T.C.
ISTANBUL GEDİK UNIVERSITY
INSTITUTE OF GRADUATE STUDIES

EVALUATING THE QUALITY OF WATER AND PERFORMANCE OF WATER TREATMENT PLANTS USING COMPUTER AIDED TECHNIQUES AND FUZZY-TOPSIS

MASTER THESIS

Ayad Khalaf Dhari AL-MOHAMMEDI

Engineering Management Department

Engineering Management Master in English Program

JULY 2022

T.C.
ISTANBUL GEDİK UNIVERSITY
INSTITUTE OF GRADUATE STUDIES

EVALUATING THE QUALITY OF WATER AND PERFORMANCE OF WATER TREATMENT PLANTS USING COMPUTER AIDED TECHNIQUES AND FUZZY-TOPSIS

MASTER THESIS

Ayad Khalaf Dhari AL-MOHAMMEDI
(191281046)

Engineering Management Department

Engineering Management Master in English Program

Thesis Advisor: Prof. Dr. Gözde ULUTAGAY

JULY 2022

T.C

İSTANBUL GEDİK ÜNİVERSİTESİ

LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ MÜDÜRLÜĞÜ

Yüksek Lisans Tez Onay Belgesi

Enstitümüz, Engineering Management Department İngilizce Tezli Yüksek Lisans Programı (191281046) Ayad Khalaf Dhari AL-MOHAMMEDI"nin “Evaluating the Quality of Water And Performance of Water Treatment Plants Using Computer Aided Techniques and Fuzzy-Topsis” adlı tez çalışması Enstitümüz Yönetim Kurulunun 18.07.2022 tarihinde oluşturulan jüri tarafından ***Oy Birliği*** ile Yüksek Lisans tezi olarak ***Kabul*** edilmiştir.

Öğretim Üyesi Adı Soyadı

Tez Savunma Tarihi: (18/07/2022)

1) Tez Danışmanı: Prof. Dr. Gözde ULUTAGAY

2) Jüri Üyesi: Dr. Öğr. Üyesi Tuğba Burçin GÜMÜŞ

3) Jüri Üyesi: Dr. Öğr. Üyesi Ayşe Övgü KINAY

DECLARATION

I, Ayad Khalaf Dhari AL-MOHAMMEDI, do hereby declare that this thesis titled as "Evaluating the Quality of Water And Performance of Water Treatment Plants Using Computer Aided Techniques and Fuzzy-Topsis" is original work done by me for the award of the master's degree in the faculty of Engineering Management. I also declare that this thesis or any part of it has not been submitted and presented for any other degree or research paper in any other university or institution. (18/07/2022)

Ayad Khalaf Dhari AL-MOHAMMEDI

DEDICATION

I would like to present this dissertation and my humble efforts for accomplishing this work to my kindly family, classmate and all my sincere friends for the great support, advising and encouragement along the period of my trip for education, search and life. Special dedication goes to my supervisor Prof. Dr. Gözde Ulutagay, my father, my mother and my wife for their support and prayers during my research work, and thanks so much to my university "Istanbul Gedik University".

PREFACE

I would really be presenting my appreciation to every one supported me all through study and searching period of this voyage. I might to present my thank to my advisor, Prof. Dr. Gözde Ulutagay, for being my guide whenever I thought I was lost myself during research work and being in extraordinary role to haulage the culmination in this significant result. Addition to that, l would like to thank my supervisor for all the supportive and perfect advices that greatly enhanced my steps in the optimization of this work. Finally, I might to thank my university and especially the institution for hosting me during these wonderful years. I am very thankful to my mother, my father, my wife and all my friends, whose instructions motivated me to keep on my aim. To my family, to everyone and to my country great the appreciation and love.

July 2022 Ayad Khalaf Dhari AL-MOHAMMEDI

TABLE OF CONTENT

Page

LIST OFABBREVIATIONS

WTP	: Water Treatment Plant
Ph	: A chemical parameter stands for: potential Hydrogen
CPE	: Comprehensive Performance Evaluation
WQS	: Water Quality Standards
WQPs	: Water Quality Parameters
WNL	: Water National Laboratory
RII	: Relative Importance Index
MCDMs	: Multi-Criteria Decision Making Methods
TOPSIS	: MCDM Technique for Order Preference Similarity to Ideal Solution
MDGs	: Millennium Development Goals (United Nations)
WHO	: World Health Organization
UNICEF	: United Nations International Children s Emergency Fund
DW	: Drinking or Drinkable Water
PCBs	: Polychlorinated Biphenyls
PAH	: Polycyclic Aromatic Hydrocarbons
BOD	: Biological Oxygen Demand
NTU	: Measurement of Turbidity parameter

LIST OF TABLES

Page

LIST OF FIGURE

Page

EVALUATING THE QUALITY OF WATER AND PERFORMANCE OF WATER TREATMENT PLANTS USING COMPUTER AIDED TECHNIQUES AND FUZZY-TOPSIS

ABSTRACT

The quality of drinking water always considered as a highest significance field for the researchers worldwide as it has direct impact on the population's lives. In Fallujah city- Iraq, this research was conducted to evaluate the water quality & the performance of generally and the WQPs particularly to identify the significance or the impact to number of fourteen parameters which have direct impact on the quality of drinking water. The survey carried out with 32 experts working in the same field. The assessment of the WQPs in the survey conducted based on the Likert scale 1-7. After that, The RII calculation were implemented on the primary weights to extract the weights that required for the TOPSIS method. Then, the two Fuzzy scales (1,2,3) & (0, 0.1, 0.2) applied on the survey and RII results to create a second layer of generating the MCDM\TOPSIS weights. Then, the TOPSIS method executed using Octave software where three variables were created which represents the decision matrix taken form the WQ testing results of these WTPs, the final weights which generated using the both approaches of the two fuzzy scales, and the beneficial & on-beneficial values that identified using the water quality parameters scale. The results of TOPSIS method reveals that the final ranking over the six months using both Fuzzy scales gave the similar ranking for these WTPs.

Keywords: *WTPs, WQPs, TOPSIS Method, RII, Fuzzy Scale, Octave Program, Fallujah City*.

SU KALİTESİNİN VE SU ARITMA TESİSLERİNİN PERFORMANSININ BİLGİSAYAR DESTEKLİ TEKNİKLER VE FUZZY-TOPSİS KULLANILARAK DEĞERLENDİRİLMESİ

ÖZET

Nüfusun yaşamları üzerinde doğrudan etkisi olduğu için içme suyunun kalitesi dünya çapındaki araştırmacılar için her zaman en önemli alan olarak kabul edilmiştir. Irak'ın Fallujah şehrinde, bu araştırma üç su arıtma tesisleri, su kalitesini ve performansını değerlendirmek için yapılmıştır. İçme suyu kalitesi üzerinde doğrudan etkisi olan on dört parametrenin önemini veya etkisini belirlemek için genel olarak su kalitesi ve özellikle WQP'ler ile ilgili belirli bir soru ile bir anket tasarlanmıştır. Anket aynı alanda çalışan 32 uzman ile gerçekleştirilmiştir. 1-7 Likert ölçeğine göre yapılan ankette WQP'lerin değerlendirilmesi. Daha sonra, TOPSIS yöntemi için gereken ağırlıkları çıkarmak için birincil ağırlıklar üzerinde RII hesaplaması uygulandı. Ardından, ankete ve RII sonuçlarına uygulanan iki bulanık ölçeği (1,2,3) & (0, 0.1, 0.2), MCDM\TOPSIS ağırlıklarını oluşturan ikinci bir katman oluşturur. Daha sonra, Octave yazılımı kullanılarak gerçekleştirilen TOPSIS yöntemi, bu su arıtma tesisleri WQ test sonuçlarından alınan karar matrisini, iki bulanık ölçeğin her iki yaklaşımı kullanılarak oluşturulan nihai ağırlıkları ve faydalı & on- su kalitesi parametreleri ölçeği kullanılarak tanımlanan faydalı değerler. TOPSIS yönteminin sonuçları, her iki bulanık ölçeği kullanılarak altı ay boyunca yapılan nihai sıralamanın, bu WTP için benzer sıralamayı verdiğini ortaya koymaktadır.

Anahtar Kelimeler: *WTPs, WQPs, TOPSIS Metodu, RII, Bulanık Ölçek, Octave Programı, Fallujah Şehri.*

1. INTRODUCTION

1.1 Background

Since fewer than 1% of the world's water supply is transportable and accessible, drinking water is the most crucial natural resource. The development of the public's health and wellbeing depends critically on a steady supply of potable drinking water (Omar, 2020). The most prevalent substance in the world is known to be water, however not all locations have access to drinking water. The fact that the major civilizations of antiquity were built alongside or adjacent to water sources shows how important water is (Omar, 2020).

To attain a water quality that satisfies certain objectives or requirements established by the end-user or a community through its regulatory authorities, water must be processed. The history of empirical and scientific advancements, challenges faced, and successes in the creation of water treatment facilities is extensive (Omar, 2020). A water treatment plant (WTP) is necessary to provide residents with clean, safe water. In order to properly treat raw water, it is necessary to assess the performance of the WTPs. To provide fresh drinkable water, the majority of modern drinking water treatment plants (WTPs) employ traditional treatment techniques such coagulation-flocculation, sedimentation, sand filtration, and disinfection (Omar, 2020). An intake, raw water, treatment, and transmission analysis were once employed to determine the water system's quality. Every treatment plant must take into account the various units depending on the quality of the raw water for appropriate treatment. It should be operated and maintained properly moving forward.

The method of evaluating a WTP's performance involves determining its operational efficiencies based on some pre-established performance indicators, such as the extent to which pollutants like turbidity, color, suspended impurities, etc. are removed. Water treatment and purification are regarded to be major challenges, especially in developing nations where they are necessary to protect public health and the environment by eradicating bacteria and illnesses that are spread by contaminated water (Issa, 2017). The non-optimized use of chemicals, the operation of unit processes, sludge formation, and energy consumption are the most frequent issues seen nowadays in drinking WTPs.

Despite this, the standard method for evaluating WTP efficiency nearly always relies only on the treated water's compliance with the law. Prior to being distributed to the customer in Baghdad city, (Hassan, 2018). performed research to evaluate the drinking water quality in two treatment plants. The findings revealed variations in both treatment facilities' parameter values for drinking water quality. They created the Comprehensive Performance Evaluation (CPE) for WTPs as a part of a plan to give the populace access to safe drinking water. Although the requirements for drinking water have become stricter throughout time, the method of purification has not changed. The individual treatment plant units were built with the drinking water standards in mind at the time of construction. This dissertation adds information by determining whether or not the WTP's performance and its units can supply water that complies with current drinking water standards. If performance is not optimal, it also offers insightful information about potential reasons for the performance issues and forms the foundation for more CPE discoveries (Omar, 2020).

There has been a dramatic rise in population in Fallujah. There are now no national water quality standards, which makes it difficult to manage water resources effectively via legal regulation of water quality. Fallujah City receives drinking water from three primary water treatment facilities. There is a definite need for research to concentrate on describing a performance evaluation system for treatment plants because of certain ongoing issues in the operation and maintenance of these WTPs.

This study focuses on detecting these issues by assessing each plant's efficiency for a number of characteristics through the analysis of input and output samples to determine how well these WTPs are actually performing. The analysis of WTPs' units, the performance rating of the units, and the identification of issues and suitable fixes have not yet been disclosed. This research will conduct to evaluate the water quality & the performance of three WTPs. A survey will design with a specific question related to the water quality generally and the WQPs particularly to identify the significance or the impact to number of fourteen parameters which have direct impact on the quality of drinking water. The survey carried out with 32 experts working in the same field. The assessment of the WQPs in the survey conducted based on the Likert scale 1-7. The RII calculation will implement on the primary weights to extract the weights that required for the TOPSIS method.

1.2 Research Problem

Treatment or purification of water is considered as a critical challenge especially in developing countries since this treatment is an essential facility to conserve the public health and environment by eliminating of waterborne diseases and pathogens. The trend of urbanization in Iraq is exerting stress on civic authorities to provide basic requirement such as safe drinking water, and its infrastructure. Where the rapid growth of population has exerted the potable water demand, and by 2019 a study found that 64% of Fallujah's city population using piped water for drinking purposes (M. S. Huda, 2018); which requires developing and sustain potable WTPs. Therefore, there is a need to study the WTPs processing and evaluate their operational performance to ensure proper drinking water production and give insights and recommendations to municipal decision makers about WTPs performance. A case study has been conducted to evaluate the performance of WTPs and to find out the problems of its process in WTPs lies in the city of Fallujah in Al Anbar province, Iraq.

In general, WTPs are playing an important role in purifying and supplying the potable water to the people. Deciding which are the best performing potable WTPs can be complicated, as their operations comprise different parameters. To evaluate WTPs performance, several parameters will be addressed and compared within Iraqi limits to note the performance status of the WTPs and how to sustain them in the right methods.

1.3 Study Area

Fallujah which is an Iraqi city on the Euphrates River's left bank, 60 kilometers west of Baghdad. The Euphrates River, which serves as a vital supply of fresh water for a population of nearly 530,000 people by 2019 (M. S. Huda, 2018), forms Fallujah's western border (Fig. 1.1).

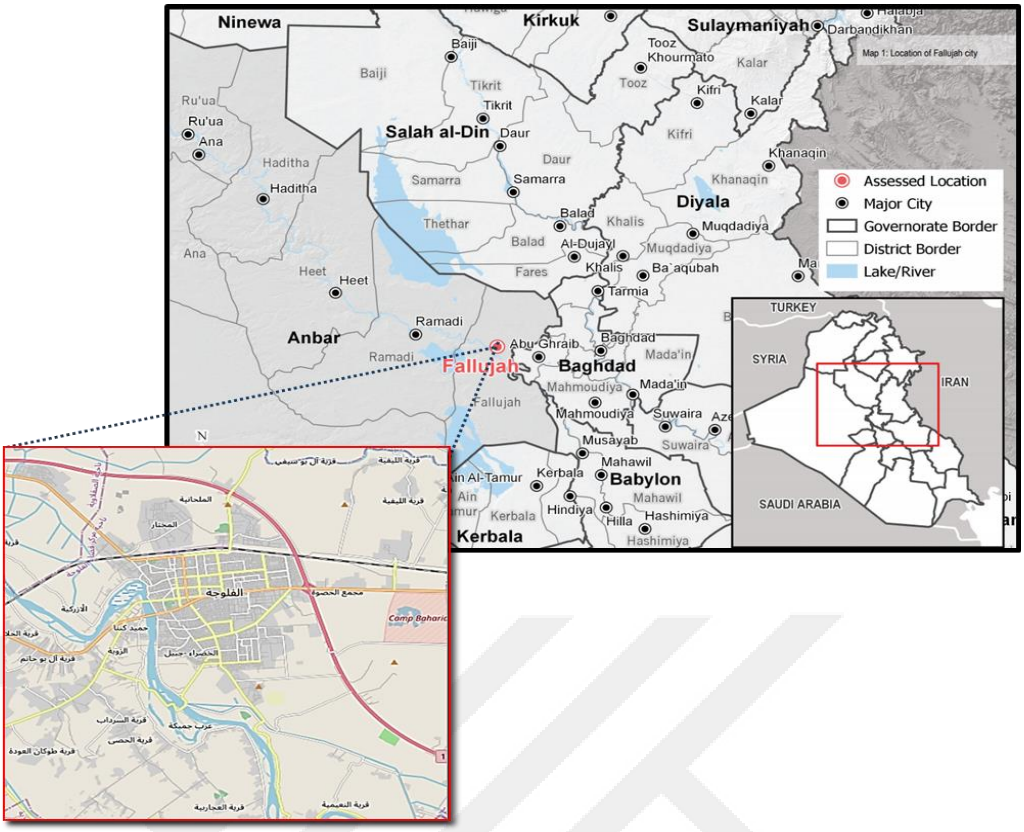


Figure 1.1: The Study Area

As the primary supply of drinking water for Fallujah city. The people have accessible piped water sourced by Euphrates River. For a long time, the residents complained of the contamination of the supplied water (H. M. Ali, 2019). The city center's treated water is supplied by three major water stations and more than five sub-stations. The Old Station, the New Station, and The Al-Resala project are the primary stations. Al-Tahade, New Shuhada, and The Old Shuhada, Al-Askary stations were classified as substations. Many of both classified WTPs which installed along the riverbank had been damaged due to the military operations between 2014 and 2016. Many of the city's community members are claiming that the water quality and availability in the city and its adjacent areas are both low. Since it is untreated well, the people used to have a small sized water station filters at home for drinking purposes; and additional to this, the mineral water also became a major safe water for 64% of the city residents (M. S. Huda, 2018).

Therefore, it is necessary to investigate the water quality and assess the performance of the water treatment plants (WTPs) to determine the challenges and to provide high quality drinking water. This will enable the water quality's decision makers, project managers and other stakeholders to identify the risk factors associated with the variation between the results of this study and the local and international standards.

1.4 Research Aims

The aim of this study is to evaluate the quality of the treated water and the performance of a WTPs generally which located at Fallujah city. Since no or quite rare previous works have been made to cover this important issue that related to the public health and the environment of this city.

The main objective of this study was to enlighten decision makers about the WTPs performance status by conducting analytical research using these WTP tests' data which collected by the Water National Laboratory (WNL). Number of physical and chemical parameters were selected as a main indicator for the evaluation of performance. The study aims to evaluate the performance of the existing potable water treatment plant using Multi Criteria Decision Making Methodology and other secondary analytical tools like RII and Fuzzy linguistic scales.

Since there are insufficient previous studies covering this important issue relating to the public health and the environment of this city. The main corresponding objectives are to: (a) assess the quality of treated water of these plants; (b) assess the general performance and the efficiency of the three WTPs; and (c) make recommendations of interest to the drinking water managers and decision makers. Findings will contribute to the understanding of generic compliance challenges with the guidelines and water quality standards WQS.

1.5 Research Methodology

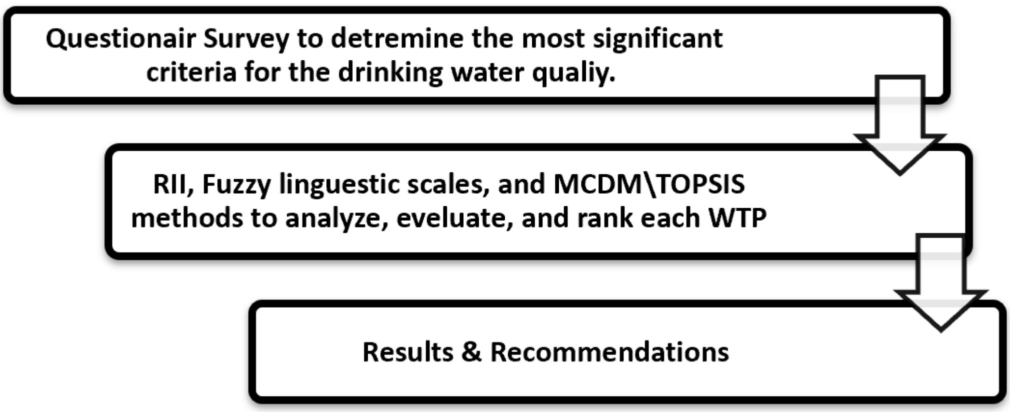


Figure 1.2: Steps of Methodology

MCDM represents well-established mathematical methodologies within the field of operation research, and it has confirmed its efficiency in solving various complicated actual decision-making issues. The main goal of MCDM is designing mathematical and computational techniques for selecting the optimum alternative among numerous choices, depending on the predefined criteria, using a single decision maker, or using group. The collection of MCDM methods can be used for comparing, ranking, and selecting multiple alternatives depending on what is called the evaluation matrix, decision matrix, payoff matrix, or evaluation table. Overall, the result of a decision matrix relies on the environment in which the decision is executed. However, a very broad decision rule is applied to MCDM issues, including all the effective alternatives in the identification, so the selection process of the optimal solution is performed depending on the data of preference that is available by the decision maker. Principally, in the evaluation process for Fallujah Water Treatment Plants, is modelled as MCDM Problem. However, most MCDM techniques that have often been used individually or integrated with other MCDM techniques in previous studies are characterised with limitations and strengths in some points of views.

1.6 Research Scope

This study scope can be elaborated by two research directions as shown below; Firstly, identification of the most influential water quality parameters WQPs of the treated water which are utilized to monitor and support sustainability and make right decision. In practical, we define a set of WQPs that used as a basic level when monitoring activities conducted to evaluate the performance of the WTPs through the literature review and the opinions of water quality experts. Secondly, an efficient performance evaluation of WTPs using a hybrid multi-criteria decision-making methodology was applied. As conclude, this study does not engage with the entire process of WTPs except the specified directions of development that mentioned above.

1.7 Organization of Thesis

This dissertation is structured as follows:

Chapter 2: Gives detail description on potable water management, water quality parameters, potable water treatment process. It next looks at the MCDM methods fundamentals and review all related methods to our practical application case. In the last part of this chapter, the critical literature review for WTPs performance evaluation based on MCDM is discussed.

Chapter 3: This chapter first presents a detailed description of the preliminary study phase followed by the conceptualization phase for the proposed Fuzzy - MCDM\TOPSIS method to evaluate the WTPs performance.

Chapter 4: This chapter presents research design and implementation by introducing a multi criteria decision making methodology for WTPs performance evaluation under various parameters. The proposed techniques, and algorithms are described in detail. Also, this chapter will explain the final indicators of the results the applicability and feasibility of the proposed approach and investigate their validation. The next chapter would draw conclusions and discuss the potential future.

Chapter 5: This chapter presents conclusions for our research objectives, which have been achieved, related to the problem statements and the research contributions. In the last part of this chapter, some potential future works will be presented for further investigation.

1.8 Summary

This chapter entirely covers the complete representation of our study. A short opening introductory and background is given throughput this chapter. In the next part, a detailed description of the problem statement is given. Then, it outlines several research questions to realize the stated objectives. These research questions are framed to depict the obvious relationship between research objectives and questions. In the following part, the proposed methodology of this research is expressed clearly, followed by explaining the significance for undertaking this research. The last part of this chapter presents a general context of the other chapters of this dissertation and visualizes our research workflow.

WATER QUALITY & MANAGEMENT

2.1 Introduction

Water is omnipresent, and it is regarded the second most important element for all organisms in this world after the air. Water is still one of our most valuable resources. We rely on it for our livelihoods, healthy ecosystems, and a strong economy.

Nonetheless, several of the obstacles, including aging infrastructure, demographic changes, and security incidents, threaten the safety and sustainability of our water supplies. Humans require water for transporting goods, municipal and industrial purposes. According to the United Nations, there is a human right to dependable access to safe and clean drinking water and sanitation, which, combined with other domestic purposes, accounts for around 7- 10% of total water usage United Nations (Catley-Carlson, 2012).

In 2002, Iraq was one of the 180 countries that agreed to set the Millennium Development Goals (MDGs) who decided that WASH access is the core to disease prevention; unhealthy water may cause death for a huge number of people. The UNICEF's Executive Director Anthony Lake saidhdk, "Every day more than 3,000 children die from diarrheal diseases". Achieving this goal will go a long way to saving children's lives. Although water covers 70% of the earth; The drinking water which is the most important natural resource, is only less than 3% of the total water on the planet (Darre, (2018). Approximately a quarter-million people on the planet do not have access to clean drinking water (Choudhury, 2018). Political, economic, water resources management infrastructure and industrial challenges also affecting the water quantity management worldwide as well as the climate change around the world generally and in Iraq particularly. Today, Tigris and Euphrates rivers in Iraq, are suffering of shortage of water quantity due to the three factors mentioned above, this indicates the urgent need for Iraq to follow a new strategy to save the drinking water sources from being discharged towards the Shatt Al-Arab River, and then wasted in the Arabian Gulf (Al-Imarah, 2017).

Figure 2.1: Elphurates Polluted with Paterol near to the Iraqi-Syrian borders

2.2 Water Quality

Notwithstanding of the scarcity of water quantity, the quality of water remains the highest priority due to its direct impact for the human health. Water quality refers to the state of water, including its chemical, physical, and biological properties, and is often measured in terms of its appropriateness for a certain purpose, such as drinking and/or other uses. In fact, the biological, chemical, and radiological attributes identify the water quality. It depends on a variety of factors, including the amount of dissolved oxygen in the water, the amount of bacteria present, the amount of salt (or salinity), and the amount of floating debris (turbidity). Because of the proper treatment and disposal of waste industrial output, it is also possible to identify the concentration of small algae as well as the quantity of pesticides, herbicides, heavy metals, and other pollutants to assess the water quality for particular water resources. (Organization, 2017).

The developed nation's commitment is not only the provision of the water, but also the quality of that water because it's considered a significant environmental factor of health. For more than 150 years, ensuring the quality of drinking water has been a keystone of preventive measures and persisted to be the fundamental element for the control and prevention of water borne diseases (World Health Organization, 2011). Especially when the contamination of drinking water sources be the major cause of health crises globally. Its leads cause of approximately 80 % of the three million early deaths reported in developing nations, owing to the presence of different organic and inorganic contaminants in the water (Choudhury, 2018). From the mentioned, to the fact that water is an essential element for human need and the connection between human existence to the availability of drinking water and its quality. The human's policy for reducing the contaminant of water also hasn't enhanced in comparing with the increasing of the population, industrial, agricultural operational activities close to water resources, and distribution channels. In addition to these pollution' resources, UNICEF clarified that climate change is also causing weather patterns to be disrupted, resulting in extreme weather events, unpredictable water availability, worsening water scarcity, and polluting water sources (Unicef, 2020). Safety and quality of water are critical components of human growth and well-being. Access to safe drinking water is one of the most effective tools for enhancing health and alleviating poverty. Commonly, potable water defined as water clean and healthy and could be used locally by the household for drinking, culinary and sanitation purposes (Organization, World Health, 2021). Defined it as water which should be free from disease causing organisms, and free from minerals and organic materials that may produce adverse physiological effects. In accordance with the criteria provided by the WHO's standards, drinking safe potable water shouldn't pose any serious risks to one's health throughout the course of a lifetime, taking into account any potential differences in sensitivity across life phases. The elderly, individuals with disabilities, and those living in filthy circumstances, as well as newborns and small children, are those who are most at risk of contracting a waterborne disease. Water that is fit for drinking may be used for all common home tasks, including personal hygiene. An adequate supply of safe and portable water assists in preventing the spread of gastrointestinal diseases (Organization, 2017). Finally, unless decision-makers across Iraq develop and implement a new strategy, frameworks, plans of actions, and policies, these effects will continue to have an increasing severe influence on both the quantity and quality of the water.

2.3 Water Quality Management

Water Quality management also known as water quality improvement can be defined as the policies and corresponding organizational practices, procedures, commitments, and evaluation techniques that guarantee the water's capabilities to fulfill standards of the quality. Accountability, quality control, efficiency, and productivity have all been shown to benefit from water quality management. deposited of scientific measurement have been used to determine quality of the water, declaring "that water is excellent" or "that water is poor" is not straightforward. Preventive management is the best strategy to ensure the safety of drinking water and should address all aspects of the supply chain from capture to consumption. This accruing due to many parts of drinking-water quality management lie beyond the authority of water providers, a multiagency approach is required to ensure that agencies responsible for certain portions of the water cycle are involved in water quality management (Graham, 2015).

Thus, the decision is usually made in terms of the water's intended use, especially when water is used for a variety of purposes, including entertainment, drinking, fishing, agriculture, and industry; each of these authorized applications has distinct chemical, physical, and biological criteria that must be met to sustain it. For example, we expect water that we drink and swim in to meet greater criteria than water used in agriculture and industry. So far, the assessment of water quality is critical for ecological sustainability, when water quality is poor, it influences aquatic organisms as well as the entire ecosystem. The evaluation of water quality can help academics in experiencing about natural events taking place in the environment, as well as examining the effect of people on the ecosystem. The above measures could also be used to benefit in recovery efforts or to ensure that environmental standards are achieved. Measuring quality of the water needs decisions of how many and which water criteria should be examined on a frequent basis. The results of the observation will also have to be swiftly investigated to see if there are other problems, or indicators of any potential challenges. This will enable the stakeholders to identify underlying factors associated with the disparities so that national efforts can be directed at addressing those underlying factors (EPA., 2010).

2.4 Water Quality Parameters (WQP)

As a result, water quality has garnered considerable attention in scientific publications. The most often used definition of water quality is the physical, chemical, and biological characteristics. water quality refers to extent to which water satisfies the requirements of different biotic species and/or human needs and objectives (Mohammed, 2015).

Water quality is classified into three categories: potable water, pleasant water, contaminated water. The first class which is known drinking or drinkable water (DW) must be safe for human, has a satisfying unique taste, and is suitable for household usage (Alley, 2007). While the water that has been contaminated by harmful bacteria, chemical substances, microbes, or radiation is referred to the second class which is the polluted water; the third type "infected water" which is water that has been contaminated with pathogenic microorganisms only. The physical, chemical, and biological water quality criteria are the three main aspects. As shown in Table 2.1.

Table 2.1: Parameters of Water Quality

No	Physical parameters	Chemical parameters	Biological Parameters
1	Turbidity	pH	Bacteria
2	Temperature	Acidity	Algae
3	Color	Alkalinity	Viruses
4	Taste and odor	Chloride	Protozoa
5	Solids	Chlorine residual	
6	Electrical conductivity (EC)	Sulfate	
7		Nitrogen	
8		Fluoride	
9		Iron and manganese	
10		Copper and zinc	
11		Hardness	
12		Dissolved oxygen	
13		Biochemical oxygen demand	
14		Chemical oxygen demand	
15		Toxic inorganic substances	
16		Toxic organic substances	
17		Radioactive substances	

Source:(Omer, Nayla Hassan,2019)

1.4.1 Physical Parameters

2.4.1.1 Turbidity

Turbidity in drinking water is unappetizing and unpleasant. Turbidity may raise the cost of water treatment for many applications, and the particles might hide hazardous microbes from the disinfection process (Gorde, 2013). Also, suspended debris may block or injure fish gills, limiting disease resistance, growth rates, egg, and larval maturation, and capturing efficiency. The suspended particles also adsorb heavy metals including mercury, chromium, lead, and cadmium, as well as organic contaminants like PCBs, PAHs, and pesticides (Al-Shandah, 2019). Furthermore, increasing turbidity boosts water temperatures, reducing available food because suspended particles absorb more solar heat. Warm water contains less dissolved oxygen than cold water; hence the concentration of dissolved oxygen may be reduced. The nephelometric turbidimeter measures turbidity in NTU or TU. A TU is 1 mg/L silica in suspension. A human may see turbidity of over 5 NTU in clear water but over 100 NTU in muddy water. Groundwater is generally quite clear due to natural filtering by the earth (Al-Shandah, 2019).

2.4.1.2 Temperature

When it comes to taste, texture, viscosity, solubility, smell, and chemical reactions all these things the temperature has an impact. Consequently, temperature affects the sedimentation and chlorination processes and the amount of biological oxygen demand (BOD) in the water. It also has an impact on the biosorption process of water-soluble heavy metals. Water that is 10–15°C in temperature is most agreeable to most individuals (Gorde, 2013).

2.4.1.3 Color

Materials degraded from plants and inorganic materials, such as soil, stones, and boulders, give water a hue that is undesirable for cosmetic reasons alone. The color of the water may be determined by comparing it to a standard solution or by using colored glass discs. A one-color unit is equivalent to the color produced by a 1 mg/L solution of platinum (potassium chloroplatinate (K2PtCl6) (Gorde, 2013).

2.4.1.4 Taste and odor

Organic molecules, inorganic chemicals, and dissolved gases all have the potential to alter the taste and odor of water. These materials may be acquired in several ways, including naturally occurring, domestic, and agricultural (Watson, (2004).

2.4.1.5 Solids

Solids may be in solution or suspended in water depending on how they are dissolved. By putting a water sample through a glass fiber filter, these two types of particles may be identified (Devesa, (2018). The dissolved particles are carried through the filter by the water, while the suspended solids are retained on the filter's top (Braun, 2019). The residue from the evaporation of the particles from the filtered water sample will be collected in a small dish. The term "total dissolved solids," or TDS, is often used to refer to this material.

Total solid (TS) = Total dissolved solid (TDS) + Total suspended solid (TSS) **(2.1**)

Water can be classified by the amount of TDS per liter as follows:

Freshwater: <1500 mg/L TDS

Brackish water: 1500–5000 mg/L TDS

Saline water: >5000 mg/L TDS.

The phrase "fixed solids" refers to TSS and TDS residues that have been dried and kept at a set temperature for a defined period. When heated to 550°C, a volatile solid will burn but not entirely (Alley, 2007).

2.4.1.6 Electrical conductivity (EC)

The electrical conductivity (EC) of water is used to determine a solution's ability to carry or conduct an electrical current. Because ions in solution conduct electricity, conductivity increases as the ion concentration increases. As a consequence, it is a critical measure for determining the suitability of water for irrigation or firefighting.

2.4.2 Chemical parameters of water quality

2.4.2.1 pH

The pH of water is a critical indicator of its quality. It is defined as the negative logarithm of hydrogen ion concentration. The pH of an acidic or basic solution is represented by this dimensionless number. The pH of water reflects its acidity or basicity. Additional hydrogen ions (H+) are visible in acidic water, whereas additional hydroxyl ions (OH) are visible in basic water (Daud, 2017).

The pH scale ranges from zero to fourteen, with seven denoting neutralities. For instance, a pH less than 7 denotes an acidic solution, while a pH more than 7 indicates a basic solution (Unicef, 2020). At a temperature of 25°C, pure water has a pH of about 7.0, making it neutral. Normal rainfall has a pH of 5.6 due to the presence of carbon dioxide in the air (slightly acidic). The pH of drinking water should be between 6.5 and 8.5 to be safe for home use and to meet the requirements of living organisms (Okoye, 2009).

A pH of 7 is ten times more acidic than a pH of 8, and a pH of 5 is one hundred times more acidic than a pH of 7 (Braun, 2019). A pH unit shift corresponds to a tenfold increase or decrease in it. pH values may be measured electrometrically or calorimetrically depending on your choice (Gorde, 2013).

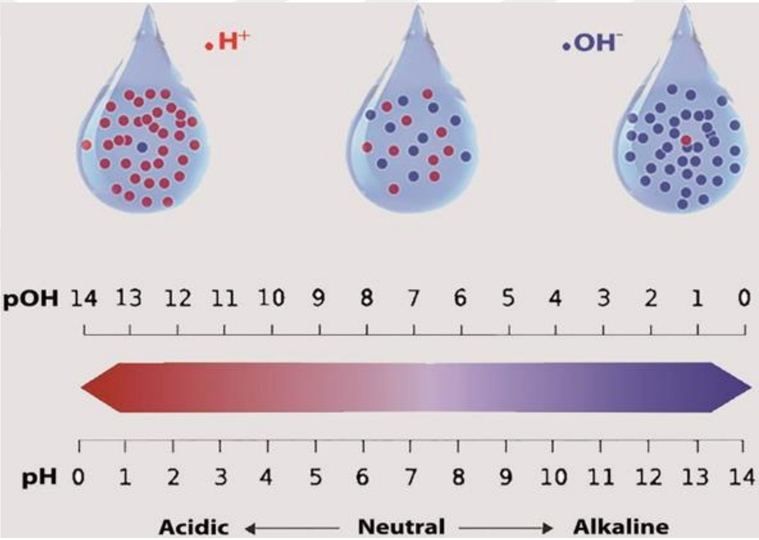


Figure 2.2: pH of Water Along With its Acid-Neutralizing Capability

Source: (Gorde, 2013)

2.4.2.2 Alkalinity

Along with its acid-neutralizing capability, the alkalinity of water is determined by adding all of its titratable bases. The amount of lime and soda needed for water softening may be calculated using the water's alkalinity (such as corrosion control in boiler feed water conditioning). Water-absorbable ions like hydroxyl (OH), bicarbonate (HCO3), carbonate (CO32), or a mixture of these ions are the major cause of alkalinity in water (Fidel, 2017).

2.4.2.4 Chloride

A relatively high quantity of freshwater chloride (approximately 250 mg/L or greater) may be an indication of wastewater contamination because it normally exists in groundwater, streams, and lakes. Numerous sources, such as wastewater, chloride-containing rock, and agricultural runoff, can introduce chlorides into surface water (Chatterjee, A. K.,1996).

Consuming water containing chloride ions Cl has no harmful health effects, but its presence in excessive amounts imparts a salty flavor to the water, which many people hate. Although chlorides are usually considered harmless for humans, the sodium in table salt has been associated with renal and cardiac issues (Braun, 2019).

2.4.2.5 Sulfate

Both naturally occurring water and wastewater include sulfate ions (SO42). Water that contains sulfates often results from the leaching of organic sodium- or magnesium-sulfate (Epson salt) deposits. There is no major risk to the public's health, although there may be unpleasant tastes or unwelcome laxative effects if large doses of this chemical are eaten in drinking water (Unicef, 2020).

2.4.2.6 Hardness

Hardness is a word used to describe the characteristics of highly mineralized water. Dissolved minerals in the water result in soap not lathering properly and scale accumulation in hot water pipes (Unicef, 2020). Most naturally occurring fluids are hard because of the calcium (Ca2+) and magnesium (Mg2+) ions present in them. When they come into touch with soil or rock, especially limestone deposits, they turn into pathogens in the water. These ions are found as bicarbonates, sulfates, chlorides, and nitrates in the environment. Even though surface water is kinder, groundwater is frequently more difficult (Hounslow, 2018). Two categories of hardness exist:

- Boiling may remove the carbonates and bicarbonates responsible for the temporary hardness, and Sulfates and chlorides are the main culprits in the persistence of hardness after boiling. tenth, twentieth, and twenty-second

- Individuals often feel hardness at levels more than 150 mg/L, whereas water with less than 75 mg/L is considered soft. Water with a hardness of more than 300 mg/L is considered very hard, although the majority of individuals do not feel it.

Hardness up to 500 mg/L is considered safe for health, but anything beyond that may have a laxative effect (Hounslow, 2018).

Table 2.2: Classification of Water According to its Hardness

Water classification	Total hardness concentration as mg/L as $CaCO_3$
Soft water	<50 mg/L as $CaCO_3$
Moderately hard	50–150 mg/L as $CaCO_3$
Hard water	150–300 mg/L as $CaCO_3$
Very hard	>300 mg/L as $CaCO_3$

Resource: (Gorde, 2013)

2.4.3 Biological parameters of water quality

The presence or absence of living organisms may provide a wealth of information about the quality of water (Gorde, 2013). Therefore, scientists consider a water body with a large diversity of well-balanced species to be a healthy system. some organisms may be used to detect the presence of pollutants (Unicef, 2020).

2.4.3.1 Bacteria

Under the proper conditions of food supply, temperature, and pH, a bacterial culture may produce up to 20 million cells per milliliter in a single day (Hassan, 2018).. The rapid growth of visible bacterium colonies on a suitable feeding medium enables the detection and quantification of bacterial populations in water (Organization, World Health, 2021) .

2.4.3.2 Algae

Chlorophyll is a photosynthetic pigment present in algae, which is why they are considered to be little plants (Hassan, 2018). Their importance in the treatment of wastewater in stabilization ponds cannot be overstated. Algae are primarily a nuisance in drinking water due to the taste and odor problems they create. Disinfection procedures employed in water treatment facilities are capable of eradicating the majority of waterborne viruses (Roy, 2019).

2.4.3.3 Protozoa

Zooplankton is another word for them. It refers to free-floating aquatic protozoa. They generate cysts, which are difficult to eradicate with disinfectant.

2.4.3.4 Indicator organisms

Coliforms are always present in water that has recently been exposed to sewage. Escherichia coli, most often abbreviated as E. coli, is a kind of coliform found in residential sewage. Due to the essential importance of the coliform bacteria test, the next section will discuss the first method in detail (Organization, World Health, 2021).

2.5 Water Quality Standards (WQS)

Water quality standards differ depending on the planned use of the water. At times, water that is unsuitable for one use is perfectly suitable for another, and vice versa. If a source of higher-quality water is unavailable, water may be considered suitable for any use. Usually, the drinking water quality standards been determined by the national governments and the World Health Organization (WHO); It must be within the quality specifications that has been developed and announced by these two authorities. The Iraqi drinking water standards are derived from the guidelines of the WHO (Organization, World Health, 2021), which are based on the best available scientific evidence.

The percentage of salts and toxic and harmful substances in liters of concentration allowed in drinking water differs. The damages resulting from the use of water that contain concentrations greater than the permissible concentrations are different for some of the poisonous substances and other harmful substances. Therefore, the ratio of the physical, chemical and biological specifications for drinking water must match the WHO’s standards and the Iraqi standards No. 417 for the year of 2001 issued by the Ministry of Municipalities (Al-Ridah, 2020). These specifications must be coordinated with the relevant government body's water quality regulations. The WHO has established minimum standards for drinking water that all countries should aim to meet. Numerous chemical components have been given standard value recommendations for drinking water. If a person eats a product throughout their life, it will have no adverse impact on their health. Fourteen criteria were chosen to evaluate the quality of water.

2.6 Drinking Water Treatment Plants Process

The delivery of safe drinking water is the responsibility of DWTPs. Physical and chemical precautions against germs and hazardous compounds in raw water are included. The amount of treatment required depends on the quality of the source water. Most Iraq's urban and rural regions already have DWTPs for processing surface water (Savic, 2016). As shown in Table 2.3.

Table 2.3: Operational Parameters Related to Water Treatment

No	Parameters	Raw Water	Coagulation	Sedimentation	Filtration	Disinfection	Distribution
1	pH		X	X		X	X
2	Turbidity	X	X	X	X	X	X
3	Temp	X		X			X
4	Dissolved Oxygen	X				X	
5	River flow						
6	Total Coliforms	X					X
7	Background Bacteria					X	X
8	Color	X					
9	Conductivity	X					
10	Alkalinity	X	X	X			
11	Alkalinity	X		X			
12	Organic Carbone	X					X
13	Algae and Algal toxins		X			X	
14	Chemical dosages		X	X	X	X	
15	Flow rate					X	
16	CT					X	
17	Disinfection Residual					X	X
18	Disinfection by Product					X	X
19	Pressure						X

Chemical and microbiological compositions vary by watershed due to contamination from urban and agricultural systems, as well as industrial activities. DWTPs' concerns include natural organic materials, salt minerals and microbial hazards. Pre-oxidation, coagulation/flocculation, settling, filtering, and disinfection are all popular DWTP treatment processes as shown in Figure 2.3.

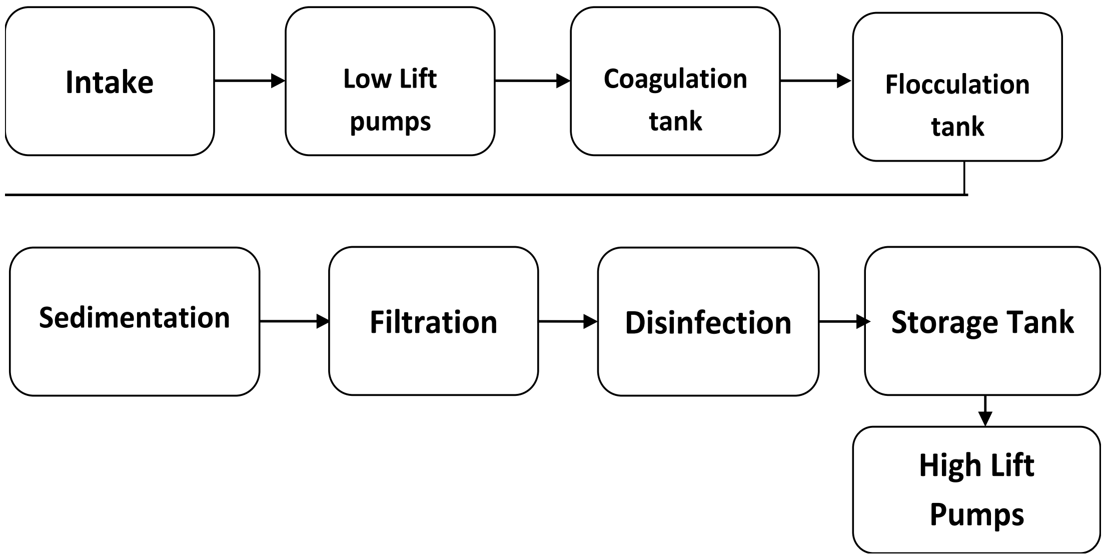


Figure 2.3: WTP Treatment Processes

Adding an oxidant to water to oxidize particular compounds and/or protect against microbes is known as pre-oxidation. Ozone, chlorine dioxide, and potassium permanganate are all oxidants used in this method. The raw water's characteristics and the creation of disinfection by-products influence the choice of chemical. To stabilize negatively charged colloidal particles such as those found in humid acids, the addition of coagulant is necessary. It is used to remove organic and inorganic pollutants from raw water. There are several common salts of iron and aluminum. Finally, flocculants are used to generate and agglomerate sediment particles big enough for gravity to settle them. Straining and clinging to the filter grains or previously deposited particles removes the remaining particles from the water (Howe, 2012).

Sand, gravel, or granular activated carbon may be used as filtering material Depending on the water quality, an additional treatment step may be necessary to remove impurities that are not eliminated by normal treatment. Reverse osmosis and electro dialysis reversal may remove bromides from water using membrane techniques

Microbiological safety and the prevention of recontamination are assured by the addition of disinfectants to the water. The effluent from the WTP is kept in tanks and then routed via the supply network before it is used. The water passes the following processes of treatment which are described in the following points:

- Coagulation and Flocculation

Coagulation and flocculation are frequently the initial processes in the treatment of water. Positively charged chemicals are introduced to the water (Ramal, 2021). These compounds' positive charge cancels out the negative charge of dirt and other dissolved particles in the water. When this happens, the particles interact with the chemicals and combine to create bigger particles known as flocs (Molinos-Senante, 2018).

- Sedimentation

During sedimentation, floc settles to the bottom of the water supply, due to its weight. This settling process is called sedimentation (Issa, 2017).

- Filtration

The clean water on top of the water supply will pass via filters with different compositions like sand, gravel, charcoal, and pore sizes to remove dissolved particles including dust, parasites, bacteria, viruses, and chemicals after the floc has dropped to the bottom of the water supply (Issa, 2017).

- Disinfection

After the water has been filtered, a disinfectant, such as chlorine or chloramine, may be added to eliminate any parasites, bacteria, or viruses that may still be present and to keep the water clean when it is piped into homes and establishments (Issa, 2017).

2.6.1 TOPSIS Method with Extended Fuzzy Sets

The TOPSIS (Approach for Order Preference by Similarity to Ideal Solution) multi-criteria decision-making technique is based on numbers. The first grouping of the criteria is into two categories: cost and benefit. This technique selects the best option that is both the most distant from the negative ideal solution (NIS) and the closest to the positive ideal solution (PIS) (NIS). In contrast to a negative optimum solution, which maximizes costs while reducing benefits, a positive optimal solution maximizes benefits while minimizing expenses. The optimum answer is compared to a number of alternatives, which are then rated in decreasing order of similarity.

Due to the subjectivity of human judgments in real-world decision-making situations, the TOPSIS approach has been implemented in two fuzzy scales, including ordinary fuzzy (F-TOPSIS), intuitionistic fuzzy (IF-TOPSIS), and picture fuzzy (PF-TOPSIS). Though it can be transformed to fuzzy numbers, the design of the fuzzy linguistic terms of the survey used in this study is similar to the Likert seven-point scale. This study uses the Triangular Membership Function (TMF) to identify a fuzzy scale as shown in Figure (2.4) below.

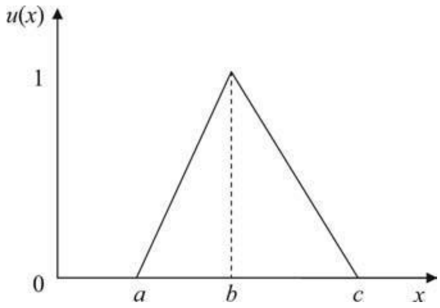


Figure 2.4: Triangular Membership Function

This study will employ the Geometric Average Method to combine the Fuzzy values from several respondents, as shown below equation

$$\tilde{P} = \left(\prod_{i=1}^{m} a_i, \prod_{i=1}^{m} b_i, \prod_{i=1}^{m} c_i \right)^{1/m} \quad \textbf{(2.2)}$$

Where:

(ai, bi, ci) is the respondents Fuzzy number; and

M it's the respondents' numbers.

The below equation will be used to apply both Fuzzy scales (0, 0.1, 0.2) & (0,1,2) to generate the TOPSIS's weights.

2.6.2 Multi-Criteria decision making based on TOPSIS method

Making a choice is the process of assessing and choosing the best option(s) from a list of possibilities based on the information available for making decisions in a particular context. Multiple candidate alternatives must be chosen from in multi-criteria decision-making (MCDM) situations depending on their qualities or performance. Invented the well-known classic MCDM strategy known as TOPSIS (technology for ranking preference by resemblance to ideal solution).

2.6.3 Application of a multi-criteria decision model to select design choices for WTPs

The complexity of wastewater management is rising as a result of additional analytical aspects being driven by stricter sanitation requirements, which integrate socioeconomic factors with related environmental concerns. Decision-makers in this setting have a wide range of effective solutions to address these new difficulties thanks to the development of modern wastewater treatment technology. Although there are more options available, this complexity in designing or upgrading treatment facilities is inevitable and necessitates the acquisition and integration of up-to-date information and well-coordinated talent, which supports a multidisciplinary approach. This study shows how an environmental decision support system has successfully complied with these standards (EDSS). The major goal of the EDSS, which was developed using a knowledge-based methodology, is to identify and evaluate the best wastewater treatment technologies for the construction of new facilities or the modernization of old plants. This study investigates the use of the EDSS to select biological treatment technologies for various scenarios that are characterized by wastewater composition (C/N ratio) and other pertinent criteria like environmental and economic factors, population size, discharge in sensitive areas, reuse, cost-benefit analysis, life-cycle analysis, and technical aspects. The removal of nutrients is crucial to this approach (use of innovative technologies, space availability, reliability, and simplicity of operation).

2.7 Literature Review

The previous research and studies focused on evaluating the water quality, the raw water, water treatment plants (WTP) outputs, distribution networks and consumers inputs. This study emphasized on the output of these WTP for its importance of both household usage and drinking purposes in different countries such as Iraq, Indi, Iran and other countries around the world. The major findings of like these studies are as listed below;

Issa, (2017), in this research, the author has found that the source raw water is of moderately low quality, whereas the treated water is comparatively more adequate. Several physicochemical and bacteriological parameters of both raw and treated water were studied in Khanaqin, Iraq to evaluate the performance and quality of drinking water studied according to Standard Methods. Also, the whole WTP's treatment process units were also evaluated. The WTP's total water turbidity removal rate is 97.88 percent. The literature confirms that the units of this WTP and its process operations must be enhanced, rescaled, and redesigned to improve plant performance and reduce the risk of infectious diseases and water pollution (Issa, 2017).

Issa H. M., (2018), in this research, a three WTPs were evaluated for drinking water quality in Erbil City, Iraq. The study was done using the drinking water quality index (DWQI), which is preferred because it summarizes all physicochemical and bacteriological properties. Over a long period of time, from 2003 to 2017, the study tested 13 parameters. The findings showed that the quality of drinking water provided by the three DWTPs continues to remain within safe range (Issa H. M., 2018).

Hassan, (2018), from December 2016 to July 2017, the study was carried out to assess two DWTPs in Baghdad, Iraq. This assessment looked at seventeen physicochemical water quality parameters as well as four bacterial indicators of drinking water pollution. For the statistical analysis, the Statistical Analysis System (SAS) software had been used. Moreover, to compare the methods of the analyzed parameters, the least significant difference (LSD) test and the T-Test also had been used. The results revealed that drinking water quality parameter values varied across both treatment plants. Furthermore, the involvement of bacteria than the acceptable limits, denoting an insufficiency in the cleaning process (Hassan, 2018).

Ramírez, (2019), In this study, the influence of energy consumption in water treatment systems (energy-for-water) and its effects on the environment are quickly and simply analyzed. As instances, the approach was applied to world average greenhouse gas emission regimes and coastal nations that were distressed by water constraint. It may also be used with different kinds of systems, such those that use untreated saltwater in industrial operations (Ramírez, 2019).

Ewaid, (2018), The objective of the project was to create a unique water quality indicator based on artificial intelligence and fuzzy logic for routine evaluation of river water quality for drinking. Four water quality parameters—biological oxygen demand, total dissolved solids, total hardness, and fecal coliform—were examined because of their significance for the waterways of Iraq. To assess the quality of the

Tigris River's drinking water in Baghdad, MATLAB software created a new fuzzy water quality index (FWQI). To assess the quality of the Tigris River's drinking water in Baghdad, MATLAB software created a new fuzzy water quality index (FWQI). The technique of fuzzy inference system was a straightforward, practical, and applicable water quality evaluation tool for human drinking water, and the FWQI may utilize particular rules to assess the water quality during the study's time period (Ewaid, 2018).

Braun, (2019), this research aimed to evaluate a DWTP for a population of inhabitants in Bolivia in terms of performance, design, operation, and maintenance. The author sought to discover technical issues and inadequacies in the functioning of the El Fuerte water treatment facility. A methodology for sanitary facilities was used to estimate the threat of contamination from both sources. Based on the Water Safety Plan idea, a Microbial Barrier Analysis (MBA) and a Quantitative Microbial Risk Assessment (QMRA) were done to estimate the health risk. The primary difficulties are recognized as inadequate source security, a lack of qualified competence in operation, a lack of administration direction, inappropriate structure and equipment, and imperfect technologies. Suggestions are given in the form of a two-step implementation plan to ensure an access to safe drinking water in Samaipata, Bolivia (Braun, 2019).

Melo, (2019), it purposed of this study is to conduct a performance assessment of large-scale WTPs as well as to validate the treatment's modification to freshwater turbidity. Non-parametric and multivariate statistical techniques were used to investigate fresh water and processed water turbidity from a massive online surveillance database containing from six WTPs using diverse technologies from 2013 to 2015. The article proved that using the same treatment method does not necessarily result in the same effluent quality because of several aspects such as operation, maintenance, raw water variation, meteorological interferences, and others. The findings suggested that technology choices must be thoroughly researched to constantly seek the optimal option (Melo, 2019).

Ramal, (2021), this research created water quality control charts based on monthly data collected in 2013 for raw and processed water. The Ramadi WTP in Anbar province, Iraq was chosen as a case study. Water quality control charts were developed according to the data gathered in 2013 for the raw and treated water. The major purpose of this study is to develop a baseline data regarding to water quality condition and therefore, the proper management and improvement of drinking water produced from Ramadi plant. Control charts model is applied for the first time in the analysis of water quality in the case study plant. This chart provided a clear pictorial view about the water quality parameters status of the Ramadi plant as well as Euphrates River. The water quality data had already been matched to the Iraqi drinking water guidelines. The findings indicated that nearly all the variables were within permissible ranges. Nevertheless, an examination of control charts showed that the mean measurements of certain variables exceeded the upper and lower control boundaries, revealing unsatisfactory drinking water quality. The primary units are reverse osmosis units in dual media filters rather than sand filters (Ramal, 2021).

Mladenović-Ranisavljević, (2018), in this research, the Danube River quality of water in Serbia was analyzed using both (WQI) and (MCDM) techniques. Although WQI analysis indicated high to very acceptable water quality, expansion using MCDM techniques found a large excess in levels of PO4-P and E.C at virtually each point along the river's bank, as well as total N and NH4-N. The proposed method, according to the author, could assist project managers and decision-makers associated in water resource management in generating quite accurate reporting on quality of water together while facilitating decision-making in the identification of particular sites with vital water quality, in which proper contamination metrics should also be obtained (Mladenović-Ranisavljević, 2018).

Roy R. M., (2018), the research provided a non-discriminatory and thematic approach for determining the prioritization of drinking water metrics to measure WQI. Utilizing MCDM techniques like the Analytic Hierarchy Process, Fuzzy Logic Decision-Making, and its modifications, the relative relevance of the factors was determined. This case study was carried out in Tripura, India, to get the Water Quality Indices. Statistics, sensitivity analysis, and comparison with a recognized measure (NSF WQI) were performed. The MCDM WQIs were found to track common themes and to be identical to the NSF WQIs (less than 2% difference). The Hybrid AHP-FLDM approach was found to be the most similar to NSF WQI of the investigated strategies (0.29 percent variation). The MCDM WQI is therefore good at expressing overall water quality (Roy R. M., 2018).

3. METHODOLOG

3.1 Introduction

In this chapter the three-case study selected for the proposed methodology would be first demonstrated and clarified in a brief detail. Then the survey and responses based on metric would be highlighted. After that, the methodology to be handled with our proposed MCDM would be formed in steps and sections.

3.2 Case Study

In this part a three Water Treatment Plant (WTP) would be explained as Fallujah city has three major WTPs in Fallujah city in addition to number of clean water pumping stations. These WTPs called as The Old Fallujah’s (WTP-1), Fallujah New project or Al-Azrakiyah project (WTP-2) and Al-Resala project (WTP-3). These three WTPs responsible of delivering the clean water to around 70 percent of Fallujah’s population. By 2016, following the liberation of the towns of Anbar province from the hands of the terrorist group ISIS. It was difficult to gain an accurate picture of the sector's influence from wars is problematic owing to the inability to access key cities due to the high hazards of the relics of war. However, the limited evidence gathered by UN and other international organizations such as UNICEF, International Organization for Migration (IOM) and Danish Refugee Council (DRC), indicates that the war has exacerbated water and sanitation problems in liberated governorates such as Anbar province which were controlled by the terrorist organization during 2014-2017. The outcomes of these evaluations suggested that most of these WTPs and pumping stations was damaged, and bombs have caused severe disruptions in power and water distribution networks in cities. Security guards barred employees from attending WTP maintenance and repair work because they were worried of being assaulted or danger of these remnants’ explosive Figure 3.1.

Figure 3.1: WTP 2 (Al-Azrakiyah Water Treatment Plant) Before Rehabilitation in August 2016

After the liberation operations and the return of displaced people, several towns in Anbar governorate have complained about water quality and quantity shortages, which is potentially life-threatening. The conflict specifically damaged the three major DWTPs and smaller water pumping facilities. After 2017, the city's power and DWTPs were only partly functioning, and the water distribution networks were badly damaged, producing a water crisis.

During this time period, both water quantity and water quality have been a cause of concern. The DWTPs rely on the national electricity supply to run their plants. The lack of electricity also impacted the city's water supply, reducing the amount of operating hours. The main (WTPs) and smaller water pumping stations have standby generators built to assist limit the effect of power outages. These facilities also suffered from an oil scarcity, which means they lack dedicated lines and rely on unsteady generators for electricity. Due to a lack of technical staff and frequent power outages, most DWTP run at 40% of their capabilities.

UNICEF, UNDP, REACH (International Organization for Migration & Danish Refugees Council) and other national and international agencies have assessed the damage to the drinking water sector. The WASH coordination cluster and the local administration in Fallujah established a strategy to conduct rehabilitation projects and lead the swift response to this urgent and large challenge. The following operations were completed:

- The water sector analyzed DWTP infrastructure, operating performance, power supply, and human resources required to quickly repair and reopen these facilities.
- Water tankers were deployed to meet local residents' immediate requirements.
- Defective power generators at water and sewage treatment plants were rectified to assure safe water sources.
- The restoration crews rebuilt and fitted the equipment after ensuring security and testing it to current standards.

Figure 3.2: AL-Azrakiyah DWTP after Rehabilitation in 2017

3.2.1 Fallujah's Old project (WTP-1)

This WTP is located at the bank of Euphrates River, on the border of the city's only surface water source. This project produces treated water for up to 30% of Fallujah. It provides clean water to the city and some nearby villages, supplying around 1500 m3/h to a population of between 100,000 and 150,000.

Figure 3.3: WTP-1 Located at the Riverbank about 111 Meters

The raw water provided from the same intake of the WTP-2 because of poor water management and the impact of climate change, the river's flow is very irregular, with high flows in December and April and low flows in the remaining months. Table (3.1) below includes major specification of this WTP.

Table 3.1: Specification of the WTP-1

Project's Name	**The Fallujah's Old DWTP**		
Location	33°21'16.7"N 43°45'33.7"E	West of Fallujah city	2.5 Km of city center
Construction Date	2005	Last Rehabilitation date	2018
Designed Capacity	1500 m^3\h		
Staff No.	12	Project's Engineers	1

3.2.2 Fallujah's New Project\Al-Azrakiyah Plant (WTP-2)

The Azrakiyah WTP is located 207 m from the Euphrates the only surface water source of the city as shown in the Figure 3.5. below. This DWTP produces treated water for up to 60% of Fallujah. It provides clean water to the city, supplying around 2500 m3/h to the center of the city with a population between 250,000 and 350,000.

Figure 3.4: Showing the WTP-2 Location for the River and its Intake

Intake It is 4 meters deep in the Euphrates River and 217 meters from the intake to the WTP. There is no control system near the intake to measure river water extraction. The river water is then pumped up to the 3 rapid mixture basins. Rapid mixing basins are the first step in treating river water. In addition, there are no blenders in these basins and the water plant process blending sluggish at this station. The water from the intake is sent to a rapid mixture, then to sedimentation basins to remove sands and dams. On the way to the consumers, it passes through sand filters and is cleaned by high-pressure air. Table 3.2 below shows specifications and details of this WTP.

Table 3.2: Specification of the Second WTP

Project's Name	**Fallujah's New DWTP (Al-Azrakiyah plant)**		
Location	33°21'13.8"N 43°44'43.0"E	Fallujah's Northwestern5.3 Km of city center	5.3 Km of city center
Construction Date	2005	Last Rehabilitation date	2018
Designed Capacity	2500 m^3\h		
Staff No.	18	Project's Engineers	2

3.2.3 Al-Resala project (WTP-3)

The third WTP selected for our case study was the Al-Resala project. It's installed at the riverbank 17 m from the Euphrates as shown in the Figure (3.6). This WTP produces treated water for up to 10-15% of Fallujah population. It provides clean water to the old city center market in the city, supplying around 400 m3/h to a population of between 25,000 and 35,000.

Figure 3.5: Location of the WTP-3

Table 3.3: Specification of the Third WTP

Project's Name	Al-Resalah WTP-3		
Location	33.34509689743496, 43.762322345109745	Western Fallujah city 2 Km of city center	
Construction date	2004	Last Rehabilitation date	2017
Designed Capacity	800 m3\h		
Staff No.	10	Project's Engineers	1

3.3 Survey Report

After selecting the three WTP's that were clarified in the previous section, in this section a survey report would be carried out to gather sampled data from different specialist related with the same field of study. Such survey was collected from 32 sampled. These surveys include several metrics and each metric would be evaluated based on seven factors. These factors were: (extremely important, very important, somewhat important, neither important not unimportant, somewhat unimportant, not very important, not at all important,). Additionally, another factor related with the quality of water for drinking and satisfying for the quality of water provided from the three studied DWTP's. These surveyed responses were collected in Excel to be furthered handle for the next steps as shown in Figure 3.6.

	R	T	V	X	Z
1	Turbidity	Temperature	EC	pH	Alkalinity
2	Very important	Very important	Very important	Very important	Very important
3	Extremely important	Somewhat important	Very important	Extremely important	Somewhat important
4	Very important	Very important	Very important	Very important	Neither important nor unimportant
5	Very important	Extremely important	Somewhat unimportant	Very important	Somewhat important
6	Somewhat unimportant	Somewhat unimportant	Very important	Somewhat important	Somewhat unimportant
7	Very important	Very important	Extremely important	Extremely important	Extremely important
8	Not at all important	Not at all important	Not at all important	Very important	Not at all important
9	Extremely important	Somewhat important	Extremely important	Very important	Extremely important
10	Very important	Somewhat important	Neither important nor unimportant	Somewhat important	Somewhat important
11	Very important	Not very important	Somewhat important	Very important	Somewhat important
12	Somewhat important	Somewhat important	Somewhat unimportant	Somewhat important	Somewhat important
13	Very important	Not very important	Very important	Very important	Somewhat unimportant
14	Somewhat important	Not very important	Very important	Very important	Somewhat unimportant
15	Very important	Neither important nor unimportant	Somewhat important	Extremely important	Extremely important
16	Very important	Not very important	Very important	Extremely important	Very important
17	Somewhat unimportant	Very important	Very important	Very important	Somewhat important
18	Neither important nor unimportant	Not very important	Somewhat unimportant	Somewhat important	Somewhat important
19	Very important	Somewhat important	Somewhat important	Very important	Somewhat important
20	Not very important	Not at all important	Somewhat important	Very important	Very important
21	Very important	Not very important	Very important	Somewhat important	Somewhat important
22	Very important	Somewhat important	Very important	Very important	Somewhat important
23	Extremely important	Not at all important	Not at all important	Extremely important	Extremely important
24	Somewhat important	Very important	Very important	Very important	Somewhat important
25	Somewhat important	Very important	Very important	Very important	Very important
26	Very important	Neither important nor unimportant	Somewhat unimportant	Very important	Somewhat important
27	Very important	Somewhat important	Neither important nor unimportant	Very important	Neither important nor unimportant
28	Somewhat unimportant	Somewhat unimportant	Neither important nor unimportant	Very important	Neither important nor unimportant
29	Very important	Very important	Somewhat important	Extremely important	Extremely important
30	Very important	Somewhat important	Very important	Extremely important	Extremely important
31	Very important	Somewhat important	Extremely important	Very important	Very important
32	Very important	Very important	Very important	Very important	Not at all important
33	Very important	Somewhat important	Very important	Somewhat important	Very important

Figure 3.6: Survey Responses Data Collection

3.4 Relative important index (RII)

In this section, the factor scale that was collected from the survey Reponses would be transformed into values from 1 to 7 based on the selection of the responses. This transformation would be done based on Table 3.4.

Table 3.4: The Transformation of Factor Scale and the Related Values

Factor Scale	Factor Value
Extremely important	7
Very important	6
Somewhat important	5
Neither important nor unimportant	4
Somewhat unimportant	3
Not very important	2
Not at all important	1

The transformation for these factors would be listed as seen in Figure 3.7 to from the Table 3.4. These values would represent the quality water-based parameters.

Relative Important Index (RII) Values of Water Quality Parameters

Sodium	Calcium	Total Suspended Solid (TSS)	Total Dissolved Solids (TDS)	Hardness	Potassium	Magnesium	Sulphates	Chloride	Alkalinity	Electrical conductivity (EC)	pH	Temperature	Turbidity	Param / Resp
5	5	6	6	6	6	6	6	6	6	6	6	6	6	R1
6	6	6	5	7	7	2	7	7	5	6	7	5	7	R2
4	4	4	1	4	4	4	4	4	4	6	6	6	6	R3
5	5	7	6	6	5	5	6	6	5	3	6	7	6	R4
5	5	6	5	5	5	5	4	6	3	6	5	3	3	R5
7	7	7	7	6	7	7	7	7	7	7	7	6	6	R6
5	5	5	5	5	5	3	1	1	1	1	6	1	1	R7
6	7	7	7	5	7	7	6	6	7	7	6	5	7	R8
5	5	6	6	5	5	5	5	7	5	4	5	5	6	R9
6	5	6	6	7	5	5	5	5	5	5	6	2	6	R10
5	6	5	5	5	5	5	5	5	5	3	5	5	5	R11
5	5	6	7	1	2	2	2	6	3	6	6	2	6	R12
4	4	7	7	3	4	5	5	6	3	6	6	2	5	R13
6	6	7	7	6	6	6	5	6	7	5	7	4	6	R14
3	3	4	7	6	3	3	4	7	6	6	7	2	6	R15
6	6	5	7	6	6	6	6	6	5	6	6	6	3	R16
4	4	3	5	6	5	5	5	5	5	3	5	2	4	R17
5	5	5	6	6	5	5	6	5	5	5	6	5	6	R18
5	5	5	5	6	5	5	5	7	6	5	6	1	2	R19
7	7	6	7	6	5	5	6	5	5	6	5	2	6	R20
4	5	5	7	6	5	5	4	6	5	6	6	5	6	R21
7	7	7	7	7	7	7	7	7	7	1	7	1	7	R22
6	6	5	5	6	6	6	6	6	5	6	6	6	5	R23
6	6	6	6	6	6	6	6	6	6	6	6	6	5	R24
6	7	5	3	4	5	7	2	5	5	3	6	4	6	R25
6	5	6	7	4	6	5	5	7	4	4	6	5	6	R26
6	7	5	6	6	5	6	6	4	4	4	6	3	3	R27
7	6	6	6	6	7	7	7	7	7	5	7	6	6	R28
7	6	5	6	6	7	5	6	6	7	6	7	5	6	R29
2	2	7	7	3	3	3	6	6	6	7	6	5	6	R30
6	6	5	6	5	3	6	6	6	1	6	6	6	6	R31
5	5	5	5	6	6	6	7	7	6	6	5	5	6	R32
172	173	180	188	172	168	165	168	186	161	162	193	134	171	Total
0.767857	0.772321	0.803571	0.839286	0.767857	0.75	0.736607	0.75	0.830357	0.71875	0.723214	0.861607	0.598214	0.763393	RII

Figure 3.7: RII Table Showing the Values of Water Quality Parameters

After that each of the selected metric after being transported to a value would be summed to find the total of each metric per each of the selected values by the gathered from the survey responses that were collected in the previous section. The summed values can be seen clearly in the previous table/

Finally, the RII would be calculated from each metric based on below equation:

RII (i) = Total Number of Gathered Values per Metric (i) / (Number of Factors * Total Number of Responses Gathered) **(3.1)**

Where i represent the number of selected metrics for our study, the total number of gathered values represent the summation that were discussed in the previous paragraph, number of factors represented by 7 which were described previously in Table 3.4, and the number of responses gathered represent the samples which were 32 sample. The RII values can be seen in end of the Figure 3.7.

3.5 Water Quality Metric Scaling

This section will handle scaling for water quality metrics or parameters. The aim of this scale process is to formulate the actual reading gathered from DWTP to be handled in the next step by using the TOPSIS method as an MCDM method proposed by this work. The scaling would be performed by converting each value gathered from the real measurement per metric or parameter shown in previous figure with a related level. This converting is done based on the scale table showed in Figure 3.8. The related levels selected would be based on each of the studied parameter metric selected in the proposed work and as seen in Table 3.5. The final gained values ranged between (1-5) would be handled for the TOPSIS method and its related steps that would be clarified in the next section.

Levels \ Parameters		Turbidity	Temperature	TDS	TSS	Electrical conductivity (EC)	pH	Alkalinity	Chloride	Sulfate	magnesium	Hardness	Calcium	Sodium	Potassium
Excellent	5	0-2.5	15 – 20	100-300	2	500	7	125-200	0.5PPM	200	1–20	0-60	10–50	10–50	1 – 20
good	4	2.6-5	11 – 14	301-500	4	600	6.8-7.2	120-205	0.8-1	220	20-30	61-120	50–100	50-100	20-30
poor	3	5.1-7	6 – 10<Tem>21-25	501-700	50	1000	6.5-6.7/7.3-7.5	115-210	2.5	350	50-80	121-180	100–140	150-180	50-80
very poor	2	7.1-8	1 – 5<Tem>26-31	701-1000	50-100	1300	6-6.4/7.6-8.5	110-220	4	350-400	80-100	182-200	150	180-200	80-100
No suitable	1	>8	0<Tem>31	>1000	>100	>1300	>=8.6/=<5.9	<110 & >220	>4	>400	>100	>200	>150	>200	>100

Figure 3.8: Water Quality Metric Scaling

For example, for the metric parameter of Turbidity the real measurement from the three case studies were (2.4, 1.6 and 1) as shown in Figure 3.8 respectively. Based on the scaling for the Turbidity from Table 3.5. The values ranged between (0-2.5) would be scaled to five which represent the excellent level and so on.

Table 3.5: Values selected per Each Metric Parameters for Scaling the Water Quality

Levels	Value
Excellent	5
Good	4
Poor	3
Very Poor	2
No suitable	1

3.6 Integrating Fuzzy Method

Using the Fuzzy triangular analysis for the answers from the respondents of the survey. A SERVQUAL scales (0, 1, 2) & (0, 0.1, 0.2) adopted to study the Fuzzy linguistic scale and the generate the more assurance of the TOPSIS's weights for each WQPs to be included in the TOPSI method later. The study limitation of adopting SERVQUAL scale is whether the seven dimensions and 32 responses of the survey can finally get the more adequate and reliable weights of each parameter to create the weights matrix of TOPSIS method. Many studies have received different conclusions through the factor analysis method (Hu, 2010).

The exploratory possibility of the empirical study using questionnaire is provided in assessing service quality to illustrate the suggested paradigm. The participant fills out a SERVQUAL questionnaire that is meant to capture his or her assessment of and expectations for service quality. Though it can be transformed to fuzzy numbers, the design of the fuzzy linguistic SERVQUAL used in this study is similar to the Likert seven-point scale. The Triangle Fuzzy Numbers were used in this investigation, as indicated in Tables 3.6-7.

Table 3.6: Type (0, 0.1, 0.2) of Fuzzy Scale (Hu, 2010)

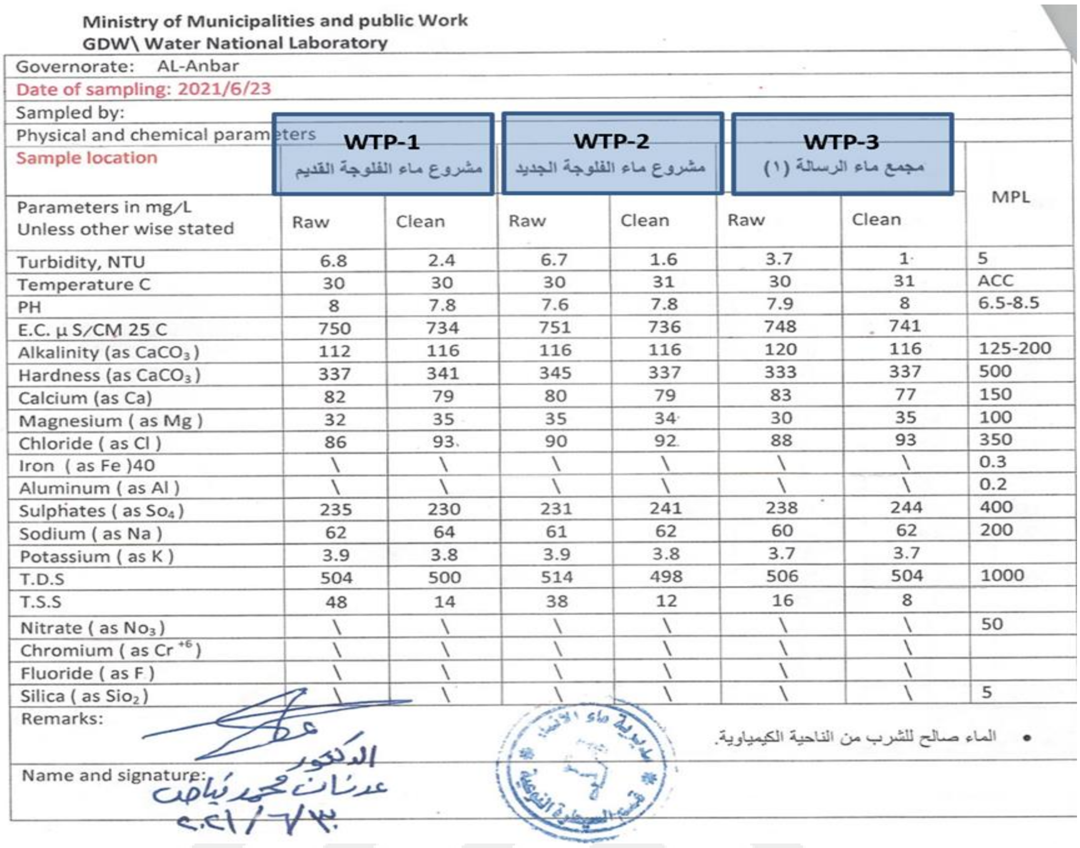
Scales	Triangle Fuzzy Numbers
Very dissatisfied (VD)	(0, 0.1, 0.2)
Dissatisfied (D)	(0.1, 0.2, 0.3)
Slightly dissatisfied (SD)	(0.2, 0.35, 0.5)
Fair (F)	(0.4, 0.5, 0.6)
Slightly satisfied (SS)	(0.5, 0.65, 0.8)
Satisfied (S)	(0.7, 0.8, 0.9)
Very satisfied (VS)	(0.8, 0.9, 1.0)

Table 3.7: Type (0, 1, 2) of Fuzzy Scale

Scales	Triangle Fuzzy Numbers
Very dissatisfied (VD)	(0, 1, 2)
Dissatisfied (D)	(1, 2, 3)
Slightly dissatisfied (SD)	(2, 3, 4)
Fair (F)	(3, 4, 5)
Slightly satisfied (SS)	(4, 5, 6)
Satisfied (S)	(5, 6, 7)
Very satisfied (VS)	(6, 7, 8)

3.7 Decision Matrix \ Dataset

Decision matrix prepared by collecting the water quality tests' result from the local Water National Laboratory (WNL). Tests' result for the three WTPs over six months from January to June 2021 were collected as shown in Figure 3.9, and WTPs output data for fourteen parameters presented in a table that shapes the decision matrix of this research.



Ministry of Municipalities and public Work
GDW\ Water National Laboratory

Governorate: AL-Anbar
Date of sampling: 2021/6/23
Sampled by:
Physical and chemical parameters

Sample location	WTP-1 مشروع ماء الفلوجة القديم		WTP-2 مشروع ماء الفلوجة الجديد		WTP-3 مجمع ماء الرسالة (١)		MPL
Parameters in mg/L Unless other wise stated	Raw	Clean	Raw	Clean	Raw	Clean	
Turbidity, NTU	6.8	2.4	6.7	1.6	3.7	1	5
Temperature C	30	30	30	31	30	31	ACC
PH	8	7.8	7.6	7.8	7.9	8	6.5-8.5
E.C. µ S/CM 25 C	750	734	751	736	748	741	
Alkalinity (as $CaCO_3$)	112	116	116	116	120	116	125-200
Hardness (as $CaCO_3$)	337	341	345	337	333	337	500
Calcium (as Ca)	82	79	80	79	83	77	150
Magnesium (as Mg)	32	35	35	34	30	35	100
Chloride (as Cl)	86	93	90	92	88	93	350
Iron (as Fe)40	\	\	\	\	\	\	0.3
Aluminum (as Al)	\	\	\	\	\	\	0.2
Sulphates (as So_4)	235	230	231	241	238	244	400
Sodium (as Na)	62	64	61	62	60	62	200
Potassium (as K)	3.9	3.8	3.9	3.8	3.7	3.7	
T.D.S	504	500	514	498	506	504	1000
T.S.S	48	14	38	12	16	8	
Nitrate (as No_3)	\	\	\	\	\	\	50
Chromium (as Cr^{+6})	\	\	\	\	\	\	
Fluoride (as F)	\	\	\	\	\	\	
Silica (as Sio_2)	\	\	\	\	\	\	5

Remarks: • الماء صالح للشرب من الناحية الكيمياوية.

Name and signature:

Figure 3.9: Example of Water Quality Tests' Result from the Local Water National Laboratory (WNL) of June

3.8 TOPSIS Method for Evaluating the Water Quality and Performance of WTPs

TOPSIS method is considered a compensatory aggregation which is a technique for comparing sets of alternatives by identifying weights for each criterion, normalizing scores for each criterion, and calculating the geometric distance between each alternative and the ideal alternative, which is the alternative with the best score in each criterion. TOPSIS is predicated on the notion that the criteria are rising or decreasing in a monotonous manner. As the parameters or criteria in multi-criteria situations are often of incongruent dimensions, normalization is normally essential to ensure that the results are comparable. Weights that will generate from the survey's result firstly will analysis using RII, and then will analysis be using Fuzzy scales (0,0.1, 0.2) & (1,2,3). Then will take two separate weights were obtained and used in the TOPSIS method. The results of TOPSIS's scores gained from both Fuzzy scales will be ranked and compared. TOPSIS method will be carried out in seven stages, as below.

3.8.1 Criteria weight determination

This is the first step of TOPSIS method, in this step the values obtained from the previous section would be formed in a table to be further handled for the other steps. These weights were obtained per each of the studied parameters selected for our case study investigation and for the three selected WTP's.

3.8.2 Normalization

In this step each weight selected for each metric parameter based the three WTP's would be handled with two mathematical equations

1- First is the sum squared of each parameter obtained from the first step and based on Equation 3.2.

Sum Squared (i) = $\sum_{1}^{j}\left(\textbf{metric parameter (i) from WTP (j)}\right)2$ **(3.2)**

Where j represents a counter for the number of WTP and i represent a counter for the selected parameters in this study to be handled with the TOPSIS based method.

2- Secondly, the squared root would be obtained from the values of sum squared per each parameter in Equation 3.1 and as seen in Equation 3.2.

Root (i) =$\sqrt{\textbf{Sum Squared (i)}}$ **(3.3)**

3.8.3 Determination of weighted normalized matrix (Normalized weight)

This is the third step of the TOPSIS based method, in this step the value of normalized weight would be obtained from the weight that was set for each parameter in step (1) and the Root values that were calculated from Equation 3.3. This step can be calculated as in equation 3.4.

Normalized Weight (NW) (i,j) = $\frac{\textbf{Metric Parameter (I)} \, \boldsymbol{from} \, \textbf{WTP (J)}}{\textbf{Root (I)}}$ **(3.4)**

Where the normalized weight would be calculated per each parameter (i) and each WTP (j).

3.8.4 Weighted normalized weight

In this step the normalized weight obtained from the previous step would be handled with the RII values that were calculated from equation (3.1) and per each selected parameter. The calculation of the weights for each normalized weight can be obtained as seen in equation (3.5)

Weighted NW (i,j) = Normalized Weight (NW) (i,j) * RII (i) **(3.5)**

It's worth to mention that RII values that were obtained previously would be one value per each parameter. So, this single value per each parameter would be used for all the normalized weights within each parameter.

3.8.5 Determination of the positive & negative ideal solution

In this fifth step the positive and negative values of ideal solution would be calculated from the values that were obtained from Equation 3.5 in previous step. The calculation of these two values can be done as seen in Equations 3.6 and 3.7 respectively.

V+ (i) = MAX (Weighted NW (i,j)) **(3.6)**

V- (i) = MIN (Weighted NW (i,j)) **(3.7)**

Noted that these two values would be calculated per each parameter (i) among the selected parameters.

3.8.6 Ideal distance from positive/negative solution

The distance in Euclidean space between all items in the ideal best and ideal worst rows. Where the ideal worst, and the worst distance found.

3.8.7 Calculating TOPSIS method Scores and Ranking

The final performance scores and ranking of the three WTPS using the weights will generate via Fuzzy scale (0,1,2) & (0,0.1,0.2), TOPSIS scores will be gained after running the designed code using the Octave GUI software. Rank will calculate using Microsoft Excel's Rank formula to ranking the three WTPs performance over six months.

4. RESULTS & DISCUSSION

4.1 Introduction

This chapter includes all generated results of the applied methodologies from the previous chapter of this research. This chapter explains the processes of when, how, and why each result is generated and their role in gaining the final ranking. It explained the process of the practical work, starting from the application of the research's survey and collecting data to analyzing the survey's answers by calculating the Relative Importance Index (RII) for each water quality parameter to find the weights of each parameter which required to run the MCDM-TOPSIS method's code.

4.2 Research Survey

This survey has addressed to 32 of engineering and non-engineer staff from both chemical and biological educational backgrounds as well as other staff working in drinking water sector. It is a part of scientific research. Where the specialists answered the main parameters that are as follows (Turbidity, pH, temperature etc.). Parameters were measured using a Likert scale to identify the weights of each parameter listed in the picture below in the opinion view. The questions of survey as shown in appendix (A1). The answers of the participants were as follows;

First of all, the participants' opinions about the turbidity parameter were different, as it was between (somewhat important _ very important), which had evaluated according to the Likert scale (5-6). The overall total of the participants concerning the turbidity parameter was equal to 171, which is an appropriate value for the other factors studied through the questionnaire.

While, the participants' opinions about the temperature parameter were different, as it was between (neither important - somewhat important), which had evaluated according to the Likert scale (4-5). The overall total of the participants answers the temperature parameter was equal to 134, this result which is an appropriate value for water temperature in the study area (Iraq) is generally normal, as it does not reach the boiling point or the freezing point in the drinking water sources in the Tigris and Euphrates rivers.

Also, the participants evaluated important parameters, including (electrical conductivity, Alkalinity, Chloride, Sulphates, Magnesium, Potassium, Hardness, Total Dissolved Solids, Total Suspended, Calcium, Sodium) the participants' opinions about the parameters was varied between (somewhat important- very important), which had evaluated according to the Likert scale (5-6).

On the other hand, the participants' opinions about the pH parameter were different, as it was between (very important _ extremely important), which had evaluated according to the Likert scale (6-7). The overall total of the participants with respect to the pH parameter was equal to 193, which is the highest value for the other factors that were evaluated through the questionnaire, because pure water has a pH of about 7.0, making it neutral. Normal rainfall has a pH of 5.6 due to the presence of carbon dioxide in the air (slightly acidic). The pH of drinking water should be between 6.5 and 8.5 to be safe for home use and to meet the requirements of living organisms.

Survey Results

Parameters / Respondants	Turbidity	Temperature	pH	Electrical conductivity (EC)	Alkalinity	Chloride	Sulphates	Magnesium	Potassium	Hardness	Total Dissolved Solids (TDS)	Total Suspended Solid (TSS)	Calcium	Sodium
R 1	6	6	6	6	6	6	6	6	6	6	6	6	5	5
R 2	7	5	7	6	5	7	7	2	7	7	5	6	6	6
R 3	6	6	6	6	4	4	4	4	4	4	1	4	4	4
R 4	6	7	6	3	5	6	6	5	5	6	6	7	5	5
R 5	3	3	5	6	3	6	4	5	5	5	5	6	5	5
R 6	6	6	7	7	7	7	7	7	7	6	7	7	7	7
R 7	1	1	6	1	1	1	1	3	5	5	5	5	5	5
R 8	7	5	6	7	7	6	6	7	7	5	7	7	7	6
R 9	6	5	5	4	5	7	5	5	5	5	6	6	5	5
R 10	6	2	6	5	5	5	5	5	5	7	6	6	5	6
R 11	5	5	5	3	5	5	5	5	5	5	5	5	6	5
R 12	6	2	6	6	3	6	2	2	2	1	7	6	5	5
R 13	5	2	6	6	3	6	5	5	4	3	7	7	4	4
R 14	6	4	7	5	7	6	5	6	6	6	7	7	6	6
R 15	6	2	7	6	6	7	4	3	3	6	7	4	3	3
R 16	3	6	6	6	5	6	6	6	6	6	7	5	6	6
R 17	4	2	5	3	5	5	5	5	5	6	5	3	4	4
R 18	6	5	6	5	5	5	6	5	5	6	6	5	5	5
R 19	2	1	6	5	6	7	5	5	5	6	5	5	5	5
R 20	6	2	5	6	5	5	6	5	5	6	7	6	7	7
R 21	6	5	6	6	5	6	4	5	5	6	7	5	5	4
R 22	7	1	7	1	7	7	7	7	7	7	7	7	7	7
R 23	5	6	6	6	5	6	6	6	6	6	5	5	6	6
R 24	5	6	6	6	6	6	6	6	6	6	6	6	6	6
R 25	6	4	6	3	5	5	2	7	5	4	3	5	7	6
R 26	6	5	6	4	4	7	5	5	6	4	7	6	5	6
R 27	3	3	6	4	4	4	6	6	5	6	6	5	7	6
R 28	6	6	7	5	7	7	7	7	7	6	6	6	6	7
R 29	6	5	7	6	7	6	6	5	7	6	6	5	6	7
R 30	6	5	6	7	6	6	6	3	3	3	7	7	2	2
R 31	6	6	6	6	1	6	6	6	3	5	6	5	6	6
R 32	6	5	5	6	6	7	7	6	6	6	5	5	5	5
Total	171	134	193	162	161	186	168	165	168	172	188	180	173	172

Figure 4.1: Results of the Conducted Survey Shows the Significance of Each WQP

As shown in Figure 4.1 of results of the questionnaire, there was a clear importance for certain elements such as pH, turbidity, as they considered among the most important criteria to examined when examining water quality, since any inappropriate change in its proportions causes a direct, rapid and dangerous health impact on human life.

4.3 Analyzing the Data of the Survey Using the Relative Importance Index (RII)

Through the questionnaire results obtained by the participants that used the Likert scale (1-7), the values for each factor collected separately and the total factor values calculated to extract the RII values from each parameter. The calculation of each parameter was as follows;

Relative importance Index= $\boldsymbol{WQP\ weight} / \boldsymbol{Total\ WQP\ Weights}$

For Turbidity = 171/2393 = 0.0714;

Temperature = 134/2393= 0.0559;

pH = 193/2393= 0.0806;

E.C = 162/2393= 0.0676;

Alkalinity = 161/2393= 0.0672;

Chloride = 186/2393= 0.0777;

Sulphates = 168/2393= 0.0702;

Magnesium = 165/2393 = 0.0689;

Potassium = 168/2393 = 0.0702;

Hardness = 172/2393 = 0.0718;

Total Dissolved Solids

(TDS) = 188/2393 = 0.0785;

Total Suspended Solid (TSS) = 180/2393 = 0.0752;

Calcium = 173/ 2393 = 0.0722;

Sodium = 172/ 2393 =0.0718;

Sum of results for (RII) values of water quality parameters = 0.0714+ 0.0554+ 0.0806+ 0.0672+ 0.0777+ 0.0702+ 0.0689+ 0.0702+ 0.0718+ 0.0785+ 0.0752+ 0.0722+ 0.0718 = 1 (Sum of RII).

As shown, after collecting the corresponding values for fourteen parameters within the questionnaire about each water quality criteria and obtaining the weight of each measure applying the RII arithmetic operation to the initial weights, the result was that the weights were more accurate for each criterion. These weights will be used after applying the Fuzzy method to obtain more accurate weights, which will be used as final weights in the TOPSIS method and the evaluation of the three water treatment plants.

Relative Important Index (RII) Values of Water Quality Parameters

Parameters / Respondant	Turbidity	Temperature	pH	Electrical conductivity (EC)	Alkalinity	Chloride	Sulphates	Magnesium	Potassium	Hardness	Total Dissolved Solids (TDS)	Total Suspended Solid (TSS)	Calcium	Sodium	
Total	171	134	193	162	161	186	168	165	168	172	188	180	173	172	2393
RII	0.071458	0.055996657	0.080651901	0.06769745	0.06728	0.0777267	0.0702048	0.068951107	0.07020476	0.07187631	0.07856247	0.07521939	0.07229419	0.07187631	1

Figure 4.2: Relative Important Index Values of Water Quality Parameters

4.4 Apply Fuzzy Linguistic Calculation to Analyze the RII Weights

In this paragraph, the results of the questionnaire analyzed in which the participants gave weights to each parameter of the quality of water treatment by Fuzzy method, and two types of Fuzzy method used, the first type (0, 0.1, 0.2), the second type (0,1,2);

➢ For the first Fuzzy scale (Hsiu-Yuan Hu) was used as an additional layer to analyze the resolution results and obtain the final equilibrium that will be used in the TOPSIS method to conclude the final evaluation of these three water treatment plants. As shown on Figure 4.3 (a-b);

➢ The second scale was used to analyze the results that the participants in the questionnaire gave, and the second scale measured them. Also result deduced from the scale was appropriate to be used in the TOPSIS method to complete the final evaluation of the three water treatment plants. As shown on Figure 4.4 (a-b);

When it compares the two results of scales, it finds that they are similar in the results, which confirms the accuracy of the analysis of the results using the two methods and their quality for use in completing the TOPSIS method.

Fuzzy Scale (0,0.1,0.2)

Parameters / Respondents	Turbidity			Temperature			pH			Electrical conductivity (EC)			Alkalinity			Chloride			Sulphates		
Respondent 1	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9
Respondent 2	0.8	0.9	1	0.5	0.65	0.8	0.8	0.9	1	0.7	0.8	0.9	0.5	0.65	0.8	0.8	0.9	1	0.8	0.9	1
Respondent 3	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9	0.4	0.5	0.6	0.4	0.5	0.6	0.4	0.5	0.6
Respondent 4	0.7	0.8	0.9	0.8	0.9	1	0.7	0.8	0.9	0.2	0.35	0.5	0.5	0.65	0.8	0.7	0.8	0.9	0.7	0.8	0.9
Respondent 5	0.2	0.35	0.5	0.2	0.35	0.5	0.5	0.65	0.8	0.7	0.8	0.9	0.2	0.35	0.5	0.7	0.8	0.9	0.4	0.5	0.6
Respondent 6	0.7	0.8	0.9	0.7	0.8	0.9	0.8	0.9	1	0.8	0.9	1	0.8	0.9	1	0.8	0.9	1	0.8	0.9	1
Respondent 7	0	0.1	0.2	0	0.1	0.2	0.7	0.8	0.9	0	0.1	0.2	0	0.1	0.2	0	0.1	0.2	0	0.1	0.2
Respondent 8	0.8	0.9	1	0.5	0.65	0.8	0.7	0.8	0.9	0.8	0.9	1	0.8	0.9	1	0.7	0.8	0.9	0.7	0.8	0.9
Respondent 9	0.7	0.8	0.9	0.5	0.65	0.8	0.5	0.65	0.8	0.4	0.5	0.6	0.5	0.65	0.8	0.8	0.9	1	0.5	0.65	0.8
Respondent 10	0.7	0.8	0.9	0.1	0.2	0.3	0.7	0.8	0.9	0.5	0.65	0.8	0.5	0.65	0.8	0.5	0.65	0.8	0.5	0.65	0.8
Respondent 11	0.5	0.65	0.8	0.5	0.65	0.8	0.5	0.65	0.8	0.2	0.35	0.5	0.5	0.65	0.8	0.5	0.65	0.8	0.5	0.65	0.8
Respondent 12	0.7	0.8	0.9	0.1	0.2	0.3	0.7	0.8	0.9	0.7	0.8	0.9	0.2	0.35	0.5	0.7	0.8	0.9	0.1	0.2	0.3
Respondent 13	0.5	0.65	0.8	0.1	0.2	0.3	0.7	0.8	0.9	0.7	0.8	0.9	0.2	0.35	0.5	0.7	0.8	0.9	0.5	0.65	0.8
Respondent 14	0.7	0.8	0.9	0.4	0.5	0.6	0.8	0.9	1	0.5	0.65	0.8	0.8	0.9	1	0.7	0.8	0.9	0.5	0.65	0.8
Respondent 15	0.7	0.8	0.9	0.1	0.2	0.3	0.8	0.9	1	0.7	0.8	0.9	0.7	0.8	0.9	0.8	0.9	1	0.4	0.5	0.6
Respondent 16	0.2	0.35	0.5	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9	0.5	0.65	0.8	0.7	0.8	0.9	0.7	0.8	0.9
Respondent 17	0.4	0.5	0.6	0.1	0.2	0.3	0.5	0.65	0.8	0.2	0.35	0.5	0.5	0.65	0.8	0.5	0.65	0.8	0.5	0.65	0.8
Respondent 18	0.7	0.8	0.9	0.5	0.65	0.8	0.7	0.8	0.9	0.5	0.65	0.8	0.5	0.65	0.8	0.5	0.65	0.8	0.7	0.8	0.9
Respondent 19	0.1	0.2	0.3	0	0.1	0.2	0.7	0.8	0.9	0.5	0.65	0.8	0.7	0.8	0.9	0.8	0.9	1	0.5	0.65	0.8
Respondent 20	0.7	0.8	0.9	0.1	0.2	0.3	0.5	0.65	0.8	0.7	0.8	0.9	0.5	0.65	0.8	0.5	0.65	0.8	0.7	0.8	0.9
Respondent 21	0.7	0.8	0.9	0.5	0.65	0.8	0.7	0.8	0.9	0.7	0.8	0.9	0.5	0.65	0.8	0.7	0.8	0.9	0.4	0.5	0.6
Respondent 22	0.8	0.9	1	0	0.1	0.2	0.8	0.9	1	0	0.1	0.2	0.8	0.9	1	0.8	0.9	1	0.8	0.9	1
Respondent 23	0.5	0.65	0.8	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9	0.5	0.65	0.8	0.7	0.8	0.9	0.7	0.8	0.9
Respondent 24	0.5	0.65	0.8	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9
Respondent 25	0.7	0.8	0.9	0.4	0.5	0.6	0.7	0.8	0.9	0.2	0.35	0.5	0.5	0.65	0.8	0.5	0.65	0.8	0.1	0.2	0.3
Respondent 26	0.7	0.8	0.9	0.5	0.65	0.8	0.7	0.8	0.9	0.4	0.5	0.6	0.4	0.5	0.6	0.8	0.9	1	0.5	0.65	0.8
Respondent 27	0.2	0.35	0.5	0.2	0.35	0.5	0.7	0.8	0.9	0.4	0.5	0.6	0.4	0.5	0.6	0.4	0.5	0.6	0.7	0.8	0.9
Respondent 28	0.7	0.8	0.9	0.7	0.8	0.9	0.8	0.9	1	0.5	0.65	0.8	0.8	0.9	1	0.8	0.9	1	0.8	0.9	1
Respondent 29	0.7	0.8	0.9	0.5	0.65	0.8	0.8	0.9	1	0.7	0.8	0.9	0.8	0.9	1	0.7	0.8	0.9	0.7	0.8	0.9
Respondent 30	0.7	0.8	0.9	0.5	0.65	0.8	0.7	0.8	0.9	0.8	0.9	1	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9
Respondent 31	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9	0	0.1	0.2	0.7	0.8	0.9	0.7	0.8	0.9
Respondent 32	0.7	0.8	0.9	0.5	0.65	0.8	0.5	0.65	0.8	0.7	0.8	0.9	0.7	0.8	0.9	0.8	0.9	1	0.8	0.9	1
Total	18.8	22.35	25.9	13.2	17	20.8	21.9	25.4	28.9	17.4	21.05	24.7	16.8	20.75	24.7	20.8	24.3	27.8	18.2	21.8	25.4
RII	22.35			17			25.4			21.05			20.75			24.3			21.8		
Normalised RII	0.07189963			0.054688757			0.081711436			0.067717549			0.066752453			0.078172752			0.070130288		

Figure 4.3: (a, b): RII Weights using Fuzzy scale (0, 0.1, 0.2)

Parameters / Respondents	Magnesium			Potassium			Hardness			Total Dissolved Solids (TDS)			Total Suspended Solid (TSS)			Calcium			Sodium		
Respondent 1	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9	0.5	0.65	0.8	0.5	0.65	0.8
Respondent 2	0.1	0.2	0.3	0.8	0.9	1	0.8	0.9	1	0.5	0.65	0.8	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9
Respondent 3	0.4	0.5	0.6	0.4	0.5	0.6	0.4	0.5	0.6	0	0.1	0.2	0.4	0.5	0.6	0.4	0.5	0.6	0.4	0.5	0.6
Respondent 4	0.5	0.65	0.8	0.5	0.65	0.8	0.7	0.8	0.9	0.7	0.8	0.9	0.8	0.9	1	0.5	0.65	0.8	0.5	0.65	0.8
Respondent 5	0.5	0.65	0.8	0.5	0.65	0.8	0.5	0.65	0.8	0.5	0.65	0.8	0.7	0.8	0.9	0.5	0.65	0.8	0.5	0.65	0.8
Respondent 6	0.8	0.9	1	0.8	0.9	1	0.7	0.8	0.9	0.8	0.9	1	0.8	0.9	1	0.8	0.9	1	0.8	0.9	1
Respondent 7	0.2	0.35	0.5	0.5	0.65	0.8	0.5	0.65	0.8	0.5	0.65	0.8	0.5	0.65	0.8	0.5	0.65	0.8	0.5	0.65	0.8
Respondent 8	0.8	0.9	1	0.8	0.9	1	0.5	0.65	0.8	0.8	0.9	1	0.8	0.9	1	0.8	0.9	1	0.7	0.8	0.9
Respondent 9	0.5	0.65	0.8	0.5	0.65	0.8	0.5	0.65	0.8	0.7	0.8	0.9	0.7	0.8	0.9	0.5	0.65	0.8	0.5	0.65	0.8
Respondent 10	0.5	0.65	0.8	0.5	0.65	0.8	0.8	0.9	1	0.7	0.8	0.9	0.7	0.8	0.9	0.5	0.65	0.8	0.7	0.8	0.9
Respondent 11	0.5	0.65	0.8	0.5	0.65	0.8	0.5	0.65	0.8	0.5	0.65	0.8	0.5	0.65	0.8	0.7	0.8	0.9	0.5	0.65	0.8
Respondent 12	0.1	0.2	0.3	0.1	0.2	0.3	0	0.1	0.2	0.8	0.9	1	0.7	0.8	0.9	0.5	0.65	0.8	0.5	0.65	0.8
Respondent 13	0.5	0.65	0.8	0.4	0.5	0.6	0.2	0.35	0.5	0.8	0.9	1	0.8	0.9	1	0.4	0.5	0.6	0.4	0.5	0.6
Respondent 14	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9	0.8	0.9	1	0.8	0.9	1	0.7	0.8	0.9	0.7	0.8	0.9
Respondent 15	0.2	0.35	0.5	0.2	0.35	0.5	0.7	0.8	0.9	0.8	0.9	1	0.4	0.5	0.6	0.2	0.35	0.5	0.2	0.35	0.5
Respondent 16	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9	0.8	0.9	1	0.5	0.65	0.8	0.7	0.8	0.9	0.7	0.8	0.9
Respondent 17	0.5	0.65	0.8	0.5	0.65	0.8	0.7	0.8	0.9	0.5	0.65	0.8	0.2	0.35	0.5	0.4	0.5	0.6	0.4	0.5	0.6
Respondent 18	0.5	0.65	0.8	0.5	0.65	0.8	0.7	0.8	0.9	0.7	0.8	0.9	0.5	0.65	0.8	0.5	0.65	0.8	0.5	0.65	0.8
Respondent 19	0.5	0.65	0.8	0.5	0.65	0.8	0.7	0.8	0.9	0.5	0.65	0.8	0.5	0.65	0.8	0.5	0.65	0.8	0.5	0.65	0.8
Respondent 20	0.5	0.65	0.8	0.5	0.65	0.8	0.7	0.8	0.9	0.8	0.9	1	0.7	0.8	0.9	0.8	0.9	1	0.8	0.9	1
Respondent 21	0.5	0.65	0.8	0.5	0.65	0.8	0.7	0.8	0.9	0.8	0.9	1	0.5	0.65	0.8	0.5	0.65	0.8	0.4	0.5	0.6
Respondent 22	0.8	0.9	1	0.8	0.9	1	0.8	0.9	1	0.8	0.9	1	0.8	0.9	1	0.8	0.9	1	0.8	0.9	1
Respondent 23	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9	0.5	0.65	0.8	0.5	0.65	0.8	0.7	0.8	0.9	0.7	0.8	0.9
Respondent 24	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9
Respondent 25	0.8	0.9	1	0.5	0.65	0.8	0.4	0.5	0.6	0.2	0.35	0.5	0.5	0.65	0.8	0.8	0.9	1	0.7	0.8	0.9
Respondent 26	0.5	0.65	0.8	0.7	0.8	0.9	0.4	0.5	0.6	0.8	0.9	1	0.7	0.8	0.9	0.5	0.65	0.8	0.7	0.8	0.9
Respondent 27	0.7	0.8	0.9	0.5	0.65	0.8	0.7	0.8	0.9	0.7	0.8	0.9	0.5	0.65	0.8	0.8	0.9	1	0.7	0.8	0.9
Respondent 28	0.8	0.9	1	0.8	0.9	1	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9	0.8	0.9	1
Respondent 29	0.5	0.65	0.8	0.8	0.9	1	0.7	0.8	0.9	0.7	0.8	0.9	0.5	0.65	0.8	0.7	0.8	0.9	0.8	0.9	1
Respondent 30	0.2	0.35	0.5	0.2	0.35	0.5	0.2	0.35	0.5	0.8	0.9	1	0.8	0.9	1	0.1	0.2	0.3	0.1	0.2	0.3
Respondent 31	0.7	0.8	0.9	0.2	0.35	0.5	0.5	0.65	0.8	0.7	0.8	0.9	0.5	0.65	0.8	0.7	0.8	0.9	0.7	0.8	0.9
Respondent 32	0.7	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.9	0.5	0.65	0.8	0.5	0.65	0.8	0.5	0.65	0.8	0.5	0.65	0.8
Total	17.3	21.3	25.3	17.7	21.7	25.7	18.9	22.5	26.1	20.8	24.45	28.1	19.6	23.45	27.3	18.6	22.45	26.3	18.6	22.35	26.1
RII	21.3			21.7			22.5			24.45			23.45			22.45			22.35		
Normalised RII	0.068521795			0.069808589			0.072382178			0.0786553			0.075438314			0.072221329			0.07189963		

Figure 4.3: (Cont.) (a, b): RII Weights using Fuzzy Scale (0, 0.1, 0.2)

Parameters / Respondents	Fuzzy Scale (1,2,3)																				
	Turbidity			Temperature			pH			Electrical conductivity (EC)			Alkalinity			Chloride			Sulphates		
Respondent 1	6	7	8	6	7	8	6	7	8	6	7	8	6	7	8	6	7	8	6	7	8
Respondent 2	7	8	9	5	6	7	7	8	9	6	7	8	5	6	7	7	8	9	7	8	9
Respondent 3	6	7	8	6	7	8	6	7	8	6	7	8	4	5	6	4	5	6	4	5	6
Respondent 4	6	7	8	7	8	9	6	7	8	3	4	5	5	6	7	6	7	8	6	7	8
Respondent 5	3	4	5	3	4	5	5	6	7	6	7	8	3	4	5	6	7	8	4	5	6
Respondent 6	6	7	8	6	7	8	7	8	9	7	8	9	7	8	9	7	8	9	7	8	9
Respondent 7	1	2	3	1	y	3	6	7	8	1	2	3	1	2	3	1	2	3	1	2	3
Respondent 8	7	8	9	5	6	7	6	7	8	7	8	9	7	8	9	6	7	8	6	7	8
Respondent 9	6	7	8	5	6	7	5	6	7	4	5	6	5	6	7	7	8	9	5	6	7
Respondent 10	6	7	8	2	3	4	6	7	8	5	6	7	5	6	7	5	6	7	5	6	7
Respondent 11	5	6	7	5	6	7	5	6	7	3	4	5	5	6	7	5	6	7	5	6	7
Respondent 12	6	7	8	2	3	4	6	7	8	6	7	8	3	4	5	6	7	8	2	3	4
Respondent 13	5	6	7	2	3	4	6	7	8	6	7	8	3	4	5	6	7	8	5	6	7
Respondent 14	6	7	8	4	5	6	7	8	9	5	6	7	7	8	9	6	7	8	5	6	7
Respondent 15	6	7	8	2	3	4	7	8	9	6	7	8	6	7	8	7	8	9	4	5	6
Respondent 16	3	4	5	6	7	8	6	7	8	6	7	8	5	6	7	6	7	8	6	7	8
Respondent 17	4	5	6	2	3	4	5	6	7	3	4	5	5	6	7	5	6	7	5	6	7
Respondent 18	6	7	8	5	6	7	6	7	8	5	6	7	5	6	7	5	6	7	6	7	8
Respondent 19	2	3	4	1	2	3	6	7	8	5	6	7	6	7	8	7	8	9	5	6	7
Respondent 20	6	7	8	2	3	4	5	6	7	6	7	8	5	6	7	5	6	7	6	7	8
Respondent 21	6	7	8	5	6	7	6	7	8	6	7	8	5	6	7	6	7	8	4	5	6
Respondent 22	7	8	9	1	2	3	7	8	9	1	2	3	7	8	9	7	8	9	7	8	9
Respondent 23	5	6	7	6	7	8	6	7	8	6	7	8	5	6	7	6	7	8	6	7	8
Respondent 24	5	6	7	6	7	8	6	7	8	6	7	8	6	7	8	6	7	8	6	7	8
Respondent 25	6	7	8	4	5	6	6	7	8	3	4	5	5	6	7	5	6	7	2	3	4
Respondent 26	6	7	8	5	6	7	6	7	8	4	5	6	4	5	6	7	8	9	5	6	7
Respondent 27	3	4	5	3	4	5	6	7	8	4	5	6	4	5	6	4	5	6	6	7	8
Respondent 28	6	7	8	6	7	8	7	8	9	5	6	7	7	8	9	7	8	9	7	8	9
Respondent 29	6	7	8	5	6	7	7	8	9	6	7	8	7	8	9	6	7	8	6	7	8
Respondent 30	6	7	8	5	6	7	6	7	8	7	8	9	6	7	8	6	7	8	6	7	8
Respondent 31	6	7	8	6	7	8	6	7	8	6	7	8	1	2	3	6	7	8	6	7	8
Respondent 32	6	7	8	5	6	7	5	6	7	6	7	8	6	7	8	7	8	9	7	8	9
Total	171	203	235	134	164	198	193	225	257	162	194	226	161	193	225	186	218	250	168	200	232
RII	203			165.3333333			225			194			193			218			200		
Normalised RII	0.071369975			0.058127271			0.079104653			0.068205789			0.067854213			0.076643619			0.070315247		

Figure 4.3: (Cont.) (a, b): RII Weights using Fuzzy Scale (0, 0.1, 0.2)

Parameters / Respondents	Magnesium			Potassium			Hardness			Total Dissolved Solids (TDS)			Total Suspended Solid (TSS)			Calcium			Sodium		
Respondent 1	6	7	8	6	7	8	6	7	8	6	7	8	6	7	8	5	6	7	5	6	7
Respondent 2	2	3	4	7	8	9	7	8	9	5	6	7	6	7	8	6	7	8	6	7	8
Respondent 3	4	5	6	4	5	6	4	5	6	1	2	3	4	5	6	4	5	6	4	5	6
Respondent 4	5	6	7	5	6	7	6	7	8	6	7	8	7	8	9	5	6	7	5	6	7
Respondent 5	5	6	7	5	6	7	5	6	7	5	6	7	6	7	8	5	6	7	5	6	7
Respondent 6	7	8	9	7	8	9	6	7	8	7	8	9	7	8	9	7	8	9	7	8	9
Respondent 7	3	4	5	5	6	7	5	6	7	5	6	7	5	6	7	5	6	7	5	6	7
Respondent 8	7	8	9	7	8	9	5	6	7	7	8	9	7	8	9	7	8	9	6	7	8
Respondent 9	5	6	7	5	6	7	5	6	7	6	7	8	6	7	8	5	6	7	5	6	7
Respondent 10	5	6	7	5	6	7	7	8	9	6	7	8	6	7	8	5	6	7	6	7	8
Respondent 11	5	6	7	5	6	7	5	6	7	5	6	7	5	6	7	6	7	8	5	6	7
Respondent 12	2	3	4	2	3	4	1	2	3	7	8	9	6	7	8	5	6	7	5	6	7
Respondent 13	5	6	7	4	5	6	3	4	5	7	8	9	7	8	9	7	8	9	4	5	6
Respondent 14	6	7	8	6	7	8	6	7	8	7	8	9	7	8	9	6	7	8	6	7	8
Respondent 15	3	4	5	3	4	5	6	7	8	7	8	9	4	5	6	3	4	5	3	4	5
Respondent 16	6	7	8	6	7	8	6	7	8	7	8	9	5	6	7	6	7	8	6	7	8
Respondent 17	5	6	7	5	6	7	6	7	8	5	6	7	3	4	5	4	5	6	4	5	6
Respondent 18	5	6	7	5	6	7	6	7	8	6	7	8	5	6	7	5	6	7	5	6	7
Respondent 19	5	6	7	5	6	7	6	7	8	5	6	7	5	6	7	5	6	7	5	6	7
Respondent 20	5	6	7	5	6	7	6	7	8	7	8	9	6	7	8	7	8	9	7	8	9
Respondent 21	5	6	7	5	6	7	6	7	8	7	8	9	5	6	7	5	6	7	4	5	6
Respondent 22	7	8	9	7	8	9	7	8	9	7	8	9	7	8	9	7	8	9	7	8	9
Respondent 23	6	7	8	6	7	8	6	7	8	5	6	7	5	6	7	6	7	8	6	7	8
Respondent 24	6	7	8	6	7	8	6	7	8	6	7	8	6	7	8	6	7	8	6	7	8
Respondent 25	7	8	9	5	6	7	4	5	6	6	7	8	5	6	7	7	8	9	6	7	8
Respondent 26	5	6	7	6	7	8	4	5	6	6	7	8	6	7	8	5	6	7	6	7	8
Respondent 27	6	7	8	5	6	7	6	7	8	6	7	8	5	6	7	7	8	9	6	7	8
Respondent 28	7	8	9	7	8	9	6	7	8	6	7	8	6	7	8	6	7	8	7	8	9
Respondent 29	5	6	7	7	8	9	6	7	8	6	7	8	5	6	7	6	7	8	7	8	9
Respondent 30	3	4	5	3	4	5	3	4	5	6	7	8	7	8	9	2	3	4	2	3	4
Respondent 31	6	7	8	3	4	5	5	6	7	6	7	8	5	6	7	6	7	8	6	7	8
Respondent 32	6	7	8	6	7	8	6	7	8	5	6	7	5	6	7	5	6	7	5	6	7
Total	165	197	229	168	200	232	172	204	236	189	221	253	180	212	244	176	208	240	172	204	236
RII	197			200			204			221			212			208			204		
Normalised RII	0.069260518			0.070315247			0.071721552			0.077698348			0.074534161			0.073127857			0.071721552		

Figure 4.4: (a, b): RII Weights using Fuzzy Scale (0, 1, 2)

4.5 MCDM TOPSIS Method

4.5.1 Applying the code to run the TOPSIS methods using weights generated via Fuzzy scale (0,1,2)

In this paragraph and after obtaining the most accurate weights using the RII scale and the Fuzzy scale (0,1,2), the water test data were obtained in the three stations issued by the Water Quality Inspection Department in the Anbar Water Directorate for the period from January to June 2021; Evidence as to the Decision Matrix for its use within the TOPSIS method, on the other hand, beneficial and non-beneficial values for water quality parameters have been determined. These values were used as basic elements in TOPSIS, where all three data were used as a decision matrix to be implemented by the Octave program, and they were obtained Final evaluation of the three stations within the TOPSIS.

4.5.1.1 Calculation the normalized matrix using Fuzzy scale (0,1,2)

In this step, the normalized matrix was calculated, where the three elements used in the octave program were defined, as shown in the Figure 4.5.

Where X= Decision Matrix

W criteria= Beneficial & Non-Beneficial values

W= weights

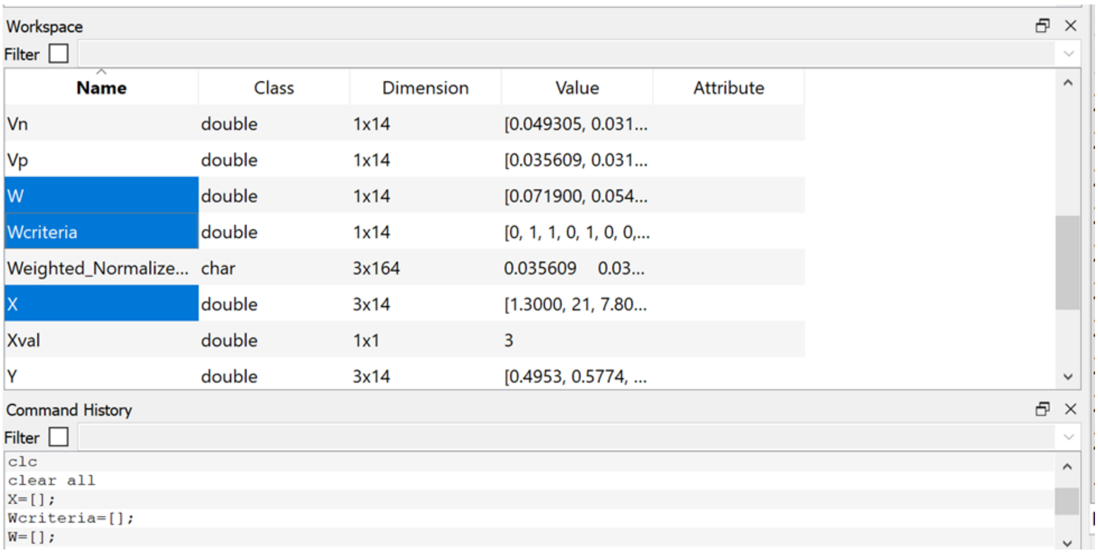


Figure 4.5: Defining the Elements in the Octave Program to Calculation the Normalized Matrix using Fuzzy Scale (0,1,2)

After defining the values, a special code was designed in the program to calculate the normalization matrix for water stations within six months.

```
Xval=length(X(:,1));
Y = zeros([Xval,length(W)]);
%% calculating the normalized matrix
for j=1:length(W)
    for i=1:Xval
    Y(i,j)=X(i,j)/sqrt(sum((X(:,j).^2)));
    end
end
```

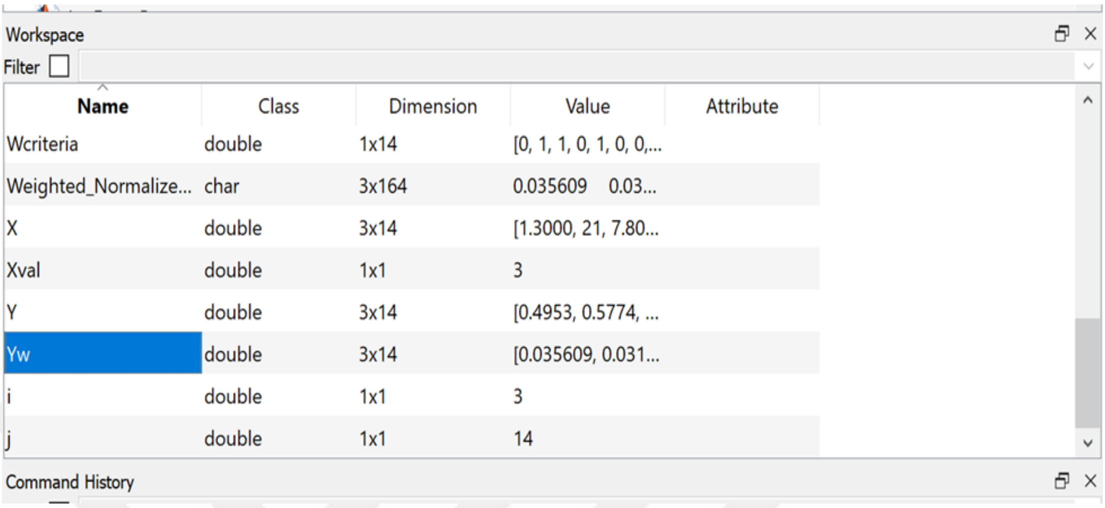
After running the code, the required values for water stations were obtained from January to June. As shown in Figure 4.6.

Calculating the Normalized Matrixces														
Normalized Matrix (January, 2021)														
WTP-1	0.49526	0.57735	0.57001	0.57668	0.68624	0.58354	0.58889	0.76963	0.54965	0.57798	0.5803	0.52981	0.58501	0.57379
WTP-2	0.53336	0.57735	0.57732	0.57735	0.723	0.57112	0.57439	0.44402	0.57001	0.57609	0.58128	0.66227	0.56962	0.59429
WTP-3	0.68575	0.57735	0.58463	0.57802	0.07965	0.57733	0.56858	0.45882	0.61072	0.57798	0.57041	0.52981	0.57732	0.56355
Normalized Matrix (February, 2021)														
WTP-1	0.46222	0.57735	0.57735	0.5787	0.56362	0.58144	0.58865	0.41282	0.59702	0.57735	0.57997	0.57735	0.57475	0.57386
WTP-2	0.50074	0.57735	0.57735	0.57735	0.60388	0.56907	0.58293	0.41282	0.55722	0.57735	0.58195	0.57735	0.57475	0.59399
WTP-3	0.73185	0.57735	0.57735	0.576	0.56362	0.58144	0.56007	0.81188	0.57712	0.57735	0.57007	0.57735	0.58252	0.56379
Normalized Matrix (March, 2021)														
WTP-1	0.57577	0.57735	0.57229	0.57064	0.57714	0.55609	0.57557	0.61658	0.58398	0.57898	0.57614	0.43685	0.55162	0.5876
WTP-2	0.62811	0.57735	0.57229	0.57949	0.5579	0.58769	0.59492	0.54807	0.56385	0.58229	0.57346	0.78633	0.60678	0.56698
WTP-3	0.52342	0.57735	0.58735	0.58185	0.59637	0.58769	0.56106	0.5652	0.58398	0.57071	0.58242	0.43685	0.5723	0.57729
Normalized Matrix (April, 2021)														
WTP-1	0.62757	0.57735	0.57494	0.5528	0.5806	0.58535	0.57307	0.57201	0.55401	0.5695	0.57734	0.66742	0.56858	0.57195
WTP-2	0.58835	0.57735	0.57494	0.59072	0.56571	0.57931	0.57307	0.58789	0.59556	0.57889	0.58077	0.57208	0.57511	0.5567
WTP-3	0.5099	0.57735	0.58213	0.58776	0.58556	0.56724	0.58581	0.57201	0.58171	0.58358	0.57392	0.47673	0.58819	0.60246
Normalized Matrix (May, 2021)														
WTP-1	0.54823	0.59577	0.57479	0.57735	0.09666	0.56887	0.55874	0.54924	0.56203	0.58188	0.57389	0.65493	0.57969	0.58661
WTP-2	0.70052	0.55853	0.56732	0.57501	0.70681	0.58783	0.58764	0.58252	0.57722	0.57337	0.57734	0.60455	0.58694	0.5773
WTP-3	0.45686	0.57715	0.58972	0.57968	0.70077	0.57519	0.58523	0.59917	0.59241	0.57677	0.5808	0.45341	0.5652	0.56799
Normalized Matrix (June, 2021)														
WTP-1	0.78615	0.56473	0.57242	0.575	0.57735	0.57942	0.55699	0.58285	0.58241	0.58189	0.57657	0.69653	0.58222	0.58957
WTP-2	0.5241	0.58356	0.57242	0.57656	0.57735	0.57319	0.58362	0.5662	0.58241	0.57507	0.57427	0.59702	0.58222	0.57114
WTP-3	0.32756	0.58356	0.58709	0.58048	0.57735	0.57942	0.59089	0.58285	0.56709	0.57507	0.58119	0.39801	0.56748	0.57114

Figure 4.6: Calculating Normalized Matrix for Six Months using Fuzzy Scale (0,1,2)

4.5.1.2 Calculation the weighted normalized matrix using Fuzzy scale (0,1,2)

In this step, the normalized matrix was calculated, where the Y_w element used in the octave program were defined, as shown in the Figure 4.7.



Name	Class	Dimension	Value	Attribute
Wcriteria	double	1x14	[0, 1, 1, 0, 1, 0, 0,...	
Weighted_Normalize...	char	3x164	0.035609 0.03...	
X	double	3x14	[1.3000, 21, 7.80...	
Xval	double	1x1	3	
Y	double	3x14	[0.4953, 0.5774, ...	
Yw	double	3x14	[0.035609, 0.031...	
i	double	1x1	3	
j	double	1x1	14	

Figure 4.7: Defining the Element in the Octave Program to Calculation the Weighted Normalized Matrix using Fuzzy Scale (0,1,2)

After defining the values, a special code was designed in the program to calculate the weighted normalization matrix for water stations within six months.

```
%% calculating the weighted normalized matrix
for j=1:length(W)
   for i=1:Xval
      Yw(i,j)=Y(i,j).*W(j);
   end
end
Weighted_Normalized_Matrix = num2str([Yw])
```

After running the code, the required values for water stations were obtained of weight normalization from January to June. As shown in Figure 4.8.

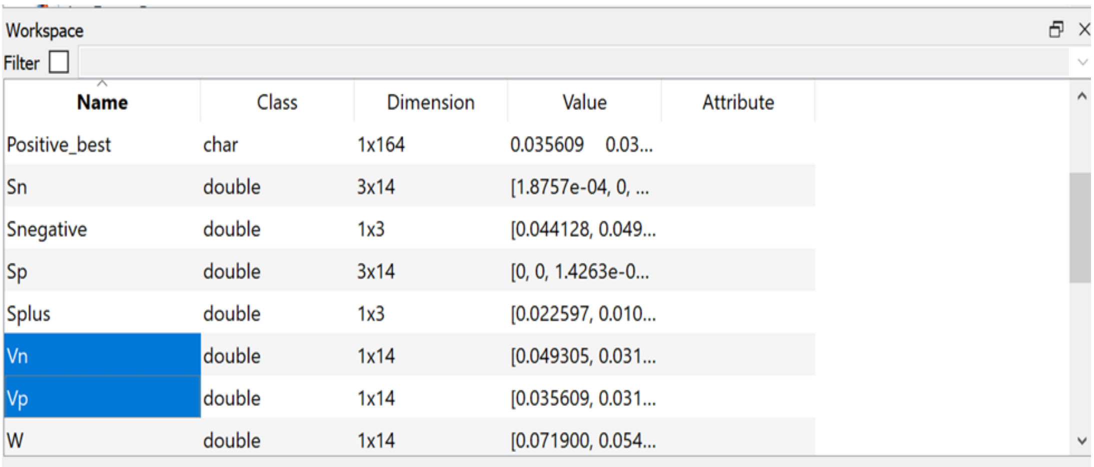
Weighted Normalized Matrix

Weighted Normalized Matrix (January, 2021)														
WTP-1	0.035347	0.033560	0.045091	0.039333	0.046564	0.044724	0.041408	0.053305	0.038649	0.041453	0.045088	0.039489	0.042781	0.041153
WTP-2	0.038066	0.033560	0.045669	0.039379	0.049059	0.043773	0.040388	0.030753	0.040080	0.041318	0.045165	0.049361	0.041655	0.042623
WTP-3	0.048942	0.033560	0.046247	0.039425	0.005405	0.044249	0.039980	0.031778	0.042943	0.041453	0.044320	0.039489	0.042218	0.040418
Weighted Normalized Matrix (February, 2021)														
WTP-1	0.032989	0.033560	0.045671	0.039471	0.038244	0.044564	0.041391	0.028592	0.041980	0.041408	0.045062	0.043032	0.042030	0.041158
WTP-2	0.035738	0.033560	0.045671	0.039379	0.040976	0.043616	0.040989	0.028592	0.039181	0.041408	0.045216	0.043032	0.042030	0.042602
WTP-3	0.052232	0.033560	0.045671	0.039287	0.038244	0.044564	0.039382	0.056231	0.040580	0.041408	0.044293	0.043032	0.042598	0.040436
Weighted Normalized Matrix (March 2021)														
WTP-1	0.041092	0.033560	0.045271	0.038921	0.039161	0.042621	0.040471	0.042705	0.041063	0.041526	0.044765	0.032560	0.040339	0.042143
WTP-2	0.044828	0.033560	0.045271	0.039525	0.037856	0.045043	0.041832	0.037960	0.039647	0.041763	0.044557	0.058609	0.044373	0.040665
WTP-3	0.037357	0.033560	0.046462	0.039686	0.040467	0.045043	0.039451	0.039146	0.041063	0.040932	0.045253	0.032560	0.041851	0.041404
Weighted Normalized Matrix (April, 2021)														
WTP-1	0.044790	0.033560	0.045481	0.037704	0.039396	0.044863	0.040296	0.039617	0.038955	0.040845	0.044859	0.049746	0.041579	0.041021
WTP-2	0.041990	0.033560	0.045481	0.040291	0.038386	0.044401	0.040296	0.040718	0.041877	0.041519	0.045125	0.042639	0.042057	0.039927
WTP-3	0.036392	0.033560	0.046049	0.040089	0.039733	0.043476	0.041191	0.039617	0.040903	0.041855	0.044592	0.035533	0.043013	0.043209
Weighted Normalized Matrix (May, 2021)														
WTP-1	0.039127	0.034630	0.045468	0.039378	0.006559	0.043600	0.039288	0.038040	0.039519	0.041733	0.044590	0.048815	0.042392	0.042073
WTP-2	0.049996	0.032466	0.044878	0.039219	0.047960	0.045053	0.041320	0.040346	0.040587	0.041123	0.044859	0.045060	0.042922	0.041405
WTP-3	0.032606	0.033548	0.046649	0.039538	0.047550	0.044085	0.041151	0.041499	0.041655	0.041367	0.045127	0.033795	0.041332	0.040737
Weighted Normalized Matrix (June, 2021)														
WTP-1	0.056107	0.032826	0.045281	0.039218	0.039176	0.044409	0.039165	0.040368	0.040953	0.041734	0.044799	0.051915	0.042577	0.042285
WTP-2	0.037405	0.033921	0.045281	0.039325	0.039176	0.043931	0.041038	0.039215	0.040953	0.041245	0.044620	0.044499	0.042577	0.040963
WTP-3	0.023378	0.033921	0.046442	0.039592	0.039176	0.044409	0.041549	0.040368	0.039875	0.041245	0.045157	0.029666	0.041499	0.040963

Figure 4.8: Calculating Weighted Normalized Matrix for Six Months using Fuzzy scale (0,1,2)

4.5.1.3 Calculating the Positive & Negative Bests using Fuzzy scale (0,1,2)

In this step, the Positive & Negative Bests was calculated, where the elements (V_n and V_p) used in the octave program were defined, as shown in the Figure 4.9.



Workspace

Filter

Name	Class	Dimension	Value	Attribute
Positive_best	char	1x164	0.035609 0.03...	
Sn	double	3x14	[1.8757e-04, 0, ...	
Snegative	double	1x3	[0.044128, 0.049...	
Sp	double	3x14	[0, 0, 1.4263e-0...	
Splus	double	1x3	[0.022597, 0.010...	
Vn	double	1x14	[0.049305, 0.031...	
Vp	double	1x14	[0.035609, 0.031...	
W	double	1x14	[0.071900, 0.054...	

Figure 4.9: Defining the Elements in the Octave Program to Calculation the Positive & Negative Bests using Fuzzy Scale (0,1,2)

After defining the values, a special code was designed in the program to calculate the Positive & Negative Bests using Fuzzy scale (0,1,2) for water stations within six months.

```
%% calculating the positive and negative best
for j=1:length(W)
   if Wcriteria(1,j)== 0
      Vp(1,j)= min(Yw(:,j));
      Vn(1,j)= max(Yw(:,j));
   else
      Vp(1,j)= max(Yw(:,j));
      Vn(1,j)= min(Yw(:,j));
   end
end
 Positive_best = num2str([Vp])
 Negative_best = num2str([Vn])
```

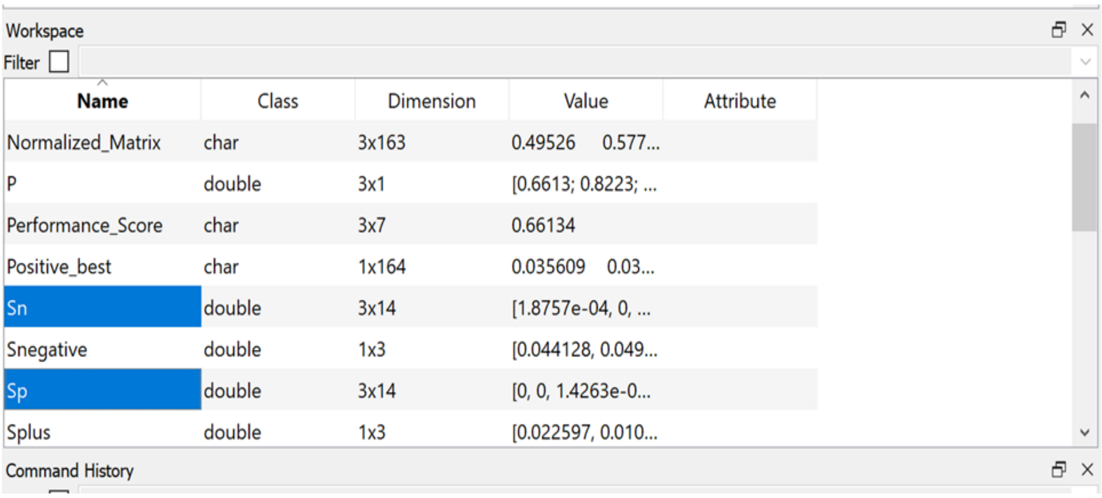
After running the code, the required values for Positive & Negative Bests of water stations were obtained from January to June. As shown in Figure 4.10.

Calucluating the Positive and Negative Bests														
Positive and Negative Bests (January, 2021)														
Positive Best	0.035347	0.03356	0.046247	0.039333	0.049059	0.043773	0.03998	0.030753	0.038649	0.041318	0.04432	0.039489	0.041655	0.040418
Negative Best	0.048942	0.03356	0.045091	0.039425	0.005405	0.044724	0.041408	0.053305	0.042943	0.041453	0.045165	0.049361	0.042781	0.042623
Positive and Negative Bests (February, 2021)														
Positive Best	0.032989	0.03356	0.045671	0.039287	0.040976	0.043616	0.039382	0.028592	0.039181	0.041408	0.044293	0.043032	0.04203	0.040436
Negative Best	0.052232	0.03356	0.045671	0.039471	0.038244	0.044564	0.041391	0.056231	0.04198	0.041408	0.045216	0.043032	0.042598	0.042602
Positive and Negative Best (March, 2021)														
Positive Best	0.037357	0.03356	0.046462	0.038921	0.040467	0.042621	0.039451	0.03796	0.039647	0.040932	0.044557	0.03256	0.040339	0.040665
Negative Best	0.044828	0.03356	0.045271	0.039686	0.037856	0.045043	0.041832	0.042705	0.041063	0.041763	0.045253	0.058609	0.044373	0.042143
Positive and Negative Bests (April, 2021)														
Positive Best	0.036392	0.03356	0.046049	0.037704	0.039733	0.043476	0.040296	0.039617	0.038955	0.040845	0.044592	0.035533	0.041579	0.039927
Negative Best	0.04479	0.03356	0.045481	0.040291	0.038386	0.044863	0.041191	0.040718	0.041877	0.041855	0.045125	0.049746	0.043013	0.043209
Positive and Negative Best (May, 2021)														
Positive Best	0.032606	0.03463	0.046649	0.039219	0.04796	0.0436	0.039288	0.03804	0.039519	0.041123	0.04459	0.033795	0.041332	0.040737
Negative Best	0.049996	0.032466	0.044878	0.039538	0.006559	0.045053	0.04132	0.041499	0.041655	0.041733	0.045127	0.048815	0.042922	0.042073
Positive and Negative Best (June, 2021)														
Positive Best	0.023378	0.033921	0.046442	0.039218	0.039176	0.043931	0.039165	0.039215	0.039875	0.041245	0.04462	0.029666	0.041499	0.040963
Negative Best	0.056107	0.032826	0.045281	0.039592	0.039176	0.044409	0.041549	0.040368	0.040953	0.041734	0.045157	0.051915	0.042577	0.042285

Figure 4.10: Calculating the Positive & Negative Bests for Six Months using Fuzzy scale (0,1,2)

4.5.1.4 Calculating the Euclidean Distance from Ideal Best & Worst best using Fuzzy scale (0,1,2)

In this step, the Positive & Negative Bests was calculated, where the elements (S_n and S_p) used in the octave program were defined, as shown in Figure 4.11.



Workspace

Filter

Name	Class	Dimension	Value	Attribute
Normalized_Matrix	char	3x163	0.49526 0.577...	
P	double	3x1	[0.6613; 0.8223; ...	
Performance_Score	char	3x7	0.66134	
Positive_best	char	1x164	0.035609 0.03...	
Sn	double	3x14	[1.8757e-04, 0, ...	
Snegative	double	1x3	[0.044128, 0.049...	
Sp	double	3x14	[0, 0, 1.4263e-0...	
Splus	double	1x3	[0.022597, 0.010...	

Command History

Figure 4.11: Defining the Elements in the Octave Program to Calculation the Euclidean Distance using Fuzzy Scale (0,1,2)

After defining the values, a special code was designed in the program to calculate the Euclidean distance using Fuzzy scale (0,1,2) for water stations within six months.

```
%% Euclidean distance from Ideal Best and Worst
for j=1:length(W)
    for i=1:Xval
        Sp(i,j)=((Yw(i,j)-Vp(j)).^2);
        Sn(i,j)=((Yw(i,j)-Vn(j)).^2);
    end
end
for i=1:Xval
    Splus(i)=sqrt(sum(Sp(i,:)));
    Snegative(i)=sqrt(sum(Sn(i,:)));
end
```

After running the code, the required values for Euclidean distance of water stations were obtained from January to June. As shown in Figure 4.12.

Euclidean Distance from Ideal Best and Worst			
(January, 2021)			
	WTP-1	**WTP-2**	**WTP-3**
Ideal Positive	0.022837	0.010629	0.045941
Ideal Negative	0.044688	0.050441	0.023882
(Febreuary, 2021)			
	WTP-1	**WTP-2**	**WTP-3**
Ideal Positive	0.0046236	0.0039615	0.033836
Ideal Negative	0.033715	0.032445	0.0034019
(March, 2021)			
	WTP-1	**WTP-2**	**WTP-3**
Ideal Positive	0.0067247	0.027775	0.0036306
Ideal Negative	0.026815	0.005217	0.027722
(April, 2021)			
	WTP-1	**WTP-2**	**WTP-3**
Ideal Positive	0.016618	0.010112	0.0049118
Ideal Negative	0.0051178	0.0084352	0.016706
(May, 2021)			
	WTP-1	**WTP-2**	**WTP-3**
Ideal Positive	0.044575	0.021281	0.0046921
Ideal Negative	0.012105	0.041613	0.047096
(June, 2021)			
	WTP-1	**WTP-2**	**WTP-3**
Ideal Positive	0.039682	0.02059	0.0027695
Ideal Negative	0.0024396	0.020252	0.039662

Figure 4.12: Calculating the Euclidean Distance from Ideal Best & Worst Best for Six Months using Fuzzy scale (0,1,2)

4.5.1.5 The Performance Score & Ranking of the three WTPs using Fuzzy scale (0,1,2)

In this step, the Positive & Negative Bests was calculated, where the element (P) used in the octave program were defined, as shown in Figure 4.13.

Workspace

Filter

Name	Class	Dimension	Value	Attribute
Negative_best	char	1x164	0.049305 0.03...	
Normalized_Matrix	char	3x163	0.49526 0.577...	
P	double	3x1	[0.6613; 0.8223; ...	
Performance_Score	char	3x7	0.66134	
Positive_best	char	1x164	0.035609 0.03...	
Sn	double	3x14	[1.8757e-04, 0, ...	
Snegative	double	1x3	[0.044128, 0.049...	
Sp	double	3x14	[0, 0, 1.4263e-0...	

Figure 4.13: Defining the Elements in the Octave Program to Calculation the Performance Score of the Three WTPs using Fuzzy Scale (0,1,2)

After defining the values, a special code was designed in the program to calculate the Performance Score of the three WTPs using Fuzzy scale (0,1,2) for water stations within six months.

```
%% calculating the performance score
P=zeros(Xval,1);
for i=1:Xval
    P(i)=Snegative(i)/(Splus(i)+Snegative(i));
end
Performance_Score =  num2str([P])
```

After running the code, the required values for Performance Score of the three WTPs of water stations were obtained from January to June. As shown in Figure 4.14.

Performance Score & ranking of the WTPs

WTP	Performance Score (January 2021)	Rank
WTP-1	0.6618	2
WTP-2	0.82595	1
WTP-3	0.34204	3
WTP	**Performance Score (Febreuary 2021)**	**Rank**
WTP-1	0.8794	2
WTP-2	0.89119	1
WTP-3	0.091356	3
WTP	**Performance Score (March 2021)**	**Rank**
WTP-1	0.7995	2
WTP-2	0.15813	3
WTP-3	0.8842	1
WTP	**Performance Score (April 2021)**	**Rank**
WTP-1	0.23545	3
WTP-2	0.45481	2
WTP-3	0.77279	1
WTP	**Performance Score (May 2021)**	**Rank**
WTP-1	0.21356	3
WTP-2	0.66164	2
WTP-3	0.9094	1
WTP	**Performance Score (June 2021)**	**Rank**
WTP-1	0.057917	3
WTP-2	0.49586	2
WTP-3	0.93473	1

Figure 4. 14: Calculating the Performance Score of the Three WTPs for Six Months using Fuzzy Scale (0,1,2)

It looks the final performance scores and ranking of the three WTPS using the weights generated via Fuzzy scale (0,1,2) which showed that the first two months

(January & February) the WTP-2 was better than the WTP-1 and WTP-3; and for the last four months of the study period, The results of TOPSIS method reveals that the final ranking over the six months using Fuzzy scale (0,1,2) gave accurate results for WTPs stations.

4.5.2 Applying the code to run the TOPSIS methods using weights generated via Fuzzy Scale (0,0.1,0.2)

4.5.2.1 Calculation the normalized matrix using Fuzzy scale (0,0.1,0.2)

In this step, the normalized matrix was calculated, where the three elements used in the octave program were defined, as shown in Figure 4.15.

Where X= Decision Matrix

W criteria= Beneficial & Non-Beneficial values

W= weights

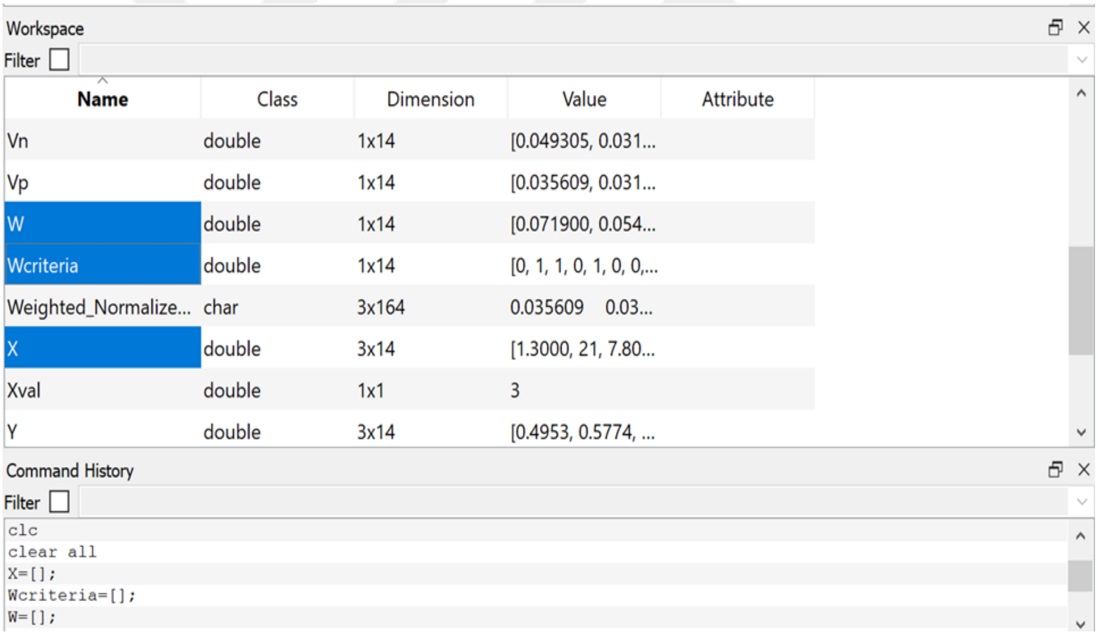


Figure 4.15: Defining the Elements in the Octave Program to Calculation the Normalized Matrix using Fuzzy Scale (0,0.1,0.2)

After defining the values, a special code was designed in the program to calculate the normalization matrix for water stations within six months.

```
Xval=length(X(:,1));
Y = zeros([Xval,length(W)]);
%% calculating the normalized matrix
for j=1:length(W)
```

```
    for i=1:Xval
    Y(i,j)=X(i,j)/sqrt(sum((X(:,j).^2)));
    end
end
```

After running the code, the required values for water stations were obtained from January to June. As shown in Figure 4.16.

Calculating the Normalized Matrixces

Normalized Matrix (January, 2021)

WTP-1	0.49526	0.57735	0.57001	0.57668	0.68624	0.58354	0.58889	0.76963	0.54965	0.57798	0.5803	0.52981	0.58501	0.57379
WTP-2	0.53336	0.57735	0.57732	0.57735	0.723	0.57112	0.57439	0.44402	0.57001	0.57609	0.58128	0.66227	0.56962	0.59429
WTP-3	0.68575	0.57735	0.58463	0.57802	0.07965	0.57733	0.56858	0.45882	0.61072	0.57798	0.57041	0.52981	0.57732	0.56355

Normalized Matrix (February, 2021)

WTP-1	0.46222	0.57735	0.57735	0.5787	0.56362	0.58144	0.58865	0.41282	0.59702	0.57735	0.57997	0.57735	0.57475	0.57386
WTP-2	0.50074	0.57735	0.57735	0.57735	0.60388	0.56907	0.58293	0.41282	0.55722	0.57735	0.58195	0.57735	0.57475	0.59399
WTP-3	0.73185	0.57735	0.57735	0.576	0.56362	0.58144	0.56007	0.81188	0.57712	0.57735	0.57007	0.57735	0.58252	0.56379

Normalized Matrix (March, 2021)

WTP-1	0.57577	0.57735	0.57229	0.57064	0.57714	0.55609	0.57557	0.61658	0.58398	0.57898	0.57614	0.43685	0.55162	0.5876
WTP-2	0.62811	0.57735	0.57229	0.57949	0.5579	0.58769	0.59492	0.54807	0.56385	0.58229	0.57346	0.78633	0.60678	0.56698
WTP-3	0.52342	0.57735	0.58735	0.58185	0.59637	0.58769	0.56106	0.5652	0.58398	0.57071	0.58242	0.43685	0.5723	0.57729

Normalized Matrix (April, 2021)

WTP-1	0.62757	0.57735	0.57494	0.5528	0.5806	0.58535	0.57307	0.57201	0.55401	0.5695	0.57734	0.66742	0.56858	0.57195
WTP-2	0.58835	0.57735	0.57494	0.59072	0.56571	0.57931	0.57307	0.58789	0.59556	0.57889	0.58077	0.57208	0.57511	0.5567
WTP-3	0.5099	0.57735	0.58213	0.58776	0.58556	0.56724	0.58581	0.57201	0.58171	0.58358	0.57392	0.47673	0.58819	0.60246

Normalized Matrix (May, 2021)

WTP-1	0.54823	0.59577	0.57479	0.57735	0.09666	0.56887	0.55874	0.54924	0.56203	0.58188	0.57389	0.65493	0.57969	0.58661
WTP-2	0.70052	0.55853	0.56732	0.57501	0.70681	0.58783	0.58764	0.58252	0.57722	0.57337	0.57734	0.60455	0.58694	0.5773
WTP-3	0.45686	0.57715	0.58972	0.57968	0.70077	0.57519	0.58523	0.59917	0.59241	0.57677	0.5808	0.45341	0.5652	0.56799

Normalized Matrix (June, 2021)

WTP-1	0.78615	0.56473	0.57242	0.575	0.57735	0.57942	0.55699	0.58285	0.58241	0.58189	0.57657	0.69653	0.58222	0.58957
WTP-2	0.5241	0.58356	0.57242	0.57656	0.57735	0.57319	0.58362	0.5662	0.58241	0.57507	0.57427	0.59702	0.58222	0.57114
WTP-3	0.32756	0.58356	0.58709	0.58048	0.57735	0.57942	0.59089	0.58285	0.56709	0.57507	0.58119	0.39801	0.56748	0.57114

Figure 4.16: Calculating Normalized Matrix for Six Months using Fuzzy Scale (0,0.1,0.2)

4.5.2.2 Calculation the weighted normalized matrix using Fuzzy scale (0,0.1,0.2)

In this step, the normalized matrix was calculated, where the Y_w element used in the octave program were defined, as shown in the Figure 4.17.

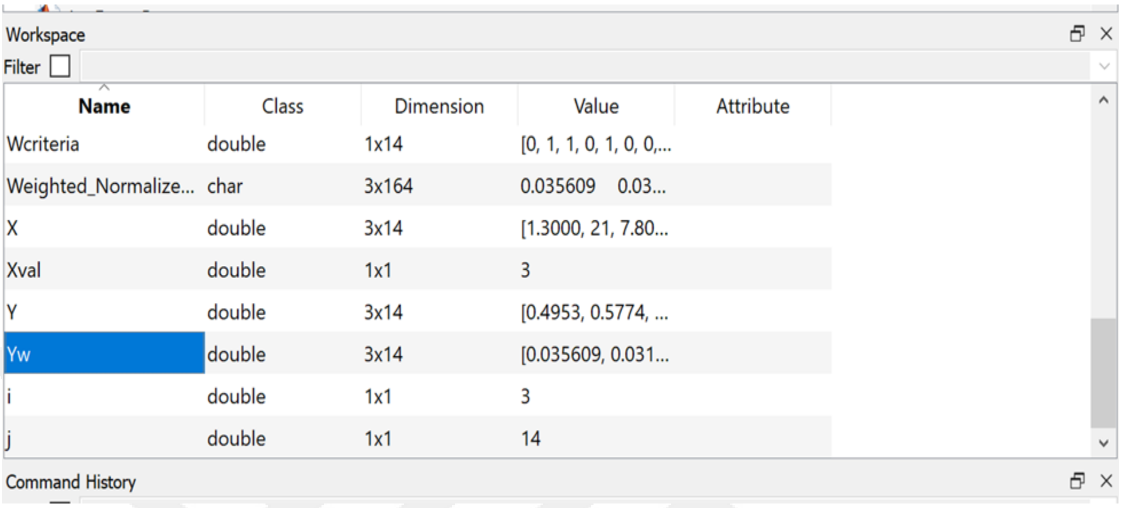


Figure 4.17: Defining the Element in the Octave Program to Calculation the Weighted Normalized Matrix using Fuzzy Scale (0,0.1,0.2)

After defining the values, a special code was designed in the program to calculate the weighted normalization matrix for water stations within six months.

```
% calculating the weighted normalized matrix
for j=1:length(W)
   for i=1:Xval
      Yw(i,j)=Y(i,j).*W(j);
   end
end
Weighted_Normalized_Matrix = num2str([Yw])
```

After running the code, the required values for water stations were obtained of weight normalization from January to June. As shown in Figure 4.18.

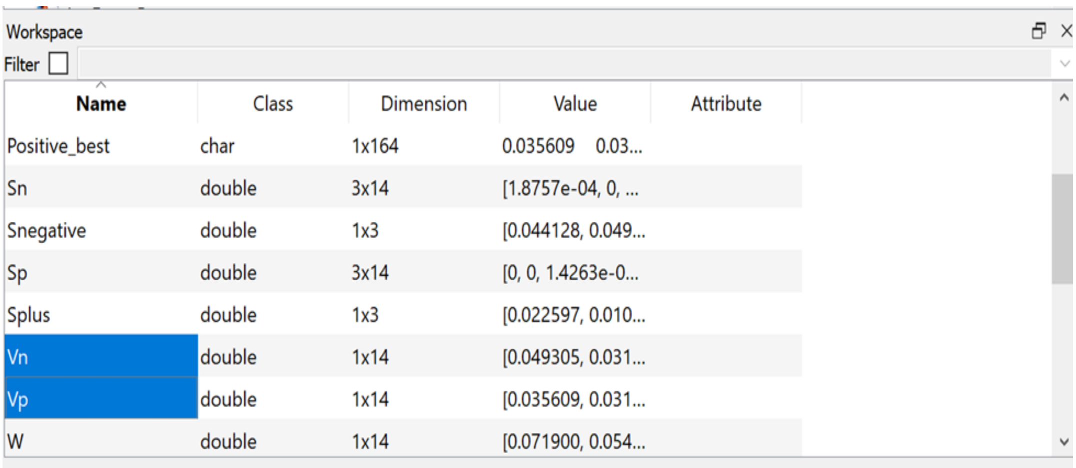
Weighted Normalized Matrix

Weighted Normalized Matrix (January, 2021)														
WTP-1	0.035347	0.033560	0.045091	0.039333	0.046564	0.044724	0.041408	0.053305	0.038649	0.041453	0.045088	0.039489	0.042781	0.041153
WTP-2	0.038066	0.033560	0.045669	0.039379	0.049059	0.043773	0.040388	0.030753	0.040080	0.041318	0.045165	0.049361	0.041655	0.042623
WTP-3	0.048942	0.033560	0.046247	0.039425	0.005405	0.044249	0.039980	0.031778	0.042943	0.041453	0.044320	0.039489	0.042218	0.040418
Weighted Normalized Matrix (February, 2021)														
WTP-1	0.032989	0.033560	0.045671	0.039471	0.038244	0.044564	0.041391	0.028592	0.041980	0.041408	0.045062	0.043032	0.042030	0.041158
WTP-2	0.035738	0.033560	0.045671	0.039379	0.040976	0.043616	0.040989	0.028592	0.039181	0.041408	0.045216	0.043032	0.042030	0.042602
WTP-3	0.052232	0.033560	0.045671	0.039287	0.038244	0.044564	0.039382	0.056231	0.040580	0.041408	0.044293	0.043032	0.042598	0.040436
Weighted Normalized Matrix (March 2021)														
WTP-1	0.041092	0.033560	0.045271	0.038921	0.039161	0.042621	0.040471	0.042705	0.041063	0.041526	0.044765	0.032560	0.040339	0.042143
WTP-2	0.044828	0.033560	0.045271	0.039525	0.037856	0.045043	0.041832	0.037960	0.039647	0.041763	0.044557	0.058609	0.044373	0.040665
WTP-3	0.037357	0.033560	0.046462	0.039686	0.040467	0.045043	0.039451	0.039146	0.041063	0.040932	0.045253	0.032560	0.041851	0.041404
Weighted Normalized Matrix (April, 2021)														
WTP-1	0.044790	0.033560	0.045481	0.037704	0.039396	0.044863	0.040296	0.039617	0.038955	0.040845	0.044859	0.049746	0.041579	0.041021
WTP-2	0.041990	0.033560	0.045481	0.040291	0.038386	0.044401	0.040296	0.040718	0.041877	0.041519	0.045125	0.042639	0.042057	0.039927
WTP-3	0.036392	0.033560	0.046049	0.040089	0.039733	0.043476	0.041191	0.039617	0.040903	0.041855	0.044592	0.035533	0.043013	0.043209
Weighted Normalized Matrix (May, 2021)														
WTP-1	0.039127	0.034630	0.045468	0.039378	0.006559	0.043600	0.039288	0.038040	0.039519	0.041733	0.044590	0.048815	0.042392	0.042073
WTP-2	0.049996	0.032466	0.044878	0.039219	0.047960	0.045053	0.041320	0.040346	0.040587	0.041123	0.044859	0.045060	0.042922	0.041405
WTP-3	0.032606	0.033548	0.046649	0.039538	0.047550	0.044085	0.041151	0.041499	0.041655	0.041367	0.045127	0.033795	0.041332	0.040737
Weighted Normalized Matrix (June, 2021)														
WTP-1	0.056107	0.032826	0.045281	0.039218	0.039176	0.044409	0.039165	0.040368	0.040953	0.041734	0.044799	0.051915	0.042577	0.042285
WTP-2	0.037405	0.033921	0.045281	0.039325	0.039176	0.043931	0.041038	0.039215	0.040953	0.041245	0.044620	0.044499	0.042577	0.040963
WTP-3	0.023378	0.033921	0.046442	0.039592	0.039176	0.044409	0.041549	0.040368	0.039875	0.041245	0.045157	0.029666	0.041499	0.040963

Figure 4.18: Calculating Weighted Normalized Matrix for Six Months using Fuzzy scale (0,0.1,0.2)

4.5.1.3 Calculating the Positive & Negative Bests using Fuzzy scale (0,0.1,0.2)

In this step, the Positive & Negative Bests was calculated, where the elements (V_n and V_p) used in the octave program were defined, as shown in the Figure 4.19.


Workspace

Filter

Name	Class	Dimension	Value	Attribute
Positive_best	char	1x164	0.035609 0.03...	
Sn	double	3x14	[1.8757e-04, 0, ...	
Snegative	double	1x3	[0.044128, 0.049...	
Sp	double	3x14	[0, 0, 1.4263e-0...	
Splus	double	1x3	[0.022597, 0.010...	
Vn	double	1x14	[0.049305, 0.031...	
Vp	double	1x14	[0.035609, 0.031...	
W	double	1x14	[0.071900, 0.054...	

Figure 4.19: Defining the Elements in the Octave Program to Calculation the Positive & Negative Bests using Fuzzy Scale (0,0.1,0.2)

After defining the values, a special code was designed in the program to calculate the Positive & Negative Bests using Fuzzy scale (0,0.1,0.2) for water stations within six months.

```
%% calculating the positive and negative best
for j=1:length(W)
   if Wcriteria(1,j)== 0
      Vp(1,j)= min(Yw(:,j));
      Vn(1,j)= max(Yw(:,j));
   else
      Vp(1,j)= max(Yw(:,j));
      Vn(1,j)= min(Yw(:,j));
   end
end
Positive_best = num2str([Vp])
Negative_best = num2str([Vn])
```

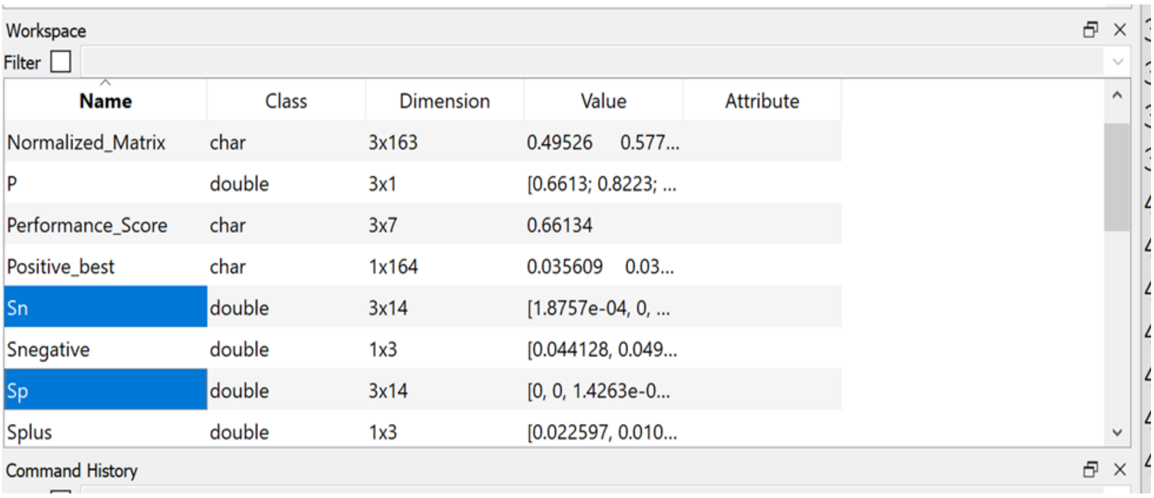
After running the code, the required values for Positive & Negative Bests of water stations were obtained from January to June. As shown in Figure 4.20.

Caluculating the Positive and Negative Bests														
Positive and Negative Bests (January, 2021)														
Positive Best	0.035347	0.03356	0.046247	0.039333	0.049059	0.043773	0.03998	0.030753	0.038649	0.041318	0.04432	0.039489	0.041655	0.040418
Negative Best	0.048942	0.03356	0.045091	0.039425	0.005405	0.044724	0.041408	0.053305	0.042943	0.041453	0.045165	0.049361	0.042781	0.042623
Positive and Negative Bests (February, 2021)														
Positive Best	0.032989	0.03356	0.045671	0.039287	0.040976	0.043616	0.039382	0.028592	0.039181	0.041408	0.044293	0.043032	0.04203	0.040436
Negative Best	0.052232	0.03356	0.045671	0.039471	0.038244	0.044564	0.041391	0.056231	0.04198	0.041408	0.045216	0.043032	0.042598	0.042602
Positive and Negative Best (March, 2021)														
Positive Best	0.037357	0.03356	0.046462	0.038921	0.040467	0.042621	0.039451	0.03796	0.039647	0.040932	0.044557	0.03256	0.040339	0.040665
Negative Best	0.044828	0.03356	0.045271	0.039686	0.037856	0.045043	0.041832	0.042705	0.041063	0.041763	0.045253	0.058609	0.044373	0.042143
Positive and Negative Bests (April, 2021)														
Positive Best	0.036392	0.03356	0.046049	0.037704	0.039733	0.043476	0.040296	0.039617	0.038955	0.040845	0.044592	0.035533	0.041579	0.039927
Negative Best	0.04479	0.03356	0.045481	0.040291	0.038386	0.044863	0.041191	0.040718	0.041877	0.041855	0.045125	0.049746	0.043013	0.043209
Positive and Negative Best (May, 2021)														
Positive Best	0.032606	0.03463	0.046649	0.039219	0.04796	0.0436	0.039288	0.03804	0.039519	0.041123	0.04459	0.033795	0.041332	0.040737
Negative Best	0.049996	0.032466	0.044878	0.039538	0.006559	0.045053	0.04132	0.041499	0.041655	0.041733	0.045127	0.048815	0.042922	0.042073
Positive and Negative Best (June, 2021)														
Positive Best	0.023378	0.033921	0.046442	0.039218	0.039176	0.043931	0.039165	0.039215	0.039875	0.041245	0.04462	0.029666	0.041499	0.040963
Negative Best	0.056107	0.032826	0.045281	0.039592	0.039176	0.044409	0.041549	0.040368	0.040953	0.041734	0.045157	0.051915	0.042577	0.042285

Figure 4. 20: Calculating the Positive & Negative Bests for Six Months using Fuzzy scale (0,0.1,0.2)

4.5.1.4 Calculating the Euclidean Distance from Ideal Best & Worst best using Fuzzy scale (0,0.1,0.2)

In this step, the Positive & Negative Bests was calculated, where the elements (S_n and S_p) used in the octave program were defined, as shown in the Figure 4.21.



Name	Class	Dimension	Value	Attribute
Normalized_Matrix	char	3x163	0.49526 0.577...	
P	double	3x1	[0.6613; 0.8223; ...	
Performance_Score	char	3x7	0.66134	
Positive_best	char	1x164	0.035609 0.03...	
Sn	double	3x14	[1.8757e-04, 0, ...	
Snegative	double	1x3	[0.044128, 0.049...	
Sp	double	3x14	[0, 0, 1.4263e-0...	
Splus	double	1x3	[0.022597, 0.010...	

Figure 4. 21: Defining the Elements in the Octave Program to Calculation the Euclidean Distance using Fuzzy Scale (0,0.1,0.2)

After defining the values, a special code was designed in the program to calculate the Euclidean distance using Fuzzy scale (0,0.1,0.2) for water stations within six months.

```
%% Euclidean distance from Ideal Best and Worst
for j=1:length(W)
    for i=1:Xval
        Sp(i,j)=((Yw(i,j)-Vp(j)).^2);
        Sn(i,j)=((Yw(i,j)-Vn(j)).^2);
    end
end
for i=1:Xval
    Splus(i)=sqrt(sum(Sp(i,:)));
    Snegative(i)=sqrt(sum(Sn(i,:)));
end
```

After running the code, the required values for Euclidean distance of water stations were obtained from January to June. As shown in Figure 4.22.

Euclidean Distance from Ideal Best and Worst			
(January, 2021)			
	WTP-1	WTP-2	WTP-3
Ideal Positive	0.022837	0.010629	0.045941
Ideal Negative	0.044688	0.050441	0.023882
(Febreuary, 2021)			
	WTP-1	WTP-2	WTP-3
Ideal Positive	0.0046236	0.0039615	0.033836
Ideal Negative	0.033715	0.032445	0.0034019
(March, 2021)			
	WTP-1	WTP-2	WTP-3
Ideal Positive	0.0067247	0.027775	0.0036306
Ideal Negative	0.026815	0.005217	0.027722
(April, 2021)			
	WTP-1	WTP-2	WTP-3
Ideal Positive	0.016618	0.010112	0.0049118
Ideal Negative	0.0051178	0.0084352	0.016706
(May, 2021)			
	WTP-1	WTP-2	WTP-3
Ideal Positive	0.044575	0.021281	0.0046921
Ideal Negative	0.012105	0.041613	0.047096
(June, 2021)			
	WTP-1	WTP-2	WTP-3
Ideal Positive	0.039682	0.02059	0.0027695
Ideal Negative	0.0024396	0.020252	0.039662

Figure 4.22: Calculating the Euclidean Distance from Ideal Best & Worst best for Six Months using Fuzzy scale (0,0.1,0.2)

4.5.1.5 The Performance Score & Ranking of the three WTPs using Fuzzy scale (0,0.1,0.2)

In this step, the Positive & Negative Bests was calculated, where the element (P) used in the octave program were defined, as shown in the Figure 4.23.

Workspace

Filter

Name	Class	Dimension	Value	Attribute
Negative_best	char	1x164	0.049305 0.03...	
Normalized_Matrix	char	3x163	0.49526 0.577...	
P	double	3x1	[0.6613; 0.8223; ...	
Performance_Score	char	3x7	0.66134	
Positive_best	char	1x164	0.035609 0.03...	
Sn	double	3x14	[1.8757e-04, 0, ...	
Snegative	double	1x3	[0.044128, 0.049...	
Sp	double	3x14	[0, 0, 1.4263e-0...	

Figure 4.23: Defining the Elements in the Octave Program to Calculation the Performance Score of the Three WTPs using Fuzzy Scale (0,0.1,0.2)

After defining the values, a special code was designed in the program to calculate the Performance Score of the three WTPs using Fuzzy scale (0,0.1,0.2) for water stations within six months.

```
%% calculating the performance score
P=zeros(Xval,1);
for i=1:Xval
   P(i)=Snegative(i)/(Splus(i)+Snegative(i));
end
Performance_Score =  num2str([P])
```

After running the code, the required values for Performance Score of the three WTPs of water stations were obtained from January to June. As shown in figure 4.24

Performance Score & ranking of the WTPs

WTP	Performance Score (January 2021)	Rank
WTP-1	0.6618	2
WTP-2	0.82595	1
WTP-3	0.34204	3
WTP	**Performance Score (Febreuary 2021)**	**Rank**
WTP-1	0.8794	2
WTP-2	0.89119	1
WTP-3	0.091356	3
WTP	**Performance Score (March 2021)**	**Rank**
WTP-1	0.7995	2
WTP-2	0.15813	3
WTP-3	0.8842	1
WTP	**Performance Score (April 2021)**	**Rank**
WTP-1	0.23545	3
WTP-2	0.45481	2
WTP-3	0.77279	1
WTP	**Performance Score (May 2021)**	**Rank**
WTP-1	0.21356	3
WTP-2	0.66164	2
WTP-3	0.9094	1
WTP	**Performance Score (June 2021)**	**Rank**
WTP-1	0.057917	3
WTP-2	0.49586	2
WTP-3	0.93473	1

Figure 4.24: Calculating the Performance Score of the Three WTPs for Six Months using Fuzzy Scale (0,0.1,0.2)

Also, as the result of last Fuzzy scale, the results of performance scores and ranking of the three WTPS using the weights generated via Fuzzy scale (0,0.1,0.2). which showed that the first two months (January & February) the WTP-2 was better than the WTP-1 and WTP-3; and for the last four months of the study period, The results of TOPSIS method reveals that the final ranking over the six months using Fuzzy scale (0,0.1,0.2) gave accurate results for WTPs stations.

4.5.3 Comparison for the Performance Scores & Ranking of both Fuzzy Scales (0,1,2) & (0, 0.1, 0.2)

The analysis showed the performance results for January and February in the three water treatment plants, Whereas WTP-2 performed better than WTP-1, and WTP-3, respectively. As for March, the performance of WTP-3 was much better than WTP-2, and WTP-1 maintained its performance during the three months compared to the rest of the stations. During the other three months, we see that WTP-3 performs better than the rest of WTP-1 and WTP-2.

The results of performance scores & ranking for the two approaches of fuzzy scales integrated with TOPSIS emphasis that the performance was similar over the six months. This indicates the accuracy of the analysis carried out on the stations in determining the water quality in the three stations. As shown in Figure 4.25.

Fuzzy Sclae (1,2,3)	Scores of January	Ranking	Scores of February	Ranking	Scores of March	Ranking	Scores of April	Ranking	Scores of May	Ranking	Scores of June	Ranking
WTP-1	0.6618	2	0.8794	2	0.7995	2	0.23545	3	0.21356	3	0.057917	3
WTP-2	0.82595	1	0.89119	1	0.15813	3	0.45481	2	0.66164	2	0.49586	2
WTP-3	0.34204	3	0.091356	3	0.8842	1	0.77279	1	0.9094	1	0.93473	1

Fuzzy Sclae (0,0.1,0.2)	Scores of January	Ranking	Scores of February	Ranking	Scores of March	Ranking	Scores of April	Ranking	Scores of May	Ranking	Scores of June	Ranking
WTP-1	0.66134	2	0.8797	2	0.80175	2	0.23251	3	0.21624	3	0.057308	3
WTP-2	0.82231	1	0.89016	1	0.1555	3	0.45544	2	0.65626	2	0.49537	2
WTP-3	0.34377	3	0.091736	3	0.88482	1	0.77507	1	0.90944	1	0.93544	1

Figure 4.25: Comparison for the Performance Scores of Both Fuzzy Scales (0,1,2) & (0, 0.1, 0.2)

5. CONCLUSION AND RECOMMENDATIONS

The water quality & the performance WTPs evaluation for is globally and especially in Iraq facing shortage in research study in this field. In this thesis an evaluation of a three WTPs located in Fallujah city was conducted. A survey was designed with a specific question related to the water quality generally and the WQPs particularly to identify the significance or impact to number of fourteen parameter like (Turbidity, Temperature, pH, electrical conductivity, Alkalinity, Chloride, Sulphates, Magnesium, Potassium, Hardness, Total Dissolved Solids, Total Suspended, Calcium, Sodium) whom has direct impact on the quality of drinking water. The survey carried out and 32 answers with required data was collected from different experts working in the same field of study. This survey included several metrics, and each metric would be evaluated based on Likert 1-7 scale. These factors were: (extremely important, very important, somewhat important, neither important not unimportant, somewhat unimportant, not very important, not at all important,). Then, the result of the survey scale valued and the sum for each parameter collect to generate the primary weights for these parameters. After that, The RII calculation were conducted on the primary weights to extract the weights that required for the TOPSIS method. In the other hand, it used two Fuzzy scales (0,1,2) & (0, 0.1, 0.2) and applied on the survey and RII results to create a second layer of generating the TOPSIS weights. Then, the MCDM\TOPSIS method executed using Octave software where three variables were created with represent the decision matrix which taken form the WQ testing results of these WTPs, the final weights which generated using the both approaches of the two fuzzy scales, and the beneficial & on-beneficial values that identified using the water quality parameters scale. After identifying these three major elements which required to run the code. TOPSIS method application has been done using the two fuzzy scale that the four main steps of TOPSIS method which are the normalized matrix, the weighted normalized matrix, the positive and negative bests, Euclidean distance from Ideal Best and Worst, and finally obtaining the final performance scores and ranking of the three WTPS using the weights generated via both Fuzzy scales which showed that the first two months (January &

February) the WTP-2 was better than the WTP-1 and WTP-3; and for the last four months of the study period. The results of TOPSIS method reveals that the final ranking over the six months using both Fuzzy scales gave the similar ranking for these WTPs.

REFERENCES

Al-Imarah, F. J.-A. (2017). Assessment of Water Quality for Drinking Water Supplies Plants at Basrah, Iraq. journal of kerbala university, 11(3), 187-198.

Alley, E. R. (2007). Water quality control handbook. United States of America: McGraw-Hill Education.

Al-Ridah, Z. A.-Z. (2020). Drinking water quality assessment by using water quality index (WQI) for Hillah River, Iraq. Ecology, Environmental & Conservation, 26, 390-399.

Al-Shandah, B. T. (2019). Reduction Turbidity of Water in Tikrit Drinking Water Treatment Plant by Using Alum Which was Quantified by a Jar Test Apparatus, with limnological Study of Treated and Raw Water. Indian Journal of Public Health, 10(8).

Braun, M. (2019). Performance Evaluation of a Drinking Water Treatment Plant in Samaipata. Bolivia: Chalmers Open Digital Repository.

Catley-Carlson, M. (2012). Why water management starts at the local level. UN Chronicle, 49(2), 40-43.

Choudhury, S. . (2018). Prediction of operation efficiency of water treatment plant with the help of multi-criteria decision-making. Water Conservation Science and Engineering, 3(2), 79-90.

Darre, N. C. ((2018). Desalination of water: a review. Current Pollution Reports, 4(2), 104-111.

Daud, M. K. (2017). Drinking water quality status and contamination in Pakistan. BioMed research international.

Devesa, R. ((2018). Guidance for optimizing drinking water taste by adjusting mineralization as measured by total dissolved solids (TDS). Desalination, 439, 147-154.

EPA., U. (2010). A Framework Incorporating Community Preferences In Use Attainment and Related Water Quality Decision-Making . Washington, DC: U.S. Environmental Protection Agency.

Ewaid, S. H. (2018). Fuzzy Logic Inference Index to Assess the Water Quality of Tigris River within Baghdad City. Al-Mustansiriyah Journal of Science, 29(3), 16-20.

Fidel, R. B. (2017). Characterization and quantification of biochar alkalinity. . Chemosphere, 167, 367-373.

Gorde, S. P. (2013). Assessment of water quality parameters: a review. J. Eng. Res. Appl., 3(6), 2029-2035.

Graham, B. (2015). City of Kenora Water Treatment and Distribution System Drinking Water Quality Management System Operational Plan. The City of KenoraDWQMS Operational Plan.

H. M. Ali, D. Z. (2019). Performance Evaluation of Drinking Water Treatment Plant in Iraq. Orient. J. Phys. Sci., vol. 4, no. 1, pp. 18–29.

Hassan, F. M. (2018). Evaluate the efficiency of drinking water treatment plants in Baghdad City–Iraq. J. Appl. Environ. Microbiol, 6(1), 1-9.

Hounslow, A. W. (2018). Water quality data: analysis and interpretation. CRC press., 56-85.

Howe, K. J. (2012). Principles of water treatment. John Wiley & Sons., 50-62.

Hu, H. Y. (2010). Service quality gaps analysis based on Fuzzy linguistic SERVQUAL with a case study in hospital out-patient services. The TQM Journal, 22(5), 499-515.

Issa, H. M. (2017). valuation of water quality and performance for a water treatment plant: Khanaqin city as a case study. Journal of Garmian University, 802-821.

Issa, H. M. (2018). Long-term drinking water quality assessment using index and multivariate statistical analysis for three water treatment plants of Erbil City, Iraq. UKH Journal of Science and Engineering, 2(2), 39-48.

M. S. Huda, M. S. (2018). Evaluating the Performance of Water Treatment Plant Evaluating the Performance of Water Treatment Plant (Case Study . www.elixirpublishers.com, p.9.

Melo, L. D. (2019). Adequacy analysis of drinking water treatment technologies in regard to the parameter turbidity, considering the quality of natural waters treated by large-scale WTPs in Brazil. . Environmental monitoring and assessment, 191(6), 1-12.

Mladenović-Ranisavljević, I. I. (2018). Water quality assessment based on combined multi-criteria decision-making method with index method. Water Resources Management, 32(7), 2261-2276.

Mohammed, Z. B. (2015). Evaluation The Quality of Raw and Treated Water for Number of Water Treatment Plants in Baghdad, Using a Water Quality Index. Engineering and Technology Journal, 33(6), 1429-1441.

Molinos-Senante, M. &.-G. (2018). Evaluation of energy performance of drinking water treatment plants: Use of energy intensity and energy efficiency metrics. Applied energy, 229, 1095-1102.

Okoye, C. O. (2009). Physico-chemical quality of shallow well-waters in Gboko, Benue state, Nigeria. Bulletin of the Chemical Society of Ethiopia, 23(1), 123-128.

Omar, I. A. (2020). Performance Evaluation and Improvement of Ifraz-2 Water Treatment Plant. Advances in Environmental Biology, 14(7), 1-10.

Organization, W. H. (2017). Guidelines for drinking-water quality: first addendum to the fourth edition. Geneva: WHO Library Cataloguing-in-Publication Data.

Organization, World Health. (2021). WHO guidelines on recreational water quality: volume 1: coastal and fresh waters. World Health Organization, 40-50.

Ramal, M. M. (2021). Heavy metal assessment in taps drinking water of Ramadi city using water quality Indices, Anbar Province, Iraq. International Journal of Sustainable Development and Planning, 16(7), 1349-1357.

Ramírez, Y. K. (2019). Decision-support framework for the environmental assessment of water treatment systems. . Journal of Cleaner Production, 225, 599-609.

Roy, R. (2019). An introduction to water quality analysis. ESSENCE Int. J. Env. Rehab. Conserv, 9(1), 94-100.

Roy, R. M. (2018). nsemble MCDM approach to determine priorities of parameters for WQI. Springer, Singapore., (pp. 549-566).

Savic, D. A. (2016). Serious gaming for water systems planning and management. Water, 8(10), 456.

Unicef. (2020). Water and the global climate crisis: 10 things you should know.

Watson, S. B. ((2004). Aquatic taste and odor: a primary signal of drinking-water integrity. Journal of Toxicology and Environmental Health, Part A, 67(20-22), 1779-1795.

World Health Organization. (2011). Strategies for the Safe Management of Drinking-Water for Human consumption.

APPENDIX

Appendix-A: TOPSIS Ocatve Software Code

```
Xval=length(X(:,1));
Y = zeros([Xval,length(W)]);
%% calculating the normalized matrix
for j=1:length(W)
    for i=1:Xval
    Y(i,j)=X(i,j)/sqrt(sum((X(:,j).^2)));
    end
end
Normalized_Matrix = num2str([Y])
%% calculating the weighted mormalized matrix
for j=1:length(W)
    for i=1:Xval
        Yw(i,j)=Y(i,j).*W(j);
    end
end
Weighted_Normalized_Matrix = num2str([Yw])
%% calculating the positive and negative best

for j=1:length(W)
    if Wcriteria(1,j)== 0
        Vp(1,j)= min(Yw(:,j));
        Vn(1,j)= max(Yw(:,j));
    else
        Vp(1,j)= max(Yw(:,j));
        Vn(1,j)= min(Yw(:,j));
    end
end
 Positive_best = num2str([Vp])
 Negative_best = num2str([Vn])

%% Euclidean distance from Ideal Best and Worst
for j=1:length(W)
    for i=1:Xval
        Sp(i,j)=((Yw(i,j)-Vp(j)).^2);
        Sn(i,j)=((Yw(i,j)-Vn(j)).^2);
    end
end

for i=1:Xval
    Splus(i)=sqrt(sum(Sp(i,:)));
    Snegative(i)=sqrt(sum(Sn(i,:)));
end
%% calculating the performance score
P=zeros(Xval,1);
for i=1:Xval
    P(i)=Snegative(i)/(Splus(i)+Snegative(i));
end
Performance_Score =  num2str([P])
```

RESUME

Ayad Khalaf Dhari AL-MOHAMMEDI

EDUCATION:

- B.Sc. in Computer Techniques Engineering from Al-Ma'mon University College 2008-2012

WORK EXPERIENCE:

- 2012-2022 working as projects Manager for number of Water Treatments Plants within the National Directorate of Water