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Characteristics study of ammonia-n and phosphorus in sewage wastewater effluent: a case study of Alkhumrah, Jeddah Wastewater Treatment Plant

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Abstract. Ammonia-N ($\text{NH}_3\text{-N}$) and Phosphorus (P) pollutions remain highly challenging pollutants to the Saudi environment. The sewerage treatment plant can be one of the main contributors to $\text{NH}_3\text{-N}$ and P pollutants. The main aim of this study is to investigate the concentration of $\text{NH}_3\text{-N}$ and P released from the Al Khumrah wastewater treatment plant in Jeddah. The treatment process used in this treatment plant consists of screening, aerated grit removal chambers, surface aeration, sedimentation and sludge thickening and de-watering via belt filter presses. For this study, primary data of N and P is obtained from the Ministry of Environment & Agriculture, Kingdom of Saudi Arabia. The data is collected from the wastewater treatment plant of Al Khumrah, Jeddah. A total of 101 data is collected for $\text{NH}_3\text{-N}$ and P within a period of 6 months from September 2019 to February 2020. Descriptive statistic was used to analyse the data. It was found that the highest mean concentration of $\text{NH}_3\text{-N}$ and P in the effluent are 4.2 mg/L and 1.7 mg/L respectively. The concentration of $\text{NH}_3\text{-N}$ and PO_4^{3-} in the influent exceeded the maximum limit of 1.0 mg/L stated in General Environmental Regulations and Rules for Implementation (2001) provided by the Kingdom of Saudi Arabia Presidency of Meteorology and Environment. A low effluent concentration is set up by the authorities to meet the requirement of water reuse and recycling. The result has shown that the removal efficiency of $\text{NH}_3\text{-N}$ during the treatment is 55%. However, the removal efficiency of PO_4^{3-} is very inconsistent with the percentage removal varied from 0% - 61.5 %. This finding demonstrated that the treatment plant will continuously not be able to comply with the standard discharge limit especially if a higher concentration of $\text{NH}_3\text{-N}$ and PO_4^{3-} entering the treatment plant. In this case, the changes of the current treatment process or addition of tertiary treatment would be needed to ensure the discharge wastewater met the reuse and recycling requirement.

1. Introduction

Freshwater for public use is a valuable natural resource around the globe is becoming more limited because of environmental influences and increased human activities [1]. At the same time, the demand for high water quality is increasing especially for the urban population that focuses on a good and healthy lifestyle. Therefore, water purity, and treatment process have become a major concern for the public. Realizing the importance of clean and safe water supply, sustainable water and sanitation is included in the 2030 agenda of United Nations Sustainable Development Goals (SDGs). It can be said that water quality the prerequisite for sustainable water and sanitation which equally important for many other SDGs related to health, food security and biodiversity.



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The degradation of water sources by organic and inorganic pollutants arising from sewage, agriculture, as well as industrial sources, negatively impact the environment and human wellbeing. Around 80% of the wastewater generated is disposed of without receiving any treatment. According to Qayoom et al. [2], there is an increasing recognition regarding cross-linkages of wastewater management and water quality and the need for good wastewater management and its contribution to protecting water quality. This matter is also highlighted in the SDG Target 6.3 whereby 2030, the improvement of water quality should be achieved by reducing pollution and halving the proportion of untreated wastewater and urges countries to increase wastewater collection and treatment so that effluent consistently meets national standards [3]. To date, high concentration of Nitrogen (N) and Phosphorus (P) in the water body caused by unsatisfactory treatment of sewage wastewater remains a challenging issue that requires special and enormous attention [4].

Domestic wastewater is a significant source of inorganic nutrients includes nitrogen in form of $\text{NH}_3\text{-N}$ and phosphorus in form of orthophosphate ($\text{PO}_4\text{-P}$). Thus, an increase in population especially in the urban area directly increase the volume of sewage water containing $\text{NH}_3\text{-N}$ and P. Phosphorus is a crucial nutrient for bacteria as a biologically stabilize the organic wastes that required to be degrading. Phosphorus is commonly present in the form of orthophosphate (i.e. condensed phosphate or polyphosphate) in natural and wastewaters [5]. $\text{NH}_3\text{-N}$ and P are commonly derived from animal and human wastes, agronomic runoff, industry and domestic wastewater [8]. Generally, the concentration of P in domestic wastewater ranges between 3–15 mg/L levels; simply about 3 mg/L is produced from the breakdown of protein wastes whereas the bulk derives from the usage of detergents [6]. The release of excessive volume of $\text{NH}_3\text{-N}$ and P ions from wastewater treatment plants can adversely affect the water quality of a receiving reservoir or supply.

The $\text{NH}_3\text{-N}$ release from sewage wastewater is one of the key contributions to the ecological issues including algal blooming and ultimately eutrophication [4]. Generally, excessive $\text{NH}_3\text{-N}$ and P in the water results in algae rapid growth more than what ecosystems can cope with [7]. A substantial proliferation in algae is detrimental to the water quality, plants, and environments of Saudi Arabia which reduce oxygen needed by fishes and other aquatic animals to survive [8]. Enormous developments of algae are known as algal blooms, which can scrupulously lessen or eradicate oxygen in the water, results in infections in fish and the loss of a huge amount of fish [4]. Certain algal blooms are toxic or poisonous to humans as they produce high toxins and microbial development, which make human sick when coming in contact with polluted water, eat contaminated fish, or drink polluted water [9, 10].

$\text{NH}_3\text{-N}$ and P in domestic wastewater treatment systems are crucial problems that have not yet been adequately resolved. Furthermore, ongoing eutrophication, particularly in freshwater, has resulted in an increasing governmental regulatory burden and enforcement for reducing P concentrations via improved P removal from wastewater [1]. In Saudi Arabia, the total phosphorus (TP) limit for effluent release in wastewater treatment plants is permitted with ranges of 1–2 mg/L, while in some areas, more strict measures of around 0.5–0.8 mg P/L are adopted to control eutrophication [11]. Algal blooming can occur if the concentration of $\text{PO}_4\text{-P}$ exceeds 0.1–0.5 mg/L which cause “eutrophication” in the receiving water, therefore phosphate removal is an indispensable aspect of domestic wastewater treatment [12]. However, achieving these standards constituted a great challenge in managing phosphorus level in domestic water resources.

These pollutants in domestic wastewater treatment systems are crucial problems that have not yet been adequately resolved. Furthermore, ongoing eutrophication, particularly in freshwater, has resulted in an increasing governmental regulatory burden and enforcement for reducing P concentrations via improved P removal from wastewater [1]. Domestic wastewater treatment has enhanced considerably in the past decades [4], but P pollution treatment in urban or domestic wastewater in Saudi regions has not been fruitful [13]. Wastewater from the Saudi treatment requires onsite treatment systems, in which soils or filter materials accountable for P retention [7]. Thus, this study aims to analyse N and P concentration in Wastewater Treatment Plant in Jeddah, Kingdom of Saudi Arabia. By understanding the treatment efficiency of the wastewater treatment plant, the

possibility of shifting the paradigm of wastewater management from ‘treatment and disposal’ to ‘reuse, recycle and resource recovery’ would be achievable.

2. Material and Methods

2.1. Description of STPs evaluated

Al Khumrah is the largest wastewater treatment plant situated in the southern part of Jeddah City near the industrial area of Al Khumrah District. It is made up of four existing segments with a collective hydraulic capacity of approximately 250,000 m³ /d [9]. Out of these four segments, the wastewater treatment plant Al Khumrah 2 (AK2) was authorized in 1998. It was structured for a capacity of 60,000 m³/d and a BOD pack of 320 mg/L to receive domestic wastewater from 621 km of the collection system of Al Khumrah [9]. The treatment process includes ventilation, ventilated grit elimination chambers, surface ventilation, sedimentation and sludge solidifying and dewatering through belt sieve pressures. It employs a triggered sludge process [14]. In 2004, the wastewater treatment plant is upgraded with a structured capacity of 140,000 m³/d and equip with a UV-disinfection process. This new additional structure is known as Al Khumrah 3 (AK3) and presently receives approximately 125,000 m³ /d of wastewater. The total treatment capacity for the Al Khumrah wastewater treatment plant (WWTP) is approximately 250,000 m³/d. This plant also provides the P-removal using precipitation and final clarifiers, while N-removal is by in galvanized sludge and dripping filter processes [9]. The advanced treatment includes disk filtration and UV disinfection. The final stage comprises slurry hardening, dewatering, and treatment silos [15].

2.2. Data Analysis

The data used for the analysis in this study was obtained from the Monitoring and Analysis Division of Al Khumrah, Wastewater Treatment Plant, Kingdom of Saudi-Arabia. A sampling of these data was performed over a period of six months from September 2019 to February 2020. The data was collected in the interval of 1 day for each month which making approximately 15 data collected per month with a total of 101 data for a period of 6 months. According to the Monitoring and Analysis Division of Al Khumrah Wastewater Treatment Plant, this time interval was projected to be sufficient and satisfactory, as no unusual events or accidental overflows were noted during the sampling period.

In this study, MINITAB 18.0 version is used for the descriptive analysis. The data of NH₃-N and PO₄³⁻ are used to represent N and P concentration in the influence and effluent of the Al Khumrah Wastewater Treatment Plant respectively. This data is subjected to descriptive statistical analysis. The descriptive statistical parameters include mean, minimum, maximum, standard deviation, and variance. The result from the analysis is used to measures the central tendency or measures of variability, also known as measures of dispersion. Generally, measures of central tendency focus on the average or middle values of data sets, whereas measures of variability focus on the dispersion of data. Removal efficiencies were calculated as the difference between mean concentrations in influent and effluent. The finding is presented in a table and graph to help people understand the meaning of the analysed data.

3. Results and Discussion

Table 4.1 displays the analysis of NH₃-N concentrations in the influent and effluent of Al Khumrah Wastewater Treatment Plant for the period of September 2019 until February 2020. The analysis of the data revealed that the wastewater entering Al-Khumrah Wastewater Treatment Plant has a mean NH₃-N concentration of 8.0 mg/L with a standard deviation of 1.2 mg/L. The small deviation of the mean value indicates a small variation of NH₃-N concentration in the wastewater. In general, from September 2019 to February 2020, the concentration of NH₃-N in the influent wastewater is varying between 6.2 mg/L to 9.4 mg/L. The highest monthly mean of NH₃-N concentration (9.4 mg/L) was recorded in the month of February 2020. Meanwhile, the mean concentration of NH₃-N loading for the six months duration is demonstrated in Figure 4.1(a). From the figure, NH₃-N concentration shows a

decreasing pattern from October 2019 to January 2020 but a sudden spike in February 2020. According to Almazroui, [16], Saudi Arabia is facing a wet season from October to May and a dry season from June to September. Thus, it can be said that the mean value of $\text{NH}_3\text{-N}$ in Table 4.1 is representing the concentration of $\text{NH}_3\text{-N}$ at the end of the dry season (September) and mid wet season (October to February). It is also expected that the continuous reduction of $\text{NH}_3\text{-N}$ in the influent wastewater from October 2019 to January 2019 (Figure 4.1(a)) is a result of dilution by the continuous precipitation during the wet season. Meanwhile, the highest decrease of precipitation in January [16], may contribute to the spike of $\text{NH}_3\text{-N}$ in February 2020. The contrast between the mean and the median results indicate variation in the $\text{NH}_3\text{-N}$ concentration of the influent stream within 15 days of sampling, suggesting a change in the normal to higher concentration obtains during this period.

Table 1. Descriptive statistics of nitrogen concentrations ($\text{NH}_3\text{-N}$ mg/L) in the influent and effluent streams of Al-Khumrah Wastewater Treatment Plant of the months from September 2019 to February 2020.

| | Sept 2019 | | Oct 2019 | | Nov 2019 | | Dec 2019 | | Jan 2020 | | Feb 2020 | |
|---------------|-----------|------|----------|------|----------|-------|----------|------|----------|-------|----------|-----|
| | Inf | Eff | Inf | Eff | Inf | Eff | Inf | Eff | Inf | Eff | Inf | Eff |
| Mean (mg/L) | 7.3 | 3.4 | 9.0 | 4.2 | 8.8 | 3.8 | 7.2 | 2.8 | 6.2 | 3.8 | 9.4 | 3.2 |
| Median (mg/L) | 6.8 | 2.7 | 7.6 | 4.9 | 7.9 | 3.7 | 6.0 | 2.5 | 6.1 | 4.0 | 7.6 | 3.3 |
| Mode (mg/L) | 6.3 | 2.7 | 7.8 | 4.7 | 6.6 | 3.0 | 5.2 | 2.4 | 5.7 | 2.8 | 6.4 | 2.1 |
| Max (mg/L) | 7.4 | 4.3 | 9.6 | 5.0 | 9.0 | 4.0 | 7.8 | 3.6 | 7.0 | 4.0 | 9.7 | 4.4 |
| Min (mg/L) | 2.0 | 1.5 | 3.4 | 1.0 | 6.0 | 1.1 | 3.5 | 0.5 | 2.0 | 0.0 | 4.0 | 0.5 |
| STD* | 5.0 | 1.9 | 3.8 | 1.0 | 4.4 | 1.2 | 5.6 | 0.8 | 5.0 | 0.9 | 4.4 | 0.5 |
| Variance | 2.2 | 2.5 | 3.0 | 1.0 | 4.6 | 3.0 | 3.6 | 0.6 | 2.1 | 0.8 | 6.9 | 0.5 |
| Skewness | 0.9 | 2.41 | 3.60 | 1.23 | -0.13 | 0.83 | 0.11 | 1.92 | -0.23 | 0.02 | -0.60 | - |
| Kurtosis | 4.2 | 6.25 | -1.10 | 1.11 | -1.70 | -0.35 | 0.72 | 3.71 | -1.60 | -1.50 | -0.70 | - |

*STD: Standard deviation, inf= influent streams, eff=effluent streams

Overall, the concentration of $\text{NH}_3\text{-N}$ entering the wastewater treatment plant is high and required treatment before discharge to any water body. According to the General Environmental Regulations and Rules for Implementation (2001) provided by the Kingdom of Saudi Arabia Presidency of Meteorology and Environment, the permissible limit for Ammonia (as nitrogen) at the discharge point for sewage effluent wastewater is 1.0 mg/L. Thus a good wastewater treatment system is required to assist the removal of $\text{NH}_3\text{-N}$ in the wastewater to achieve this standard. In this study, the concentration of $\text{NH}_3\text{-N}$ in the effluent is recorded to inspect the efficiency of the wastewater treatment system used in the Al Khumrah Plant. Referring to the effluent data analysis, the mean concentration of $\text{NH}_3\text{-N}$ after going through treatment in the Al Khumrah WWTP is 3.5 mg/L with a standard deviation of 0.5 mg/L. This mean value represents an average of the monthly mean value from September 2019 to February 2020. The concentration of $\text{NH}_3\text{-N}$ recorded in the effluent exceeded the maximum limit of 1.0 mg/L stated in General Environmental Regulations and Rules for Implementation. It can be seen from Figure 4.1(a) that the concentration of $\text{NH}_3\text{-N}$ in the effluent is nearly constant with the value ranging between 2.8 mg/L to 4.2 mg/L.

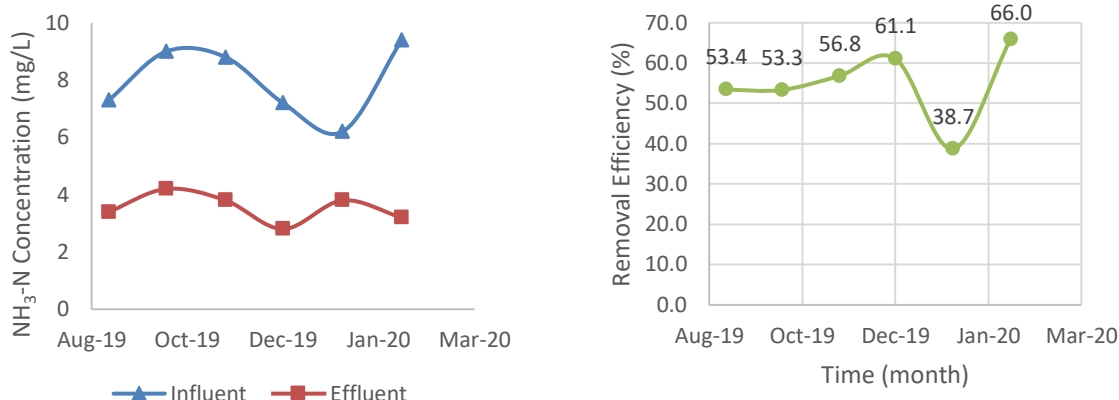


Figure 4.1(a). Mean concentration of NH₃-N in the influent and effluent of the wastewater.

Figure 4.1(b). The efficiency of NH₃-N removal by Al-Khumrah wastewater treatment system.

The effluent stream standard deviation remains consistent around 1.0 except in September where the value is slightly higher (1.9) compared to other months (October 2019 until February 2020). This suggests that there are no variations in NH₃-N concentrations data during the 6 months of sampling. The percentage removal of NH₃-N by Al-Khumrah WWTP is presented in Figure 4.1(b). The findings show that the removal efficiency is approximately 58.1% except for January 2020 where the removal efficiency reduces to 38.7% for an unknown reason. These results imply that the Al-Khumrah WWTP with the current treatment system is only capable to remove approximately half of the NH₃-N content in the influent wastewater. The remaining NH₃-N will be directly discharged to the water body and cause pollution in the freshwater. In addition, NH₃-N is considered as the representative water quality parameter that the most significantly correlates with other water quality parameters affecting river water quality [17].

The variance dispersals for September 2019 and November 2019 for the effluent streams are found to be near the means and medians, while for October 2019, December 2019, and January 2020, with February 2020 having the highest value for the effluent stream are completely platykurtic, which implies that results are far lesser than the mean values. This subsequently unflattens the Skewness curve based on the computed kurtosis coefficients. All these values, suggest well distribution and variations in N concentration through the six months. The results are comparable with findings by [18] for N and P in Al Khumrah sewage effluent distribution and behaviour in the coastal area, Jeddah, KSA.

Table 4.2 depicts descriptive statistics of phosphorus (P) concentrations for the period September 2019 to February 2020 in the Saudi influent and effluent streams (Wastewater Treatment Plant of Al Khumrah, Kingdom of Saudi-Arabia). In this study, PO₄³⁻ is used to represent P concentration in the Al Khumrah WWTP. The result shows that the means do not deviate far from the medians. This indicates that there are only small variations of P concentration in influent and effluent wastewater data. The highest concentration of PO₄³⁻ in influent is detected in November with the mean value of 2.6 mg/L. Meanwhile, the average monthly means is 2.1 mg/L. The trend of PO₄³⁻ in influent and effluent wastewater of Al Khumrah WWTP is illustrated in Figure 4.2(a) while removal efficiency of PO₄³⁻ is displayed in Figure 4.2(b). It was found that the concentration of PO₄³⁻ in the effluent wastewater in October, December, January and February is higher than the allowable limit of 1.0 mg/L stated in General Environmental Regulations and Rules for Implementation (2001). The highest removal efficiency of PO₄³⁻ is 61.5% which is achieved during the month of November while no removal is recorded in October and January.

Table 4.2. Descriptive statistics of phosphorus concentrations (PO_4^{3-} mg/L) in the influent and effluent streams of Al-Khumrah Wastewater Treatment Plant of the months from September 2019 to February 2020.

| | Sept 2019 | | Oct 2019 | | Nov 2019 | | Dec 2019 | | Jan 2020 | | Feb 2020 | |
|---------------|-----------|-------|----------|-------|----------|-------|----------|------|----------|------|----------|------|
| | Inf | Eff | Inf | Eff | Inf | Eff | Inf | Eff | Inf | Eff | Inf | Eff |
| Mean (mg/L) | 2.0 | 1.1 | 1.6 | 1.7 | 2.6 | 1.0 | 2.4 | 2.0 | 1.7 | 2.0 | 2.3 | 1.7 |
| Median (mg/L) | 2.0 | 1.0 | 2.0 | 1.3 | 1.1 | 1.0 | 1.7 | 1.5 | 1.7 | 1.6 | 1.2 | 1.1 |
| Mode (mg/L) | 2.6 | 0.7 | 1.6 | 1.0 | 1.6 | 0.8 | 1.8 | 1.3 | 1.4 | 1.3 | 1.9 | 1.1 |
| Max (mg/L) | 2.0 | 1.9 | 1.8 | 2.0 | 2.8 | 2.0 | 2.1 | 1.6 | 2.0 | 2.2 | 2.0 | 2.1 |
| Min (mg/L) | 0.9 | 1.2 | 1.4 | 1.1 | 1.0 | 1.1 | 1.5 | 1.2 | 1.0 | 1.0 | 1.0 | 0.9 |
| STD* | 0.2 | 0.3 | 0.8 | 0.5 | 0.4 | 1.0 | 1.2 | 1.2 | 1.0 | 0.8 | 0.5 | 0.9 |
| Variance | 0.1 | 0.5 | 1.1 | 0.3 | 1.0 | 1.0 | 1.4 | 1.4 | 1.1 | 0.6 | 0.2 | 0.8 |
| Skewness | - | 0.10 | 0.01 | -0.15 | 0.06 | -0.91 | 1.20 | 1.95 | -0.14 | 0.11 | 1.60 | - |
| | 0.93 | | | | | | | | | | | 0.02 |
| Kurtosis | 1.09 | -1.25 | -1.22 | -2.34 | -3.46 | -0.07 | 2.41 | 3.77 | 0.83 | 0.42 | 1.65 | - |
| | | | | | | | | | | | | 0.15 |

*STD: Standard deviation, inf= influent streams, eff=effluent streams

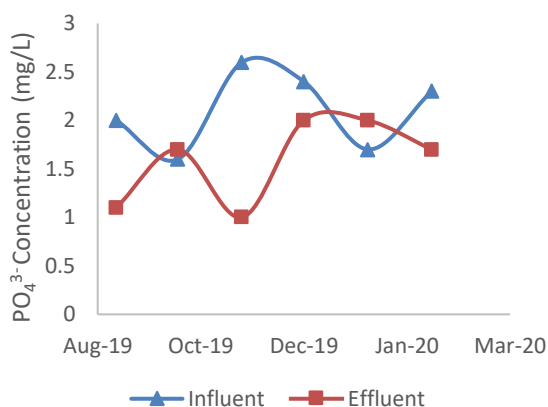


Figure 4.2(a). Mean concentration of PO_4^{3-} in the influent and effluent of the wastewater.

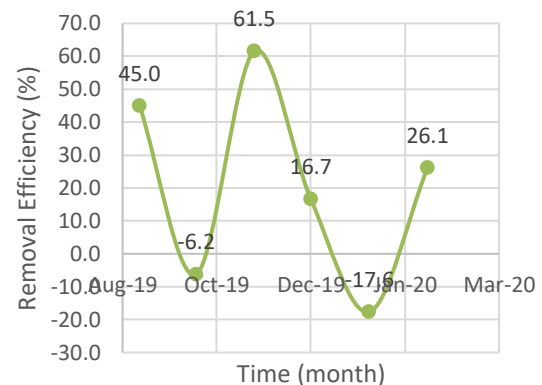


Figure 4.2(b). The efficiency of PO_4^{3-} removal by Al-Khumrah wastewater treatment system.

The coefficients of skewness and kurtosis revealed the level of regularity and peakedness/flatness in the distribution of phosphorus concentration in the wastewater throughout the months from September 2019 to February 2020. The effluents phosphorus concentrations in October and November 2019 are revealing of negative skewed and platykurtic discharge of the wastewater. This implies that the data deviate of the means toward upper ideals, while those analysed for December 2019, January 2020, and February 2020 were documented to be positively skewed. These months have higher kurtosis than the normal distribution (leptokurtic in distribution), this illustrates that these results lean towards lower rates with an extreme peak.

Stringent regulation for the discharge of wastewater has been regulated by Arab Saudi. All wastewater treatment plants are consolidated in KSA under the General Directorate for Water. According to Kaddoura et al. [20], Saudi standard requirement include effluent must comply with reuse or discharge standards suitable to its use; conversely, protocols propose by the WHO, are not

compulsory. Based on these standards, pollution levels ought to be as low as feasible to circumvent eutrophication. In such as that the emission measurement assesses effluent release capacities in connection with streamflow adequate such that concentration reduction can be assured [20]. However, these guidelines are not fully implemented by the wastewater treatment plants across Saudi Arabia resulting in water pollution.

The irregularity of removal efficiency shown in Figure 4.2(b) indicates the current treatment system applied in the Al- Khumrah plant not capable of effectively remove PO_4^{3-} in the wastewater. To achieve the 2030 SDGs target of sustainable water management, improvement of wastewater treatment system is a must. This finding also suggested that the current precipitation treatment process is inconsistent for PO_4^{3-} removal. According to Ouda, [13] and Kaddoura et al. [19], Al Khumrah WWTP used activated carbon, activated charcoal layer, and/or activated sludge to remove P and N from wastewater or sludge. Thus the variation of removal efficiency may be related to the type of precipitant used in the treatment. However further study should be conducted to understand the actual factor that causes the inconsistency of the precipitation process in removing PO_4^{3-} in sewage wastewater.

The discharge of sewage wastewater containing inorganic nitrogen and phosphorus from the treatment plant, greatly impact the natural waters [21]. The nutrient largely contributed to algae blooming which cause a drastic reduction of dissolved oxygen in waters. The problem has occurred more than a decades ago [22], but the same problem persists until today with an increase of sewage wastewater volume release to the coastal area. It was estimated that 21,261 and 3,360 kg of nitrogen and phosphorus associate with sewage wastewater is discharged daily [21].

4. Conclusion

Globally, treated sewage effluent reuse is encouraged to address overall water scarcity problems especially in the region with fewer freshwater sources. In this study, the high average concentration of $\text{NH}_3\text{-N}$ (8mg/L) is detected in the influent. The average concentration of PO_4^{3-} entering the wastewater treatment is 2.1 mg/L. It was estimated that the current wastewater treatment system is only capable to reduce the concentration of $\text{NH}_3\text{-N}$ and PO_4^{3-} into half of the influent concentration. The low efficiency of current wastewater treatment reveals an urgent need for a technological upgrade for safe water recycling and reuse to support the achievement of Target 6.3 (SDGs) which is critical for achieving the entire Agenda.

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