	.110	.060
	December	.084	.273	.013	.118	.066
	January	.088	.268	.017	.115	.064
Control	October	.002	.035	.003	.003	.002
	November	.010	.042	.004	.005	.004
	December	.008	.045	.003	.004	.005
	January	.005	.065	.002	.008	.005

APPENDIX III – Data for Soil Physiochemical Parameters

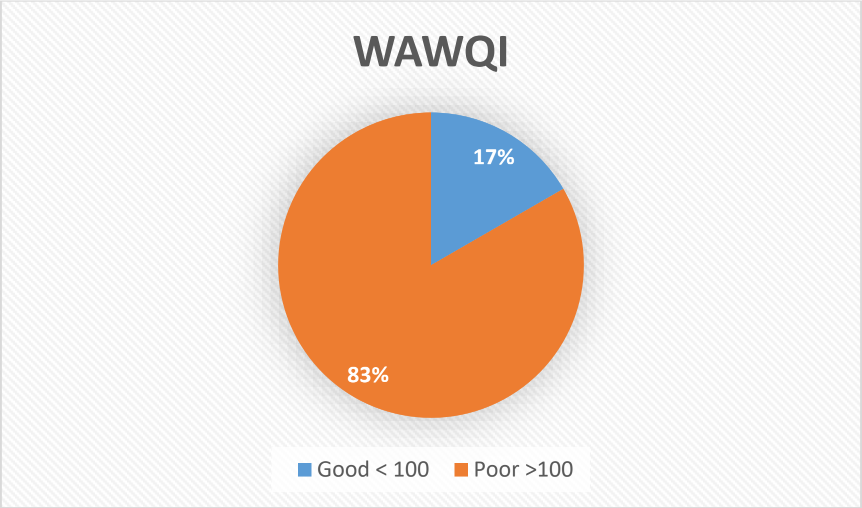
Sampling points	Month	pH	TDS (mg/L)	EC (uS/cm)	D.O (mg/L)	Oil & grease (mg/L)	PO (mg/L)	SO (mg/L)	Cl (mg/L)	Na (mg/L)	Mg (mg/L)	Ca (mg/L)	K (mg/L)
Bikgate	October	7.17	28.75	41.90	2.10	0.45	0.04	10.80	60.00	0.02	1.260	4.90	0.01
	November	5.70	29.60	54.33	2.80	0.40	0.19	15.35	54.00	0.03	1.030	6.13	0.15
	December	5.49	26.20	56.10	2.90	0.38	0.22	16.00	69.00	0.03	1.000	6.30	0.17
	January	6.33	13.10	49.00	2.50	0.40	0.09	13.40	9.00	0.02	1.130	5.60	0.08
Water Works	October	6.00	22.65	32.00	2.80	0.50	0.76	15.20	49.00	0.01	.860	11.20	0.10
	November	5.93	36.30	41.00	2.90	0.42	0.73	14.15	42.00	0.01	.860	11.20	0.11
	December	5.70	27.20	68.20	3.20	0.35	0.64	11.00	57.00	0.01	1.200	5.20	0.14
	January	5.85	28.20	50.10	3.00	0.38	0.70	13.10	38.00	0.01	1.030	8.20	0.12
Oroago	October	5.26	25.00	52.80	4.10	0.05	0.84	10.67	39.00	0.05	2.910	6.95	0.22
Garage	November	5.78	29.80	45.15	4.30	0.03	1.06	12.03	33.00	0.07	2.930	5.85	0.18
	December	5.01	26.60	56.70	4.00	0.03	0.73	10.00	30.00	0.05	2.900	7.50	0.25
	January	5.52	76.20	49.00	4.20	0.04	0.95	11.35	36.00	0.06	2.920	6.40	0.20
Secretariat	October	5.33	64.20	141.50	3.56	5.20	0.25	9.95	67.50	0.10	11.700	5.20	0.26
	November	5.93	82.20	116.60	3.44	4.50	0.65	7.85	24.50	0.14	13.500	6.00	0.38
	December	5.03	70.20	154.00	3.62	4.24	0.05	11.00	89.00	0.08	10.800	4.80	0.20
	January	5.93	32.95	129.10	3.50	4.36	0.45	8.90	46.00	0.12	12.600	5.60	0.32
Big uncle	October	5.74	31.05	62.00	4.90	0.63	0.13	11.45	51.00	0.04	1.590	6.55	0.26
	November	6.47	33.90	56.40	4.64	0.61	0.16	14.35	41.50	0.06	1.560	4.65	0.31
	December	5.37	32.00	64.80	4.60	0.55	0.11	10.00	34.50	0.03	1.600	7.50	0.23
	January	6.10	22.60	59.20	4.50	0.48	0.14	12.90	18.00	0.05	1.570	5.60	0.28
Control	October	6.75	25.00	39.00	6.60	0.00	2.12	12.56	24.00	0.28	.300	16.80	0.30
	November	6.90	29.00	38.21	6.95	0.00	2.45	11.24	26.50	0.27	.330	14.50	0.25
	December	7.05	23.50	38.50	6.72	0.00	2.36	8.50	23.50	0.24	.300	18.55	0.32
	January	6.98	28.75	38.80	6.90	0.00	2.58	7.83	27.00	0.25	.310	14.00	0.45

APPENDIX IV– Data for Soil Heavy Metal Parameters

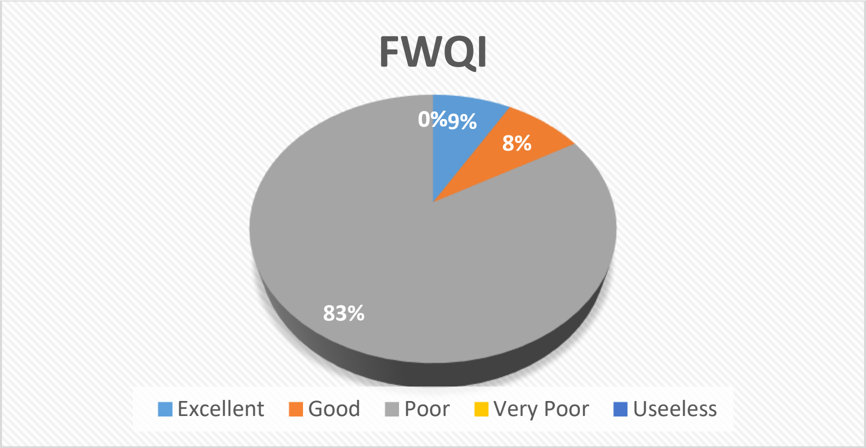
Sampling points	Month	Pb	Fe	Cd	Cr	As
Bikgate	October	.050	.210	.010	.060	.010
	November	.050	.200	.010	.070	.020
	December	.050	.202	.010	.072	.016
	January	.050	.206	.012	.068	.015
Water Works	October	.070	.140	.010	.090	.030
	November	.070	.140	.010	.100	.030
	December	.071	.130	.019	.098	.028
	January	.070	.134	.015	.096	.027
Oroago Garage	October	.050	.150	.040	.120	.010
	November	.060	.140	.030	.110	.020
	December	.058	.151	.037	.116	.014
	January	.057	.146	.035	.114	.017
Secretariat	October	.110	.190	.020	.070	.080
	November	.100	.180	.030	.060	.080
	December	.106	.186	.022	.070	.085
	January	.104	.185	.025	.066	.082
Big uncle	October	.090	.270	.020	.120	.070
	November	.090	.270	.020	.110	.060
	December	.084	.273	.013	.118	.066
	January	.088	.268	.017	.115	.064
Control	October	.002	.035	.003	.003	.002
	November	.010	.042	.004	.005	.004
	December	.008	.045	.003	.004	.005
	January	.005	.065	.002	.008	.005

APPENDIX V

Water Quality Indices

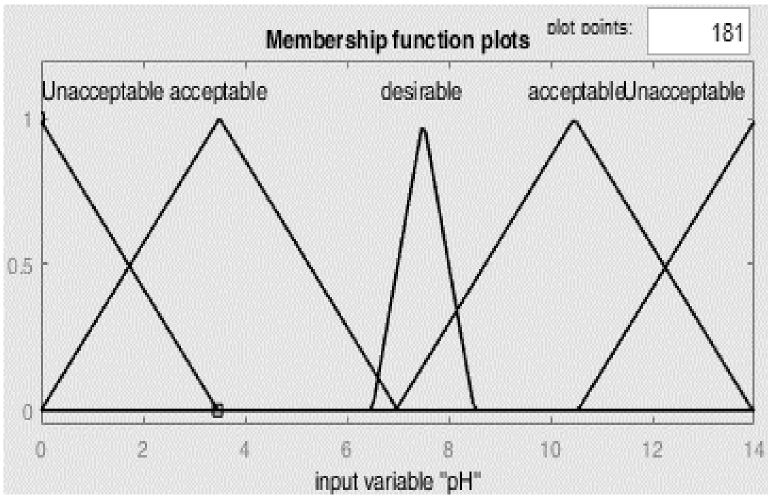


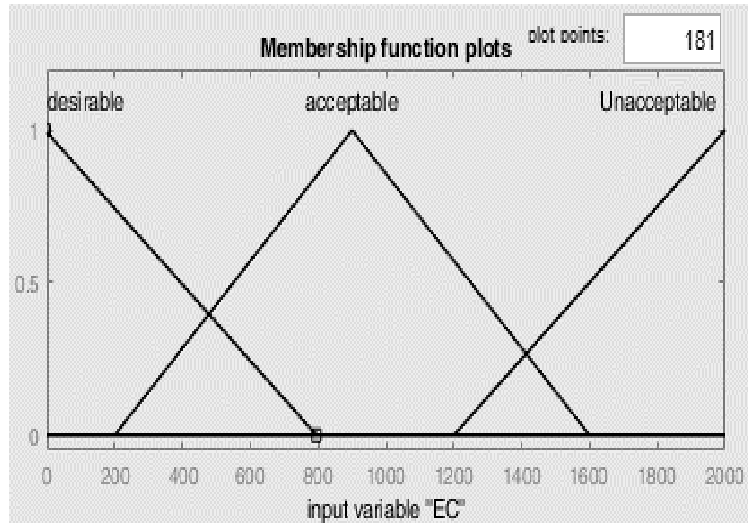
Fuzzy Water Quality Indices

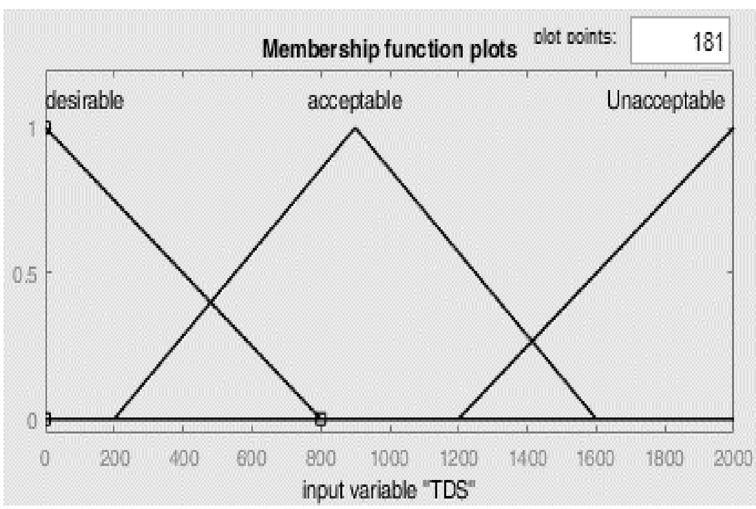


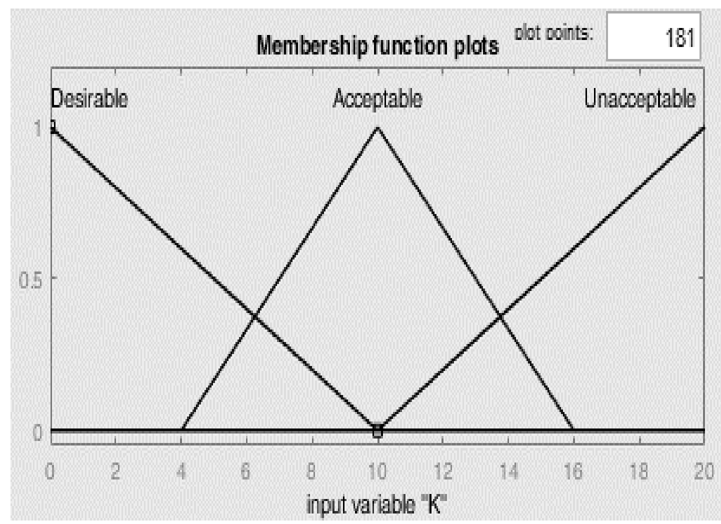
APPENDIX VI

Membership functions for input and out variables. pH, TDS, EC and K



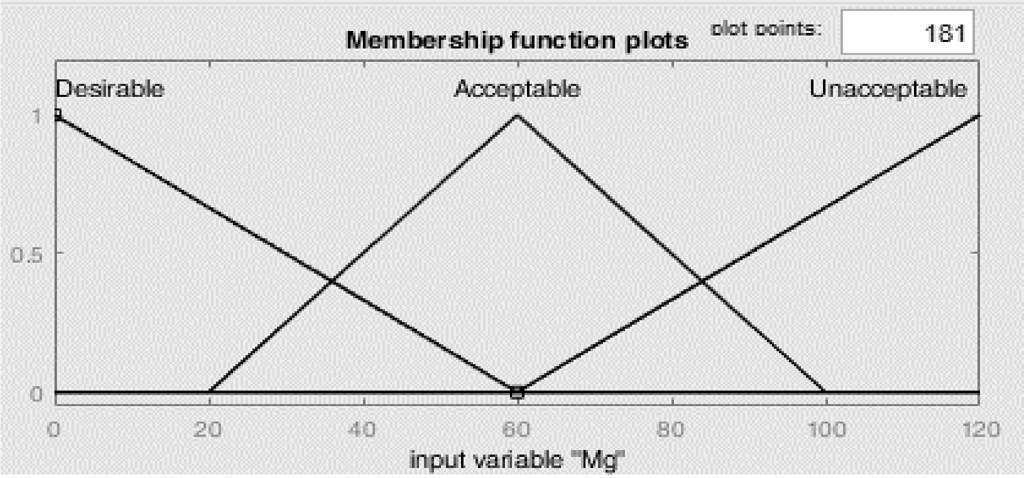


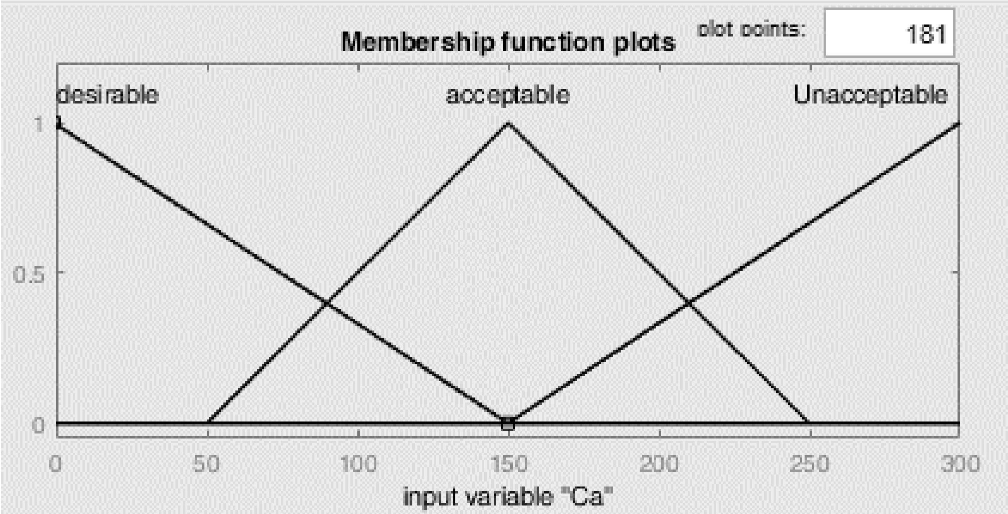




APPENDIX VII

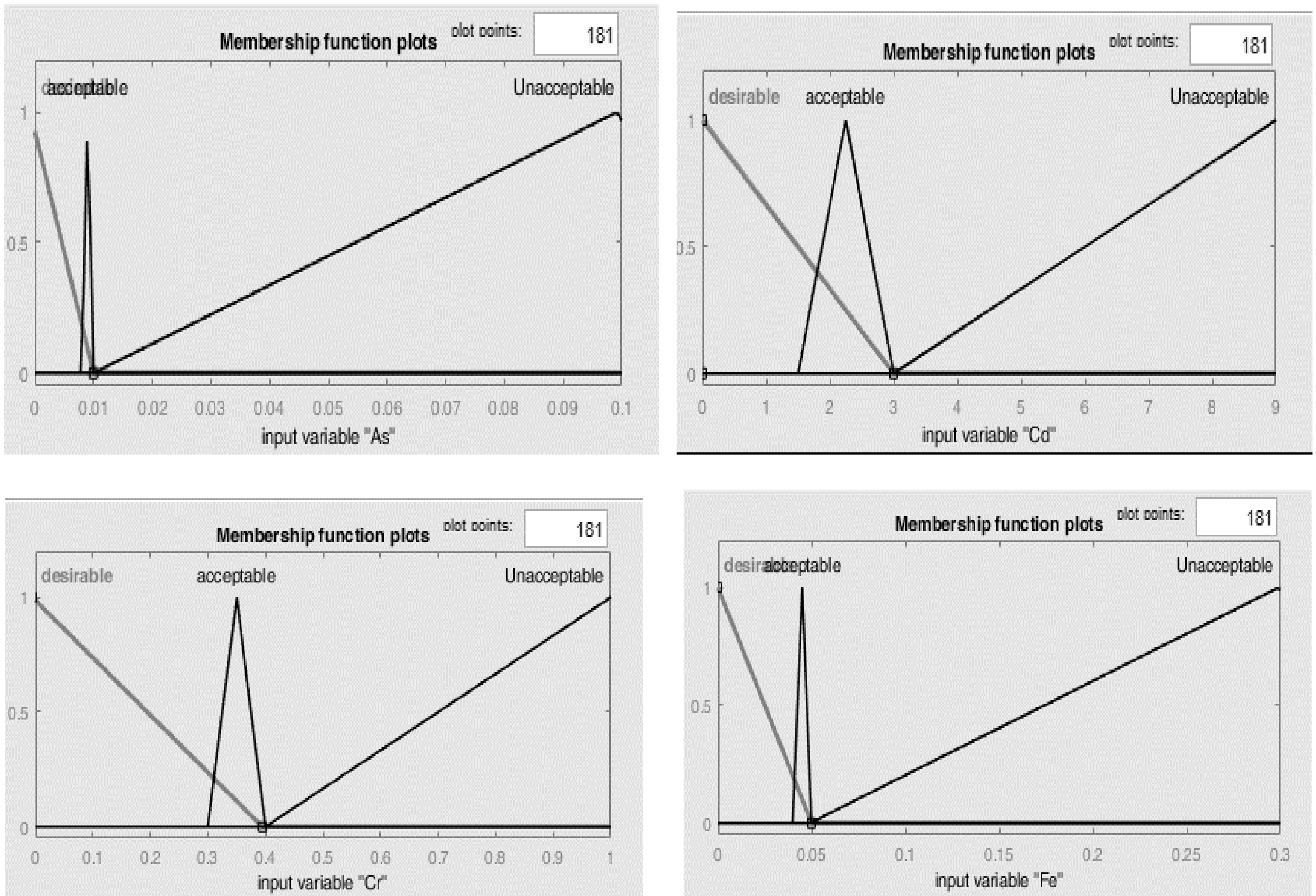
Membership functions for input variables (Ca and Mg)





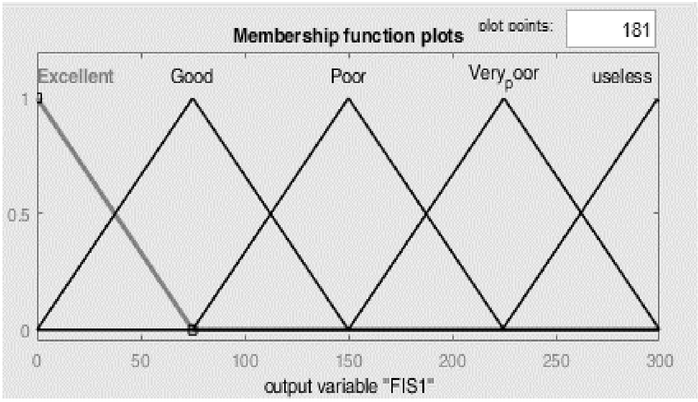
APPENDIX VIII

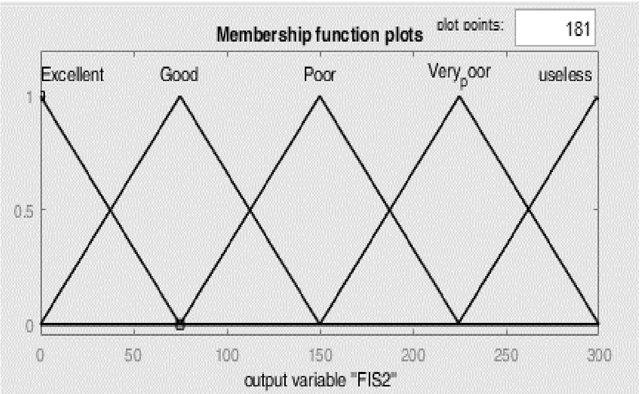
Membership functions for output variables (As, Cd, Cr and Fe)

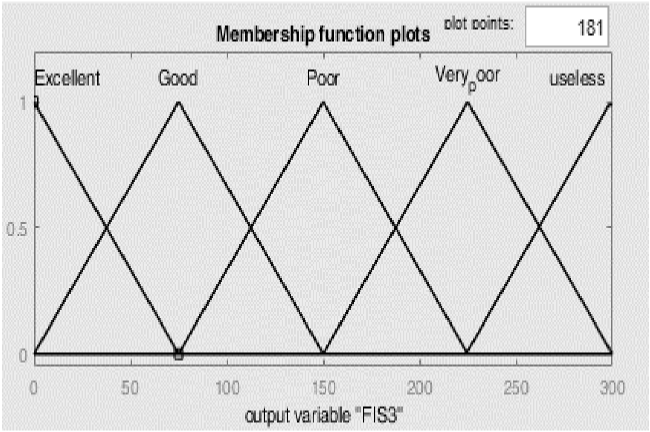


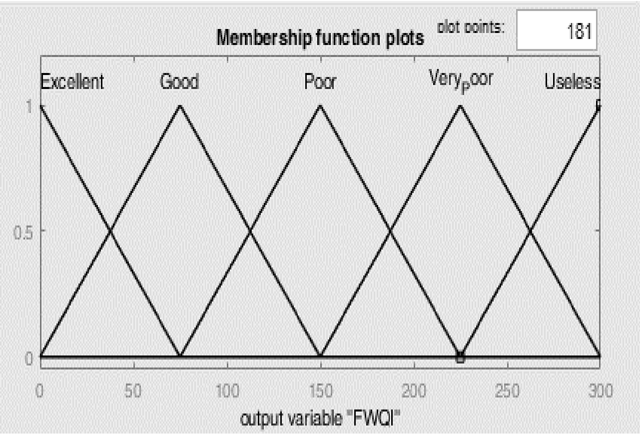
APPENDIX IX

Membership functions for output variables (FIS1, FIS 2, FIS 3 and FWQI)



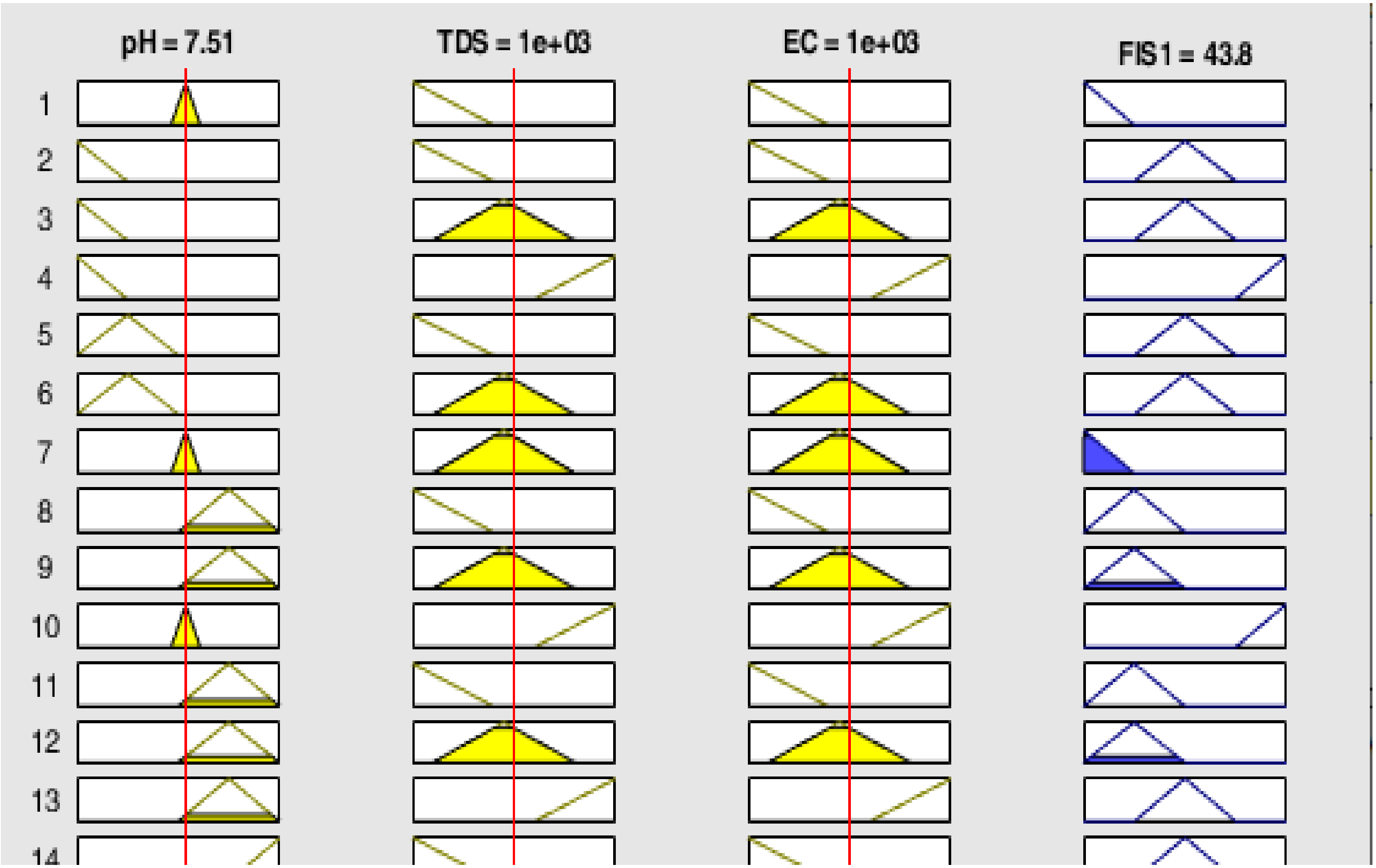






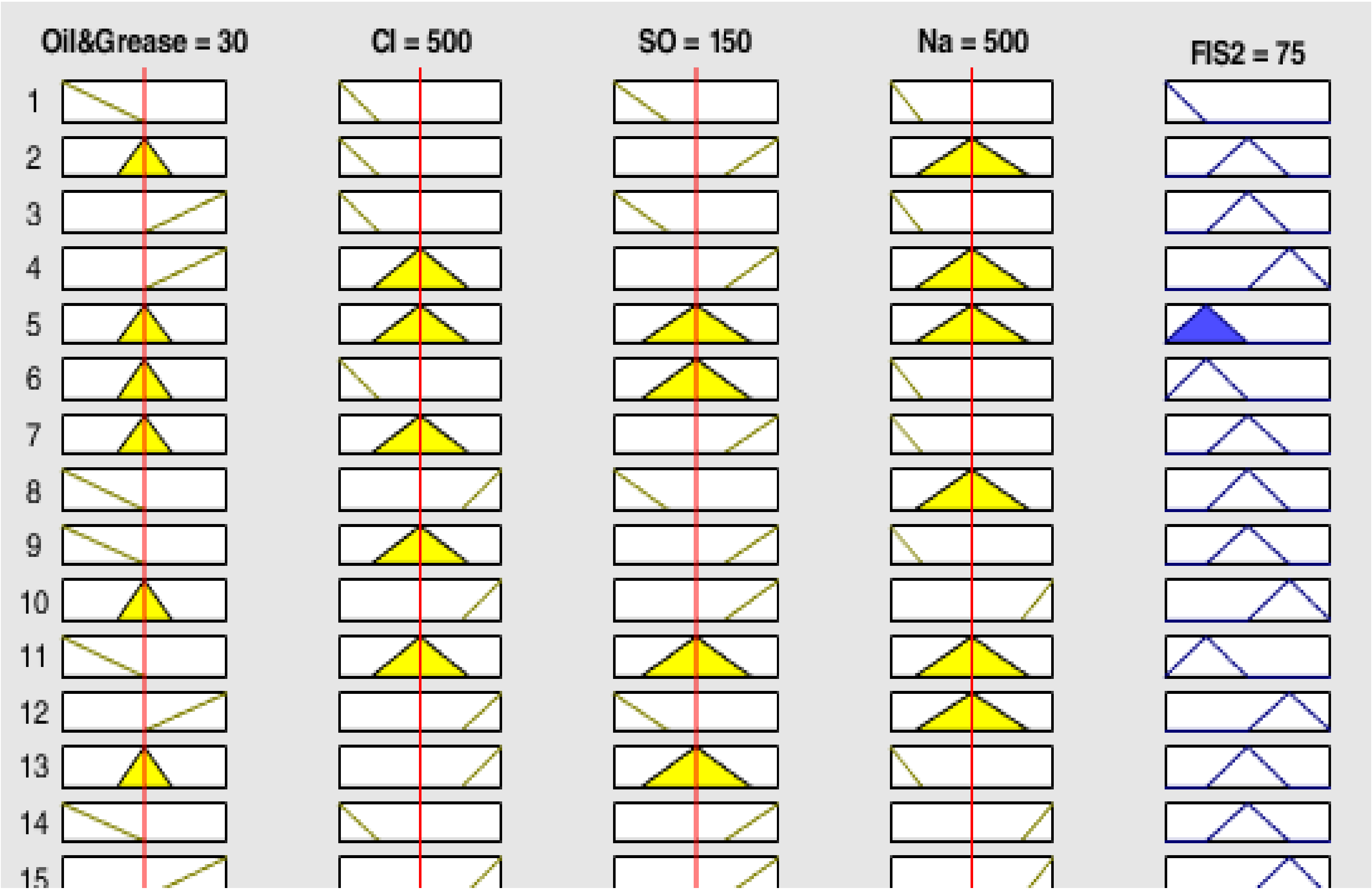
APPENDIX X

Rule base system design of FIS1



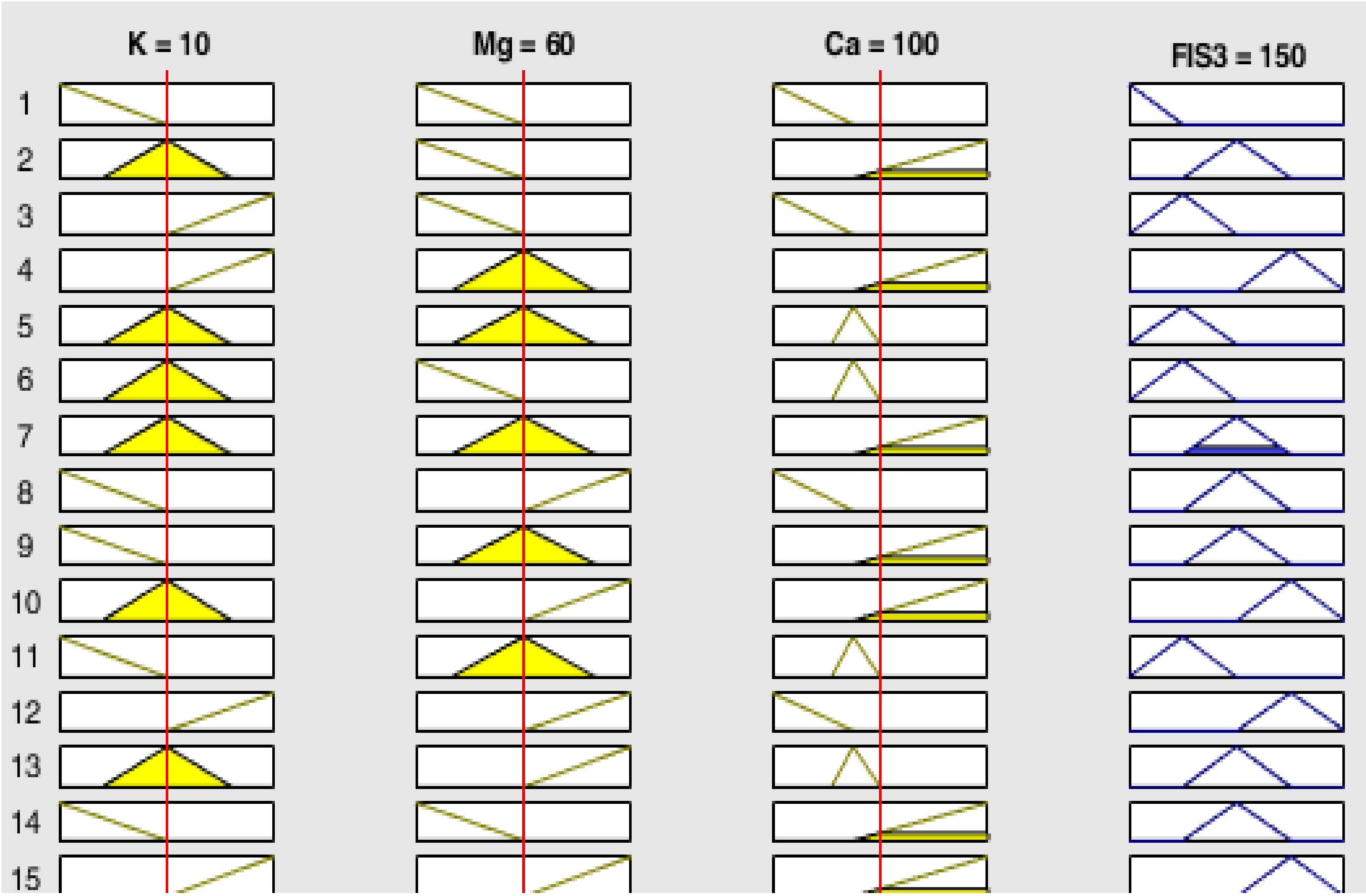
APPENDIX XI

Rule base system design of FIS2



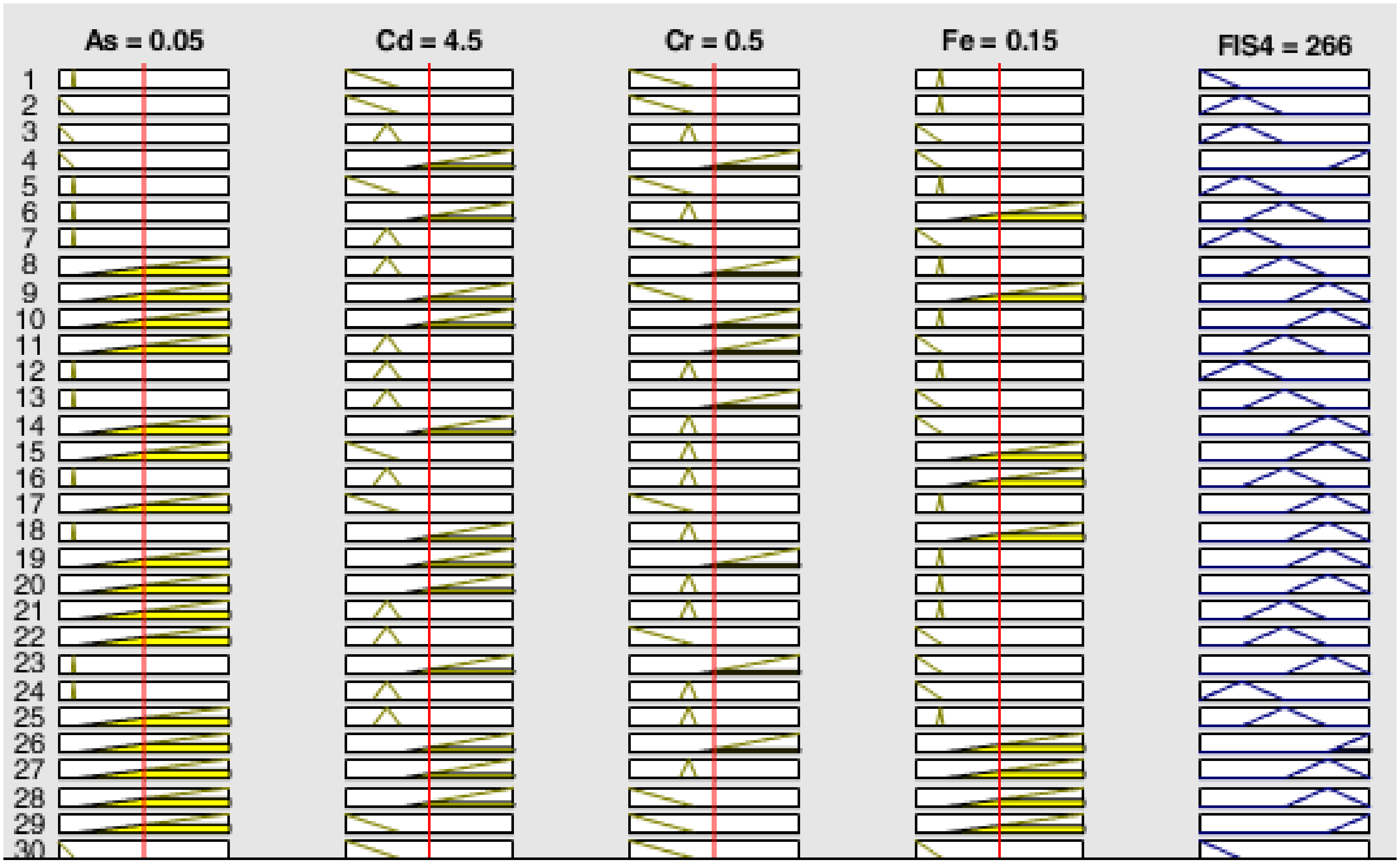
APPENDIX XII

Rule base system design of FIS3



APPENDIX XIII

Rule base system design of FIS 4



APPENDIX XIX

Rule base system design of FWQI