INFLUENCE OF RICE FARMING ON WATER QUALITY IN THE DAKALT BRANCH CANAL, NILE DELTA, EGYPT

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work, and has not been presented to this University or any other for the award of any degree.

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Recommendation

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DEDICATION

This thesis is dedicated to my parents, Mr. Elisha Onyango, and Mrs. Teresa Cornelia, my sisters and nieces.

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ABSTRACT

The Nile Delta is an extensive area important to Egypt due to its ecological and agricultural functions. It is an area known for supporting large-scale farming practices in the country for centuries, providing food and income for millions, and regulating the climate in the northern part of the country where it is situated. Unfortunately, over the years, the water quality of the Nile Delta has deteriorated due to the increasing economic development, industrialisation, urbanisation, and human settlement along the Nile River. The study aimed to evaluate the influence of rice farming on water quality in the Dakalt Branch Canal. The physical and chemical water quality parameters of water samples from the Dakalt Branch Canal were measured in space and time to understand the effects of rice farming on the canal's water quality. A cross-sectional research design was employed where quantitative data was analysed to give the desired output. The study area was divided into three sampling sites as guided by the study objectives, and triplicate water samples were collected from each sampling site. Data was analysed using descriptive and inferential statistics where one-way Analysis of Variance (ANOVA) was used to compare the differences in means, while correlation analysis was used to measure the association amongst various study variables. The experimental results showed significant spatial and temporal variation in the water quality parameters ($p<0.05$). A significant spatial variation in both physical and chemical water quality parameters was observed amongst the study sites and this was attributed to untreated waste discharge from the rice paddies. However, significant temporal variation was only observed in temperature and turbidity for physical parameters and in Biological Oxygen Demand, phosphates and nitrates for chemical parameters. The Water Quality Index (WQI) also revealed that all the sampling stations were polluted with an index of more than 100. Moreover, the research established that rice farming activities significantly impact the water quality of the canal and the River Nile both spatially and temporally causing adverse effects on human health, aquatic life and the environment. The study recommends embracing and enforcing Best Management Practices (BMPs) in agricultural production in the Dakalt Branch Canal Irrigation Scheme to protect quality and overall environmental and human health.

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LIST OF ABBREVIATIONS & ACRONYMS

APHA	American Public Health Association
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EC	Electrical conductivity
FAO	Food and Agriculture Organisation
SDWA	The Safe Drinking Water Act
TA	Total Alkalinity
TDS	Total Suspended Solids
TH	Total Hardness
USGS	United States Geographical Survey
WASH	Water, Sanitation and Hygiene
WQA-SPA	Water quality assessment model-set pair analysis theory
WQI	Water quality index

CHAPTER ONE
INTRODUCTION

1.1 Background Information

Globally, various studies have confirmed that the impairment of water quality is attributed to an influx of physical, chemical and biological contaminants (Mozumder & Berrens, 2007; Njue et al., 2022). Choi et al. (2017) observed that rice paddies are often the major sources of nutrients that are discharged to the water body in areas where the predominant land use is rice cultivation. Song (2016) noted that rice production practices (for example, over-pumping of groundwater, improper application of chemicals and loss of biodiversity in rice paddies) are linked to water contamination, excessive salinity, and other environmental problems.

Several studies done in Arica have revealed that excessive use of inorganic fertilisers to increase agricultural production contributes to the pollution of water bodies (Essam, 2011; Naz et al., 2022; Njue et al., 2022; Yaro et al., 2005). A study done by Njue et al. (2022) in Thiba River, a sub-catchment of Tana River Basin, located in Kirinyaga County, Kenya, revealed that agricultural nutrient influx was extremely high in river parts adjacent to agricultural fields, specifically in areas adjacent to rice paddies. This poses a significant threat to humans, livestock and aquatic organisms. Aquatic macroinvertebrates are susceptible to pollutants from agrochemical applications in conventional rice cultivation. The bioaccumulation of these harmful contaminants is detrimental to human health when they consume aquatic products from these contaminated rivers (Rizo-Patrón et al., 2013). Ammonium fertiliser, one of the extensively used fertilisers in rice farming is highly toxic for fish, whereas excessive nitrogenous fertiliser application causes eutrophication, affecting the oxygen supply for aquatic biota (Berka et al., 2001).

Previous studies in Egypt have attributed the deteriorating quality of the Nile River to population increase and anthropogenic activities. El-Sheekh (2009), in his study, found that the major anthropogenic activities that have led to the degradation of River Nile's water quality are the discharge of untreated sewage from open drains, agricultural return flows, domestic sewage, and industrial wastewater. He further noted that pollutants are derived from industrial wastewater, oil pollution, municipal wastewater, and agricultural drainage, including natural cyanotoxins. These pollutants have both environmental and socioeconomic consequences; for example, the blooming of cyanobacteria, elicited by excess nutrients (eutrophication), leads to the production of cyanotoxins, which affect the health of fish and may have adverse human health effects (APRP, 2002; El-Sheekh, 2009; El-Sheekh, 2016). Essam (2011) found that increased industrial growth and intensified agriculture in the countries have directly impacted the quality of water bodies, specifically the River Nile. He also records that industrial activities and the development of urban centres close to water bodies negatively affect the water quality as wastewater is deposited directly without being properly treated.

These studies have helped identify anthropogenic activities as a major cause of non-point pollutants in water bodies, and their impacts on aquatic organisms and human health. However, they have not assessed the various contaminants associated with rice farming and the spatial and temporal variation in physico-chemical water parameters as an impact of rice farming in the Nile River, specifically in the study area. In this study, the spatial and temporal variation in physical and chemical water quality parameters associated with rice farming in the Dakalt Branch Canal was assessed. Additionally, the water quality results from the study area were compared with that of the Egyptian standard regularities of article 60 -law No. 48/1982 and The World Health Organisation set standards.

1.2 Statement of the Problem

Over the past decade, the quality of the River Nile has deteriorated at an alarming rate due to anthropogenic activities such as poor waste disposal, urbanisation, poor agricultural practices, construction, and development, among others. In the Kafrelsheikh governorate, which is characterised by large-scale rice farming and irrigation made possible by canal construction, there has been increased use of inorganic fertilisers and chemicals, coupled with inappropriate rice farming practices. Consequently, the effluent and runoff from these fields are highly toxic, containing chemicals and inorganic fertilisers used to control pests and enrich the soil, respectively. These toxic contaminants find their way into the river, having detrimental effects including biodiversity loss, human health implications i.e., the methemoglobinemia as experienced in parts of Asia specifically the Philippines and other chronic diseases, destruction of aquatic habitats through pollution and eutrophication, and poor water quality in the river Nile. Additionally, in the recent past, there have been cases of fish kills and other aquatic organisms' deaths that are related to water contamination with toxic pollutants from agricultural activities. Therefore, the study assessed the spatial and temporal variation in physical and chemical water quality parameters associated with rice farming in the study area.

1.3 Objectives

1.3.1 Broad Objectives

To contribute towards the conservation and improvement of the water quality of the River Nile through the assessment of the influence of rice farming on water quality in the Dakalt Branch Canal, Nile Delta, Egypt.

1.3.2 Specific Objectives

i. To determine the spatial variation in physical water quality parameters (Turbidity, TDS, EC and Temperature) associated with rice farming in the Dakalt Branch Canal, Kafrelsheikh governorate;

ii. To assess the spatial variation in chemical water quality parameters (BOD, COD, pH, DO, Ammonia, Phosphates and Nitrates) associated with rice farming in the Dakalt Branch Canal, Kafrelsheikh governorate;

iii. To establish the temporal variation in physical water quality parameters (Turbidity, TDS, EC and Temperature) associated with rice farming in the Dakalt Branch Canal, Kafrelsheikh governorate;

iv. To determine the temporal variation in chemical water quality parameters (BOD, COD, pH, DO, Ammonia, Phosphates and Nitrates) associated with rice farming in the Dakalt Branch Canal, Kafrelsheikh governorate; and

v. To compare the study area water quality parameters with the Egyptian standard regularities of article 60 -law No. 48/1982 and the World Health Organisation Standards.

1.4 Research Hypotheses

$H_0$1 There is no significant spatial variation in physical water quality parameters (Turbidity, TDS, EC and Temperature) in water associated with rice farming in the Dakalt Branch Canal, Kafrelsheikh governorate.

$H_0$2 There is no significant spatial variation in chemical water quality parameters (BOD, COD, pH, DO, Ammonia, Phosphates and Nitrates) associated with rice farming in the Dakalt Branch Canal, Kafrelsheikh governorate.

$H_0$3 There is no significant temporal variation in physical water quality parameters (Turbidity, TDS, EC and Temperature) associated with rice farming in the Dakalt Branch Canal, Kafrelsheikh governorate.

$H_0$4 There is no significant temporal variation in chemical water quality parameters (BOD, COD, pH, DO, Ammonia, Phosphates and Nitrates) associated with rice farming in t the Dakalt Branch Canal, Kafrelsheikh governorate.

$H_0$5 There is no significant difference in the study area water quality parameters with the Egyptian standard regularities of article 60 -law No. 48/1982 and the World Health Organisation Standards

1.5 Justification of the Study

Ensuring the availability and sustainable management of good-quality water is one of the Sustainable Development Goals. This is a significant concern for policymakers and Water Sanitation and Hygiene (WASH) practitioners, particularly in the face of changing climatic conditions, increasing populations, poverty, poor agricultural practices and negative effects of human development. Findings from the proposed research study will enable the government, ministries, scholars, and policymakers to make informed decisions on how best to protect and conserve the quality of the Nile River water. Such measures could minimise the impact of poor rice farming practices in the study area. This is in line with the country's development agenda of ensuring sustainable agriculture and promoting the well-being of its citizens. The findings of the study will also enable the government to streamline its development plans to achieve Sustainable Development Goal number 6: Clean water and sanitation (Ensure availability and sustainable management of water and sanitation for all.), Goal 12: Responsible consumption and production (Ensure sustainable consumption and production patterns), and Goal 14: Life below water (conserve and sustainably use the ocean, seas and marine resources for sustainable development. This will ultimately contribute to mitigating the impact of climate change; SDG number 13 on climate actions.

Egypt, a country with limited water resources due to the climatic condition of the region, and the limited sources highly susceptible to pollution, will likely benefit from this study significantly. The findings highlight the impact of poor management of rice paddies and offer recommendations for sound agricultural practices and safe use of chemicals. Additionally, the findings of the study will enable the government to align and affirm its commitment to the achievement of the African Union Agenda 2063 goals number 5, 6 and 7: which advocates for a healthy life and a well-nourished society, modern agriculture for increased productivity and production; Blue/ocean economy for accelerated economic growth (Sustainable consumption and production patterns and, sustainable natural resource management and biodiversity conservation); Environmentally sustainable climate and resilient economies and communities (This involves putting in place measures to sustainably manage the continent's rich biodiversity, forests, land and waters and using mainly adaptive measures to address climate change risks).

1.6 Scope and Limitations of the Study

The study was carried out along the Dakalt branch canal originating from the Damietta branch, an eastern distributary of the Nile River, Kafrelsheikh Governorate in Egypt. The area is characterised by extensive crop cultivation, predominantly rice. It focused on the analysis of physical and chemical water quality parameters from water samples collected from three points along the canal in the study area. The water sample collection points included a point upstream (where little to no agricultural activity takes place on Damietta Branch), along the canal (The canal serving the rice fields), and downstream (irrigation wastewater discharge outlet of the rice field). The study was carried out within the stipulated 3 months. The type of data collected was physical and chemical parameters of water quality.

This study anticipated that the diversity of field and lab assistants would lead to language barriers. To overcome this challenge, a translator was recruited to facilitate communication and translation between the researcher and the team who spoke different languages. The translator facilitated effective communication by accurately interpreting and conveying the intended meaning of messages exchanged between the two parties. This helped minimise the impact of language barriers on the study. Overall, hiring a translator proved valuable in dealing with the language barrier and ensuring the study's success. Changes in water quality in the study area were ascribed to rice farming activities.

1.7 Definition of Terms

Canal: As used in the study, a canal is an artificial or man-made waterway constructed to convey water from the main river for rice irrigation.

Chemical water quality parameters: include pH, acidity, alkalinity, chlorine, hardness, dissolved oxygen, and biological oxygen demand.

Contaminant: It is defined as any physical or chemical substance or matter in water that alters its natural quality.

Delta: an area of low, flat land shaped like a triangle, where a river splits and spreads out into several branches before entering the sea. The deposition of rich, fertile soil from high up the river makes the area a perfect spot for agricultural activities.

Distributary: It is defined as an outflowing branch of a stream that flows away from a main stream and does not re-join the river again, especially on a delta.

Eutrophication: Eutrophication is the enrichment of water by nutrient salts that causes structural changes to the ecosystem, such as increased production of algae and aquatic plants, depletion of fish species, general degradation of water quality and other effects that reduce and preclude use.

Irrigation: a system of supplying farmland with water through artificial canals and ditches to promote rice growth, especially during dry seasons.

Physical water quality parameters: include colour, taste, odour, temperature, turbidity, solids, and electrical conductivity.

Spatial Variation: As used in the study, it is the change in water quality parameters that is exhibited in the difference in values of the parameters at different locations along the canal.

Temporal Variation: As used in the study, it is the change in water quality parameters that is exhibited in the difference in values of the parameters over a period of time along the canal.

Water Quality Index: It is a dimensionless number that combines multiple water-quality factors into a single number by normalizing values to subjective rating curves. Factors to be included in the WQI model could vary depending on the designated water uses and local preferences, including DO, pH, BOD, COD, total coliform bacteria, temperature, nutrients (nitrogen and phosphorus), etc. These parameters occur in different ranges and are expressed in different units.

The WQI takes the complex scientific information of these variables and synthesises them into a single number.

Water quality: as used in the study, water quality is a term used to describe water's physical, chemical, and biological characteristics.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

This chapter entails a review of various works of literature relevant to this study by examining major issues as depicted by the research objectives. The chapter highlights scholarly work related to the effects of agricultural practices on water quality with the main focus being on rice farming and management and the effect of these practices on water quality. Sub-section 2.2 illustrates the rice farming management practices and their influence on water quality. Sub-section 2.3 elucidates the spatial and temporal variation in physical water quality parameters associated with rice farming while sub-section 2.4 presents the spatial and temporal variation in chemical water quality parameters associated with rice farming. Subsection 2.5 expands on the Egyptian Water and Wastewater Regulatory Agency and The World Health Organisation Standards. Lastly, sub-section 2.6 is the theoretical framework while sub-section 2.7 points out the conceptual framework. Various research gaps emanating from the prevailing pieces of literature have been highlighted in this chapter.

2.2 Rice Farming Management Practices and its Influence on Water Quality

Rice (*Oryza sativa*) is one of the most consumed cereals in the world. According to Liu et al. (2019), approximately one-half of the world's population is wholly dependent on rice as the main staple food. Globally, rice plantations cover approximately 161 million ha of land on Earth, with 10% grown in temperate regions (Krupa et al., 2011). In Egypt, rice plantations cover approximately 650,000 ha of the whole cultivated area which is approximately 3.3 million ha. This is around 20% of the total cultivated area (Elbasiouny & Elbehiry, 2020). Egypt is the largest rice producer in the Middle East region and it is one of the most important crops which Egypt exports around the world (in about 60 countries). This crop takes approximately five months from planting to harvest. High solar radiation, long days and cool nights between May and September favours the optimal growth of rice in the northern part of the county. Its cultivation begins around April till the end of June and its harvest season starts in August to October.

According to Seeboonruang (2012), rice farming has a major impact on water quality. A similar finding was also reported in a study conducted in the Mekong Delta, Vietnam (Wilbers et al., 2014). This is attributed to poor rice paddy management, overuse of inorganic fertiliser, and excessive use of agrochemicals to control pests and diseases (Njue et al., 2022). Uwimana et al., (2018) in their study observed that water quality deterioration was at its peak during the ploughing, weeding and fertiliser application phases. During the ploughing period, the total suspended solid (TSS) was very high due to the mechanical breakdown of soil which was washed back into the river as runoff causing ecological imbalance. Rice is grown on submerged land in the coastal plains, tidal deltas, and river basins of tropical, semitropical, and temperate regions.

In Egypt, the crop is grown in the Nile Delta which is rich in alluvial soil and offers a fairly flat ground suitable for irrigation which favours the crop's requirement for large amounts of water for survival (Essam et al., 2011). Flood irrigation being the most commonly used irrigation method in rice paddies, leads to the discharge of large amounts of contaminated water back into water bodies (Bouman et al., 2007). Interestingly, Egypt relies on the Nile for 97% of its water requirements of which 86% of the water is used for irrigation. This indicates that a large amount of water contaminated with agrochemicals and high in nutrient load is discharged back into the river causing unprecedented effects on the water quality and aquatic life. Liu et al. (2019) confirm that environmental and ecological concerns related to rice paddy production have been outlined as a global issue, particularly the water quality. As Song (2016) noted, rice production practices including over-pumping of groundwater, improper application of agrochemicals and fertilisers, and poor tillage methods in rice paddies, are linked to water contamination, excessive salinity, and other environmental problems. The same sentiment was echoed by Choi et al. (2017) who observed that rice paddies are often the major sources of nutrients that are discharged to the water body. The main types of fertilisers used in rice farming are nitrates (NO_3 and NH_4), phosphates (PO_4) and potassium which when applied in excess quantities; enrich water bodies with nutrients causing eutrophication.

Though this crop is an important staple food across the globe, its poor management practices during cultivation have led to unprecedented environmental and human health implications. The main problem is the contamination of water bodies as a result of discharged of contaminated runoff from the rice paddies (Rizo-Patrón et al., 2013). This discharge is high in contaminants, nutrients and pollutant loads used in pest control and soil nourishment. Therefore, the management of nutrient source, rate, timing, placement, and proper agrochemical use should be combined with the management of irrigation water to reduce the negative influence on river water quality and both environmental and human health implications (Liu et al., 2019).

2.3 Spatial and Temporal Variation in Physical Water Quality Parameters

According to Fathi et al. (2018), the monitoring and control of surface waters are important to ensure sustainability and the availability of good water quality to consumers. Similar observations were made by Sánchez et al. (2007) who noted that monitoring and controlling surface waters are necessary and vital to assure the availability of high-quality water for its numerous uses. Hence, it is important to plan and define parameters and variables to indicate the quality of an aquatic environment. Physical, chemical and microbiological variables are of great importance in assessing the environmental quality of a region, such as hydrographic basins (Oliveira et al., 2018).

One of the most notable methods to quantify the conditions of water is the use of water quality indices (Barakat et al., 2018; Hoseinzadeh et al., 2014). This method classifies surface water quality based on temperature, phosphate, nitrate, dissolved oxygen, total solids, biological oxygen demand, pH, and faecal coliform bacteria. It has proved to be comprehensive for the qualitative classification of surface water where it produced an appropriate view regarding the water quality of water bodies (Sánchez et al., 2007). It is therefore important to note that the variation of physical parameters in water bodies over time and space is a crucial variable to assess the quality of a water body especially those that are at risk of pollution from anthropogenic activities such as intensive agricultural activities.

The physical parameters that are commonly used to assess the quality of a water body include; turbidity, temperature, colour, solids and Electrical conductivity. The variation of these parameters from one point to another over a period of time enables water resource managers to recommend if the water is fit for human consumption and aquatic flora and fauna. A study by Shrestha and Kazama (2007), observed significant spatial and temporal variations in the physical parameters of Fuji River basin water quality where most of the physical parameters had significantly higher values in the dry season as compared to the wet season. The parameters found responsible for water quality variations are mainly related to discharge and temperature (natural), organic pollution (from domestic wastewater) in relatively less polluted areas; organic pollution (from domestic wastewater) and nutrients (from agriculture and orchard plantations) in moderately polluted areas; and organic pollution and nutrients (from domestic wastewater, wastewater treatment plant and industries) in highly polluted areas in the basin.

Qadir et al. (2007) reported that the spatial and temporal variations in physical parameters are responsible for water quality change and suggest the possibility of industrial, municipal and agricultural runoff as the primary sources of pollutants. Turbidity is one of the physical parameters used to evaluate the quality of water (Bedim-Godoy et al., 2021). It is defined in simple terms as how cloudy water is and occurs as a result of high concentrations of silt, clay and organic materials. High turbidity shows that a specific water source in question is not ideal for use and may affect aquatic life (Arora, 2018). The latter adds that silt and suspended material will affect fish growth rate, ability to get food, and ability to flee from predators and worse lead to their death in extreme turbid levels. Such water is also unfit for human consumption and its treatment will be more costly to make it fit for consumption. According to Bedim-Godoy et al. (2021), turbidity in a river increases with the anthropogenic activities that are carried in close proximity including construction and agricultural activities. Agricultural runoff contains silt, clay and organic material which greatly affect turbidity (Shil et al., 2019). The flow rate of a river is also a factor that influences turbidity.

Electrical conductivity (EC) is an estimate of the total amount of dissolved ions in the water. Moniruzzaman et al. (2009) in their study discovered that the Buriganga River's EC value was comparatively high from February to April (774 to 917 S/cm), with the month of April recording the highest average EC value of water (917 S/cm). The spatial variation in the sampling points was observed in February and April which showed high EC (800-1100 µS/cm). High EC levels in river water were mostly caused by diverse industrial and urban activities during the dry season, while relatively low EC levels were seen during the wet season from June to October (109 to 498 S/cm) due to the diluting effect. Electrical conductivity is influenced by several factors from point to point over a period of time which include; temperature and the presence of inorganic dissolved solids such as nitrate, chloride, sulphate and phosphate anions (EPA, 2022).

Electrical conductivity increases as the number of ions in the water increases. This implies that a high electrical conductivity indicates high contaminant levels thus insinuating poor water quality. According to WHO (2003), the recommended EC level should not exceed 400 μS/cm. Any figure higher than that indicates that the water source is polluted. The Food and Agriculture Organisation notes that due to population increase, land under agricultural irrigation has more than doubled in recent decades (from 139 million hectares (Mha) in 1961 to 320 Mha in 2012) (Mateo-Sagasta et al., 2018). Hence, the amount of fertiliser and agrochemicals used has increased exponentially with irrigation playing a strategic role in improving productivity and rural livelihoods while also transferring agricultural pollution to water bodies. This implies that the quantity of ions and metals washed into water bodies has increased tenfold making water bodies more polluted than ever before. Therefore, the analysis of these ions and metals using EC to determine the quality of water is paramount.

Temperature is one of the most important physical parameters in characterising an aquatic system that affects water quality and its variation can be used to evaluate the quality of water. Hassan (2020) notes that temperature affects solubility, odour, palatability and chemical reactions. In Addition, he notes that it also affects the bio-sorption process of dissolved heavy metals in water quality. Anthropogenic pollution from urban sewage, industrial effluent and agricultural runoff are some of the factors that cause variation in the temperature of water bodies according to Chitmanat and Traichaiyaporn (2010). Water temperature fluctuates between day and night (diurnal temperature changes) and over longer periods. Debela et al. (2020) report that the amount of dissolved oxygen decreases as the water becomes warmer. In her study, she further found that low oxygen levels in a water body can cause harm or even death to the aquatic organisms residing in it. It can also cause an increase in the photosynthetic rate of aquatic plants and algae according to their findings. This can lead to increased plant growth and algal blooms, which can be harmful to the water ecosystem.

Human activities such as agriculture, discharge of heated industrial effluent, and urban development among others affect the temperature of a water body. Kumar et al. (2011) in their study found that temperature showed a gradual increase from the month of March till the onset of the monsoon season in July and a gradual decrease from the rainy season to the post-monsoon months indicating a temporal variation within the seasons. The rise in temperature could be due to the fact that in winter the photoperiod was shorter and less intense than in summer. Total solids also demonstrated a distinct spatial and temporal variation, peaking at 11300 mg/l in September. The main causes of this elevated TDS level in the river water were determined to be agricultural runoff, cement and other raw material particulate matter, leaching of contaminated soil, and point sources of water pollution, specifically discharge from industrial and sewage treatment plants. They observed that spatial and temporal variation in the river showed an increasing value of various parameters from upstream to downstream and relatively high pollution load at two sites of the Kharicut canal that were located downstream.

2.4 Spatial and Temporal Variation in Chemical Water Quality Parameters

Similar to physical water parameters, chemical water quality parameters also vary from point to point in a water body over time due to various anthropogenic activities and natural causes. The chemical water quality indicators commonly used to assess the quality of water bodies include; pH, Biological Oxygen Demand (BOD), Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), hardness, ammoniacal nitrogen, phosphorus and potassium content.

A study done by Benhamiche et al. (2016) on spatial and temporal variation of water quality in Soummam River, recorded a spatial variation highlighted in the two sites (The first site was upstream and central sites of the river, and the second site was located downstream). The study found that in the downstream area, the pollutant load was almost twice as high as in the first area and the percentage saturation of dissolved oxygen was relatively weak (<55%) revealing poor water quality as the water flowed downstream. This was attributed to the significant volume of urban and industrial emissions in the river, the high temperature during low-water-level periods, and flood events, which occurred just before the period of low water level. Dissolved oxygen is the amount of gaseous oxygen dissolved in an aqueous solution. It gets into water by diffusion from the surrounding air, by aeration, and as a by-product of photosynthesis (Prasad et al., 2019).

Most aquatic organisms need oxygen in its dissolved form to survive and grow. The absence of enough oxygen in water can lead to the death of adults and juveniles, reduction in growth, failure of eggs/larvae to survive, and change of species present in a given water body (Arora, 2018). Qadir et al. (2007) found that the variations in DO levels were attributed to the activities that were carried out in different locations along the river Nulla Aik River and the different seasons. Low DO levels were attributed to human impacts like fishing, car and human washing, and muddy water with agricultural runoff while high levels of DO were attributed to the presence of macrophytes and phytoplankton with higher biomass and abundance among other factors. The pollutant load was found to be high downstream just past areas where land use change included agriculture, urbanisation and settlement compared to points upstream where these activities were not present (Qadir et al., 2007). The variation also depended on the season where the physical parameters had significantly higher values in the dry season as compared to the wet season (Shrestha & Kazama, 2007). This was attributed to the dilution of pollutants during rainy seasons when the water levels were high compared to dry seasons. The same findings were recorded by Chitmanat and Traichaiyaporn (2010) who noted that seasonal variations and flooding affected water flow rate and subsequently led to pollutant dilution.

During their investigation, Kumar et al. (2011) noted a spatial and temporal change in the nitrate concentration. Nitrate levels were noticeably higher during the monsoon, which may have been caused by farm runoff and early-rainstorm stormwater runoff into rivers. Eutrophication was found to be caused by the high nitrogen levels, as indicated by the numerous shallow patches near the bank of the river. The construction of reservoirs and dams also contributes to eutrophication as it decreases flow velocities within rivers. Nitrogen concentration is an important indicator of water quality, noting that it causes eutrophication in water bodies making it toxic for aquatic organisms and hazardous to public health (Godoy et al., 2021; Srivastav et al., 2023). Additionally, Hammoumi et al. (2024) noted that this variable affects the dissolved oxygen concentration when oxidised to its nitrate form. The WHO recommends a maximum of (10 mg/l) of nitrogen in water for health purposes (WHO, 2017).

Eutrophication depletes the oxygen present in water causing a deficiency of the important gas to aquatic flora and fauna leading to their death. Moreover, it prevents light from reaching the plants at the bottom of the river or lake bed leading to further decomposition of these plants releasing toxins and toxic gases (Mateo-Sagasta et al., 2018). These toxins degrade the water quality and are extremely detrimental to human health and aquatic life (Powlson et al., 2008; WHO, 2017). Xue et al. (2016) also affirmed that high concentrations of nitrate might result in blooms of toxic algae, eutrophication of lakes and reservoirs, and impacts on aquatic ecosystems. Njue et al. (2022) reveal that excessive use of nitrogenous fertilisers in rice paddies leads to the introduction of this nutrient into water bodies thereby causing eutrophication. He found that excess water from rice irrigation contains high amounts of nutrients, especially nitrogen.

Phosphorus is another nutrient of great importance to be monitored in aquatic ecosystems. The importance of phosphorus is that this element is an essential and limiting nutrient in aquatic ecosystems, controlling primary production. Phosphate is present in natural waters as soluble phosphates and organic phosphates. Phosphate levels in Sabarmati River water ranged from 0.29 mg/l at S-1 in January to 7.50 mg/l at S-3 in July, according to Kumar et al. (2011). In the months of June and July, which are the monsoon season, there was a significant concentration of phosphate, which can be linked to agricultural runoff and the outflow of water from cities that contain detergents and other chemicals.

However, comparably lower phosphorus levels were seen in the summer, which may be related to the fact that algae and other aquatic plants need phosphate as a fertiliser. In higher concentrations, phosphates can cause explosive algae and macrophyte growth (Baldwin, 2013). According to USGS, this can lead to a variety of water-quality problems, including low dissolved oxygen concentrations, which can cause fish kills and harm other aquatic life. Therefore, high phosphorus concentration is a key water-quality concern in many rivers and streams that are in close proximity to agricultural activities.

Another crucial parameter for the characterisation and evaluation of water quality is BOD. As reported by Bedim-Godoy et al. (2021), BOD indicates contamination from organic pollution noting the difference between values he found over a period of time and in different station points. He further notes that the evaluation of BOD in water bodies is of great importance because it is a parameter for the assessment of biodegradable organic matter concentration in water bodies. This implies that there is an input of domestic, agricultural or industrial wastewater into the water. Tibebe et al. (2022) in their study recorded a spatial and temporal variation in the BOD concentration indicating that the water body had suffered deterioration and degradation due to the continuous discharge of partially treated effluent. Biological Oxygen Demand is related to microbial growth, the depletion of dissolved oxygen and disturbance in the aquatic ecosystem (Wan et al., 2014).

Complementarily, COD is another parameter related to organic matter concentration, however, it includes a higher range of organic components than BOD, thus presenting a superior representability of organic matter concentration and as an advantage, less difficulty to standardise and a smaller time required compared to BOD (Alom et al., 2024). Additionally, COD is a more accurate indicator of the amount of organic pollutants present in a sample because it measures a wider range of organic compounds. The aforementioned statement underscores the increased reliability of this parameter in evaluating water quality and pollution levels. Furthermore, the quicker results obtained through COD analysis allow for more timely and efficient decision-making in water management and treatment processes.

Another important water quality parameter is pH, which measures the acidity or basicity of water as the negative log of the hydrogen ion concentration. The range of natural pH in fresh waters extends from around 4.5, for acid, peaty upland waters, to over 10.0 in waters where there is intense photosynthetic activity by algae. Changes in pH may alter the concentrations of other substances in the water to a more toxic form. Ammonia toxicity, chlorine disinfection efficiency, and metal solubility are all subjective to changes in pH value. pH outside a range of 6–9 could impact the aquatic ecosystem including the reduction of biodiversity, the disappearance of species sensitive to acidification, modification of trophic status and a decrease in fish quantity (Bedim-Godoy et al., 2021; Moiseenko, 2005).

The decomposition of organic matter, low primary productivity, reduction of salinity and temperature, removal of carbon dioxide by photosynthesis through bicarbonate degradation, the input of freshwater and dilution of seawater can all be ascribed to temporal changes in pH (Dhinamala et al., 2015). The recorded high pH values during summer were due to the influence of seawater penetration and high biological activity. pH of water is an important environmental factor and is generally considered an index for the suitability of the environment. Increased pH was associated with increased use of alkaline detergents in residential areas and alkaline material from wastewater in industrial areas.

2.5 Egyptian Standard Regularities of Article 60 -Law No. 48/1982 and the World Health Organisation Standards

Due to the imminent risk of contamination of water bodies, the World Health Organisation established a list of water quality standards that are universal to assist in regulating pollution or contamination of water bodies and ensuring that the environment and human health protection is prioritised. The Safe Drinking Water Act (SDWA) defines a contaminant in the context of water quality as any physical, chemical, biological or radiological substance or matter in water. Currently, one of the major global issues is the contamination of water bodies, resulting from several anthropogenic activities including; improper discharge of used water from industries into water bodies, excessive use of agro-chemical and fertilisers in agricultural fields, road constructions, and buildings to mention a few (Sharma and Bhattacharya, 2016). The quality of drinking water has attracted great attention worldwide because of implied public health impacts. Many common and widespread health risks are associated with drinking water in developing countries (El-Sheikh et al., 2014).

According to USEPA 2015, Water quality standards (WQS) are provisions of state, territorial, authorised tribal or federal law that describe the desired condition of a water body and how that condition will be protected or achieved. These standards are what inform the fitness of the use of water for a given purpose. This is a very integral part of ensuring that both the environment and human health are protected at all times. In addition to being the habitat of numerous aquatic organisms, water bodies can be used for recreational activities (such as swimming and boating), aesthetic enjoyment, and fishing. States, territories, or countries establish water quality standards to safeguard both human health and aquatic life in these waters. Water quality standards serve as a legal foundation for regulating contaminants entering water bodies. Each country has its own water quality standards in addition to the World Health Organisation (WHO) standards.

Hamed (2019) affirms that water quality monitoring is one of the highest priorities in surface water protection policy and this can only be achieved when there are water quality standard guidelines put in place. In Egypt, the Ministry of Health is the body responsible for providing the guidelines for water quality standards. These standards were established because of the closed water system of the country which makes it more vulnerable to quality deterioration in the northern part where water quality in irrigation and drainage canals deteriorates to reach alarming levels in the Delta (Abdel-Dayem, 2011). He further notes that due to the complexity of the water management system, a more efficient tool was required leading to the development of other mechanisms including policies quality standards, institutional and governance arrangements, infrastructure for monitoring and analytic laboratories, awareness and skilled human resources.

The country’s water quality standards are more or less similar to the WHO guidelines on water quality standards for drinking water. In a comparison study done by El Sheikh et al. (2014), on the water quality of studied samples against the permissible limit of the Egyptian water quality standards in Menoufia Governorate, parameters such as turbidity, ammonia, iron, and manganese in addition to the presence of residual chlorine concentrations were found to be above the WHO limit. Similarly, drinking water was also contaminated with coliform bacteria. Therefore it is recommended that regular water quality monitoring with special emphasis on proper maintenance of water distribution systems should be carried out to compare the water quality with the set standards for the safety of public health and environment.

2.6 Theoretical Framework

The thorough assessment of water quality is a crucial foundational task for environmental planning and management. One of the proposed models is the Water Quality Assessment Model based on the Set Pair Analysis Theory (WQA-SPA). This model is used to assess the river mainstream's water quality, considering the fuzzy and imprecise characteristics of river water systems (Zhao & Xuan, 1996). The WQA-SPA approach combines identity, discrepancy and contradictory (IDC) tests using set pair analysis and fuzzy logic. This model states that the data on river water quality can be used to calculate the capacity and quality of the water environment for water resources planning and management. Calculating the degree of connection between the samples and assessment indicators allows for the preliminary classification of the samples. The identity, difference, and antagonism set pair analyses are then used to rank the samples further. The weights of evaluation factors in the model are obtained from the avail value of data reflecting the information entropy, culminating in a more logical weight distribution. Research demonstrates that the evaluation outcome is reliable and accurate and has a certain value in the thorough analysis of various types of known systems.

The other theory that has been used to quantify water quality is the Water Quality Index (WQI). The water quality index is considered one of the most effective methods of measuring water quality (Akter et al., 2016). Essentially WQI is calculated by comparing the water quality data to set water quality standards. One of the benefits of this method is that it requires fewer parameters to compare water quality for a specific use. Horton developed the index in 1965 to measure water quality by using the 10 most regularly used water parameters. However, the method has over the years been modified to achieve the best outcome where parameters to be included in the WQI model could vary depending upon the intended water uses and local preferences. The parameters used in the calculation of the WQI included; turbidity, DO, pH, BOD, COD, conductivity, temperature, nutrients (nitrogen and ammonia) and phosphates.

These parameters have various ranges and are stated in various units. Each parameter is given weight depending on its respective standards where the assigned weight indicates the parameter's significance and impact on the index. The index follows three steps: selecting parameters; determining the quality function for each parameter; and aggregation through a mathematical equation. The Water Quality Index (WQI) was calculated using the Weighted Arithmetic Index method where the quality rating scale for each parameter Qi was calculated using the expression:

$$\text{Quality rating, } Q_i = 100\,[(V_n - V_i) / (V_s - V_i)] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(i)}$$

Where, Vn: is the actual amount of the nth parameter, Vi: is the ideal value of this parameter. Vs: the recommended WHO standard of the corresponding parameter.

Relative weight (Wi) was calculated by a value inversely proportional to the recommended standard (Si) of the corresponding parameter.

$$W_i = 1 / S \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(ii)}$$

Where, Wi; Relative weight of each parameter, S; Standard value of each parameter.

The result gave a single number representing the general water quality at a specific location and time based on the analysed water parameters.

The overall WQI is calculated using Equation:

$$\text{Water Quality Index} = \sum (Q_i) W_i / \sum W_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(iii)}$$

2.7 Conceptual Framework

The relationship between the independent and dependent variables in this study is presented diagrammatically using a conceptual framework with the aim to make it easier to understand these relationships. There is an existing relationship between water quality (Dependent variable) and the spatial-temporal variations in the physicochemical water quality parameters (Independent variables) which include temperature, turbidity, pH, electrical conductivity, Total Dissolved Solids (TDS), and dissolved oxygen. Climate change, government policy and geology act as the moderating factor where its changes indirectly affects the relationship between the two variables as shown in Figure 2.1

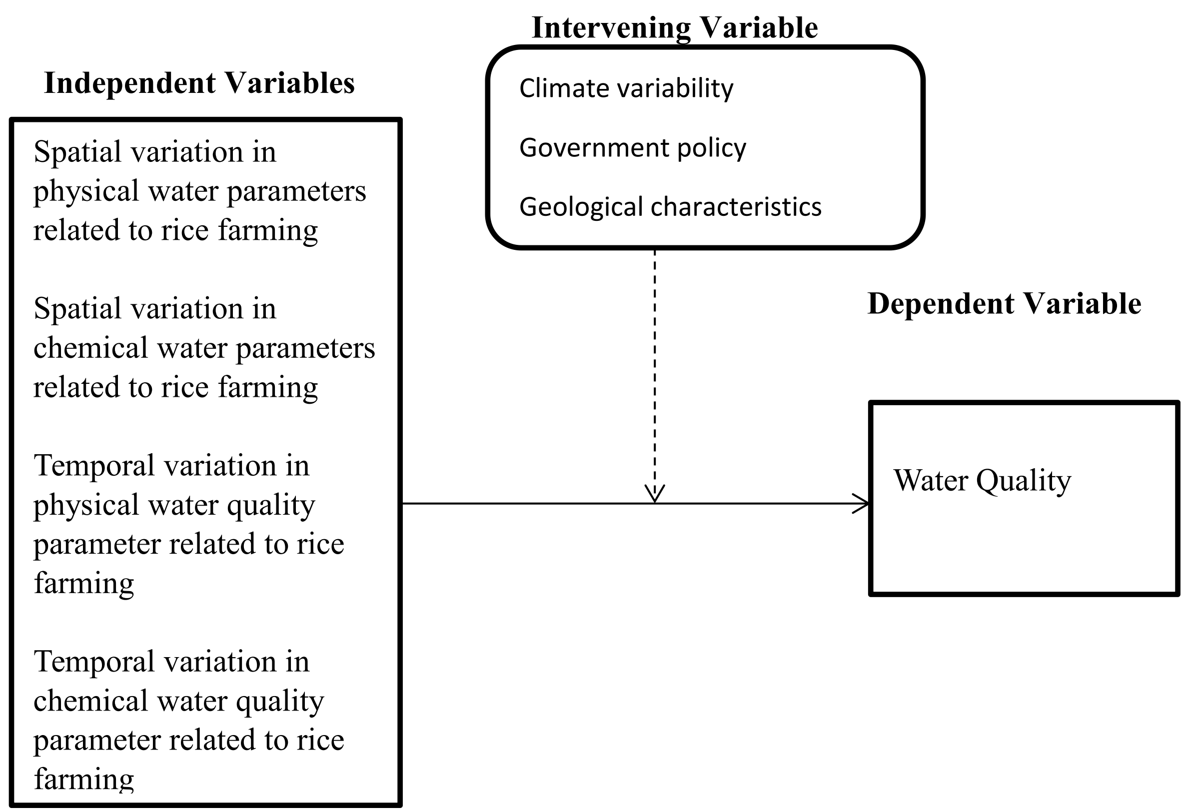

Figure 2.1: Diagrammatic Representation of the Conceptual Framework

CHAPTER THREE
MATERIALS AND METHODS

3.1 Introduction

This chapter presents an overview of the materials and methods used to achieve the objective of the study. Subsection 3.2 elucidates the study area component in totality while subsection 3.3 highlights the research design. Subsection 3.4 accentuated the technique used for population and sampling while Chapter 3.5 highlighted the sampling processing and analysis. Lastly, subsection 3.6 highlighted the data collection methods used in investigating the study problem whereas subsection 3.7 discussed the techniques that were used to analyse the data collected from the field.

3.2 Study Area

3.2.1 Location

The study site was located in the middle northern part of the Nile Delta (Kafrelsheikh Governorate) in Egypt (Figure 3.1)

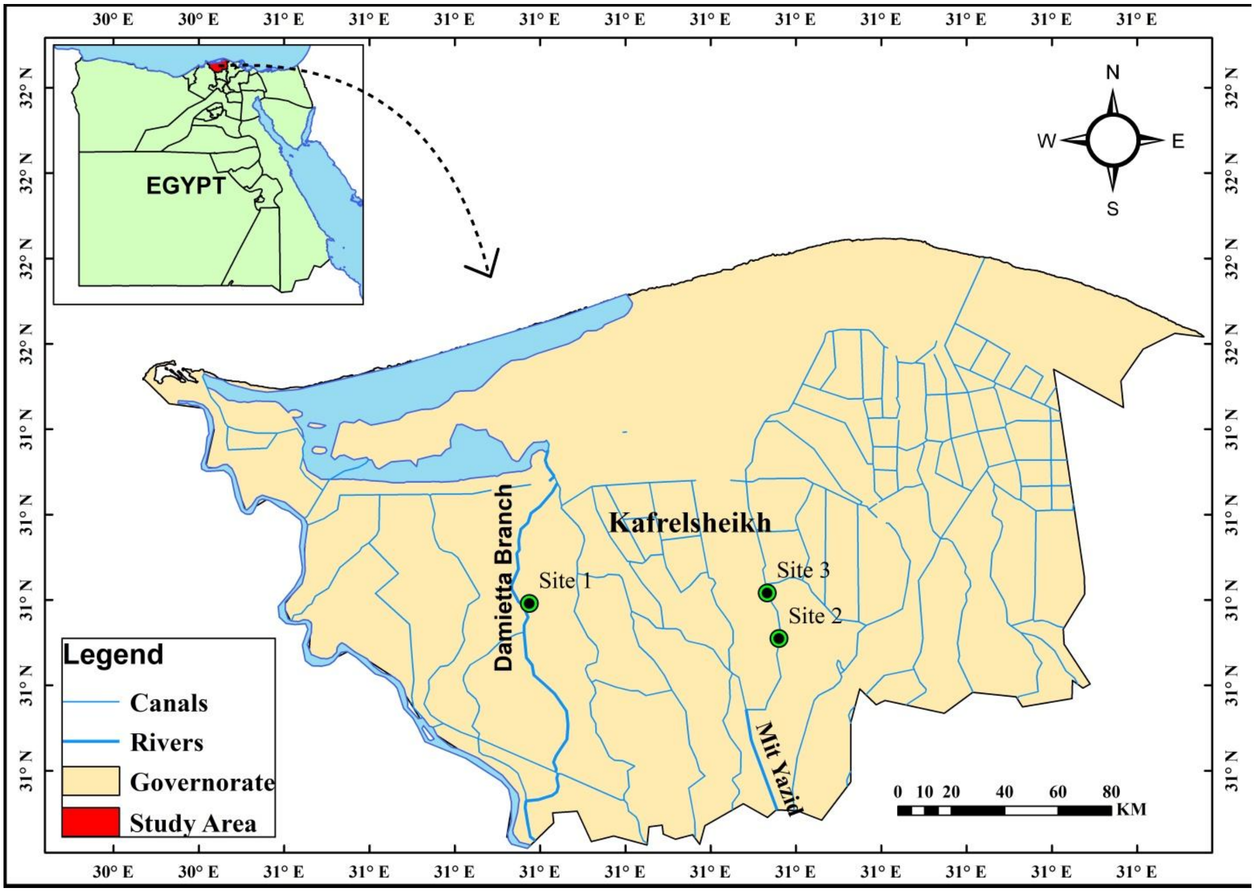

Figure 3.1: Map of the Study Area.

Source: Modified from Glovis (2022).

It has an elevation of approximately 6 meters above sea level. It is a branch of the main irrigation canal Mit Yazid, 63 km in length, serving approximately 82,470 ha. Its coordinates are located between latitudes 31°05′11.6800 to 31°22′0.5500N and longitudes 30°46′400 to 31°08′24.9400 E. The canal is located on the right-hand side of the Mit Yazid canal. The length of the Dakalt Canal is 11.42 km, and it serves approximately 2310 ha of land.

3.2.2 Climate

The study area has a Mediterranean climate with hot, dry summers (May to September) and mild winter seasons (November to April) with daily temperatures ranging between 9°C-19°C during the coldest month (November to April) and 30°C-36°C during the hottest months (May to October). It receives an annual average rainfall of 46mm. It has a homogenous clay-silt soil. The main crops farmed during winter are wheat, clovers and beets, while in summer; the main crops are rice, maize, and cotton.

3.2.3 Vegetation

The vegetation in the study area consists mostly of papyrus (*Cyperus papyrus*), Nile grass (*Acroceras macrum*), reed mace ambatch (*Typha latifolia*), water lettuce (*Pistia stratiotes*), and the South American water hyacinth (*Pontederia crassipes*). This is because of the presence of canals that have been constructed in the study area. Due to human activities which include clearing the vegetation for agricultural activities and economic use, the amount of vegetation cover has greatly reduced.

3.2.4 Topography and Geology

The study area has a broad, alluvial land, sloping to the sea at an average of 6 metres above sea level. It consists of fertile alluvial soils that comprise Nile deposits due to the frequent flooding during geological periods. It is bounded by several sedimentary basins and desert sands that alluvial soils have settled upon.

3.3 Research Design

A cross-sectional research design was used in this study to assess the relationship between the variables. A stratified sampling technique was employed to subdivide the sample collection points into sub-zones and water samples from the selected sites. The sampling area was divided into three stations as guided by the study objectives. Thereafter, the samples were randomly collected in triplicate at each sampling site.

3.4 Population and Sampling

The study area was divided into three distinct sampling sites. Sampling site 1 was a point upstream with very minimal to no agricultural activities (On the river Nile, Damietta branch, an eastern distributary). In this site, sampling was done in triplicates and served as the reference point (control) on account of the minimal to no agricultural activities taking place. The second sampling site was the midpoint along the canal characterised by extensive rice farming and irrigation schemes (This is the water used for irrigation of the rice paddies). The third sampling site was the outlet at which point water exits the canal in a drainage discharge canal.

Three sampling points that are equally spaced were selected in each sampling site and samples were collected at each point. The required number of samples was estimated as follows:

$$N \geq \left(\frac{ts}{U}\right)^2$$

Where: N number of samples, t=statistic for a given confidence level, s=overall standard deviation, and U = acceptable level of uncertainty. To assist in calculations, For example, the following value was used as per the APHA (2018) where s = 0.5, U = 0.5, and a 95% confidence level is desired. A total of 36 samples were taken. The above equation assumed that total error (population variability) was known.

3.4.1 Sampling Procedure

Water samples were collected from the selected points along the canal in triplicates at the central half of the canal avoiding the edges. The samples were stored in sterilised 250 ml plastic bottles and transported to the lab in an ice box at 4°C. The physical and chemical parameters analysed were temperature, turbidity, pH, electrical conductivity, Total Dissolved Solids (TDS), and dissolved oxygen which were recorded in situ using a portable digital multimeter model. Nutrients analysed were (nitrogen (NO_3 and NH_4) and phosphates (PO_4) which in addition to BOD and COD were determined by following the standard procedures as outlined in the American Public Health Association (APHA, 2018) using a UV/Visible spectrophotometer in the laboratory at Ain Shams University Water Engineering Department.

3.5 Sample Processing and Analysis

3.5.1 Sampling and Laboratory Analysis

Samples were collected for the analyses of physico-chemical water quality parameters and nutrients at the selected sampling sites at fixed locations spanning three months. Three sampling sites were selected and evenly distributed from the Main River to the disposal drainage canal.
Water samples were collected in triplicate at the central half of the canal avoiding the edges and then kept in pre-rinsed plastic sample storage bottles for nutrient analysis following the standard guideline articulated in the APHA (2018). The samples were then stored in an ice cooler box and transported to the laboratory on the same day.

The standard operating procedures were strictly followed during sampling and laboratory analysis as directed by APHA (2018) to ensure quality control and avoid contamination.

3.5.2 Chemical Analysis

The concentrations of NO^3-N, PO^4-P and NH^3-N were determined for all samples following the standard procedures outlined in APHA (2018). Table 1 summarises the analytical methods for the water samples.

Table 3.1: The Standard Methods Used in Chemical Analysis of Nitrates, Phosphates and Ammonia

Parameter	Method	Description
Nitrates	SMWW 4500- NO^3 - B	Spectrophotometric, Colorimetric
Phosphates	APHA 4500-P A	Spectrophotometric, Ascorbic Acid
Ammonia	APHA 4500 - NH^3-A	Spectrophotometric, Phenate

3.5.3 Apparatus and Equipment

A portable multi-meter (YSI MPS 556, USA); UV-visible spectrophotometer (Cary 60, UK); and Field portable Turbid-meter (PW, USA) were used in the experiments.

3.5.4 In-situ Measurements

The portable multi-meter used for in-situ measurements was calibrated according to the recommended standards following the manufacturer's specifications. The following parameters were measured in situ; Temperature, conductivity, Total Dissolved Solids (TDS), Dissolved Oxygen (DO), pH and turbidity.

3.6 Data Collection

The primary data was obtained directly from the study area. It involved obtaining samples from the three selected sampling sites in triplicate and storage done in sample storage bottles at 4°C. A multimeter was used in situ to measure various water quality parameters and data was recorded for further analysis. The secondary data was collected from existing literature that is relevant to the study which included data from government ministries on rice cultivation, water quality standards and fertiliser application and use of online literature from accredited websites. Relevant materials from Ain Shams and Egerton University libraries and online repositories were also used as sources of data for the study.

3.7 Data Analysis

Data was analysed using descriptive and inferential statistics as presented in Table 3.1. Analysis of variance (ANOVA) was conducted to test the differences between, and within, sampling stations at a 95% confidence level while correlation analysis was used to measure the association between the variables. Thereafter, the results were presented in tables, figures and plates.

Table 3.2: A Summary Table of Data Analysis and Result Presentation

Objective	Variables	Analysis tool
Spatial variation in physical water quality parameters associated with rice farming	Turbidity, temperature, Total Dissolved Solids and Electrical conductivity	Mean, percentages, Frequencies and ANOVA
Spatial variation in chemical water quality parameters associated with rice farming	pH, Hardness, Dissolved oxygen, COD, BOD, nitrates, phosphates and potassium	Mean, percentages, Frequencies and ANOVA
Temporal variation in physical water quality parameters associated with rice farming	Turbidity, temperature, Total Dissolved Solids and Electrical conductivity	Mean, percentages, Frequencies, t-test;
Temporal variation in chemical water quality parameters associated with rice farming	pH, Hardness, Dissolved oxygen, COD, BOD, nitrates, phosphates and potassium	Mean, percentages, Frequencies, t-test;
Comparison of the studied result against the water quality standards	Physical and chemical water quality parameters	Content analysis

CHAPTER FOUR

RESULTS

4.1 Introduction

This chapter entails the results of the study. Subsection 4.2 highlights the spatial variation in physical water quality parameters associated with rice farming, while subsection 4.3 presents the results on spatial variation in chemical water quality parameters. Subsections 4.4 and 4.5 also present the results on temporal variation in chemical water quality parameters and physical parameters associated with rice farming, respectively. Last but not least, subsection 4.6 highlights the results by comparing the study findings to the WHO and Egyptian water regulatory standards, while subsection 4.7 presents the correlation matrix among the water quality parameters.

4.2 Spatial Variation in Physical Water Quality Parameters Associated with Rice Farming

Significant temperature variation was observed amongst the sampling sites ($F=8.65$; $p=0.001$) as shown in Table 4.2. Electrical conductivity, TDS and turbidity all showed significant variation amongst the sampling sites ($F=90.29$; $p=0$; $F=91.88$; $p=0$; $F=16.40$; $p=0$).

Table 4.1: Descriptive Statistics for Various Physical Water Quality Parameters at Each Sampling Site

Station		Temperature	Conductivity	TDS	Turbidity
Station 1	Mean	30.08	360.67	216.92	10.44
	Std. Deviation	0.84	34.02	16.87	0.71
Station 2	Mean	28.38	392.08	241.92	13.54
	Std. Deviation	1.61	62.74	44.72	1.21
Station 3	Mean	27.68	773.17	495.25	14.68
	Std. Deviation	1.74	126.22	83.7	2.93
Average	Mean	28.72	508.64	318.03	12.89
	Std. Deviation	1.74	206.79	138.49	2.57

The mean spatial variation values of all physical water quality parameters in the three sampling sites are given in Table 4.1. The mean temperature was recorded to be 28.72±1.74 °C, with sampling site 1 having the highest mean temperature (30.08±0.84 °C) while sampling site 3 recorded the lowest mean average temperature (Figure 4.1).

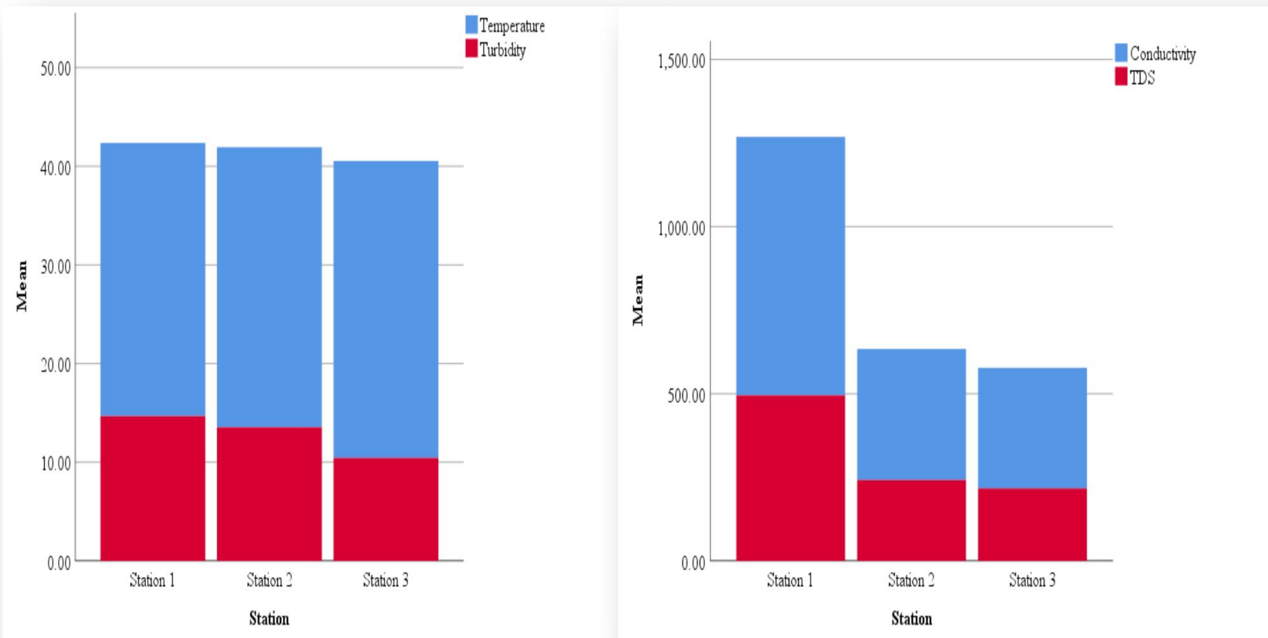

Figure 4.1: A Stacked Bar Means of Temperature, Turbidity, Conductivity and TDS

Table 4.2: ANOVA Values for Various Physical and Chemical Water Quality Parameters

	df	Std. Deviation	Variance	Std. Error of Mean	Mean Square	F	Sig.
Temperature	2	1.74	3.04	0.29	18.28	8.646	0.001
Conductivity	2	206.79	42764.01	34.47	632736	90.286	0
TDS	2	138.49	19179.51	23.08	284544	91.884	0
DO	2	1.79	3.22	0.30	53.555	314.801	0
pH	2	0.59	0.35	0.10	0.021	0.056	0.945
Turbidity	2	2.57	6.61	0.43	57.696	16.398	0
COD	2	3.40	11.55	0.57	133.719	32.24	0
BOD	2	3.14	9.84	0.52	84.205	15.778	0
Phosphates	2	0.08	0.01	0.01	0.051	15.188	0
Nitrates	2	1.11	1.24	0.19	10.945	16.883	0
Ammonia	2	0.08	0.01	0.01	0.009	1.421	0.256

The average electrical conductivity (EC) value in the study site was 508.64 µS/cm ±206.79. The mean values ranged from 327.0 to 1001.0 µS/cm with station 1 recording the lowest mean EC (360.67 µS/cm) while station 3 recorded the highest mean values of 773.17 µS/cm as illustrated in Table 4.1. Total dissolved solids (TDS) ranged from 203 to 646 mg/l with a total mean of 318.03mg/l ±138.49. The lowest mean average value was recorded at sampling site 1 (216.92 mg/l) and the highest mean average value was recorded at sampling site 3 (495.25 mg/l) as shown in Table 4.1. Turbidity in the study sites ranged from 9.0 to 21.10 mg/l as shown in Table 4.1 with a total mean of 12.89± 2.57 mg/l. Sampling site 1 showed the lowest mean average value (10.44 mg/l) while the highest mean average value (14.68 mg/l) was recorded at sampling site 3 (Figure 4.1).

Plate 4.1: A Photograph of Damietta Branch, River Nile Distributary (Sampling Site 1) and the Rice Fields/Paddies Respectively

4.3 Spatial Variation in Chemical Water Quality Parameters Associated with Rice Farming

Significant variation in DO, BOD, COD and phosphates was observed amongst the sampling sites ($F=314.80$; $p<0.05$; $F=15.78$; $p<0.05$; $F=32.24$; $p<0.05$; $F=15.19$; $p<0.05$) respectively as shown in Table 4.2. However, no significant variation was observed in pH ($F=0.06$; $p=0.95$). The level of dissolved oxygen (DO) ranged from 1.7 mg/l to 6.7 mg/l with a mean value of 3.54 mg/l ±1.79 as shown in Table 4.3. The lowest mean value was recorded at station 3 (2.22 mg/l) whereas the highest value was recorded at station 1 (5.98mg/l). The mean pH value was observed to be 7.4 ±0.59 (Table 4.3).

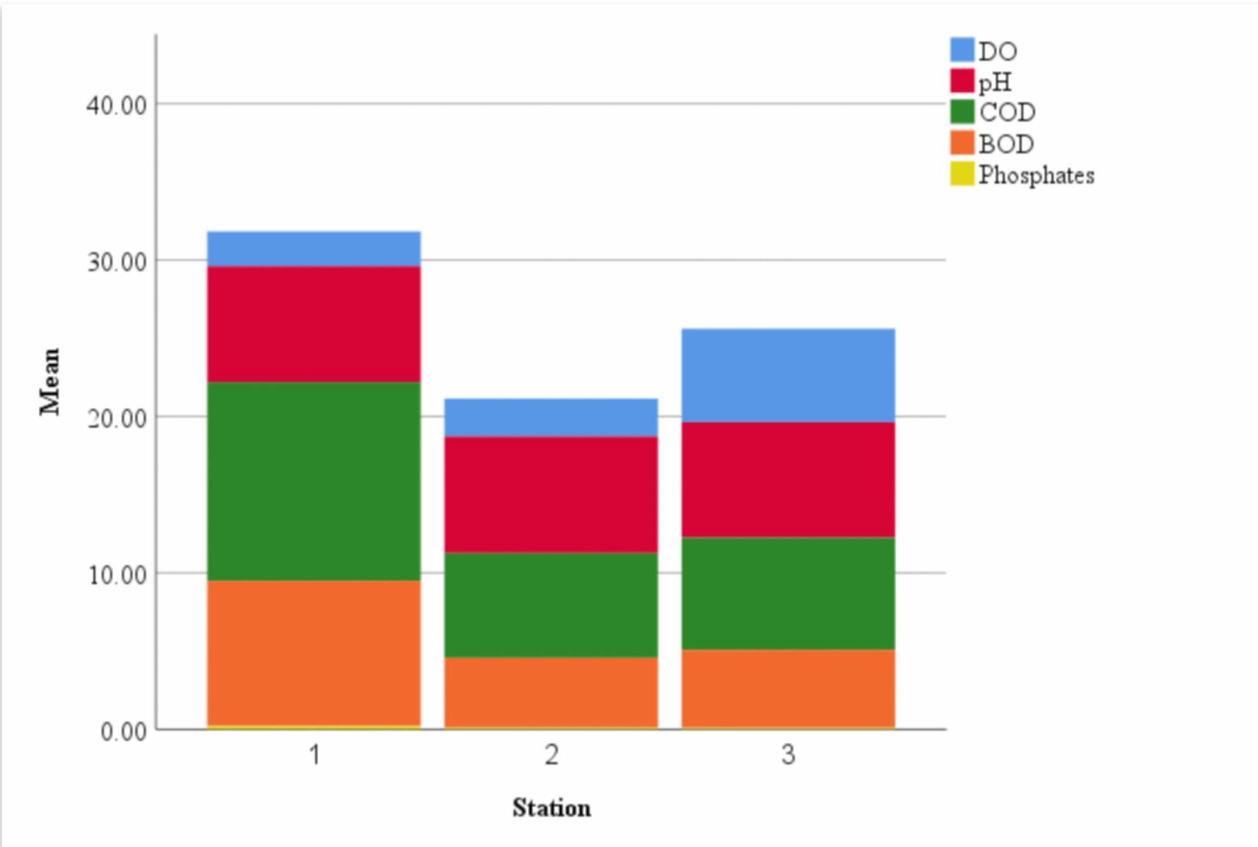

Figure 4.2: Stacked Bar Graph Mean of DO, pH, COD, BOD and Phosphates

Table 4.3: Descriptive Statistics for Various Chemical Water Quality Parameters at Each Sampling Site

Station		COD	BOD	Phosphates	DO	pH
Station 1	Mean	7.18	4.99	0.08	5.98	7.38
	Std. Deviation	2.57	3.11	0.05	0.51	0.27
Station 2	Mean	6.69	4.46	0.1	2.43	7.46
	Std. Deviation	0.66	1.5	0.07	0.35	0.27
Statio3	Mean	12.7	9.29	0.21	2.22	7.41
	Std. Deviation	2.33	2.02	0.04	0.37	0.99
Average	Mean	8.86	6.25	0.13	3.54	7.42
	Std. Deviation	3.4	3.14	0.08	1.79	0.59

.

The mean value for COD and BOD was 8.86 mg/l ±3.4 and 6.25 mg/l ±3.14 respectively. Additionally, the COD and BOD ranged from 3.0 to 16.4 mg/l and 0.98 to 11.6 mg/l respectively with the highest and the lowest mean values for both parameters being recorded at sampling stations 3 and 1 respectively (Table 4.1). The pH remained relatively constant across all three sampling sites at an average of 7.42 units ±0.59. It ranged from 7.3 and 7.4 (Table 4.3). The highest and the lowest values of pH were recorded at sampling sites 3 and 1 at 9.5 and 6.6 units respectively.


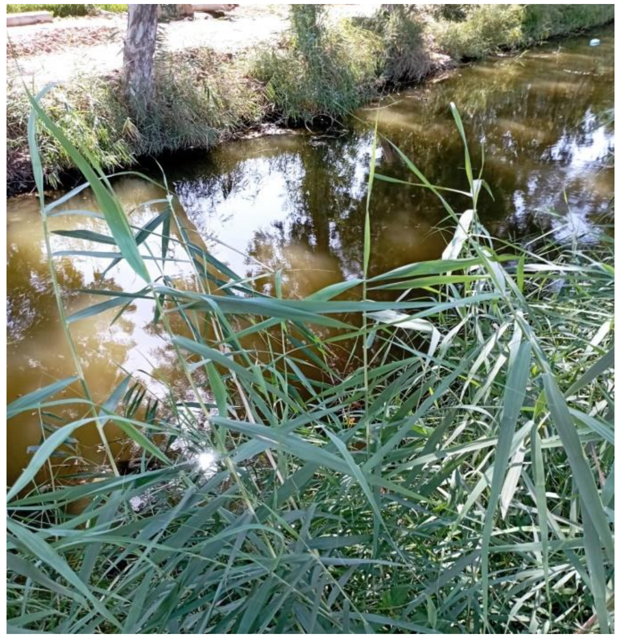

Plate 4.2: A Photographic Representation of Sampling Sites 2 and 3 Respectively

The average phosphates concentration was recorded at 0.13mg/l ± 0.08 and it ranged from 0.02 to 0.28 mg/l with sampling site 3 having the highest mean average concentration (0.21 mg/l) while sample station 1 having the lowest concentration (0.085 mg/l) as shown in table 4.2.

4.3.1 Nutrients Analyses

Significant variation in nitrate concentrations was observed amongst the sampling sites (F=16.89; p=0) as illustrated in Table 4.2. However, no significant variations were observed in Ammonia concentrations amongst the sampling sites (F=1.42; p=0.26). The mean NO_3-N concentration was recorded at 3.26 mg/l ±1.11 and it ranged between 1.8 to 6.8 mg/l (Table 4.4). The highest mean average NO_3-N was recorded at sampling site 3 while the lowest value was in sampling site 2.

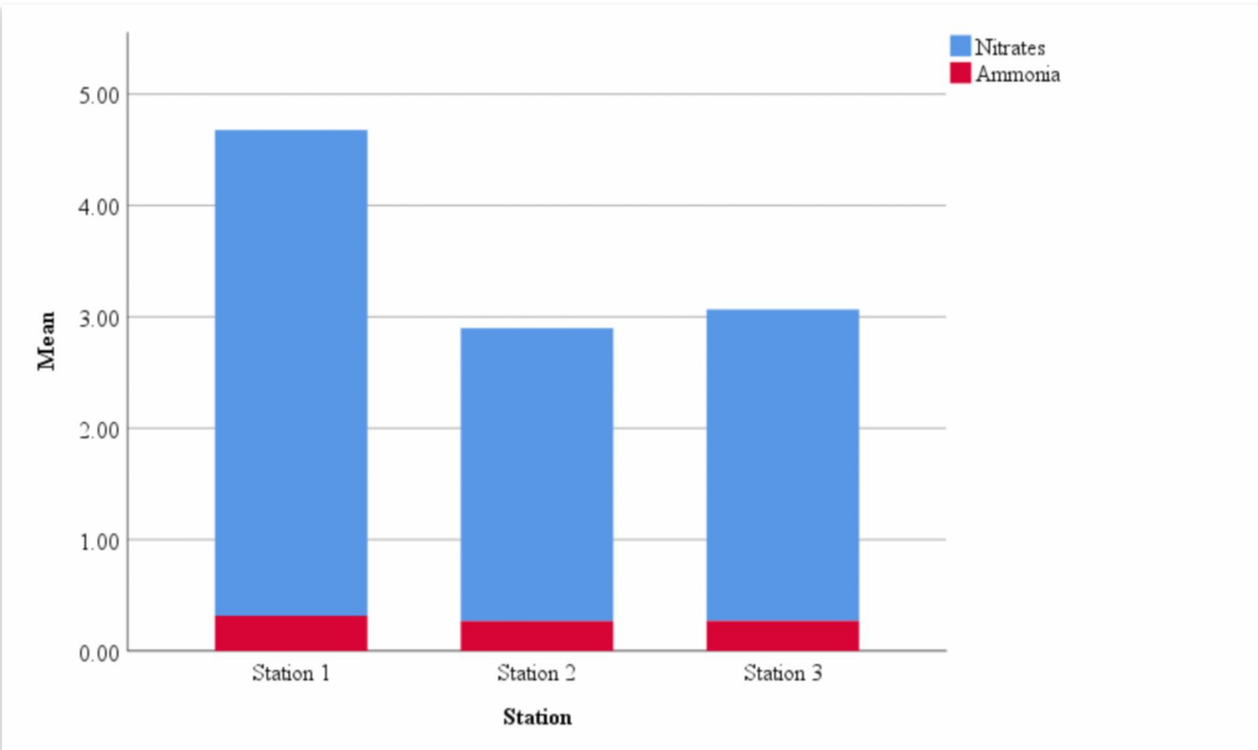

Figure 4.3: A Stacked Bar Means of Nitrates, Ammonia by Sampling Site

Table 4.4: Descriptive Statistics for Nitrates and Phosphates at Various Sampling Sites

Station		Nitrates	Ammonia
Station 1	Mean	2.8	0.27
	Std. Deviation	0.52	0.05
Station 2	Mean	2.63	0.27
	Std. Deviation	0.41	0.1
Station 3	Mean	4.36	0.32
	Std. Deviation	1.23	0.08
Average	Mean	3.26	0.28
	Std. Deviation	1.11	0.08

The average ammonia concentration was 0.28 mg/l ±0.08. The highest mean concentration of ammonia (NH3-N) was recorded at sampling site 3 (0.32 mg/l) while the lowest concentration was recorded at sampling site 2 (0.26 mg/l) as shown in Figure 4.3. The concentration ranged from 0.11 mg/l to 0.42.

4.4 Temporal Variation in Physical Water Quality Parameters Associated with Rice Farming in the Dakalt Branch Canal

Significant variation in temperature and turbidity was observed between August and September ($F=6.89$; $p=0.01$; $F=6.97$; $p=0.01$) respectively as shown in Table 4.5. However, no significant variations were observed in conductivity and TDS between August and September ($F=1.11$; $p=0.30$; $F=0.77$; $p=0.39$) respectively.

Table 4.5: T-Test Values for Various Physical and Chemical Water Quality Parameters

	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Temperature	6.89	**0.01**	2.55	34.00	0.02	1.38	0.54
Conductivity	1.11	0.30	-1.06	34.00	0.30	-72.72	68.82
TDS	0.77	0.39	-0.88	34.00	0.38	-40.94	46.31
DO	0.02	0.89	0.06	34.00	0.96	0.03	0.61
pH	1.73	0.20	2.06	34.00	0.05	0.39	0.19
Turbidity	6.97	**0.01**	-1.61	34.00	0.12	-1.35	0.84
COD	1.64	0.21	1.75	34.00	0.09	1.92	1.10
BOD	6.63	**0.02**	3.34	34.00	0.00	3.08	0.92
Phosphates	5.37	**0.03**	3.19	34.00	0.00	0.07	0.02
Nitrates	7.07	**0.01**	2.58	34.00	0.01	0.89	0.34
Ammonia	2.93	0.10	-5.35	34.00	0.00	-0.11	0.02

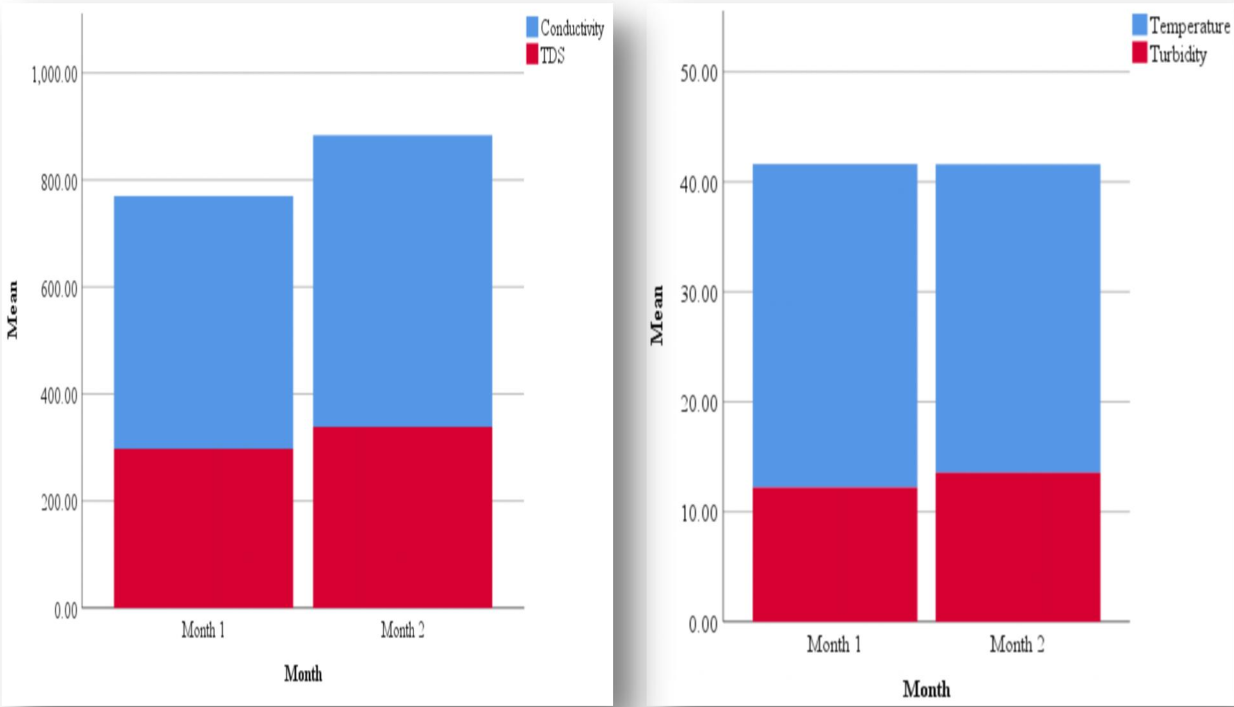

Figure 4.4: A Stacked Bar Means of Conductivity, TDS, Temperature and Turbidity

The average temperature between the two study periods indicated that August had a slightly higher temperature (29.4±1.34 °C) compared to September (28.03±1.86 °C) as shown in Table 4.6 with the first month having the highest temperature of 32 °C. The mean value of EC and TDS was 508.64±206.79 µS/cm and 318.03±138.49 mg/l respectively. The month of September exhibited higher mean EC and TDS values of 545 ±233.62 µS/cm and 338±156.17 mg/l respectively compared to August (472.28±175.12 µS/cm and 297.56±119.20 mg/l) as shown in table 4.6. Moreover, the highest EC value of 1001µS/cm was recorded in September. The average turbidity value was 12.89±2.57 mg/l with September having the highest average of 12.89±3.21 mg/l.

Table 4.6: Descriptive Statistics for Various Physical Water Quality Parameters at Each Sampling Site

Month		Temperature	Conductivity	TDS	Turbidity
August	Mean	29.41	472.28	297.56	12.21
	Std. Deviation	1.34	175.12	119.20	1.53
September	Mean	28.03	545.00	338.50	13.56
	Std. Deviation	1.86	233.62	156.17	3.21
Average	Mean	28.72	508.64	318.03	12.89
	Std. Deviation	1.74	206.79	138.49	2.57

4.5 Temporal Variation in Chemical Water Quality Parameters Associated with Rice Farming in the Dakalt Branch Canal

Significant variation in BOD and phosphates was observed between August and September ($F=6.63$; $p=0.02$; $F=5.37$; $p=0.03$) respectively (Table 4.5). However, no significant variations were observed in pH, DO and COD between August and September ($F=1.73$; $p=0.20$; $F=0.02$; $p=0.89$; $F=1.64$; $p=0.21$) respectively. The DO concentration between the two months remained almost constant. The mean pH was 7.42±0.59 with the highest mean pH value (7.6±0.711) being recorded in August.

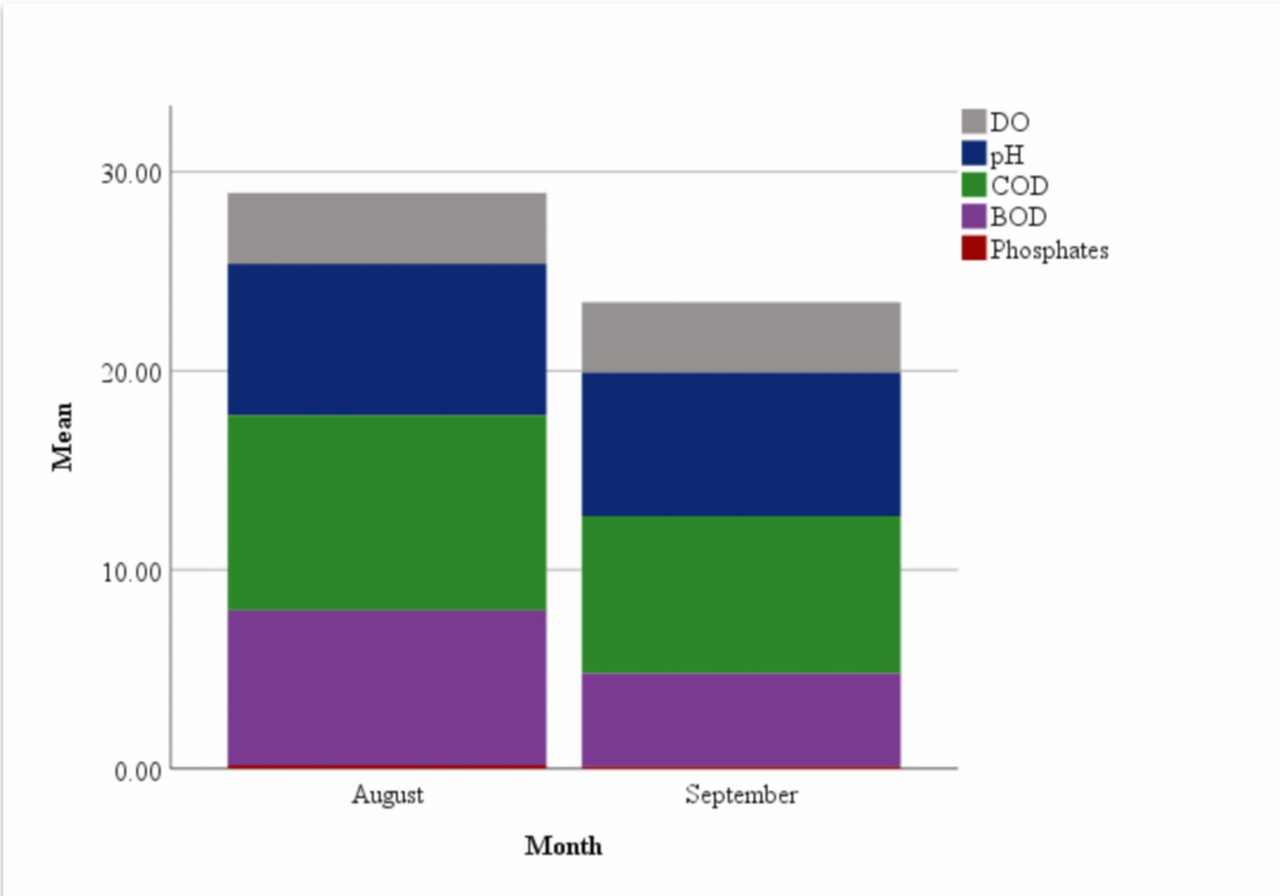

Figure 4.5: Stacked Bar Graph Mean of DO, pH, COD, BOD and Phosphates

Table 4.7: Descriptive Statistics for Various Chemical Water Quality Parameters at Each Sampling Site

Month		DO	pH	COD	BOD	Phosphates
August	Mean	3.56	7.61	9.82	7.78	0.17
	Std. Deviation	1.82	0.71	2.87	1.87	0.06
September	Mean	3.52	7.22	7.89	4.71	0.09
	Std. Deviation	1.82	0.38	3.69	3.43	0.08
Total	Mean	3.54	7.42	8.86	6.25	0.13
	Std. Deviation	1.79	0.59	3.40	3.14	0.08

The research recorded the highest mean concentrations of 9.82±2.87 mg/l and 7.78±1.87 mg/l for both COD and BOD in August respectively. The highest values for the same were also recorded during the same period. The mean phosphate concentration was observed to be 0.13±0.08 mg/l between August and September. The highest mean concentration of phosphates was observed in August (0.17±0.06 mg/l). Therefore, it is important to note that the highest mean concentration of all the chemical parameters was recorded in August compared to September.

4.5.1 Nutrients Analyses

Significant variation in nitrates concentration was observed between August and September ($F=7.07$; $p=0.01$) as shown in Table 4.5. However, no significant variation was observed in ammonia concentration between August and September ($F=2.93$; $p=0.10$). The highest mean concentration (3.7 ±1.34 mg/l) of nitrates was recorded in August as shown in Table 4.8. However, the highest mean concentration of Ammonia was recorded during September at 0.33±0.05 mg/l.

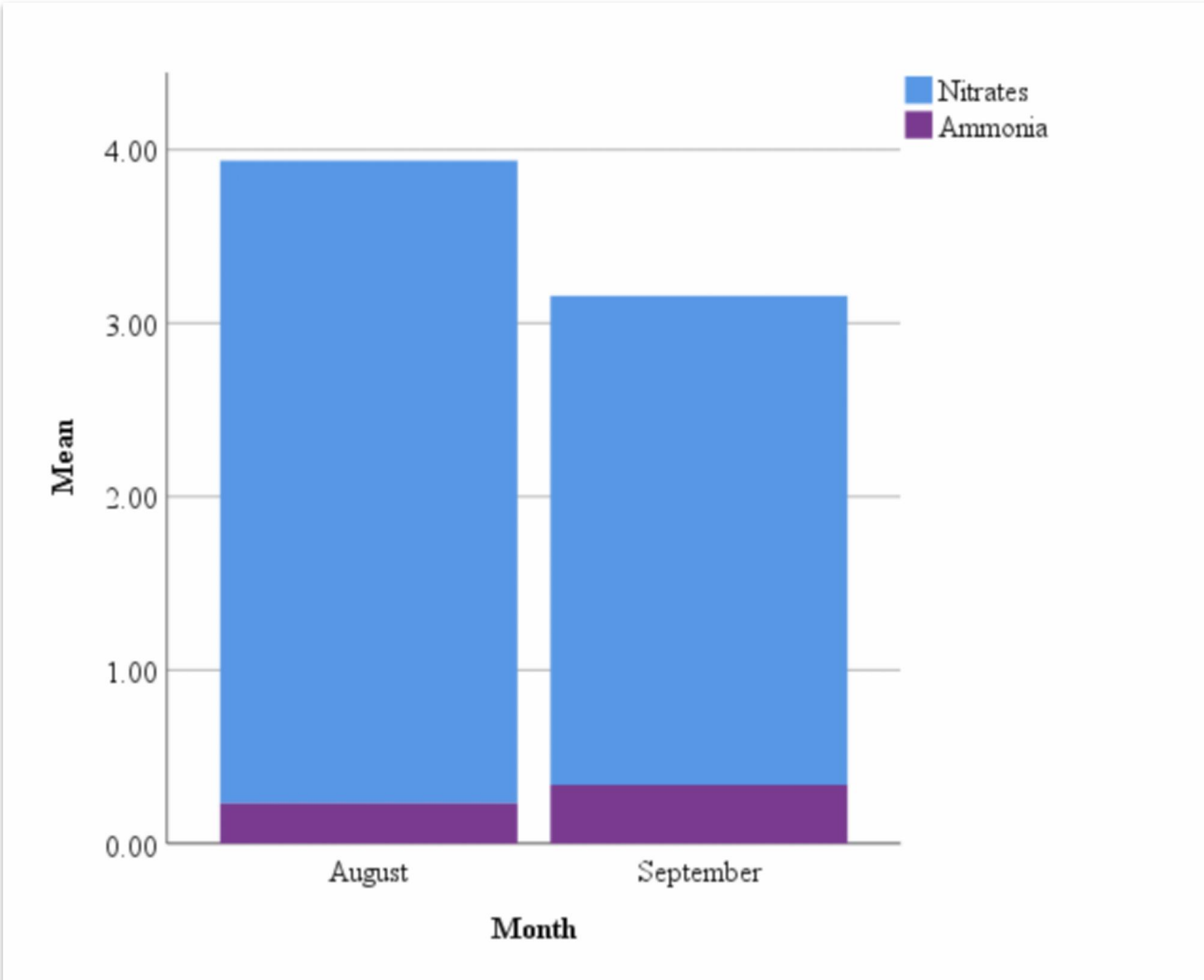

Figure 4.6: Stacked Bar Graph Mean of Nitrates and Ammonia

Table 4.8: Descriptive Statistics for Nitrates and Ammonia at Each Sampling Site

Month		Nitrates	Ammonia
August	Mean	3.71	0.23
	Std. Deviation	1.34	0.07
September	Mean	2.82	0.34
	Std. Deviation	0.59	0.05
Total	Mean	3.26	0.28
	Std. Deviation	1.11	0.08

4.6 Water Quality Parameters in Comparison to the Egyptian Standard Regularities of Article 60 -Law No. 48/1982 and the World Health Organisation Standards

Table 6 highlights the water quality parameters tested during the study in comparison to the recommended Egyptian Water Quality Standards under the Egyptian standard regularities of Article 60 -law No. 48/1982 and the World Health Organisation (WHO) Standards. Electrical conductivity was higher at all the sampling sites in comparison to both standards with the drainage canal (sampling site 3) having the highest mean value of 773.17µS/cm. Sample site 1 recorded the lowest value of 360.67µS/cm which is still way above the recommended standards of a maximum of 250µS/cm illustrating poor water quality. The TDS was however within the recommended value of 500 mg/l with sampling site 3 still exhibiting the highest mean average recording of 495.25 mg/l and site 1 having the lowest recorded value. Sampling sites 2 and 3 recorded a very poor DO value below the recommended standards at 2.22 mg/l and 2.43 mg/l respectively. This indicated low oxygen levels at the two sampling sites. However, sampling site 1 had a fairly good DO concentration of 5.98 mg/l exhibiting good oxygen circulation at this station.

Table 4.9: Study Area Water Quality Parameters Compared to the Egyptian Water Quality Standards and the WHO Guidelines

Parameters	SI Unit	WHO standards	Egyptian Standards	Site 1	Site 2	Site3
Conductivity	υ s/cm	250	250	360.67	392.08	773.17
TDS	mg/l	500	500	216.92	241.92	495.25
DO	mg/l	>5	>5	5.98	2.43	2.22
PH	Units	6.5-8.5	6.5-8.5	7.38	7.46	7.41
Turbidity	NTU	<5	<5	10.44	13.54	14.68
COD	mg/l	<10	-	7.18	6.69	12.7
BOD	mg/l	<5	<6	4.99	4.46	9.29
Phosphates	mg/l	<0.1	-	0.08	0.1	0.21
Nitrates	mg/l	<50	<45	2.8	2.63	4.36
Ammonia	mg/l	<0.2	<0.5	0.27	0.27	0.32

The pH was excellent at all three sampling sites being within the recommended limits by the two bodies. The pH among the three sites varied between 7.3 units and 7.4 units. Turbidity was very high at all three sampling stations with site 3 having the highest mean recording of 14.68 NTU and the lowest value of 10.44 NTU being recorded in sampling site 1. In comparison to the WHO standards (<10 mg/l), the COD illustrated an excellent recording in sampling sites 1 and 2 as 7.18 mg/l and 6.69 mg/l respectively. However, in sampling site 3 the research recorded a high value of 12.70 mg/l exceeding the WHO recommended standard. Similarly, the BOD also indicated good mean values in sampling sites 1 and 2 with site 3 recording a value of 9.29 mg/l almost doubling the recommended standards. Phosphate concentration was within the recommended limits of the WHO in sites 1 and 2 but above this limit in sampling site 3 with a mean concentration of 0.21 mg/l.

The mean ammonia concentration was above the WHO recommended limit in all the sampling sites with site one exhibiting the highest mean concentration of 0.32 mg/l. It was however within the recommended Egyptian standard regularities of article 60 -law No. 48/1982 in all the sampling sites. The nitrate concentration was within the recommended standards of the WHO. Sampling site 1 still recorded the highest mean concentration among the three sites.

4.7 Correlation Analysis between Physico-Chemical Constituents

The association between the variables evaluated in the water quality assessment in the study area was demonstrated by the correlation analysis between physico-chemical water quality parameters. A direct or positive correlation exists when the variables vary in the same direction while an indirect or negative correlation occurs when the variables change in the opposite direction. Table 7 shows the matrix inter-correlation among the parameters assessed in the study area.

Table 4.10: The Correlation Matrix between the Physico-Chemical Constituents of Water Quality in the Study Area

	Temperature	Conductivity	TDS	DO	pH	Turbidity	COD	BOD	Phosphates	Nitrates	Ammonia
Temperature											
Conductivity	**.62****										
TDS	**.61****	.99**									
DO	**-.61****	**-.56****	-.58**								
pH	.46**	-0.20	-0.13	-0.06							
Turbidity	**.41***	.39*	.38*	**.60****	-0.13						
COD	-0.30	.64**	.63**	-.37*	-0.13	.48**					
BOD	-0.12	.48**	.48**	-0.29	-0.05	.38*	**.94****				
Phosphates	-0.26	.52**	.52**	**-.41***	-0.07	.36*	**.82****	**.88****			
Nitrates	-0.18	.54**	.53**	-0.32	0.00	0.22	**.81****	**.75****	**.74****		
Ammonia	**.43****	.33*	0.31	-0.17	-0.31	.35*	0.22	0.05	-0.02	0.11	

N=36. $^{*}p<.05$; $^{**}p<.01$

The inspection of the correlation matrix shows that there is a strong negative correlation between temperature and D.O ($r=-0.61, p\leq0.01$) while a strong positive correlation was exhibited between temperature and both EC ($r=0.62, p\leq0.01$ and TDS ($r=0.61, p\leq0.01$) as illustrated in Table 4.10. A moderate positive correlation was observed between Temperature and Turbidity ($r=0.41$ $p\leq0.05$), Temperature and Ammonia ($r=0.43$ $p\leq0.01$) while a positive moderate correlation was shown between temperature and pH ($r=0.46, p\leq0.01$). Conductivity and TDS showed a very strong positive correlation ($r=0.99, p\leq0.01$) similar to that exhibited between EC and COD ($r=0.64, p\leq0.01$). A moderate positive correlation was observed for several variables such as TDS and BOD, TDS and Phosphates, TDS and Nitrates, Turbidity and COD, EC and BOD, EC and Phosphates, EC and nitrates (Table 6). These variables expressed moderate negative correlation; EC and DO ($r=-0.56, p\leq0.01$), TDS and DO ($r=-0.58, p\leq0.01$), DO and phosphates ($r=-0.41, p\leq0.05$). Additionally, a very strong positive correlation was established between COD and BOD ($r=0.94, p\leq0.01$), COD and phosphates ($r=0.82, p\leq0.01$), COD and Nitrates ($r=0.81, p\leq0.01$), BOD and phosphates ($r=0.88, p\leq0.01$), and phosphates and nitrates($r=0.74, p\leq0.01$). A strong positive correlation was also seen between BOD and Nitrates ($r=0.75, p\leq0.01$). Turbidity and DO ($r=0.60, p\leq0.01$) showed a strong positive correlation while pH showed a very weak negative correlation with other variables in most cases showing no correlation. The Electrical conductivity exhibited a negative correlation with DO ($r=-0.56, p\leq0.01$). pH however showed a weak correlation with ammonia ($r=-0.31$).

CHAPTER FIVE

DISCUSSION

5.1 Introduction

This chapter highlights the interpretation of the results of each objective in relation to known facts and literature. Subsection 5.2 elucidates the spatial variation in physical water quality parameters while subsection 5.3 discusses the spatial variation in chemical water quality parameters associated with rice farming in the Dakalt Canal, Egypt. The subsection 5.4 and 5.5 highlight the interpretation of the temporal variation in physical water quality parameters associated with rice farming and temporal variation in chemical water quality parameters associated with rice farming respectively. Subsection 5.6 discusses the study's water quality parameters findings in comparison to the Egyptian Water and Wastewater Regulatory Agency and The World Health Organisation Standards while subsection 5.7 expands on the relationship among water quality parameters.

5.2 Spatial Variation in Physical Water Quality Parameters Associated with Rice Farming

The study area had no general trend of high or low-temperature values in the three sampling sites because the area experiences a fairly constant temperature throughout the year. Moreover, the range in the present study was probably due to the sun's heating, dependent on the time of sampling (Suratman et al., 2016). This finding is consistent with Ruhakana et al. (2012) and Mohamed and Robert (2016). The variation observed might be because, around the canals, many trees and papyrus cover protect the water from direct heat from the sun. The same sentiment was echoed by Njue et al. (2022) who recorded that a thick canopy shielding rivers from direct sunlight creates cool conditions, explaining why water temperature is low at those specific points. The 25.4 - 32.0 °C temperature range is within the range recorded in a study in Nigeria that revealed that surface temperatures for main rivers ranged from 22.6 °C to 31.0 °C (Ajibade et al., 2008).

The high EC in the drainage canal (station 3) of 773.2μS/cm is a significant indicator of major cations and anions, likely attributed to the excessive use of dissolved agrochemicals in the rice paddies. This is a strong indicator of inputs from both anthropogenic (runoff-carrying pollutants) and natural sources (mineral weathering) (Molekoa et al., 2021). Moreover, the mean electrical conductivity (EC) values in the sampling sites ranged from 360.67±34.02 to 773.17±126.22 µS/cm (Table 4.1). In comparison to values recorded by Ezzat et al. (2012), our study recorded values significantly below their findings. However, the EC values at all the sampling sites were above the WHO recommended value of 250µS/cm (WHO, 2003), indicating poor water quality. Turbidity at all the sampling sites was higher (> 10 NTU) than the WHO (2003) recommended standard (<5NTU). The high values in this study can be attributed to siltation due to land tillage, catchment degradation and lack of proper vegetation cover along the water body and the canal (Charkhabi & Sakizadeh, 2006).

TDS had an average concentration of 318.03 mg/l and was within the range of 203 to 646 mg/l. The high concentration values recorded in sampling site 3 (drainage canal) of 495.25 mg/l can be attributed to effluents from the rice paddies. El-Tohamy et al. (2018), in their study on the evaluation of spatial and temporal variations of surface water quality in the Nile River Damietta branch, noted that untreated effluents from agricultural and industrialised zones are directed into the river course, which increases the concentrations of TDS in the water body. The TDS mean range and average in this study are consistent with their study, which recorded almost similar values.

The first objective of our rigorous study was to determine the spatial variation in physical water quality parameters associated with rice farming in the Dakalt Branch Canal, Kafrelsheikh governorate. To support this research objective, we meticulously tested the null hypothesis that there is no significant spatial variation in physical water quality parameters in water associated with rice farming in the Dakalt Branch Canal, Kafrelsheikh governorate. Therefore, based on the robust study result, we confidently reject the null hypothesis that there is no significant spatial variation in physical water quality parameters in water associated with rice farming in the Dakalt Branch Canal, Kafrelsheikh governorate.

5.3 Spatial Variation in Chemical Water Quality Parameters Associated with Rice Farming

The low DO values in sampling sites 2 and 3 were attributed to agricultural runoff from the rice paddies, poor disposal of organic waste and human impacts such as discharge of untreated household waste disposal, respectively. These results correspond to the findings of Suratman et al. (2016), who found that in sections where agricultural activities were highest, the lowest DO values and highest levels of nutrient pollution were recorded. The report further records that the organic wastes from these rice paddies eventually end up in the river through runoff, where oxygen-demanding microbial decomposition occurs (Sullivan et al., 2010). The high values of DO reported at sample site 1 might be attributed to the presence of macrophytes and phytoplankton with higher biomass and abundance than other sites (Tamire & Mengistou, 2012) and probably due to high dilution as the amount of water at this site significantly increases.

The overall mean DO concentration in this study (3.5 mg/l) almost corresponds to the value reported by Norlida et al. (2023) (3.76 mg/l). These results reflect those of Kumar et al. (2011), who found the DO concentration between 2.42 and 4.06 mg/l around the floriculture effluent. According to EPA (2022), concentrations below 4.0 mg/l adversely affect aquatic life. Compared to the study findings, sites 2 and 3 were not within the permissible limits, while only sampling site 1 was within the permissible limit of more than 5.0 mg/l. WHO (2003) records the standard for DO value for fisheries and aquatic life to be between 5.0 and 9.0 mg /l. Sampling sites 2 and 3 still reflected low values against these standards. High DO values lead to fish and other aquatic life deaths (Arora, 2018), and could be the cause of fish deaths reported in the River Nile between 2015 and 2019, according to the local news outlet, Egypt Independent, within the mentioned timeline.

The mean pH value of the study area was 7.4, indicating that the value was within the permissible recommended by WHO (2003). According to Suratman et al. (2016), pH is probably influenced by the anthropogenic inputs from agricultural activities near water bodies, which is also consistent with the observed DO reduction at sampling sites 2 and 3. The study notes that the waste produced from these anthropogenic activities, when discharged into water bodies, may increase the production of dissolved CO_2 gases through organic matter decomposition, making the water more acidic (Moran & Stottrup, 2011). The constant pH values are mainly a result of the exudation of freshwater that regulates the acidity of the water body. EPA (2022) considered a pH range of 6.5- 8.5 to be safe for human and animal consumption. This same range is also considered to be optimal for the growth of common fish such as Nile tilapia. However, this single parameter cannot be used to verify fish rearing in such waters unless other parameters are also optimal.

The BOD of a water body is estimated by determining the amount of oxygen required by aerobic microorganisms to degrade the organic matter in the water to carbon dioxide and water (Jouanneau et al., 2014). It is one of the most important parameters used to assess organic pollution of water. The high mean value of BOD recorded at sampling site 3 could mainly be attributed to the pollution of the river by agricultural runoff from the rice paddies. According to Brenniman (1999), high concentrations of these contaminants may cause aerobic microbes to use up all the oxygen in the water for their breakdown, resulting in anaerobic conditions that kill aquatic life and produce unpleasant odours. The BOD in the study area ranged from 0.98 mg/l – 11.60mg/l, indicating an extensive variation attributed to the discharge of untreated irrigation wastewater from the rice paddies. However, these values are lower than Mohamed and Robert's (2016) findings and Ezzat et al. (2012). According to Kumar et al. (2011), COD is a general indicator of organic pollution in rivers, given that it measures the amount of oxygen equivalent to the organic matter content of the water vulnerable to oxidation. The study's sampling site 3 had the highest mean COD value (12.70 mg/l), exceeding the recommended threshold of 10 mg/l for drinking water (WHO, 2003). The discharge of highly oxidised chemicals from the farmlands is the main cause of the high value of COD (Charkhabi & Sakizadeh, 2006).

The results of this study indicate that the mean phosphate concentration in the study area is increasing from the river through the water supply canal to the drainage canal. The highest value of 0.21mg/l was recorded at sampling site 3, indicating an increased concentration of phosphates in the discharged water that can be attributed to the use of phosphate-rich fertiliser in the rice paddies (Kilic & Yucel, 2019).

5.3.1 Nutrients Analysis

Generally, agricultural land use strongly influences nutrient parameters in river water, such as nitrogen (Bu et al., 2014). In the study, both of the nutrients showed an increasing trend from the inlet to the drainage channel. The mean nitrate concentration among the three sampling sites varied from 2.6mg/l - 4.4mg/l, with a range of 1.8 – 6.8mg/l. The wide variation can be attributed to the introduction of nitrate fertiliser into the water body at sampling site 3, where fertiliser rich in nitrates is used to enrich the farmlands (Suratman et al., 2016). These high values recorded in the study indicate that there is a potential overall increased pollution in the River Nile. However, the values are low compared to El-Shakour and Mostafa's (2012) study findings. An examination of the long-term nitrate level in Poland's Warta River revealed a tendency toward increasing nitrate concentration, which was connected to an increase in the usage of inorganic fertilisers (Górski et al., 2017; Maghanga et al., 2013). Pastén-Zapata et al. (2014) attribute the reduced quantities found at sampling sites 1 and 2 to the river's aquatic vegetation absorbing nutrients, microbial action from nitrifying bacteria, and nutrient binding to sediments.

Ammonia exists in water in two forms: unionised Ammonia (NH_3) and ionised Ammonia (NH_4^+). The unionised Ammonia is considered the toxic form of the two forms and is dependent on temperature (r -0.43), as illustrated in the correlation matrix in Table 4.10. In their study, Hargreaves and Tucker (2004) also stated that the proportion of the two Ammonia forms depends on pH. The WHO (2003) records that Ammonia in levels of 0.53 mg/l – 22.8 mg/l is considered toxic to freshwater organisms, leading to poor feed conversion, reduced growth, and low immunity, of which, at lethal concentrations, fish go into a coma and die. According to our study findings, the average value of Ammonia ranged from 0.27 to 0.32mg/l. These values are within the range recommended for aquatic organism survival. However, it is above the WHO (2003) guideline for drinking water quality standards but within the Egyptian standard regularities of article 60 -law No. 48/1982 for drinking water quality standards. The significant variation may be explained by the fact that there is excessive and continuous input of nitrogen contaminants into the river from fertiliser application, leading to high concentrations of ammonia nitrogen in the canals as well as the River Nile. This finding agrees with Zhang et al. (2007), who observed that the excessive and continuous input of nitrogen contaminants into the Yellow River was the fundamental reason for the high ammonium nitrogen concentration.

The study's second objective was to determine the spatial variation in chemical water quality parameters associated with rice farming in the Dakalt Branch Canal, Kafrelsheikh governorate. To support the research objective, the null hypothesis that there is no significant spatial variation in chemical water quality parameters in water associated with rice farming in the Dakalt Branch Canal, Kafrelsheikh governorate, was tested. Therefore, from the study result, we can confidently reject the null hypothesis that there is no significant spatial variation in chemical water quality parameters in water associated with rice farming in the Dakalt Branch Canal, Kafrelsheikh governorate.

5.4 Temporal Variation in Physical Water Quality Parameters Associated with Rice Farming in the Dakalt Branch Canal

The water quality parameter data was collected within three months. During this period, there is a transition in which rice paddies management practices such as fertilser application, agrochemical use and land tillage are greatly reduced. The researcher wanted to establish if there is a temporal variation within this period of transition and how this affected water quality to inform future management practices. The independent sample t-test established that Temperature and turbidity were significantly different between August and September ($F=6.89$; $p=0.01$; $F=6.97$; $p=0.01$ respectively) as shown in Table 4.5 while no significant variation was observed in EC and TDS. A similar result was noted by Poudel et al. (2013) who recorded a significant variation in temperature and turbidity between August and September with lower values recorded in September. Additionally, their study concluded that the temporal variation was a result of the drastic shift from high-intensity farm management practices like land preparation, fertiliser and agrochemical application in August, to the low intensity of these practices in September (Demcheck et al., 2004).

The highest mean values of conductivity, TDS and turbidity were recorded in the month of September (545.0±233.62µS/cm;338.50±156.17mg/l;13.56±3.21mg/l respectively) except temperature of which the highest mean value was recorded in the month of August. This is however contrary to the expectation that during the transition from high-intensity rice management activities to reduced intensity of farm management practices such as tillage, fertiliser and agrochemical application, the concentration of these physical parameters reduces (Kannel et al., 2007). Interestingly, these unanticipated variations of these parameter concentrations can be attributed to the low level of water that was experienced in the month of September limiting the dilution of pollutants from the rice paddies hence affecting water quality significantly. This was connected to the filling of the Grand Ethiopian Renaissance Dam at that time of the study which significantly lowered the water level in the River Nile resulting in some canals drying up during this period. This low level of water could have contributed to the higher concentration of this nutrient since there was no significant dilution.

5.5 Temporal Variation in Chemical Water Quality Parameters Associated with Rice Farming in the Dakalt Branch Canal

The research established that the highest mean for all the chemical parameters was recorded in August, when high-intensity rice paddies management practices were witnessed, compared to September. This clearly illustrates that the reduced application of agrochemicals and reduced land management practices lead to improved water quality parameters (Poudel et al., 2013). The study further notes that agrochemicals and fertiliser application are the major water pollutants that significantly causes variation in water quality. The same findings were reported by Karafistan et al. (2002), who, in their study on the spatial and temporal variation of water quality parameters on the Mediterranean Sea, highlighted that both agricultural and industrial waste discharge into water bodies was a major cause of excess phosphorus concentration in the water body.

5.5.1 Nutrients Analysis

In the study area, nitrate readings tended to be greater during the month of August compared to the month of September. However, the mean ammonia reading was higher in September compared to the month of August. The peak nitrate content at this time is most likely a result of the Nitrogen-based fertiliser used for top-dressing that many growers apply at this time of year. The fertiliser is applied aerially onto the flood water, thus causing it to be prone to removal through surface flow (Krupa et al., 2011). Interestingly, the unexpected variation of ammonia concentration can be attributed to the low level of water experienced in September, which was blamed on the filling of the Grand Ethiopian Renaissance Dam at that time of the study. A low level of water was experienced in the River Nile, causing some canals to go dry during this period. This low level of water could have contributed to the higher concentration of this nutrient since there was no significant dilution. According to Kilic et al. (2019), increasing trends of Nitrates and ammonia were a result of excessive fertiliser application, noting that the variability is mainly controlled by agricultural soil leaching and dilution processes. MOPE et al. (2001) also noted that the average use of chemical fertilisers, such as nitrogen, phosphorus, and potassium per hectare, significantly increased, in addition to the expansion of land under agriculture.

5.6 Water Quality Parameters in Comparison to the Egyptian Standard Regularities of Article 60 -Law No. 48/1982 and the World Health Organisation Standards

Electrical conductivity was poor at all the sampling sites in comparison with both standards. The drainage canal (sampling site 3) was recorded as having the highest mean value of 773.17µS/cm. Sample site 1 recorded the lowest value of 360.67 which is still way above the recommended standards of a maximum of 250µS/cm illustrating poor water quality (Table 4.9). The high EC in the drainage canal (sample size 3) is an indicator of an increase in the concentration of major cations and anions attributed to the excessive use of dissolved agrochemicals in the rice paddies and is a strong indicator of inputs from both anthropogenic (runoff carrying pollutants) and natural sources (mineral weathering) (Molekoa et al., 2021). The EC value at all the sampling sites was way above the WHO and Egyptian standard regularities of article 60 -law No. 48/1982 value of 250µS/cm (WHO, 2003) indicating poor water quality.

DO is often used as an indicator of water quality, such that high concentrations indicate good water quality (Juahir et al., 2011). Site 2 and 3 recorded very low DO values that are below the recommended standards by Egyptian standard regularities of article 60 -law No. 48/1982 and WHO standards (DO should not be than 5 mg/l) at 2.22 mg/l and 2.43 mg/l respectively. This indicated low oxygen levels at the two sampling sites. However, sampling site 1 had a fairly good DO concentration of 5.98 mg/l exhibiting good oxygen circulation at this station. The good value exhibited at this site might be a result of the large amount of water and proper mixing that takes place at this site.

The pH was excellent at all three sampling sites being within the recommended limits by the two bodies. The pH among the three sites varied between 7.3 units and 7.4 units. Turbidity was very high in all three sampling sites with site 3 having the highest mean recording of 14.68 NTU and the lowest value of 10.44 NTU being recorded in sampling site 1. The increasing values from upstream to downstream in the study area may be attributed to drain discharge. In comparison to the WHO standards, the COD illustrated an excellent recording in sampling sites 1 and 2 but higher than the recommended value in sampling site 3. Similarly, the BOD also indicated low mean values within the recommended WHO standards in sampling sites 1 and 2 with site 3 recording a value of 9.29 mg/l almost doubling the recommended standards. This can be attributed to agricultural chemicals used in the rice paddies and the decomposition of organic material from the farmland in the water (Bedim-Godoy et al., 2021).

Phosphate concentration was within the recommended limits of the WHO in sampling sites 1 and 2 but above this limit in site 3 with a mean concentration of 0.21 mg/l. The mean ammonia concentration was above the WHO recommended limit in all the sampling sites with site 3 exhibiting the highest mean concentration of 0.32 mg/l. It was however within the recommended Egyptian standard regularities of article 60 -law No. 48/1982 in all the sampling sites. The nitrate concentration was within the recommended standards of the WHO.

The results from the water quality test in the study area indicated that most of the parameters exceed both the WHO and Egyptian standard regularities of Article 60 -law No. 48/1982. Therefore, we reject the null hypothesis that stated that there is no significant difference in the study area water quality parameters with the Egyptian standard regularities of article 60 -law No. 48/1982 and The World Health Organisation Standards.

5.7 Relationship between Surface Water Quality Parameters

Higher water temperatures result in lower levels of DO due to the decreased solubility of oxygen in the water. This inverse relationship between DO and Temperature has also been reported by other researchers (Hanson et al., 2006; Poudel et al., 2013). The strong correlation ($r = 0.94$) between the BOD and COD is related to the fact that they are closely related with the contamination of organic matter and represents anthropogenic pollution (Juahir et al., 2011). The study further noted that, the correlations between nitrates and phosphates indicated that the adjacent agricultural areas used mostly ammonium phosphates and ammonium nitrates as fertiliser. Hence, this can be attributed to discharge of untreated waste water from the rice paddies (Kilic & Yucel, 2019)

Additionally, the extensive use of nitrogen and phosphorous fertilisers are common in the adjacent rice paddies to the Dakalt canal, which ultimately returns into the River Nile through as untreated waste water discharge. Khatiwada et al. (2002) had also reported high levels of ammonia and sulphate in the river water of the Kathmandu valley which was adjacent to agricultural fields where extensive use of fertilisers was observed.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary of the Findings

i. The study observed significant spatial variation in physical water quality parameters associated with rice farming in the Dakalt Branch Canal. Agricultural practices, rice farming per se, were the major cause of the variation observed causing sediment loss and introduction of pollutants into the water system. The other factor was human encroachment in terms of development projects and settlement along the river and canal which led to the subsequent pollution of the water source. Failure to control pollution and monitor water quality could lead to unsustainability of the water.

ii. Significant spatial variation in chemical water quality parameters was observed in the study. The study identified low dissolved oxygen (DO) values at sampling sites 2 and 3 attributed to agricultural runoff from rice paddies. Phosphate concentrations increased from the river to the drainage canal, with sampling site 3 recording the highest value due to phosphate-rich fertiliser use. Nitrate and ammonia concentrations varied, indicating potential overall increased pollution in the river.

iii. The research established that there was a significant temporal variation in temperature and turbidity but no significant variation in electrical conductivity and TDS. The variation in turbidity could be partly attributed to the introduction of dust particles and soil as a result of wind action and human movement along the canal. This is possible given that the roads are situated just next to the canals and are not tarmacked at all. Thus the constant disturbance of soil might have resulted in the high turbidity reading in September which experienced intense wind action compared to August.

iv. The results indicated there was significant temporal variation in all the chemical water quality parameters. There was a trend showing water quality improvement in the second month compared to the first month. This is because, during the second month of the study period, the intensity of fertiliser application and farm tillage significantly reduced explaining the variation. In the absence of many previous credible scientific study or reports, this study sheds light on issues regarding water resource management in regard to rice paddies management.

v. The study also established that there was a significant different between the results of water quality parameters and the established standards by WHO and the Egyptian standard regularities of article 60 -law No. 48/1982. Most of the parameters either doubled or tripled the recommended values, especially in the drainage canal which showed poor records in all the parameters except pH and nitrates concentration. Therefore without proper management of the rice paddies and discharged waste, the quality of the River Nile will continue to deteriorate.

6.2 Conclusions

i. The study showed that poor rice paddies management practices impacted the physical water quality parameters. It found significant differences in mean water temperature, electrical conductivity (EC), turbidity, and total dissolved solids (TDS) across the three sampling sites. The findings support the conclusion that there is indeed spatial variation in physical water quality parameters in the studied area, highlighting the potential impact of rice farming on water quality in the region.
ii. Poor rice paddies management contributed to the variation in chemical water quality parameters. It also highlighted the impact of pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), and phosphate concentration on water quality, underscoring the influence of anthropogenic activities on these parameters.
iii. The study observed significant temporal variations in temperature and turbidity between August and September, attributed to the shift from high-intensity to low-intensity rice farming practices. Unexpectedly, higher concentrations of certain physical parameters in the water during the transition period may be linked to the low water levels caused by the filling of the Grand Ethiopian Renaissance Dam. This finding underscores the importance of considering external factors such as water levels when assessing the impact of farming practices on water quality. It is evident that the management practices in rice paddies significantly impact water quality parameters.

iv. The study highlights that reduced application of agrochemicals and improved land management practices lead to better water quality. Additionally, the nutrient analysis further indicates that nitrate readings tended to be higher in August due to nitrogen-based fertiliser application, while the unexpected variation in ammonia concentration in September was attributed to low water levels caused by the filling of the Grand Ethiopian Renaissance Dam.
v. Water quality assessment of the sampling sites revealed poor electrical conductivity (EC) and dissolved oxygen (DO) levels, high turbidity, and elevated levels of chemical pollutants such as COD, BOD, phosphate, ammonia, and nitrates. These findings indicate that the water quality parameters exceed both the WHO and Egyptian standard regularities of Article 60 -law No. 48/1982. This highlights the urgent need for measures to address and improve the water quality in the study area.

6.3 Recommendations

From the study findings, the following recommendations were made:

i. The optimum method of managing water and soil in the study region will be to utilise Best Management Practices (BMPs) to lessen agricultural influence on water quality while increasing agricultural production in the irrigation scheme. This will guarantee quality and fair distribution of the water resources.

ii. Water quality monitoring stations should be established along the River Nile and within the canals to ensure that periodic monitoring is carried out to establish the peak pollution seasons. This will help in managing the impact of pollution before it causes unprecedented harm to the environment and also ensure prompt response to pollution by employing the BMPs.

iii. The establishment of a buffer zone around the rice plantation scheme is necessary to help in pollutant absorption and improvement of wastewater quality from the farmlands before they are directed into water bodies. This however should be done after the wastewater from the rice paddies has been treated in wastewater stabilisation ponds to eliminate very toxic pollutants that cannot be absorbed by the buffer zone establishment.

iv. Public awareness campaigns on water quality management and implementation of BMPs by farmers are recommended. The use of traditional soil amendment and management practices like the use of animal and plant manure instead of inorganic fertilisers should be encouraged. Other traditional pest and predator control methods should be encouraged in the study area to reduce the impact of the long-lasting and detrimental effects of agrochemicals.

6.4 Suggestions for Further Research

The main tenet of this study was the assessment of the temporal and spatial variations in water quality related to rice cultivation in the Dakalt Canal. This study was the first of its kind to be undertaken in this field, particularly with regard to irrigation water quality, and there has never before been any kind of comparative analysis carried out. By extending the sample period and testing for toxicity, heavy metals, and bacteriological parameters, the research can be repeated in the study region.

i. Future research is advised to cover the entire river and additional canal networks in detail, including additional sample sites for a longer period in the analysis of water quality data, and examine both point and non-point causes of pollution.
ii. A comparison analysis of the surface water quality in the research site, adjacent rice paddies, and the canal network is necessary in light of the implications of land use and land cover change.
iii. Assessment of the effect of heavy metals on aquatic life Delta associated with agricultural activities in the Nile Delta.

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APPENDICES

Appendix I: Research Permit

AIN SHAMS UNIVERSITY
Faculty of graduate studies
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مكتب العميد
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To whom it May Concern

This is a support and acceptance letter for the Student **Mr. Cersey Ochieng Onyango from Kenya, Passport Number: CK87426**, to visit our Faculty of Environmental Studies and Research, Ain Shams University, Egypt.
as a visiting student for a study period of three months' field visit to conduct his case study work based on his accepted proposal. Mr. Cersey is a student at Egerton University, Faculty of Environment and Resources Development (FERD), Department of Environmental Science, Egerton-Kenya. His research proposal is accepted for funding under the project **" NILE STUDENTS EXCHANGE PROJECT"** supported by Nile Basin Capacity Network Foundation (NBCBN-Foundation) of Egypt, IHE -Delft and Wageningen University of the Netherlands, and funded by the Netherlands Embassy in Cairo. The student visit and overall research expenses will be covered by this project.
Based on this acceptance from our faculty to host the student for his research case study, I hereby kindly ask the support of the Egyptian Embassy in Kenya to accept Mr. Cersey Ochieng Onyango Visa application as a visiting student to Ain Shams University, Faculty of Environmental Studies and Research from 1st of July till October, 2023.

Your support in this matter will be highly appreciated.

Dean

Prof. Dr. Noha Donia

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Appendix II: Journal Article Published in Refereed Journal

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RESEARCH ARTICLE

WILEY

Spatial variation in physicochemical water quality parameters associated with Rice farming in the Dakalt Branch Canal, Kafrelsheikh governorate, Egypt

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Abstract
The inappropriate use of chemical fertilizers and pesticides in rice farming has been identified as a significant source of pollution in the aquatic environments. The declining water quality has been a cause of concern for the riparian communities owing to ill health associated with the usage of contaminated water from lotic systems draining such rice-growing areas and its potential to cause lethal and sublethal effects on aquatic organisms. The spatial variation of selected water quality parameters was assessed using multivariate techniques. Data from three sampling stations, collected in triplicates, were analyzed to understand the effects of rice farming practices on the Dakalt Branch Canal's water quality. Eleven physicochemical parameters were measured in situ with a portable multimeter, while nutrients and other chemical parameters were determined following the standard procedures outlined in the American Public Health Association using the UV/Visible spectrophotometer. One-way ANOVA was used to establish whether or not there were significant differences among means of various parameters. The findings revealed considerable spatial variability in the means for nearly all water quality parameters ($p < 0.05$). The Water Quality Index revealed that all

