Spectrum of Engineering Sciences
ISSN (e) 3007-3138 (p) 3007-312X
Volume 4, Issue 2, 2026

QUALITY ASSESSMENT OF EFFLUENT FOR SUSTAINABLE REUSE: A CASE STUDY

Muhammad Jaffar Memon[*1], Saleemullah Siyal[2], Abdul Rehman Memon[3], Hemu Karira[4], Abdul Razzaque Sandhu[5]

[*1,2,4,5]*Department of Civil Engineering, Mehran University of Engineering Science and Technology (SZAB), Khairpur Mirs, Sindh, Pakistan*
[3] *Sindh Institute of Management and Technology (SIMT) Karachi*

DOI: https://doi.org/10.5281/zenodo.18669810

Keywords
Effluent, Wastewater, Sustainable, Reuse, Agriculture, human health, Environment

Article History
Received: 18 December 2025
Accepted: 02 February 2026
Published: 17 February 2026

Corresponding Author: *
Muhammad Jaffar Memon

Abstract
Due to the growing need of water supply in agricultural activities and the water scarcity, there has been an increased interest in using wastewater to irrigate crops. This research examines agricultural reuse of effluents and gives a comprehensive analysis on the quality of wastewater in Sukkur city, Pakistan. The issue of the urgency of this study is the necessity to investigate the possibility of wastewater to be used in irrigation and its safety in case of the extensive use of untreated wastewater in the area, which has the significant risk of damaging the environment and human health. One concern that this technique has raised is that there are hazardous contaminants that may adversely affect the health of crops, soil quality, and ultimately food safety. The key objectives of the investigation are the important contaminants, including heavy metals, minerals, and pathogens, and comparing their values to establish threshold safety levels to be used in agriculture. Based on the findings, the wastewater in Sukkur contains large levels of contaminants like arsenic, copper, magnesium, and nitrites in excess of the permissible levels of these contaminants in irrigation. In addition, this research examines the possibility of reducing risks of using wastewater in agriculture. Direct sources are not recommended to use in any agricultural activity as a result of the existence of arsenic, however, when there are need, then conjunctive use of water needs to be applied. The findings indicate the necessity to consider the effluent water reuse in farming activities and be attentive of the conditions of human beings and nature.

1. INTRODUCTION

Water scarcity and fresh water pollution by numerous factors are a significant socioeconomic challenge to development of the world countries. The farmers of the arid and semi-arid parts of the world where water is a luxury commodity have a critical task of dealing with this problem. The circumstances have led to some of them using wastewater to irrigate their lands which has its merits and demerits. According to the latest studies, the sources of groundwater are being exploited in alarming ways; approximately a quarter of ground water aquifers on earth are already overexploited. The monstrous pressure on freshwater is caused by the fact that every year, approximately 4000 cubic kilometers of freshwater are drained all over the world (Connor et al., 2017).

As countries such as China, United States, and the European Union have seen a tangible annual increase in its utilization to grow agricultural products, the application of wastewater in crop production has seen a remarkable rise in the recent years. This trend has been nurturing in Australia specifically, and it has been estimated that the trend can go up to 41%. This tendency is a sign of an increasing recognition of the possible benefits of using wastewater in the cultivation of such as attending water shortages as well as enhancing the crop incomes. Nevertheless, it also highlights the need to have adequate guidelines and monitoring so as to promote the safety and sustainability of this form of agriculture. (Aziz and Farissi, 2014). Other contemporary researches have recognized Mexico India Pakistan China and Iran as the top five countries in the globe in using untreated wastewater in agricultural practices specifically in regions with semiarid to arid environments. These ways of irrigation, though tainted, have evolved a general observation in these nations owing to the water shortage woes. The use of untreated wastewater in agriculture is associated with the risk of potential health hazards and environmental impacts, emphasizing the need to implement the use of ecological water management methods (Natasha et al., 2018).

Wastewater treatment is one of the major concerns in high-income countries because about 70 percent of wastewater is taken into consideration before being released into the environment. This focus on wastewater treatment demonstrates a commitment to environmental safety and health. Conversely, only 8 percent of the wastewater in the low-income nations is treated and then disposed, posing a threat to poor treatment practices. This disparity is an attention-grabbing fact that draws an interest in the inequality in access to infrastructure and resources between rich and poor nations. To stimulate sustainable growth and ensure a clean and healthy environment of every country, it is necessary to solve this imbalance and treat more wastewater in low-income countries (Zheng and Kamal, 2020). The diminishing freshwater reserves caused by numerous contaminants, organic and inorganic, and the high rate of populating the planet and growing bio fuel production puts tremendous pressure on the limited water resources.

The given problem is especially acute in the situation of Pakistan, which currently has 217 million people, whereas the nation is estimated to have 250 million by 2030 and will become the sixth most populated republic in the world (GOP Web 2017; PBS). The growing population puts an additional strain on food and water resources that directly affect the freshwater availability. The use of land and water in farming increases the predicament when either of the two vital resources is limited. Pakistan is now facing a challenge of freshwater shortage, which is a common problem within numerous developing countries in the world. This scarcity has pushed farmers to employ the use of wastewater in their irrigation activities, despite alarming levels of the existence of dangerous heavy metals like lead (Pb), zinc (Zn), cadmium (Cd), nickel (Ni), iron (Fe), manganese (Mn), and chromium (Cr) in the water. The primary factors that compel this technique are that wastewater is available all year long and it contains nutritional value. The biggest issue, however, is that farmers tend to prioritize short-term financial benefits over the potential long-term health and environmental risks associated with the use of untreated wastewater as irrigation source.

Application of wastewater in agricultural practices is a significant risk to various aspects including the soil quality, quality of crops and consumer health. These effects have been highly reported in some Pakistani cities by research studies, including Sawabi (Ali et al., 2021), Karachi (Shehnaz et al., 2019), Lahore, Attock, and Faisalabad (Rashid et al., 2018). Moreover, the recent studies have indicated that only 2 percent of cities in Pakistan have approach to wastewater treatment facilities, which is a great concern in the cities. The fact that approximately 80 percent of cities dispose of untreated wastewater directly onto agricultural land since the wastewater treatment structures are insufficient is also an alarming statistic (Bashir et al. 2021). The impacts of this practice are far-reaching as they do not only affect the fertility of the soil and farming output in the area but also act as a guise to be hazardous to the health of users and the environment in general. The current state of

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wastewater treatment in Pakistan requires an improvement because the current practices endanger the health of people, as well as the sustainability and integrity of agricultural systems in the country. Although agronomic and economic reasons can be offered to justify the use of wastewater to cultivate crops, it must be handled and treated with all the necessary care to minimize the possible harmful impact on the environment and community health (FAO, 2024).

Given that little to no effort is directed at the characterization of the wastewater (WW) in the Sukkur area, where a large percentage of farmers use untreated WW to irrigate their farms, it will be necessary to characterize it. This is essential in determining its suitability in agricultural activities and setting baseline information on wastewater treatment programs. Therefore, this study is carried out in light of no detailed research has been conducted on the contamination of wastewater in Sukkur city to establish the risks of its use and suggest proper treatment before its application.

2. MATERIAL AND METHODS

2.1 Analytical Procedure

To achieve the aims and objectives of the study extensive number of laboratory tests were carried out to determine the quality and the level of contamination of the water. Among the most important tests conducted was the Temperature assessment that enabled the researcher to know the thermal conditions under which the quality of water was evaluated. The PH levels were also taken to identify the acidic or alkaline nature of the water that would give valuable information on the chemical composition of the water. Besides, Total Suspended Solids (TSS) and Total Dissolved Solids (TDS) assessments were carried out to measure the concentration of the number of particulate material and dissolved material in the water. Besides these tests it was also tested whether there were any heavy metals, such as arsenic cadmium nickel chromium zinc iron lead and copper, to determine whether there was any possibility of any harmful contamination. This played a crucial role in knowing the possible health risks that were related to the water source. The calcium and magnesium tests were conducted aiming at identifying the water hardness with the sodium and chloride tests that were conducted to evaluate the salinity levels and recognize possible sources of pollution. In addition, the Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD) were estimated to understand the quantity of organic matter that exists in the water that is required in determining the overall quality of the water source. In general, these comprehensive laboratory tests offered important information that was significantly used to reach the general findings of the research. They assisted in the systematic research of the condition of the water and its contamination rates, the light of which illuminates potential problems, which may negatively impact human health and environment. Combining to provide a comprehensive insight into the problem of water quality and contamination issues these tests highlighted the impact of taking up the sources of pollution and implementing the precautionary measures to secure the health of people and the environment. The outcomes of these lab tests have highlighted the importance of current surveillance and control of water resources to ensure their sustainability and being safety to everyone.

Figure 1 shows the flow chart comprising of the components involves in the research plan.

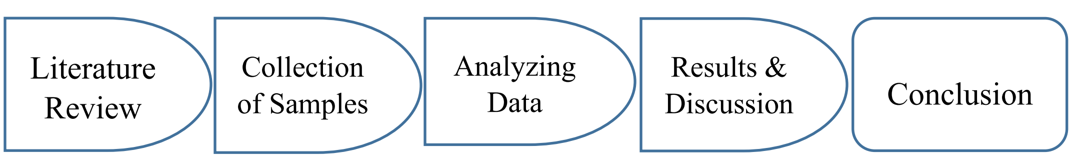

Figure 1. Flow chart of research plan

2.2 Study Area

The experiment was carried out in Sukkur city (27.7244 o N, 68.8228 o E) in the northern Sindh, Pakistan, on the west bank of the Indus River. The research was particularly in 2 sources and five places where wastewater was directly used as irrigation source or was discharged into irrigation canals. This study especially analyzed two water sources i.e. Abad Lakha, a nearby vegetable cultivation region where farmers apply wastewater directly to their fields and the Kirthar Canal, which supplies water to irrigation and most of the wastewater of Sukkur City flows through the Maka Disposal site.

Figure. 3.1: Map Plan for Study Area

2.3 Sample Collection

Specified locations were sampled under strict sampling guidelines, with the collection of the samples being done with care in pre-sterilized 1. 5-liter bottles. Five sets of samples were collected altogether consisting of samples of five different locations. These samples then underwent a profile of 19 elaborate tests as follows. The comprehensive sampling and experimentation procedure ensured flawless and uniform outcomes that give good ideas and information to be analyzed and studied. This systematic nature of this examination was meant to uphold reliability and precision during the collection of sampling process.

2.4 Sample Location

Source-1 (Location A): The exact point of effluent directly utilized for irrigation.

Source -2 (Location B): The upstream spot in the canal, prior effluent discharge

(Location C): The point in Keerthar Canal where effluent is discharged into the waterway

(Location D): 500 meter downstream from the point of effluent discharge.

(Location E): 1000 meter downstream from the point of effluent discharge.

2.5 Time & Date, and Conditions while sample accumulation

1st Sample: Accumulated at 11:00 AM on 11-June 2024

Duration (Canal was flowing, summer conditions)

2nd Sample: Collected at 11:00 AM on 07 July 2024

Duration (Canal was shut, due to heavy precipitation night)

3rd Sample: Collected at 4:00 PM on 09-8-2024

Duration (Canal was flowing, after rainy weather)

4th Sample: Collected at 4:00 PM on 04-9-2024

Duration (Canal was flowing, at full capacity under normal conditions)

5th Sample: Collected on 11: 00 AM on 25-9-2024

Duration (@ the end of September, changing of weather from summer to autumn)

3. RESULTS AND DISCUSSIONS

The PH of all the samples are within the permissible limits as shown in Table 3.1 below but there was some variation in pH: the point of direct usage had higher PH values compared to other locations. The high PH at Abad Lakha is attributed to the use of alkaline detergents and cleaning supplies that are commonly found in residential homes (Islam, et al 2019). Moreover, the decomposition of organic substances and food waste in particular results in the formation of ammonia and contributes to the increase of the pH level in the sewage system (Murtaza, et al. 2010). Conversely, the organic acids that are formed during the decomposition of flora and organic waste in these waterways can explain the reduced values of pH found in canal water In addition, the respiration activity in water bodies can be the source of significant levels of dissolved carbon dioxide, which is also a major cause of low pH (Hanumanthanaik, et al. 2022). Total suspended solids of water quality at the point of direct usage was still within acceptable range, however, the water in the canals at higher elevations contained much higher levels. The high concentration of the pollutants in the canal water may have many causes. One of the reasons that have led to the higher levels of silt and particle matter that flow to the water is the erosion of canal banks. The fact that the wastewater released into the canals is not treated worsens this issue even further by introducing the pollutants and reducing the quality of the water even further. Furthermore, the lack of proper maintenance and de-siltation in the canals causes the accumulation of sediments and organic debris that ultimately increases the amount of pollutants contained in the water flowing downstream. Water having high content of total suspended solids (TSS) as shown in Figure 3.1 may be unusually insecure to the conservation circumstances and farming observers. Improved TSS may obstruct the air and water infiltration of the soil, the next in defective soil structure and impoverished better yield. The irrigation process using water with high suspension of solids may expose crops to many diseases and contaminants and thus, have adverse impacts on crop health and food safety. Among other posturing risks to the crops themselves, it is possible that the existence of such pollutants can pose an opposing result on human health until the contaminated products are utilized, as indicated by (Natasha, et al 2020). Therefore, control of the total suspended solids (TSS) in irrigation water is a key to the sustainable irrigation practices and the protection of crops and human health.

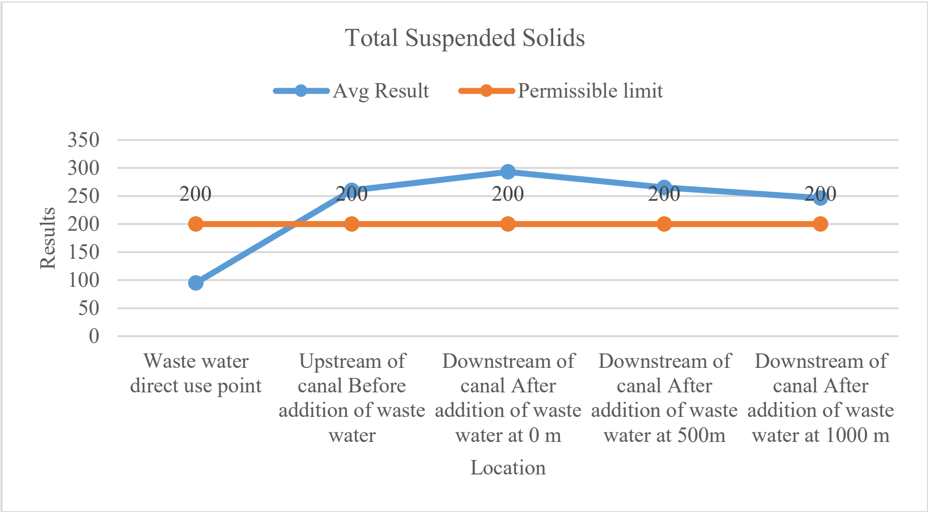

Figure 3.1: TSS Values at Different locations

The nitrite was detected within acceptable limit. And there is no danger or threat involved on this basis. Canal water samples were found to be safe, however at the direct use point of the wastewater, the nitrate level was reported to be 117.92 mg/l which is far more than the permitted amount.

One of the primary causes is the waste produced by livestock which contributes to the water by depositing some substantial amount of nitrates to the wastewater, result in the degradation of organic waste in domestic sewage.

The rise in the nitrate levels has several significant implications on the environmental sustainability and the human health. High concentration of nitrate may cause health complications particularly in newborns with blue baby syndrome a condition that may lead to difficulties in transferring blood oxygen. Even though excess of nitrate may increase the crop production, it also poses serious health risks to the consumer such as increased risks of developing chronic diseases (Lanjwani, et al 2022). Thus, it is necessary to watch and regulate the amount of nitrates in the farming fields and wastewater treatment in order to safeguard the population and minimize soil degradation.

As per the investigation (as indicated in below Table 3.1), the direct use point water is not suitable in irrigation, probably due to factors such as sewage blockages, reduced water flow, and an increased level of organic substances. The injected garbage has a higher Biological Oxygen Demand (BOD), and this aspect leads to the worsening of the water quality. The high BOD irrigation water is a great threat to the crop safety and the soil health since it is likely to induce waterlogging, depletion of oxygen in the root zone, and extent the harmful infections to crops. (Panhwar, et al. 2022)

This is indicated in below Table 3.1 that Chemical Oxygen Demand (COD) has the highest value at the point of direct usage is greater than the permissible limit at every point of observation. The primary reason of this increase is the occurrence of higher quantities of organic compounds in those areas where sewage is directly discharged into irrigation. The household activities include cooking, cleaning and sanitation among other tasks that significantly increase the organic load in sewage and increase the COD (Islam et al. 2019, Panhwar, et al. 2022).

As shown in Figure 3.2 the Arsenic values of different locations. The use of crops grown with arsenic-contaminated water poses severe health risks, especially severe risks like cancer and skin lesions (Rehman, et al. 2020). In addition to the direct health impacts on the consumers, arsenic may also pollute the soil with negative effects to the microbial communities that are essential in keeping the soil healthy and promoting nutrient cycling (Youseuf, et al. 2022). Such disturbances may cause low soil fertility and impaired agricultural output. In addition, chronic exposure to arsenic by eating contaminated crops may also lead to cumulative toxicity of human beings in the long term. The effects of such exposure in the long term highlight the necessity of proper monitoring and management measures to reduce the risks of contamination of arsenic content in irrigation water and agricultural activities.

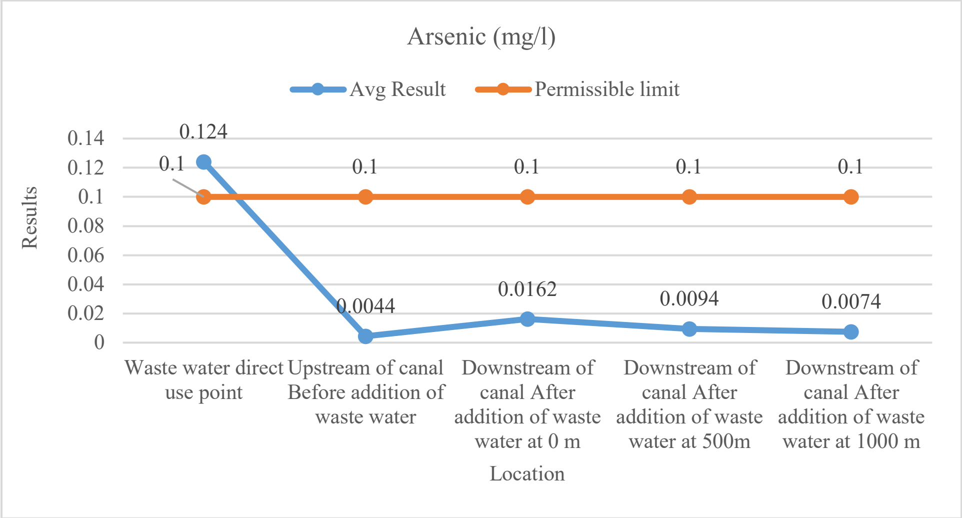

Figure 3.2: Arsenic Values at Different locations

The higher copper levels in the effluent are indicated by the increased copper level in the effluent as demonstrated in Figure 3.3 of Copper at different locations. Abandoned electronics may be an alternative since they often have copper parts that may pollute the water system. Moreover, Corroding and old-fashioned plumbing fixtures may also cause copper (Riaz., et al. 2020). Also, since waste products and runoffs of these companies might emit copper to the environment, the electrical wiring and air conditioning repair stores activities can also cause copper pollution. These factors highlight the need to use effective management methods to reduce copper pollution in wastewater and protect the quality of water.

Consuming water with a high concentration of copper may inclined into the food chain causing harm to the human body by accumulating copper in plant organisms, which may cause significant risks to human health through food ingestion (Mir, et al 2021).

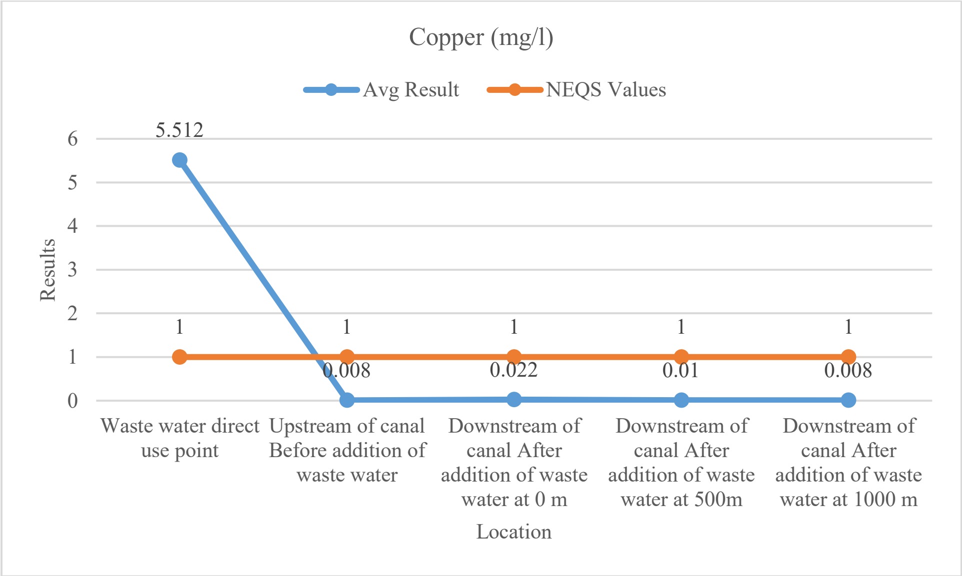

Figure 3.3 Copper Values at Different locations

The Table 3.1 below shows all average results of each test at different location for deeper analysis to shed light on their suggestions and potential outcomes. This is a thorough analysis of the results in line with industrial standards that one can measure in the context of which presents the predicaments align itself to perceived norms. Similarly, it describes the profits and possible health risks of the crop cultivation and expenditure of these crops. It also depicts further understanding the sustainability of these practices by looking at both the consequences in terms of long term and short term practices for sustainable irrigation purposes.

Table 3.1: Detail Summary of Varied Test Samples Results

Sr. No.	Tests /Parameter	Unit	NEQS Value	FAO Values	relevant study results	Avg result of five sets				
						Waste water with no dilution	Canal water (Kirthar)			
						Direct use point	U/s of canal	D/S at 0 m	D/S at 500 m	D/S at 1000m
1	pHs	-	6~9	5~9	7 - 9	8.000	6.000	6.400	6.000	6.000
2	Temperature	°C	40	35		28.140	27.980	27.900	27.220	27.980
3	Total Suspended Solids (TSS)	mg/l	200	45		94.800	260.400	293.000	265.200	246.600
4	Total Dissolved Solids (TDS)	mg/l	3500	2000		1943.200	120.600	372.200	170.600	153.800
5	Arsenic	mg/l	1	0.1	0.31	0.124	0.004	0.016	0.009	0.007
6	Calcium	mg/l		400		128.560	15.600	32.960	22.080	20.080
7	Magnesium	mg/l		60		95.808	15.072	24.864	14.880	13.536
8	Iron	mg/l	8	5	1.75 - 23	0.022	0.068	0.190	0.040	0.000
9	Copper	mg/l	1	0.2	0.12 - 18.2	5.512	0.008	0.022	0.010	0.008
10	Chloride	mg/l	1000	250		1707.600	22.000	187.300	74.600	74.000
11	Nitrite	mg/l	1			0.016	0.000	0.006	0.001	0.000
12	Nitrate	mg/l	10	15		117.920	0.960	1.280	1.000	0.780
13	Chemical Oxygen Demand (COD)	mg/l	150	90	491- 577	328.000	46.800	92.600	82.800	75.000
14	Biochemical Oxygen Demand (BOD)	mg/l	80	30	226 -414	193.200	25.200	47.800	44.800	40.600
15	Cadmium	mg/l		0.01	0.02 - 2	0.009	0.003	0.003	0.003	0.003
16	Nickel	mg/l	1	0.2	0.04 - 5	0.011	0.008	0.008	0.008	0.008
17	Chromium	mg/l	1	0.1	.05 -4.7	0.007	s	0.005	0.005	0.005
18	Zinc	mg/l		2	0.01 -10	0.045	0.022	0.034	0.029	0.027
19	Lead	mg/l		2	0.14 - 7.8	0.078	0.013	0.018	0.017	0.016

4. Conclusion

Conclusively, the results revealed that all the critical variables such as pH, temperature, TDS, calcium and iron and nitrite levels under tolerable limits at all sites. This means that such properties of the water quality are normally applicable for cropping. Also, it was found no hazardous levels of heavy metals existed in the water of any of the locations, and the levels of cadmium, zinc, lead, nickel, and chromium were acceptable. It was observed that both the TDS and pH levels were above the desirable level and it is therefore necessary to monitor them continuously to ensure that the two variables remain within acceptable limits. The maintenance of the sustainable agricultural practices and the protection of the ecology around is a matter that must always be addressed in detail. Nevertheless, tests on total suspended solids (TSS), arsenic, magnesium, copper, chloride, nitrate, BOD and COD have revealed that the level of these parameters was greater as compared to permissible standards according to the regulatory requirements. The existence of high levels of concentration is of great concern as they can threaten the integrity of the soil, consumer health, and agricultural productivity. As an example, the TSS was recorded to be 293 mg/L, which is above the 200 mg/L permissible level. Due to the prevention of sunlight that is vital in photosynthesis, this high level may impact water quality which is vital to aquatic life. Similarly, we found out high concentrations of copper of 5.5mg/L as compared to the allowable level of 0.2mg/L, which is detrimental to crops in general and results in toxicity in plants. High chloride level, which is beyond the permissible range of 250 mg/L to 1700mg/L, may also adversely affect the soil microbial populations which are important in the recycling of nutrients and soil richness. Moreover, the concentration of arsenic was found to be 0.124mg/L, which exceeds the maximum concentration of 0.1mg/L, which presents a serious hazard to the health of consumers, including the potential of long-term adverse effect.

The impact of the elevated indicators has been discussed comprehensively through the course of the research, with a strong emphasis on the urgent necessity of targeted interventions and effective management strategies. In order to resolve these problems, collaboration among stakeholders such as farmers, legislators as well as environmental regulators is essential. Policies that will mitigate the risks associated with wastewater irrigation should be in place to safeguard the health and agricultural production.

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