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Optimizing Wastewater Management in Kuwait: Characterization of Treatment Parameters

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Abstract **-** This paper presents a comprehensive analysis of the wastewater characteristics in Kuwait, focusing on the Kabd Wastewater Treatment Plant, with an emphasis on establishing local design parameters for effective treatment. Given the significant differences in wastewater attributes across regions due to factors such as climate, industrialization, and conservation efforts, this study highlights the importance of localized assessments for treatment efficiency. By examining a robust dataset spanning from 2012 to 2023, key physical, chemical, and nutrient parameters were analysed, including temperature, pH, suspended solids, COD, BOD, and nutrient concentrations like nitrogen and phosphorus. The BOD to COD ratios were specifically evaluated to determine the biodegradability of organic matter within the wastewater, revealing a mix of biodegradable and refractory organic compounds. The findings indicate that while a significant portion of the wastewater is suitable for biological treatment, the presence of industrial discharges necessitates advanced treatment solutions to address non-biodegradable pollutants. The study's insights are critical for optimizing the design and operation of wastewater treatment facilities in Kuwait, promoting sustainable practices that can handle diverse pollution loads effectively and economically. The characterization of wastewater supports compliance with environmental standards, ensuring the protection of water resources and public health in Kuwait.

Keywords**:** Wastewater Characterization, Biodegradability, Treatment Efficiency, Environmental Compliance, Sustainable Water Management

1. Introduction

Although, wastewater treatment plants (WWTPs) are designed to last for many years by installing the latest treatment technology and designs, most heuristics and design procedures are based on the typical values of wastewater in large cities located in foreign countries, such as the United States of America. However, there is a significant difference between wastewater characteristics between countries, especially when there is a large cultural difference. The variation in wastewater characteristics is due to several factors such as climate, geographic location, population density, economic conditions of the community, degree of industrialization, water supply, conservation efforts, and cost of water [1]. Regarding these factors, Kuwait has different conditions compared to the other cities that were studied for the universal typical values. Furthermore, characterization of wastewater is required to obtain the optimum design parameters to be used in designing and operating WWTPs. The main objective of this work is to characterize Kuwait's wastewater to provide local design parameters for the best treatment efficiency in Kuwait WWTPs and no such study has been made in Kuwait.

Kuwait ranks top among Arab countries and seventh worldwide in terms of sanitation coverage [2]. The amount of wastewater produced each year is increasing by around 14% (see Fig. 1). Currently, there are six WWTPs in Kuwait. These are Alriqqa, Um Alhayman, Al Wafra, AlKhairan, Kabd and ALSulaibiya. The number of wastewater treatment plants is increasing each year. An optimal design for wastewater treatment plants leads to an efficient treatment procedure with the lowest cost possible. Thus, it is important to study and characterize wastewater quality and quantity in Kuwait.

2. Methodology

2.1. Data Collection

Data for this study was sourced from the Ministry of Public Works, which is responsible for managing and overseeing all wastewater treatment operations in Kuwait. Detailed records were extracted from six major WWTPs, namely Alriqqa,

Um Alhayman, Al Wafra, AlKhairan, Kabd, and ALSulaibiya. This study primarily focuses on the Kabd plant, as it has the most comprehensive set of daily records available from 2012 to 2023, providing a robust dataset for analysis.

In this study, a range of parameters essential for assessing the characteristics of raw wastewater at the entry point of the treatment plants were evaluated. The parameters selected included Temperature, pH, Settleable Solids, Total Suspended Solids (TSS), Volatile Suspended Solids (VSS), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Oil and Grease, Total Kjeldahl Nitrogen (T-KN), and Total Phosphates ($T\text{-}PO_4$). These parameters were chosen due to their critical roles in identifying the pollution load and determining the specific treatment needs within the wastewater management framework.

2.2. Sampling Methods

In the methodology employed, samples were collected at the influent stage to document the initial conditions of the wastewater upon its entry into the treatment facility. Standardized methods were utilized to ensure the consistency and reliability of data throughout various sampling periods. At the Kabd plant, the frequency of sampling was established as daily to enable close monitoring of fluctuations and trends in the influent characteristics. The parameters collected from the Ministry of Public Works at the Kabd Plant (Raw Water) are detailed in Table 1.

Table 1: Sampling Methods and Wastewater Parameters Collected from MPW at Kabd Plant

Parameter	Standard Method	Technique Used
Temperature	–	Thermometer
pH	APHA 4500 HB	pH Meter
Settleable Solids	APHA 2540 F	Settling Column
TSS	APHA 2540 D	Gravimetry
VSS	APHA 2540 E	Gravimetry
COD	APHA 5220 D	Colorimetric Method
BOD	APHA 5210 B	5-day BOD Test (Manual)
Oil and Grease	APHA 5520 B	Gravimetry (Partition)
T-KN	APHA 4500-Norg B	Kjeldahl Method
T-PO4	APHA 4500-P E	Colorimetric Method

2.3. Data Pre-processing

This phase involved careful steps to refine the data, starting with the initial visualization to identify outliers through time series graphs, followed by the application of Tukey's method to detect and remove extreme values. After correcting irregularities and reapplying Tukey's method, more advanced machine learning techniques were evaluated using the scikit-learn library to enhance outlier detection. Concurrently, missing data was handled carefully, with gaps attributed to non-operational days excluded from the dataset to maintain analytical consistency and integrity.

2.4. Data Analysis

In the data analysis phase, descriptive statistics are employed to summarize both the concentration and load of pollutants at the Kabd WWTP, with variability and central tendencies of key wastewater characteristics being highlighted. Additionally, the biochemical oxygen demand to chemical oxygen demand (BOD/COD) ratio is calculated, providing insights into the biodegradability of organic compounds in the wastewater.

3. Results and Discussion

3.1. Physical Characteristics

The temperature of the wastewater plays a crucial role in biological treatment processes as it affects the metabolism of microorganisms involved in treatment. The average temperature recorded was 28.59°C, which is within the suitable range for most biological activities, although the range from 12.30°C to 37.70°C suggests significant variability possibly due to seasonal changes or influent water sources. The pH value, averaging at 7.09, indicates a nearly neutral condition ideal for most biological processes. The narrow range of pH from 6.48 to 8.10 suggests good buffer capacity and stable conditions for microbial life crucial in biodegradation, as shown in Table 2.

3.2. Chemical Characteristics

TSS and VSS are critical indicators of the physical contaminants in wastewater that can adversely affect light penetration and hence, aquatic life. The mean values for TSS and VSS were 172.86 mg/l and 70.85 mg/l, respectively, indicating effective preliminary removal processes but also highlighting the need for ongoing monitoring to manage spikes, as seen from their wide ranges. COD and BOD, with means of 596.32 mgO_2/l and 285.06 mgO_2/l respectively, reflect the organic load of the wastewater. The relatively high standard deviation for COD (118.26 mgO_2/l) compared to BOD (72.49 mgO_2/l) indicates more significant variability in the chemical composition of the influent, which could be attributed to industrial discharges or stormwater runoff, as shown in Table 2.

3.3. Nutrient Characteristics

Nutrients such as nitrogen and phosphorus, which were recorded at mean concentrations of 51.50 mgN/l and 16.68 mgP/l respectively, are essential for biological growth but can lead to eutrophication if not adequately treated before discharge. The presence of nutrients at these concentrations requires careful control within the treatment processes to prevent adverse environmental impacts. The variability in nutrient levels, as indicated by their range and standard deviation, necessitates efficient treatment strategies to adapt fluctuations and ensure consistent compliance with discharge standards, as shown in Table 2.

Table 2: Descriptive statistics for the raw wastewater main parameters (concentration)

Parameter	Mean	Median	Mode	STD	Variance	Kurtosis	Skewness	Minimum	Maximum
TEMP (°C)	28.59	28.9	34.2	4.6	21.16	-0.64	-0.38	12.3	37.7
pH	7.09	7.11	7.1	0.2	0.04	0.86	-0.08	6.48	8.1
SETTL (cm)	2.44	2.5	2.5	0.79	0.63	6.49	1.59	0.5	9
TSS (mg/l)	172.86	168	160	38.93	1515.43	18.81	3.11	24	572
VSS (mg/l)	70.85	68	64	32.13	1032.2	0.16	0.62	3	202
COD (mgO_2/l)	596.32	572	540	118.26	13986.14	6.38	1.89	234	1363
BOD (mgO_2/l)	285.06	290	290	72.49	5255.37	1.02	-0.51	46	541
GREASE (mg/l)	42.5	39	38	16.71	279.22	11.64	2.3	8	191
TKN (mgN/l)	51.5	49.87	34.71	16.96	287.66	0.15	0.48	14.52	123.32
T_PO_4 (mg/l)	16.68	16.7	18.1	4.81	23.12	1.99	0.59	0.6	46.1

3.3. BOD/COD Ratio Analysis

The BOD/COD ratio is recognized as a key indicator of the biodegradability of organic pollutants in wastewater [3]. Typical values for the ratio of BOD/COD for untreated municipal wastewater are in the range from 0.3 to 0.8 [4]. In our

dataset, approximately 1.3% of the observations were found to exhibit BOD/COD ratios above 0.8, suggesting that the organic matter is highly biodegradable and suitable for biological treatment processes. Conversely, ratios below 0.3 were observed in 10.71% of the data points, indicating the presence of non-biodegradable or refractory organic compounds, which are often associated with industrial discharges [5]. Industrial wastewater often contains complex organic compounds that are less susceptible to biological degradation[6].

As such, these consistent industrial inputs can significantly impact the overall biodegradability of the wastewater stream, resulting in lower BOD/COD ratios. These distributions are visually depicted in Figure 1, which highlights the varying levels of biodegradability across the dataset and underscores segments where advanced treatment strategies may be necessary.

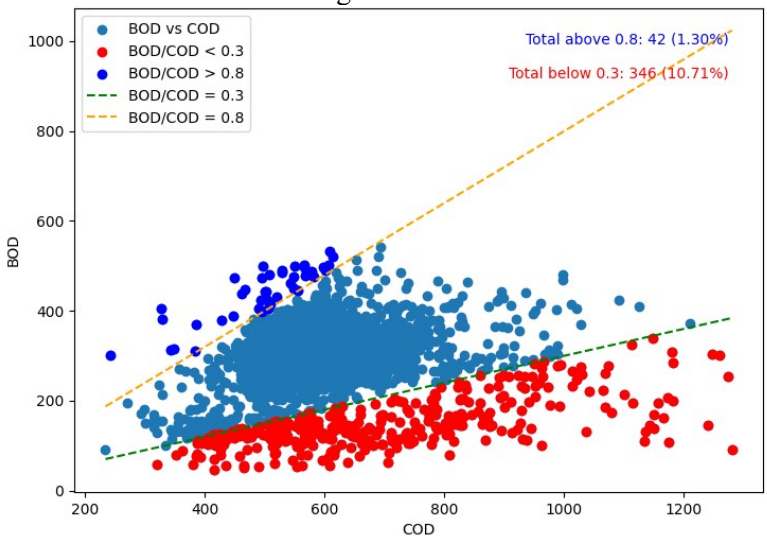

Figure 1: BOD/COD Ratio Distribution

4. Conclusion

This study has revealed the characteristics of wastewater from the Kabd Wastewater Treatment Plant in Kuwait, focusing on its physical, chemical, and nutrient profiles. Key findings, such as the significant variability in parameters like temperature, pH, and suspended solids, highlight the challenges of managing wastewater in diverse contexts. Particularly, the BOD/COD ratio analysis, indicates both high biodegradability suitable for biological treatment and the presence of refractory organic compounds necessitating advanced treatment methods. These insights highlight the need for adaptive treatment technologies and strong monitoring systems to enhance treatment efficiency and environmental compliance, thereby supporting the sustainability of local water resources and community health.

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