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Assessing the Performance of Karbala Wastewater Treatment Plant Using a Reliability Model

A Thesis Submitted to the Council of the College of the Engineering/University Of Kerbala in Partial Fulfillment of the Requirements for the Master Degree in Civil Engineering

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

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Dedication

I dedicate this work: For the sake of Allah Almighty The Prophet of Mercy, the Messenger of Allah, Muhammad, may Allah's prayers and peace be upon him,and his family, and to the family of the messenger of Allah the good and pure Ahl ul- Bayt the door of mercy of Allah Almighty To tendererness..

To the grace of Allah upon me.. my father, my mother , they were the driving force behind my passion to learn and expand my knowledge and I will be eternally grateful to them.To my beloved husband who supported me mentally and emotionally throughout my study process .To my homeland Iraq.

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Abstract

A wastewater treatment plant's reliability and efficacy are crucial factors to take into account, particularly if the treated wastewater will be recovered and used again in the future. It is necessary to ensure the protection of the environment and safety of public health. There are several factors that affect the performance of the treatment process, such as qualitative and quantitative changes in wastewater. Quality of treated and disposed water should be in compliance with local standards set by Iraqi legislation and it should therefore be possible to evaluate process performance and reliability of facilities to ensure compliance. Based on reliability analysis, the Kerbala municipal wastewater treatment plant's performance was evaluated. Wastewater flow rates and a few crucial water quality indicators, such as total suspended solids (TSS), chemical oxygen demand (COD), and five-day biochemical oxygen demand (BOD_5), were among the data examined and statistically assessed. Using the lognormal function, a probabilistic reliability model was developed and found suitable to quantitatively the performance of the plant. A significant feature of this model is that the model parameters are based on properties of original data. The development of this reliability model is the first contribution of this study; a model that can provide a quantitative performance of the studied wastewater treatment plant, and can also be used to estimate mean values of effluent quality. The quality of flowing raw wastewater and treated wastewater was studied for the years (2020-2023) in order to evaluate wastewater treatment plants.The efficiency of removing each parameter from wastewater and sewage is determined and the results are then compared with Iraqi specifications. The model results showed that the generated model's adequate accuracy made it suitable for use in subsequent

research. The probabilistic result shows very good levels of efficiency. The estimated reliability rates for the three parameters BOD_5, COD, and TSS indicate good removal efficiencies of 79%, 84%, and 78.8%, respectively. In the years 2020,2021, the plant was unstable because it was at the beginning of its operation, which makes the reliability values that indicate the removal efficiency above. Statistical analysis of the collected data shows that the values of the parameters of pollution differs significantly for wastewater at the entrance (Influent) to the plant extends between 350-420 mg/l for COD, 115-175 mg/l for BOD_5, 120-220 mg/l for TSS. At the effluent the average concentrations of the pollution parameters range between 11-18 mg/l for COD, 22-32 mg/l for BOD_5, 9-20 mg/l for TSS. The calculation method of the BOD_5, COD, and TSS effluent concentrations' coefficient of reliability (COR) was applied. The results showed that the values of COR of effluent BOD_5, COD, and TSS were close to 1 for all years, and this indicates a good removal efficiency of pollutants in Karbala WWTP.

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List of Abbreviations

Abbreviations	Description
A2/O	Anarobic /Anoxic/Oxic reactor
APHA	American Public Health Association
ANN	Artificial Neural Networks
CAS	Conventional Activated Sludge
CEPTs	Common Effluent Treatment Plants
EPA	Environmental Protection Agency
EOI	Expected Operational Impact
FTA	Fault Tree Analysis
KSOFM	Kohonen Self-Organizing Feature Map
LCA	Life Cycle Assessment
MSW	Munisaple Solid Waste
MBR	Membrane Bioreactor
MCs	Monte Carlo simulations
MADRL	Multi-Agent Deep Reinforcement Learning
POEI	Plant Operational Effectiveness
SBR	Sequencing Batch Reactors
SCADA	Supervisory Control and Data Acquisition
STP	Sewage Treatment Plants
TKN	Total Kjeldahl Nitrogen
TDS	Total Dissolve Solids
UASB	Upflow Anaerobic Sludge Blanket
WWTP	Wastewater Treatment Plant
SBR	Sequencing Batch Reactor

List of Symbols

Symbols	Description
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
COR	Coefficient of Reliability
DO	Dissolved Oxygen
F/M	Food to Microorganism
HRT	Hydraulic Retention Time
MLSS	Mixed Liquor Suspended Solids
PO_4	Phosphate
IR	Internal Recycle
RAS	Return Activated Sludge
SVI	Sludge Volume Index
SRT	Solid Retention Time
SLR	Solids Loading Rate
NH_3	Ammonia Nitrogen
FC	Fecal Coliform
TC	Total Coliform
TN	Total Nitrogen
TAN	Total Ammonia Nitrogen
TOC	Total Organic Carbon
TSS	Total suspended solids

Chapter One: Introduction

1.1 Background

The negative impacts of the changing climate, which have led to dwindling or decreasing freshwater resources, are being felt in many nations. On the other hand, the demand for freshwater is anticipated to increase as a result of the growing population. This increases the already-existing pressure on water facilities. Furthermore, due to the quickly growing industrial operations, water contamination has significantly increased. Several studies have indicated that the continuous discharge of wastewater into the environment worsens the issue of water scarcity by polluting freshwater resources. The gradual depletion of water resources worldwide and the significant presence of polluted water in industrial areas underscore the critical significance of wastewater treatment operations in mitigating water loss. Simultaneously, it is anticipated that the organic and hydraulic loadings on current wastewater treatment facilities will escalate due to the expansion of urban regions. Consequently, this circumstance necessitates the implementation of more effective wastewater treatment methodologies (Zhou et al., 2014). Currently, the primary focus of global community development is centered around ensuring that individuals have access to sufficient quantities of safe water to drink, in addition to appropriate methods for the transportation, disposal, and high-quality treatment of wastewater. In general, wastewater daily emerging from various activities, has huge hydraulic loads and varying compositions. Effluents may contain organic and inorganic materials, nutrients, solids (suspended and dissolved), heavy metals, etc. In addition, wastewater may contain infectious agents which may cause an epidemic. Therefor, it is hazardous to dispose untreated wastewater into water bodies, and has an impact for both humans and environment. As a result, Nations exhibiting elevated rates of wastewater treatment possess a greater percentage of anaerobic, anoxic, and oxic microorganisms. The A2/O (anaerobic/anoxic/oxic) technology is often selected due to its inherent stability and ease of management in daily operations (Liao et al., 2021; Zhang et al., 2016). the wastewater treatment plants (WWTPs) design improvement has been giving increasing attention recently (Obaideen et al., 2022) . The uncertain changes (including social, economic, and legal) were noticed by researchers to cause undesired results, even though designs of WWTPs are often based on carefully researched measures depending on data collected for a long period of time. Hence, it’s important to modify designs to give acceptable results even if such changes occur (Dominguez & Gujer, 2006).

1.2 Problem statement

Wastewater treatment plants are of high importance to keep water bodies pure as possible (pollution free) and to provide an alternative recycled water for various usages, especially considering the current water shortage in Iraq. Keeping these plants preforming without failing is crucial. Karbala wastewater treatment plant is the most important plant found in Iraq that requires continuous evaluation and performance optimization , due to the enormous number of visitors that Karbala city receives each year which reached 21 million visitors all together at one time in Arbaeen commemoration event last year. Hence, it’s important to adjust the performance of this plant to ensure its reliability and effectiveness to handle such varying flows without failing. In addition to finding an alternative water source, this plant helps keeping the general public health and aquatic life good by removing contaminations. In recent years, Karbala wastewater treatment plant has been facing maintenance issues, number of breakdowns, frequent shutdowns and failures. A reliability model was developed to evaluate the performance, identify the problems causing failures, and improving the plant overall effectiveness **.**

The performance evaluation and the reliability analysis of WWTPs are important tools for the design and operation of WWTPs the present aims to indicate the performance reliability of Karbala WWTP by using the cofficient of reilability (COR) value computation. This study is the first one conducted on this particular plant. The results of this study are expected to provide insights into the plant's weaknesses and challenges, which will be valuable for the plant management to address those issues. Additionally, the findings could also serve as a basis for decision-makers in Karbala governorate to implement measures aimed at enhancing and optimizing the plant's overall performance.

1.3 The Aim and Objective of the Study

1.3.1 Research Aim

The main aim of the present study is to assess the performance of the Karbala WWTP using a reliability model. This is done by collecting the required data to be analyzed by this model.

1.3.2 Research Objectives

The main objectives of the research can be summarized as follows :

- Knowing the effect of various factors, changes, and events on the performance of the plant.
- Developing a reliability model to predict the performance of the plant under different conditions and changes.
- Suggesting design adjustments and upgrades to achieve an improved long-term reliability.

1.4 Research Methodology

In the present study, the framework was as follows:

1. Collection data from Karbala wastewater treatment plant.
2. Testing of samples taken from the Karbala wastewater treatment plant by station employees according to the units in the standard way of the laboratory for a period of four years, and then analyzing them.
3. Evaluating of the performance of the Karbala wastewater treatment plant according to the data obtained by the administrative staff at plant.
4. Using a technique designed by Niku et al. (1979) for determine the coefficient of reliability (COR) of Karbala WWTP, using effluent

concentrations values of BOD_5, COD, and TSS for the period (2020-2023).

5. Studying and reviewing the results obtained from the previous steps, taking into account the statistical features of the results obtained from this method.

1.5 Thesis outlines

The present study consists of five chapters. The following items are the details of each chapter:

1. **The first chapter** is about an overview of the research problem objectives, the framework of the research, and building thesis.
2. **The second chapter** is about the previous studies and theoretical background.
3. **The third chapter** mentions materials and methods
4. **The fourth chapter** includes results and discussion.
5. **The fifth** chapter includes conclusions and recommendations.

Chapter Two: Literature Review and Theoretical Background

2.1 Introuduction

Wastewater treatment plant operation and design now frequently include the incorporation of activated sludge system modeling. According (Amrutha & Haseena, 2020) model are employed in modern disciplines including design, control, teaching, and research. As a result, some of the most significant research projects that have been achiered in this area are looked at, which are divided into two sections. The first part refers to practical and laboratory work, and the second part to computational work that has significantly enhanced the use of biological process modeling and made it indispensable as a result of recent undeniable advancements and the incorporation of computer-based modeling tools in design. It has improved accessibility and effectiveness. Engineers and operators can investigate prospective outcomes in wastewater treatment plants by using computer programming for simulations purposes like GPS-X and BioWin, which don't call for any operational adjustments that would jeopardize plant performance. On the other hand, the reliability of any wastewater treatment plant needs to be investigated to ensure its operation in the required efficient performance. Therefore, this will benefit those who one responsible for the plant's operation and the decision-makers in taking the right measures to improve the performance of the station based on the results of its reliability analysis.

2.2 Literature review of previous studies

Numerous studies were carried out in different parts of the world with the purpose of enhancing the performance of wastewater treatment plants (WWTPs). These studies used included conducting tests for influent and effluent wastewater, as well as calculating the percentage of removal for each pollutant.

2.2.1 Performance Evaluation of WWTP

Numerous global studies were undertaken to evaluate the performance of wastewater treatment plants (WWTPs). These investigations encompassed the analysis of influent and effluent wastewater, alongside the determination of pollutant removal percentages. Some of these studies are briefly shown as follows:

A study on a novel tool for improving the performance of WWTP using artificial neural networks (ANN) was published in Finland in 2005. The Pelham WWPT operating data was categorized using the artificial intelligence method of Kohonen self-organizing feature maps in order to identify the reasons for the high TSS, BOD_5, and fecal coliform levels in the effluent. The findings demonstrated that the use of the Kohonen Self-Organizing Feature Map (KSOFM) neural network is a quick and simple method to ascertain the complex relationships between the variables in the process; consequently, the most effective strategy for resolving operational issues in WWTPs can be identified. The research on the effectiveness of the aeration system in removing microbiological and physicochemical factors from the WWTP was conducted by (Rustum, 2009). According to the results, the mean removal effectiveness of these parameters for COD, BOD_5, fecal coliform (FC), total coliform (TC), and TSS, respectively, was 61.4%, 57.7%, 84.3%, 84.6%, and 70.8%. The time of hydraulic retention (HRT), sludge age (c), sludge volume index (SVI), food-to-mass ratio (F/M), and mixed liquor suspended solids (MLSS) values for the tank of aeration were calculated, and they were found to be 25 hours, 5.64 days, 48.83 ml/g, 0.28 day^{-1}, and 180 mg/l, respectively.

Additionally, it was shown that the average value of pollutants in the hot months was higher than in the cold months following treatment.In the study of (Khudair & Jasim, 2017), the focus was on analyzing and evaluating the operational efficiency and effectiveness of the Al Rustamiya Wastewater Treatment Plant (WWTP) in Baghdad, Iraq. The plant consisted of a secondary system that included both conventional activated sludge and sequencing batch reactors. The coefficient of reliability (COR) was calculated for a two-year dataset that included measurements of biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), and total suspended solids (TSS). The data were compared to the standards established by Iraq. The findings revealed that the sewage treatment was inadequate, as all parameters did not meet the established standards. These deficiencies were mainly caused by operational issues and a general lack of effectiveness. Farhan et al., (2018) developed a sequencing batch reactor (SBR) computer model at a lab scale using the GPS-X software. The 12-hour operating cycle simulation results were presented; each cycle has six phases: filling, mixing, aeration, settling, decantation, and idling. The simulations included two different kinds of aeration. The results showed that the second variant was distinguished significantly reduced pollution indicator levels in treated sewage in addition to by reduced power consumption, both of which contributed to better effluent quality and significant dephosphorylation.(Figdore et al., 2018) prepared a simulation of the refinery treatment plant at Banias using GPS-X software to assess its performance and ensure that it is functioning properly. In this facility, an activated sludge model was applied. The findings demonstrated that, in terms of TSS, VSS, and COD, the output simulation values agreed with the observed data. They also demonstrated the bacterial demise and the large levels of inert organic debris in the plant's effluent.

(Jasim, 2020) designed treatment units for the Al-Hay wastewater treatment plant (WWTP) to meet the population size of Al-Hay City using a GPS-X modeling approach. It was discovered that the total suspended particles and solids often rise as the simulation time increases. The outcomes also demonstrated a correlation between the suspended solids in mixed liquor (MLSS) and the age of the sludge, which is connected to the observed yield. The value of this correlation was between 0.2 and 0.6 kg VSS/kg (BOD_5). Additionally, it was determined that the retention period and the daily production of sludge were 27.7 days and 3339.18 kg, respectively. These findings support the notion that Al-Hay WWTP's biological tank is operated at a high level of efficiency. (JAWAD et al., 2021) studied the performance of the Albarrakiya trickling filter wastewater treatment facility, and the system was modeled by using the GPS-X Software .The findings indicated that COD, TSS, and NH3 had average yearly concentrations that exceeded Iraqi quality norms at 120 mg/L, 92 mg/L, and 11 mg/L, respectively. $BOD_5$and $PO4^{-2}$ were found to be acceptable but had critical levels of 35 mg/L and 2.8 mg/L, respectively. By employing GPS-X (version 5.0), (Bauhs, 2021) carried out a comparative study between sequencing batch reactor (SBR) and conventional(Olivera, 2008) activated sludge (CAS) to examine the performance and treatment capabilities of both systems under various operating conditions. According to the findings, the SBR system is generally more effective than the CAS system at removing total nitrogen, or TKN (Total Kjeldahl Nitrogen), and total ammonia, or NH3 concentrations.

The work which conducted by (Cao et al., 2021) proposes a GPS-X and response surface model to increase wastewater treatment facility total nitrogen (TN) removal. The study identified 6 changeable components from 61. GPS-X was validated for WWTP modeling using real operational data in static and dynamic simulations. The study indicated that biological compartment dissolved oxygen (DO) concentrations affected denitrification speed. The SRT removes TN. nitrification and denitrification rates increased to 97.1% and 85.3%, respectively, by optimizing biological unit DO and SRT. This adjustment saved 17.9% energy. Reduce total nitrogen (TN) to increase wastewater treatment facilities (WWTPs) operational efficiency in this model-based study. This study optimizes important elements to boost nitrification and denitrification rates and reduce energy use.The study increased wastewater treatment facility nitrogen removal with GPS-X and response surface approach. Screening and analysis of 61 parameters revealed 6 key change factors. GPS-X was tested for modeling WWTPs using static and dynamic simulations with real operational data. The analysis emphasized optimization parameters. Optimizing biological unit DO and SRT increased nitrification and denitrification by 97.1% and 85.3%, respectively. These improvements cut energy use 17.9%. Biological compartment dissolved oxygen (DO) levels affected denitrification, the study revealed. The SRT removes TN. Optimizing biological unit DO and SRT increased nitrification and denitrification by 97.1% and 85.3%, respectively. This change cut energy use 17.9%. The analysis emphasized optimization parameters.

According to (Kristjanpoller et al., 2021) an analytical case study was conducted on a wastewater treatment plant (WWTP) located in Chile, utilizing real-time data. The study aimed to address the inefficiency of the system by developing a methodology that assesses the impact of plant operational effectiveness (POEI) and the expected operational impact (EOI) index. This methodology facilitates the identification of design flaws within the system.

The Al-Muamirah WWTP is a new plant in Iraq that uses the oxidation ditch system. The performance of the plant was assessed, and GPS-X software was used to create the plant's model. The simulation showed that the plant has good performance efficiency.The plant should be operated at its maximum capacity to achieve the best removal efficiency.

2.2.2 Studies Related to Reliability

Different technique methods were used by researchers to analyze and predict the reliability of the treatment system that includes critical component analysis, failure mods, effect analysis, fault tree analysis, and even tree analysis (Padalkar & Kumar, 2018). The following are some of the studies that dealt with the reliability analysis of WWTP:

MESSAOUD et al., (2013) carried out a study to assess the dependability of activated sludge treatment in a wastewater treatment plant (WWTP) located in the eastern region of Algeria. This was achieved by calculating the Coefficient of Reliability (COR) using three-year-old data pertaining to the parameters of Biological Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS). Upon conducting a comparative analysis between the obtained results and the established standards, it was observed that the global effluent performances in terms of Biochemical Oxygen Demand (BOD5) and Chemical Oxygen Demand (COD) were found to be in compliance with the prescribed standards. Nevertheless, the performance of the Total Suspended Solids (TSS) did not meet the required standards as a result of mechanical issues in the grit chamber, as well as the fluctuation in both the quantity and quality of the influent.

Djeddou et al., (2014) conducted a study on the Al-Rustamiya Wastewater Treatment Plant (WWTP) located in Baghdad, Iraq. The lognormal distribution was utilized to model the effluent quality factors, a crucial component of this study. The coefficient of reliability (COR) values for all factors exhibited a low magnitude, indicating a lack of stability in the plant. Not all factors were able to meet their respective practical limits. Therefore, the reliability and performance of the system were inadequate. The low reliability and performance were ascribed to several factors, encompassing plant overloading, substandard physical condition, and inadequate maintenance. The plant's observed performance index (OPI) exhibited a low value, indicating suboptimal performance. The suggestion was made to enhance the plant's infrastructure, update the plant, and improve the quality of maintenance operations.

Taheriyoun & Moradinejad, (2015) conducted a study to assess the reliability of a wastewater treatment plant (WWTP) located in Tehran, Iran. The Fault Tree Analysis (FTA) method, in combination with Monte Carlo simulation, was employed for this purpose. The establishment of the FTA was predicated on the identification of the BOD violation as the primary event within the diagram. The findings indicated that the factors with the most significant impact on the frequency of top events were, in order, human error, mechanical issues, climate conditions, and the sewer system. Given that human error had the most significant impact on the operational efficiency of the treatment plant, the researchers proposed mitigating this error through measures such as enhanced staff training, adequate supervision, and other related interventions.

An investigation was conducted by Khudair & Jasim, (2017) at the Al-Rustamiya Wastewater Treatment Plant (WWTP) situated in Baghdad, Iraq. The primary aim of the study was to evaluate the operational efficacy of a facility consisting of conventional activated sludge (CAS) and sequencing batch reactors (SBR) as secondary treatment units. Additionally, the study sought to determine the facility's ability to meet the prescribed criteria in Iraq.

The study utilized a methodology for evaluating and analyzing the level of dependability in order to assess the stability of the plant and its ability to produce effluents that adhere to local regulations. The purpose of this study was to evaluate the reliability of effluent concentrations of BOD_5, COD, and TSS obtained from the Al-Rustamiya Wastewater Treatment Plant (WWTP) throughout a two-year timeframe (2015-2016), using the Coefficient of Reliability (COR) in accordance with Iraqi standard concentrations. The research findings suggest that there are notable issues regarding the efficacy of the Al-Rustamiya Wastewater Treatment Plant (WWTP), particularly with regards to insufficient sewage treatment. The examination of the plant effluents originating from both the continuous activated sludge (CAS) and sequencing batch reactor (SBR) systems indicated that the chosen metrics, specifically biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), and total suspended solids (TSS), failed to comply with the prescribed regulations imposed by Iraq. The deficiencies might be ascribed to a range of operational challenges, which finally resulted in a substandard performance of the treatment facility.

Padalkar & Kumar, (2018) examined the reliability and removal efficiencies of multiple common effluent treatment plants (CEPTs) installed within industrial clusters in India. Data on biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), oil concentration, and grease concentration were collected. The acquired data were utilized to ascertain the dependability and effectiveness of the removal process for each parameter and to ensure their adherence to the applicable local standards. Fluctuations were observed in the removal efficiencies and reliabilities of all parameters, with the exception of oil and grease concentrations. It was discussed that the performance can be improved by releasing the effluent loading to the Chemically Enhanced Primary Treatment (CEPT) as per standards and optimizing the treatment process (primary clarifiers and aeration tanks).

(Andraka, 2019) examines the reliability of the "Wastewater Treatment Plant (WWTP) - Receiver" system, which assesses the WWTP's impact on receiving waters. The study compares system dependability using different models to forecast the probability that the river will stay in the required purity class after receiving WWTP effluent. The study used a probabilistic model based on the total probability theorem and Monte Carlo (MC) simulations of water quality below wastewater discharge. The probabilistic model yields worse "WWTP-Receiver" system reliability than MC simulations. The MC model may offer more accurate figures, reflecting the stochastic character of the process and revealing that the "WWTP-Receiver" system's reliability is more susceptible to receiver quality than WWTP reliability.

In the study conducted by Ba-Alawi et al.,(2020), a Korean case study proposed a framework to examine the reliability and resilience of a wastewater treatment plant (WWTP) and improve its performance utilizing fault tree analysis scenarios. The daily reliability level of each effluent parameter was calculated using statistical methods, and the TN concentration exceeded effluent limitations. FTA was used to trace TN violations. The minimal cut specified in the FTA gave the WWTP 21% reliability, and MCs gave it 17%. Sensitivity study determined BE contributions to TN violation. The blower, WQ, and HRT caused most TN removal failures. After comparing four operational scenarios based on social, economic, and environmental costs, scenario 3 with supplementary chemicals was the best option for operating the WWTP at 322,600 $/yr.

Kristjanpoller et al., (2021) examines the significance of dependability and maintainability in the context of Wastewater Treatment Plants (WWTP). It emphasizes the necessity of analyzing the availability and operational conditions of these plants. The objective of this study is to utilize the P-OEI approach and actual data to discover any design defects or chances for improvement in a wastewater treatment plant (WWTP) situated in Chile. The methodology employed in this study involves a systematic breakdown of the system into many layers of disaggregation. This approach allows for a comprehensive analysis of both the upstream factors related to availability, as well as the downstream factors associated with the P-OEI analysis. The analysis extends from the overall system level to the individual elements inside subsystems. The technique also calculates an Expected Operational Impact (EOI) index, which quantifies the possible impact on the overall system's lack of efficiency. The study's findings suggest that the evaluations of P-OEI and EOI conducted in this research serve as effective methods for evaluating the design and functionality of intricate systems, with a specific focus on wastewater treatment plants (WWTPs). The research examines the application of multi-agent deep reinforcement learning (MADRL) as a novel technique for optimizing wastewater treatment facilities (WWTPs). The objective of this study is to achieve sustainable optimization in a wastewater treatment plant (WWTP) by simultaneously optimizing the levels of dissolved oxygen (DO) and chemical dose, taking into consideration the entire life cycle of the plant. The research examines five distinct scenarios, namely the baseline scenario, three variations in effluent quality, and scenarios focused on cost. The findings indicate that when employing optimization strategies informed by life cycle assessment (LCA), the environmental impacts are observed to be lower in comparison to the baseline scenario. This is evidenced by reductions in cost, energy consumption, and greenhouse gas emissions. The cost-oriented control strategy demonstrates similar overall performance to the LCA-driven strategy as it prioritizes cost reduction while compromising environmental advantages. The study's findings suggest that the implementation of novel dynamic control strategies necessitates the use of sophisticated sensors or extensive data. Therefore, while choosing control systems, it is important to take into account both economic and ecological factors. Further research is necessary to address the shortcomings of this study.

Anwar et al., (2021) studies the reliability of a Tlemcen, Algeria, wastewater treatment plant. The study develops a monitoring system for plant equipment and operational processes to enable quick and effective equipment failure intervention. The inquiry also examines chemicals released into the water after filtration. They studied the Tlemcen treatment plant from January 2013 to March 2016. The study shows that treatment reduces total suspended matter and chemical oxygen demand (COD), with certain readings exceeding NO3- and NH4+ thresholds. The research also finds failure and categorizes facility risks. This project will evaluate a wastewater treatment plant and design a method to monitor its equipment and operations. The study aims to help intervene quickly in system failures and monitor substances released into the water after filtration. The study shows that treatment reduces total suspended matter and chemical oxygen demand (COD), with certain readings exceeding $NO3^{-}$ and $NH4^{+}$ thresholds. The study also finds failures and categorizes facility dangers. 0.86 correlation coefficient shows a favorable association between biological oxygen demand ($BOD_5$5) and chemical oxygen demand (COD). There is also a strong negative link between temperature and dissolved oxygen (-0.64). The study found that the what-if method helps identify failures and classify plant dangers.

The reliability and resilience of a full-scale wastewater treatment plant (WWTP) in Korea were evaluated through a case study done by . The study employed a combination of resilience, seasonality, and statistical analyses, along with Fault Tree Analysis (FTA), to assess the overall reliability and resilience of the WWTP. The assessment of the WWTP's performance involved a comparison between the computed daily reliability of effluent parameters (TSS, BOD_5, COD, and TN) and the established environmental standards Logan, K. T et al, (2021). This analysis aimed to identify any parameters that were found to be in violation of the set standards. The performance curves of four effluent indicators were employed as a means to evaluate the resilience of the membrane bioreactor (MBR). The Fault Tree Analysis (FTA) methodology was employed to investigate the occurrences of parameter failures that surpassed their prescribed limits while accounting for the performance of mechanical equipment and operational conditions. The validity of the outcomes obtained from the Free Trade Agreement (FTA) was confirmed through the implementation of Monte Carlo simulations (MCs). The identification of key factors contributing to failures was accomplished through sensitivity analysis, which involved determining the highest percentage for each scenario that caused the greatest variation in the value of the selected limits exceeding the parameter. Subsequently, a comprehensive comparison of all scenarios was conducted, taking into account economic, environmental, and financial considerations, in order to determine the most optimal alternative operation for the wastewater treatment plant (WWTP). The findings indicated that the concentration of total nitrogen (TN) exceeded the established limits. The results of the sensitivity analysis indicated that the blower, water quality, and hydraulic retention time were identified as the primary factors contributing to the failure of total nitrogen (TN) removal.

The study evaluates the "WWTP-Receiver" system and compares models for estimating the chance of the river staying in the required purity class after receiving WWTP discharge. The study found that the MC model may yield more realistic values and that receiver quality is more sensitive than WWTP dependability. According to Silva & Rosa, (2022), a straightforward reliability-based approach was put forth to assess the actual reliability and stability of sixteen activated sludge wastewater treatment plants (WWTPs) located in Portugal. This analysis was conducted utilizing historical data that was five years old. The reliabilities of BOD_5, COD, and TSS were evaluated by calculating Niku's coefficient. The stability of each plant was assessed by quantifying the standard deviation of annual concentrations. The maximum standard deviation was permitted in order to adhere to the standards set by the European regulatory authorities. The findings indicated that extended aeration wastewater treatment plants (WWTPs) exhibited greater reliability and stability across all parameters compared to smaller conventional aeration WWTPs.

In the study conducted by Taghilou et al., (2023) an analysis was performed on the energy consumption and reliability of eight wastewater treatment plants (WWTPs) located in the province of Ontario, Canada. The objective of this study was to enhance the performance and management of these plants through the utilization of a novel analytical approach based on historical data. Additionally, the study sought to evaluate the energy cost associated with these plants. The case study involved the utilization of various treatment technologies, designs, and management strategies for the plants under investigation. The reliability was estimated through the application of probabilistic techniques, wherein the mean values of the parameters coefficient of reliability (COR), Biological oxygen demand (BOD_5), total ammonia nitrogen (TAN), and total suspended solids (TSS) were determined. The observed plants exhibited suboptimal performance in the removal of (TSS), primarily attributed to inadequate plant maintenance, inconsistencies in sludge hauling practices, and malfunctioning of auxiliary units. The researchers engaged in a discussion regarding the importance of routine sampling and monitoring of each treatment unit to enhance the performance of TSS removal. This practice enables better process control and early detection of equipment failure.

2.3 Wastewater

2.3.1 Definition

The term "wastewater" refers to water that has undergone physical, chemical, and biological alterations due to the introduction of pollutant substances(Einschlag, 2011). This text delineates the characteristics of liquid waste, which encompasses the waste materials that are conveyed through water channels from various sources such as residential, industrial, and commercial buildings, as well as any runoff water that includes stormwater. Wastewater has the potential to harbor both organic and non-organic pollutants, as well as toxic compounds and microorganisms that pose a hazard to the environment and human health. The discharge of untreated wastewater into streams or rivers can result in significant pollution, rendering the water unsuitable for both environmental health, and future drinking water purposes (Elgarahy et al., 2021) .

2.3.2 Sources

The following are the most common types or sources of wastewater : -

- **Domestic (or municipal)**

  The "Domestic wastewater" term refers to flows collected from residential sources. Thus, it includes wastewater collected from residences (households), institutions (schools, hospitals, etc.), and commercial facilities (restaurants, malls, etc.).(Owhonka et al., 2021). Domestic wastewater includes graywater and blackwater. Graywater is also known as sullage which is waste in a liquid form that doesn't contain human or animal excreta. It is collected from washrooms, kitchens, and laundries, etc. Blackwater is wastewater containing excreta (flush water, urine, and feces) which is mainly generated in toilets. If blackwater ends up in a sewerage system it is referred to as "sewage", and if it ends up in a septic tank it's referred to as septage (Einschlag, 2011).

- **Industrial**

  This includes the effluent generated from various industrial operations, such as those found in the pharmaceutical industry and poultry processing sectors. The composition of wastewater obtained from industrial sources can exhibit significant variability, which is contingent upon various factors such as the characteristics of the facility (e.g., type, size, and degree of onsite wastewater recycling) (Riffat & Husnain, 2022).

- **Stormwater**

  It refers to the water that is collected from rainfall, as well as the melting of ice and snow. Stormwater has the capacity to infiltrate the soil. The majority of runoff is not subjected to treatment and is instead directly conveyed to water bodies(Owhonka et al., 2021).

2.3.3 Characteristics

Wastewater quality varies depending on its source. Municipal wastewater composition includes about 99.9% water. The other main constituents include suspended solids, organic materials, and pathogenic microorganisms. In addition, Nutrients (mainly nitrogen and phosphorus) and endocrine-disrupting compounds (EDCs) presented in high concentrations can cause problems. Industrial wastewater (in addition to these contaminations) can contain metals, toxic compounds, and refectory organics. Storm water collected from urban and agricultural runoffs can contain silt, pesticides, and petroleum compounds. In WWTP design, determination of the various compounds that wastewater consists of is normally of no interest due to the difficulty of performing the various laboratory tests, and the inability to use results directly as design and operation elements. Thus, utilizing the character or polluting potential of wastewater as indirect parameters, is much preferred. These parameters can be classified into three group categories as shown below (López-Velázquez, K 2021): -

Table 2-1.Characteristics of wastewater (Bitton, 2014; Einschlag, 2011; Von Sperling, 2007)

Category	Parameter	Description
Physical	Electrical Conductivity	It is an indication of the salt content.
	Temperature	It is slightly higher than in drinking water. It can vary according to the seasons of the year (more stable than the air temperature). The temperature influences microbial activity,

		solubility of gases, and viscosity of the liquid.
	Color	Fresh sewage has a slight gray color, whereas septic sewage has dark gray or black color. The color comes from domestic and industrial wastes, and the naturally decaying organic materials present in wastewater.
	Odor	Fresh sewage has an oily odor which is relatively unpleasant. As for septic sewage, it has a foul odor (unpleasant) due to hydrogen sulfide gas and other decomposition by-products. For industrial wastewater, it has characteristic odors.
	Turbidity	It is caused by a great variety of suspended solids movement. Fresher or more concentrated sewage generally causes greater turbidity.

Chemical	**Total solids**	They can be also classified as physical characteristics. Total solids can be organic and inorganic (salts), suspended and dissolved, and settleable.
	Suspended	The part of organic and inorganic solids in which are not dissolved in water and non-filterable. Suspended solids causes sludge deposits and anaerobic conditions when untreated in discharged wastewater.
	Fixed	Mineral compounds, that are not oxidizable by heat, inert, which are part of the suspended solids.
	Volatile	Organic compounds which are part of the suspended solids, and that is oxidizable by heat.

	Dissolved	Part of organic and inorganic solids that are filterable. Normally considered with a dimension that is less than 10^{-3}µm. It includes Dissolved Oxygen (DO) which indicates the amount of oxygen present.
	TSS	They are mineral compounds of dissolved solids.
	Settleable	They are a part of organic and inorganic solids that settle in 1 hour in an Imhoff cone, in which can be used as an approximate indication of the settling in a sedimentation tank.
	Organic_matter	It is a heterogeneous mixture of various organic compounds and consists mainly of proteins, carbohydrates, and lipids.
	BOD_5	Biochemical Oxygen Demand is a measure of the oxygen

		consumed (or required) by aerobic microorganisms to decompose the organic matter in a period of 5 days under a temperature of 20 ◦C, and associated with the biodegradable fraction of carbonaceous organic compounds.
	COD	Chemical Oxygen Demand is the amount of oxygen that is necessary to completely oxidize organic carbon into carbon dioxide, water, and ammonia. In other words, it is the quantity of oxygen required to chemically stabilize the carbonaceous organic matter, or it is an indication for the oxygen in which is equivalent to the organic matter present in the sample that is susceptible to be oxidized. It uses strong chemical oxidizing agents under acidic conditions.

	Ultimate BOD	Represents the total oxygen consumed at the end of several days, by the microorganisms in the biochemical stabilization of the organic matter.
	TOC	Total Organic Carbon is a direct measure of the carbonaceous organic matter that can be determined directly through the conversion of organic carbon into carbon dioxide, or in other words, through oxidation of the organic matter by heat and oxygen, or chemical oxidants. TOC represents the total organic carbon inside a given sample.
	Total-nitrogen	Total nitrogen is an essential nutrient for microorganism growth in biological wastewater treatment. Organic nitrogen and ammonia together

		are called Total Kjeldahl Nitrogen (TKN).
	Organic nitrogen	It is Nitrogen in the form of proteins, amino acids, and urea.
	Ammonia	It is produced in the first stage of organic nitrogen decomposition.
	Nitrite	It is formed at the intermediate stage in the oxidation of ammonia. It is practically absent in raw sewage.
	Nitrate	It is the final product resulting from the oxidation of ammonia. It is practically absent in raw sewage.
	Totalphosphorus	Total phosphorus (of all forms which can be organic and inorganic) that exists in a sample is an essential nutrient in biological wastewater treatment.

	Organic phosphorus	It combines with organic matter.
	Inorganic phosphorus	Such as orthophosphates and polyphosphates.
	pH	It is an indicator of the acidic or alkaline conditions of the wastewater. A solution is neutral when pH is at 7. Normal biological oxidation processes result in a pH increase.
	Alkalinity	It serves as a gauge of the medium's buffer capacity, or its ability to withstand pH fluctuations. The presence of hydroxyl, carbonate, and bicarbonate ions is the cause.
	Chlorides	It is formed originally by drinking water, and both human and industrial wastes. It

		is significant for assessing the sustainability of wastewater for reuse in agriculture purposes.
	Oils and grease	It is a fraction of organic matter in which is soluble in hexane. In domestic wastewater, the main sources are oils and fats used in food.
Biological (organism contained)	Total coliforms (TC)	It includes common soil microorganisms as well. It is an indication of water contamination possibility.
	Faecal coliforms (FC)	They are an indication of water contamination with fecal matter such as bacteria.
	Bacteria	They are unicellular organisms that are present in various forms and sizes, and which are mainly responsible for the stabilization of organic matter. Some bacteria are pathogenic

		and can cause mainly intestinal diseases.
	Archaea	These are creatures that resemble bacteria in terms of size and fundamental cell components, but differ in terms of the makeup of their RNA, cell wall, and cell material. These creatures play a significant role in anaerobic reactions.
	Algae	These are chlorophyll-containing, autotrophic photosynthetic organisms. These organisms are crucial to several sewage treatment procedures as well as the generation of oxygen in bodies of water. These creatures have the potential to multiply excessively in lakes and reservoirs, which would lower the water quality.

	Fungi	They are mostly aerobic, multicellular, heterotrophic, non-photosynthetic organisms that play a significant role in the breakdown of organic materials and are able to flourish in environments with low pH.
	Protozoa	They lack a cell wall and are unicellular creatures. Most of them are facultative or aerobic. Protozoa are necessary for biological therapy to preserve the balance between the various groups since they feed on bacteria, algae, and other microorganisms. Protozoa can sometimes be pathogenic.
	Viruses	They are parasitic organisms in which are created by combining a protein structure with genetic material (RNA or DNA). It is challenging to

		eradicate pathogens from water or wastewater.
	Helminths	They are higher-order animals whose eggs can make people sick if they are found in sewage.

2.3.4 Treatment

Sustainable engineering of wastewater involves the application of engineering science principles for the treatment of wastewater in order to achieve a pollutant-free or less polluted state of the wastewater prior discharging to a water body or any environment in order to preserve (as much as possible) its purification capacity. The poor treatment of wastewater, where the treated effluent concentrations which that exceed the limits described by standards and regulations, is technically a type of failure (Padalkar & Kumar, 2018) As a result, and in general, the treatment objective is to achieve the following: -

• Elimination of biodegradable organic matter.

• Nutrients reduction.

• Pathogenic microorganisms reduction.

• Resulted recycled water re-usage.

The most common way of treatment used in treatment plants includes two main stages (preliminary and primary) and a secondary stage (Figure. 2.2). The preliminary stage usually consists of screens, grit chambers, comminutors, and primary clarifiers. The secondary stage then follows the preliminary and includes a biological process and a secondary clarifier. If the effluent coming from the secondary stage meets the described limits and regulation standards, it is then sent to the disinfectant and discharged. The primary stage includes further treatment for collected solids and sludge(Riffat & Husnain, 2022)

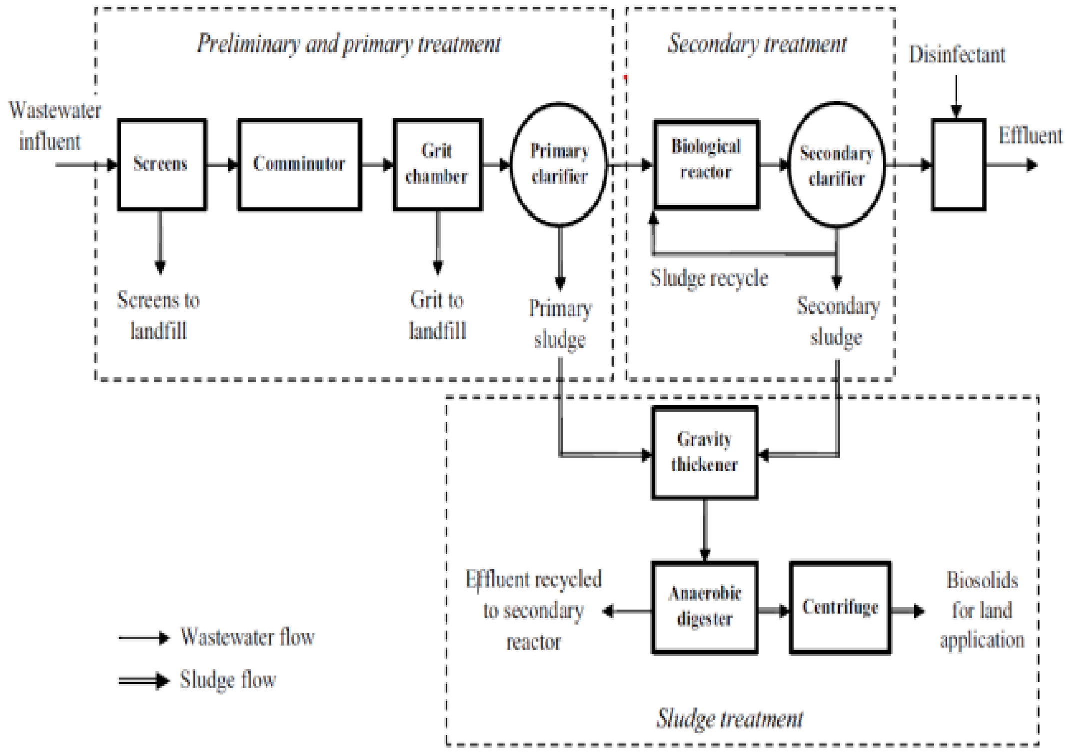


Figure 2-1. Flow diagram of a conventional WWTP (Riffat & Husnain, 2022).

2.3.5 Treatment Methods

These methods can be presented as follows:

• Physical Treatment

The process entails the elimination of contaminants present in wastewater through the application of basic physical mechanisms, including sedimentation, screening, and filtration, among others. The primary purpose of its application is the removal of suspended solids. The physical treatment processes encompass a range of physical forces that are employed to eliminate contaminants from wastewater (MESSAOUD et al., 2013). The aforementioned processes can be succinctly summarized as per the work of (Owhonka et al., 2021).

a) screening.

b) Comminution.

c) Flow equalization.

d) Sedimentation.

e) Flotation.

f) Granular-medium filtration.

• Chemical Treatment

This technique entails the introduction of chemical substances to facilitate the conversion or elimination of contaminants present in wastewater via chemical reactions, including coagulation and flocculation for the purpose of removing solid particles, disinfection to eradicate pathogenic microorganisms, and chemical precipitation to achieve phosphorus removal **(Riffat, 2022)**. According to **(Einschlag F. S. G., 2011)**, the chemical treatment processes can be succinctly summarized as follows:

a) Chemical precipitation.

b) Adsorption.

c) Disinfection.

d) De-chlorination.

e) Other chemical applications.

• Biological Treatment

The approach involves the use of microorganisms to convert or degrade wastewater pollutants, utilizing methods such as the activated sludge process, membrane bioreactor, trickling filter, and others. The primary purpose of its application is the mitigation or elimination of biodegradable organic substances to levels that conform to established regulations and standards. Additionally, it is employed for the purpose of extracting nutrients such as nitrogen and phosphorus. There are two primary categories of biological treatment processes for wastewater: suspended growth processes and attached growth processes **(Owhonka, 2021)**. The biological treatment processes can be succinctly summarized based on the works of **(Einschlag F. S. G., 2011, and Owhonka, 2023)**. The activated sludge process is a widely used method in the wastewater treatment. The units commonly used in the activated sludge process include:

a) Aerated lagoon.

b) Trickling filters.

c) Rotating biological contactors.

d) Pond stabilization.

e) Anaerobic digestion.

- **Suspended growth process**

The process in which utilizes suitable mixing devices to keep the microorganisms suspended in a biological reactor. This process can be aerobic or anaerobic such as the activated sludge process, sequencing batch reactor, lagoons, ponds, digesters, etc.

- **Attached growth process**

The process in which utilizes a biofilm that comes in contact with wastewater flowing through the reactor, to achieve bioconversion and removal of organic matter. The biofilm is a layer formed by the growing microorganisms that attach themselves to an inert medium (usually rock, gravel, slag, or synthetic media) inside the reactor. This process can be aerobic or anaerobic such as trickling filters, rotating biological contactors, and bio towers **(Riffat, 2022)**. A better understanding of microorganisms (types, growth, and nature), reactions involved, and performance affecting environmental factors leads to a more efficient design and successful processes operation.

2.3.6 Levels of Treatment

The term "Wastewater Treatment System" refers to the integration of unit operations and processes that are specifically designed to eliminate or decrease the presence of contaminants in wastewater to levels that comply with regulatory guidelines and standards. Unit operations encompass physical treatment methods that rely on the application of physical forces, while unit processes involve the utilization of biological or chemical treatment techniques to eliminate contaminants. The levels of treatment, as described by **(Einschlag F. S. G., 2011)**, allow for the grouping of unit operations.

- **Preliminary treatment**

The act of physically removing materials (such as twigs ,rags, etc.) that if entered the other appurtenances of the WWTP (such as pumps) will cause operational problems. It involves using screens (for large debris removal), comminutors (for grinding large particles), git chambers (for inert suspended solids removal such as sand, metal fragments, and broken glass pieces), and flotation (for oils and grease removal, generally, by using skimming tanks). The waste generated are residuals having low organic content, these residuals can be disposed of in landfills (Gandhi et al., 2021). Screens are utilized to keep valves and other accessories from clogging and to safeguard the other mechanical equipment. It might be made of paper, plastic, cloth, and a piece of wood. Screens are rectangular in shape with a uniform size opening covered with a perforated metal plate. Also, they come in different sizes and fineness levels (fine, medium, coarse). Additionally, they are arranged in an inclined position to the wastewater flow direction with an angle of 30 – 60 degrees **(Gandhi, 2021)**.

- **Enhanced primary treatment**

The process of applying chemical treatment (using chemical coagulants) in a sedimentation process to obtain additional solids removal, resulting in an enhanced removal of suspended solids. For example, using iron coagulant with a polymer to enhance primary clarifiers solids removal **(Riffat, 2022)**.

- **Conventional secondary treatment**

The biological treatment in which is done in a biological reactor, either after a secondary clarifier or a sedimentation tank , in order to degrade the organic matter and reduce the solids. For example, using the activated sludge process, trickling filter, etc. **(Riffat, 2022)**.

- **Secondary treatment with nutrient removal**

The treatment processes in which used when the removal of nutrients (nitrogen, phosphorus) is required. The nitrification-denitrification process used for nitrogen removal may require additional reactors. It is possible for the secondary treatment to be combined with BOD_5 removal, or to use a combination of biological and chemical treatment. The secondary treatment methods include aerobic attached growth systems and aerobic suspended growth systems. Aerobic attached growth system's methods include the usage of trickling filters and rotating biological contactors (RBC). This system involves including a particular kind of microbe (bacteria and other aerobes) and exposing the surface of the sewage to oxygen. The aerobes oxidize the organic matter and a film (slime bacterial layer) is formed at the surface. The organisms in this layer absorb more organic matter and form coagulated matter that settles down. Aerobic suspended growth system methods include the usage of an oxidation pond, aerated lagoons, and activated sludge process. The system involves suspending the aerobes in a liquid medium which is continuously mixed. This medium is responsible for the treatment in which the microorganisms convert the organic matter into gases and cell tissue by metabolizing it **(Gandhi, 2021)**.

- **Tertiary treatment**

Tertiary treatment is used to remove certain wastewater components that a secondary treatment cannot get rid of. Large volumes of phosphate, nitrogen, toxic metals, biodegradable organics, microbes, and viruses are removed during the tertiary treatment stage. Secondary effluent can be successfully filtered using both conventional sand (or other comparable medium) filters and more modern membrane materials. Helminths are eliminated by both filters and membranes, some of which have been improved. Disk filtration is the most contemporary method, which filters water using sizable cloth media disks mounted to revolving drums. At this point, the water can be disinfected using UV radiation, chlorination, and ozonation to meet the most recent international standards for agriculture and urban re-use Comber (Comber et al., 2019). The treated wastewater can be applied to non-potable tasks like vegetable gardening and flushing toilets, as well as discharged into surface waterway outfalls. Finally, tertiary treatment, which is also referred to as the "advanced" or "final" treatment, aims to further purify wastewater by eliminating any potentially harmful elements or nutrients that may still be present after secondary treatment, as well as specifically eradicating or disinfecting pathogenic bacteria. Water that has undergone tertiary treatment is safe to drink again. In addition to the aforementioned, chlorination may be applied throughout the entire treatment process to improve the quality of water.(Machineni, 2019).

• Advanced treatment

The processes in which used when additional wastewater constituents are required to be removed due to the toxic nature of certain compounds or the potential reuse of water is desired in some applications. For example, using ion exchange for specific ions removal, and activated carbon adsorption for volatile organic compounds removal. The activated carbon filter method is used to purify both domestic and industrial water. The method involves three steps starting with the interaction of the pollutants with the peripheral carbon that absorbs them, the pollutants move into carbon pores, and the final step involves pollutants absorbed on the internal carbon walls. The magnetic nanoparticles method is considered the easiest and most cost-effective method to purify wastewater. In addition, its ability to recover and to be reactivated after purification by a simple magnet, magnetic nanoparticle absorbents shows better pollutant absorption because of their magnetic properties and high surface-to-volume ratio. The ozonation method involves the treatment of wastewater using ozone by generating highly reactive and short-lived oxygen species (ROS) that are based on one atom of oxygen which results due to the ozone's instability (ozone is based on three oxygen atoms and rapidly degrades into two atoms which are oxygen leaving one atom free). ROS are capable of eliminating various pathogens and attacking organic and inorganic pollutants. This method results in no sludge and has simple operation requirements. The ultraviolet (UV) radiation treatment method is efficient for disinfection. This method involves using UV to penetrate the microorganism's cell wall and damage the genetic mutant preventing reproduction and destroying nearly 99.9% of the microorganisms present in water**.** The lime-soda (LS) process treatment method involves decreasing the water's hardness by adding calcium oxide and soda to the reaction tank that contains the extremely hot steam and the hard water. These chemicals react with the hardness present in water under the high temperature caused by the steam-generating salts which precipitated into a sedimentation tank as hydroxides and carbonates (in the form of collectable sludge from the sludge outlet). Subsequently, the sedimentation tank's sand filter receives the treated water to remove the suspended sludge particles. The zeolite process method involves removing the hardness from water by sodium ions exchange using zeolites (hydrated sodium alumina silicates) **(Gandhi, 2021)**.

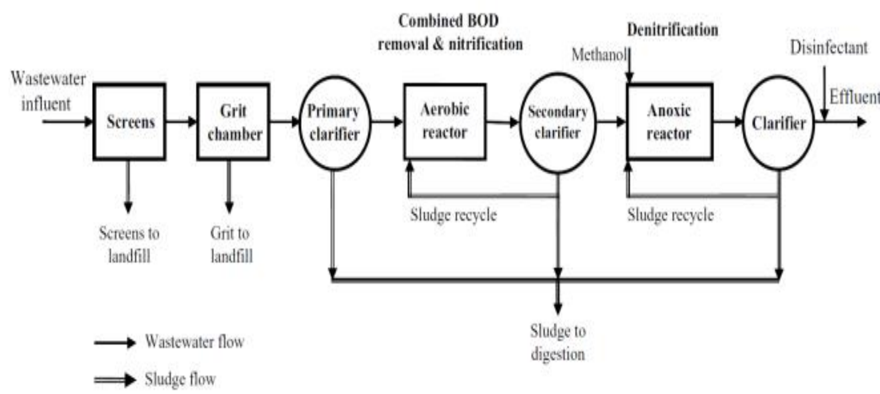


Figure 2-2. Flow diagram for treatment of wastewater with high suspended ..solids, organic matter, pathogens, and nitrogen concentrations (Riffat, 2022).

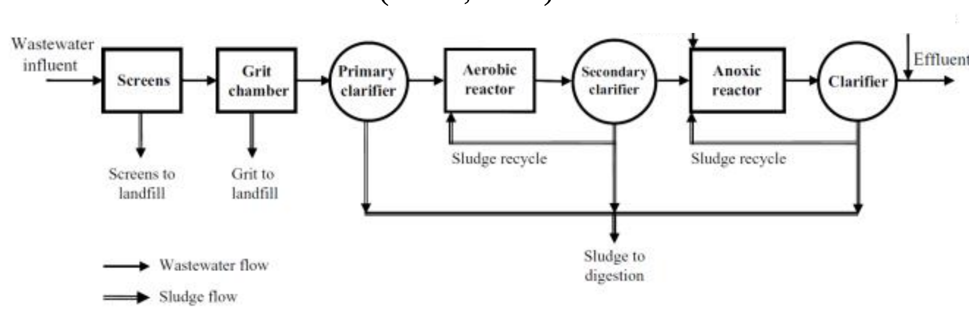


Figure 2-3. Flow diagram for treatment of wastewater with high suspended solids, organic matter, and herbicides concentrations (Riffat, 2022).

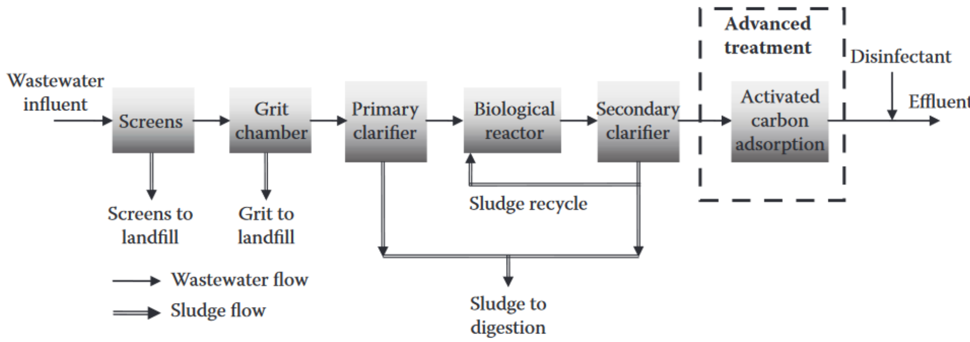


Figure 2-4. Diagram shows the flow of an advanced wastewater treatment

Table 2-2. Advantages and disadvantages of various treatment processes (Gandhi, 2021).

Process	Advantages	Disadvantages
Coagulation	Low principal cost, and Effortless procedure.	Generating a large quantity of sludge.
Trickling filters	Capability to remove a high quantity of the BOD, efficiency in treating a large amount of organic matter, high ammonia removal efficiency, minimal sludge production, and lack of need for highly technical and qualified personnel to run and maintain the system.	High principal cost, blocking of rotating arms, and high intense odor generation.
Rotating biological contactors	Aeration using atmospheric means, low operating costs,	This system requires a large area, and it is challenging to

	and minimal sludge production.	safeguard the system in a cold climate.
Activated sludge process	The benefits of atmospheric aeration include its availability for use in both residential and commercial settings, its capacity to eliminate large amounts of BOD, COD, nitrogen, and phosphorus, its ease of use, its capacity to generate electricity from biogas, and its superior effluent quality.	Concentration of the sludge to be monitored and operation cost.
Disinfection (bleaching powder)	Low cost and readily available, high water solubility, toxicity to pathogens, and potential to remove a high quantity of iron, manganese, and ammonia nitrogen during oxidation.	Corrosive, and it is difficult to handle the gas results from powder due to its hazardous nature.
Reverse osmosis	Available on domestic to industrial scale, the efficient rejection rate of (salt, organic substances, and infections), the minimal energy required	The problem in large-scale treatment is due to sludge generation, pre-treatment is essential

	is adequate, membrane replacement is simple, and maintenance is straightforward.	before purifying the water, and membranes are highly sensitive to pH.
Electrodialysis	High selectivity of ions, regeneration of the membrane is easy, and pre-treatment of water is not necessary.	Operational cost is high, ions only can be removed, and based on water quality, the membrane needs to be selective.
UASBR	Energy demand, land requirement, and sludge production is low, economical, ex	An extended stand-up period requires enough quantity of granular seed sludge, and lesser gas yield.

2.3.7 Factors Affecting the Performance of Waste Water Treatment Plants

Researchers showed that failure may happen due to various factors that make the reliability (performance) of the WWTP variable, these factors include the following **(MESSAOUD D., 2013)**: -

- Mechanical or equipment failure , design deficiencies, and electrical failure.
- Operating staff lack of experience, operator’s absence, and human error.
- Variation of the influent, loads (including the variation caused by climate change), and flow.

- Variability of the treatment process.
- Proper maintenance of the plant.

2.3.8 Wastewater Microbiology

The field of microbiology relates to the scientific investigation of organisms that are of such minuscule size that they necessitate examination through the use of a microscope. Wastewater harbors a diverse array of microorganisms, exhibiting a range of characteristics. Certain microorganisms within this milieu contribute positively to the treatment processes, assuming a crucial function in the breakdown of organic matter. Conversely, there exist pathogenic microorganisms that pose a potential threat to human health. Bacteria, protozoa, and other microorganisms actively participate in the transformation of organic materials that is biodegradable into simplified end products, thereby facilitating the stabilization of waste. This natural purification process takes place in streams and rivers. A comprehensive comprehension of these microorganisms, encompassing their inherent characteristics, growth kinetics, and essential prerequisites, facilitates the development of more effective treatment systems (Bitton, 2011). The primary biological entities encompass bacteria, archaea, and eukarya. In a broad sense, the categorization of living organisms is primarily determined by their cellular structures, which can be divided into two main groups: prokaryotic organisms encompassing bacteria, cyanobacteria (blue-green algae), archaea, eukaryotic organisms consisting of more intricate plants and animals, protozoa, fungi, and algae. One notable distinction between the two entities lies in their respective nuclear compositions (Riffat R., 2022). The biological wastewater treatment processes occur within a defined volume referred to as a "reactor" (Von Sperling, 2007).

• Nutrient Removal by the Activated Sludge Process

a) Nitrogen Removal

Nitrogen removal processes include nitrification in suspended growth reactors, denitrification in suspended growth reactors, and other nitrification-denitrification processes (Sharon–Anammox process, canon process, partial nitrification-denitrification process, and denitrifying ammonium oxidation (deamox) process) **(Bitton G., 2014)**.

b) Phosphorus Removal

Phosphorus removal processes include Mainstream Processes, Sidestream Processes, and other processes for Phosphorus Removal **(Bitton G., 2014)**.

2.4 Summary

Previous studies showed that using efficient tools like ANN techniques and the GPS-X model gives dependable performance evaluation of WWTPs. Previous studies on the reliability analysis of WWTPs have focused on assessing the performance, robustness, and sustainability of these critical infrastructure systems. These analyses aim to ensure the consistent and efficient functioning of WWTPs to meet environmental standards and protect public health. Researchers have employed various methodologies to evaluate the reliability of WWTPs, including probabilistic modeling, fault tree analysis, Monte Carlo simulations, and coefficient of reliability calculation. The present study aims to indicate the performance reliability of Karbala WWTP by using the COR value computation.

Chapter Three: Meterials and Methods

3.1 Karbala Wastewater Treatment Plant

The present study was carried out in Karbala Governorate, which is a religious tourism destination for Muslims, up to 34 million persons visit the city annually. Karbala city has a 42.4 Km^2area and of estimated population of 1,218,732 people (2018), and this adds a high load on the water and sewage utilities. Wastewater treatment plant of Karbala is located within the geographical coordinates of 32.525590°N and 44. 074909°E. Figure (3-1) shows a Google Earth satellite view of the Karbala WWTP. The plant serves about 2.5 million people. Four wastewater treatment plants utilizing the conventional activated sludge system type A2/O are incorporated into the Karbala integrated Project. Each of these plants has a daily discharge capacity of one hundred thousand cubic meters. The parameters mentioned in Table (3-1) were used to design the plant.

Table 3-1.Characteristics of Sewage for the Design WWTP of Karbala (2020-2023).

Parameter	Influent Concentration	Effluent Concentration
pH	6.8-7.5	7-7.4
COD (mg/L)	350-500	<100
BOD_5 (mg/L)	150-250	<30
TN (mg/L)	45	<10
PO_4-P (mg/L)	6	2

Figure 3-1. Google Earth Satellite View of the Karbala WWTP.

3.2 Stages of Treatment

The treatment stages of Karbala WWTP can be summarized as follows:

3.2.1 The Preliminary Phase of Treatment

Large and tiny particles, gravel, sand, and fat are all eliminated during the first step of treatment. This level consists of the following four primary units:

- **Coarse screen**: it is the first step of treatment, and it is located at the beginning of the plant. The stage is usually used to remove large object, fibers, clothes, hair and others. (see **Figure 3-2**).
- **The fine screen**: the solids of diameter more than 6 mm is removed in it. It safeguards machinery that might be more susceptible to solids, like membrane bioreactors, or gets rid of substances that might prevent the useful repurposing of bio solids. (see **Figure 3-2**).

Figure 3-2. Course and fine screen units in Karbala WWTP.

- **Grit chamber**: This basin sits in between the preliminary and fine screen sedimentation basins, and its function eliminates fat by aeration while removing sand through sedimentation (see **Figure 3-3**).

Figure 3-3. Grit chamber of Karbala WWTP.

- **Parshall flume**: It is the final unit at the ending of the preliminary treatment, and it used to measure the daily flow rate and suspended solids to control the operation of the plant. (see **Figure 3-4**).

Figure 3-4**. Parshall flume unit of Karbala WWTP.**

3.2.2 The Second Stage (Primary Treatment):

The primary sedimentation tank is the primary treatment of the plant wastewater which is carried out by four primary sedimentation tanks which are used to remove about 55% of suspended solids and about 30 % of BOD_5. Figure 3-5 shows the primary sedimentation tanks of Karbala wastewater treatment plant.

Figure 3-5. Preliminary sedimentation tank of Karbala WWTP.

3.2.3 The Third Stage (Secondary Treatment)

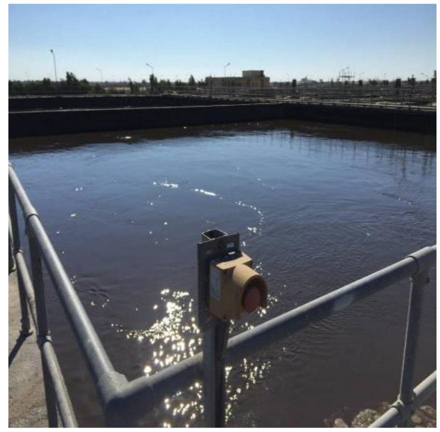
The secondary treatment is carried out by a process called A2/O. Figure (3-6) shows the secondary treatment of Karbala WWTP the secondary treatment consists of:

A. **Anaerobic Reactor**: It contains two anaerobic tanks with a volume of 8736 m^3 for both of them.

B. **Anoxic Reactor:** Two anoxic basins are including with volume of 14112 m^3

C. **Aeration Reactor:** It contains eight aeration reactor tanks with a total volume of 54054 m^3

Anaerobic



Anoxic

Oxic reactors

Figure 3-6. Anaerobic/Anoxic/Oxic reactors of Karbala WWTP.

Secondary Sedimentation Tank : There are eight sedimentation tanks with a total surface area of 6432 m^2(see **Figure 3-7**).

Figure 3-7. Secondary clarifier tank of Karbala WWTP.

3.2.4 The Fourth Stage (Tertiary Treatment) :

It includes chemical disinfection through the chlorination tank. The chlorine is added to the treated water in these basins as part of a chemical treatment process to kill germs and microbes. The total surface area of the chlorination tanks is 3000m^3.

3.2.5 The Fifth Stage (Sludge Treatment)

Sludge treatment is among the most significant and difficult ones, consists of four primary elements, which are as follows:

- **Gravity thickener**: The resulting sludge from the primary sedimentation basins is transferred to this unit, where suspended solids are thickened before being stabilized in the digestion basins. The Karbala WWTP has two basins with a combined surface area of 400 m^2 each one (see **Figure 3-8**).

Figure 3-8. Gravity thickener basins of Karbala WWTP.

Wastewater from the secondary sedimentation basins is fed into the mechanical thickening, where it is thickened by the addition of chemicals like polymer before being sent to the digestion tanks for treatment and size reduction. The Karbala WWTP has three basins (**Figure 3-9**).

Figure 3-9. Mechanical thickener units in Karbala WWTP.

Anaerobic digestion tanks: Four anaerobic digesters are included in these reactors. The sludge decreased in size and fixed. The methane gas that generated is used in electricity production. (see **Figure 3-10**).

Figure 3-10. Anaerobic digester of Karbala WWTP.

Drying beds: It is the last unit of sludge treatment facilities. The drying beds include 60 cells with a total surface area of 50,000 m2 then the sludge is spread over sunlight and wind (see **Figure 3-11**).

Figure 3-11. Drying bed of Karbala WWTP.

3.3 Operational Data Collection

The management of the Karbala wastewater treatment plant provided operational data of the present study, which are displayed in **Table 3.2**. Physical and operational data must be included correctly into the model, which is very significant.

Table 3-2. The parameters of the Karbala WWTP.

Parameter	Value
Flowrate (Qavg)	60,000 m^3/day
V. anaerobic reactor	8736 m^3
V. anoxic reactor	14112 m^3
V. aeration reactor	54054 m^3
Primary sludge	230 m^3/day
Surface area of primary sedimentation	3216 m^2
Surface area of final clarifier	6432 m^2
V. anaerobic digester	13600 m^3
Surface area of gravity thickener	400 m^2
Surface area of mechanical thickener	60 m^2
Volume chlorination tank	3000 m^3
Surface area of drying bed	50,000 m^2
Dissolved Oxygen	2-3 mg/L
Mixed liquor suspended solids	3500 mg/L

surface loading rate (SLR)	2.17 kg mlss/m^{2}h
HLR	9 m3/m^{2}day
WAS	3000-4000 m^3/day
RAS	36000 m^3/day
F/M	0.05
IR	3
SVI	80 mL/g

3.4 Sampling method

Sampling is critical to giving a complete impression of the plant performance for four years . Samples were collected for four years of plant management and all tests performed as per specification methods of water and sanitation inspection and measurement. The methods are presented in **Table 3-3**.

Table 3-3. Physico-chemical parameters and methods of analysis.

Parameters	Method of analysis	Measuring devices
pH	Direct measurement	pH Meter
Dissolved oxygen (mg/l)	Direct measurement	DO meter
Temperature (°C)	Direct measurement	Thermometer
Biochemical oxygen demand (BOD_5) (mg/l)	Manometric/respirometric	Using WTW MARK 6 OxiTop®

Chemical oxygen demand (COD) (mg/l)	Colorimetric (closed reflux)	Using WTW C2/25 COD1500 photometer
Total nitrogen (mg/l)	Kjeldhal	Using 0.02N H2SO4 Titration
Total phosphorus, nitrate and nitrite (mg/l)	Colorimetric	Using SP75UV/VIS Spectrophotometer

3.5 Treatment Efficiency Determination

The proportion of the average concentration of pollutants entering and leaving the plant is used to calculate its efficiency. Based on the physical, chemical, and biological processes occurring inside the reactor, each pollutant is measured in a distinct proportion, and the efficiency is calculated using **equation 3-1**.

$$Removal\ Efficiency = \frac{C_{in} - C_{eff}}{C_{in}} \times 100\% \qquad \textbf{(3-1)}$$

Where:

C_{in} = Concentration of pollutant in the influent (mg/L).

C_{eff} = Concentration of pollutant in the effluent (mg/L).

3.5.1 Reliability Coefficient Method

The concept of reliability that can be used to predict the effectiveness of a process of wastewater treatment, whether in the design phase or in operation, has been developed by **(Niku et al., 1979)** who applied the concept of reliability to assess the efficiency of 37 wastewater treatment plants in the USA using the sludge process activated to form a basis for statistical correlation. Data analysis concluded that the log-normal distribution of BOD5 and MES for the inlet effluent. This distribution can be used to predict the efficiency, the quality of treated water, and the reliability of wastewater treatment plants. Mathematically, a treatment facility is completely reliable if there are no failures in the purification process (for example, violations of discharge standards). Failure of a treatment process is mentioned when the discharge standards of the treatment plant exceed the standard discharge standards mentioned by the legislation in force. **(Niku et al., 1979)** simplified the failure by the following equation :

$$F = C_e > C_S \qquad \textbf{(3-2)}$$

where:

F: failure.

C_e: selected treated effluent quality parameter concentration.

C_S: selected treated effluent quality parameter concentration. requirement set by standards.

From a technical perspective, "probability of success" is the fundamental idea of reliability. " or "probability of adequate performance", which is the percentage of time that selected treated effluent quality parameters concentration comply with the requirements **(Niku et al., 1979)**. The reliability can be determined by **equation 3-**3.

$$\boldsymbol{R = 1 - P(F)} \qquad \textbf{(3-3)}$$

where:

R: Reliability.

P(F): probability of failure.

Substituting **equation 3-2** into **equation 3-3**, the value of R is equal to:

$$\boldsymbol{R = 1 - P(C_e > C_s)} \quad \textbf{(3-4)}$$

P(F) is extremely sensitive to the probability distribution function of the effluent concentration. Thus, to calculate the maintainability (M), the distribution of the effluent concentration should be modelled. To perform such an analysis, data on the concentrations of the various physico-chemical parameters of the effluent must adapt given distribution, for this we will have to use several analysis techniques statistics for the determination of the appropriate distribution law. The assessment of the dependability of a wastewater treatment facility can be conducted through the utilization of the reliability coefficient approach. The approach entails evaluating the dependability of the equipment and operational procedures employed by the plant, together with monitoring the compounds discharged into the water subsequent to the purification process (**Sweetapple, et al., 2011**). Through the implementation of a comprehensive monitoring system and the subsequent analysis of the plant's performance, it becomes feasible to detect instances of malfunction and evaluate the potential hazards inherent to the facility (**Taheriyoun and Moradinejad, 2015)**. Furthermore, the evaluation of water treatment plant reliability can be conducted by the utilization of quantitative measures that gauge the quality of treated water, including turbidity and chromaticity (**Taghilou, et al., 2023)**. The evaluation of dependability can be determined by considering the mean time between failure, mean time to repair, and the plant's readiness coefficient (**Silva and Rosa, 2022**). The

Weibull probability model has been employed for the analysis of pollution removal reliability in wastewater treatment plants (**Hegazy and Gawad, 2016).** The enhancement of system reliability can be achieved by prioritizing maintenance tasks according to their benefit-to-cost ratios.

In other words, it can be said the reliability of a treatment plant is based on knowledge of the behavior of the process. **(Niku et al., 1979)** conducted an analysis of data from 37 treatment plants waste water and came to the following conclusion:

For the BOD_5 parameters and the suspended solids of the effluent at the entrance to the station, the distribution is the adequate choice to model these parameters, and therefore, the log-normal distribution can be used to predict the performance of effluent quality and the reliability of wastewater treatment facilities. Due to variations in effluent quality performance, atreatment must be designed to respect an average concentration of the effluent below the rejection standards. The question is, what is average value guarantees a concentration of the effluent consistently below a standard with some reliability?The reliability coefficient can be introduced in relation to the ratio of mean values(dimensioning value) to the rejection standard which must be achieved on the basis of probability. For example, for 90% of the operating time of the treatment process, the process should be designed to achieve an average value mx obtained from **equation 3-5**:

$$m_X = \text{COR} \times C_S \qquad \textbf{(3-5)}$$

where

m_x: average concentration of the constituent; regulation fora selected treated effluent quality parameter concentration

COR: coefficient of reliability.

C_S: selected treated effluent quality parameter concentration . requirement set by standards.

and:

$$\boldsymbol{COR = (C_v^2 + 1)^{\frac{1}{2}} \times e^{-Z_{1-\alpha}[\ln(C_v^2+1)]^{1/2}}} \qquad \textbf{(3-6)}$$

$$\boldsymbol{C_v = \frac{\sigma_x}{\bar{x}}} \qquad \textbf{(3-7)}$$

Where:

Cv = The coefficient of variation which is the ratio of the standard deviation (σ_x) to the mean value ($\bar{x}$), where x is the concentration value of the constituent.

$\boldsymbol{z_{1-\alpha}}$ = the standaradized normal distribution value which is found from the standard normal variate tables of z corresponding to the probability of no exceedence at a confidence threshold of (1-α), where α is a significance level. Also, it can be found in **Table 3-4**.

Table 3-4.Values of standaradized normal distribution (Niku et al., 1979).

Cumulative Probability $1-\alpha$	Percentiles $Z_{1-\alpha}$
99.9	3.090
99	2.326
98	2.054
95	1.645
92	1.405
90	1.282
80	0.842
70	0.525
60	0.253
50	0

The values of the coefficient of reliability (COR) for the effluent concentrations for the different coefficients of variation at different levels of reliability are presented in **Table 3-5**.

Table 3-5. COR as a function of Cv and reliability on true log- normal distribution.

Reliability level	Reliability coefficient, COR							
	50%	80%	90%	92%	95%	98%	99%	99.9%
C_V								
0.3	1.04	0.81	0.71	0.69	0.64	0.57	0.53	0.42
0.4	1.08	0.78	0.66	0.63	0.57	0.49	0.44	0.33
0.5	1.12	0.75	0.61	0.58	0.51	0.42	0.37	0.26
0.6	1.17	0.73	0.57	0.54	0.47	0.37	0.32	0.21
0.7	1.22	0.72	0.54	0.50	0.43	0.33	0.28	0.17
0.8	1.28	0.71	0.52	0.48	0.40	0.30	0.25	0.15
0.9	1.35	0.70	0.50	0.46	0.38	0.28	0.22	0.12
1.0	1.41	0.70	0.49	0.44	0.36	0.26	0.20	0.11
1.2	1.56	0.70	0.46	0.41	0.33	0.22	0.17	0.08
1.5	1.80	0.72	0.45	0.39	0.30	0.19	0.14	0.06

The values presented in **Table 3-5** can be used in the design of a processing station provided for given levels of reliability.The coefficient of variation of effluent concentration (Cv) must be estimated according to selection of the reasonable value of desired performance. To have a reliability of 95%, the concentration of the BOD_5must be lower than a certain concentration Cs, when the coefficient of variation (Cv) of the station is estimated at 0.70, the station must be designed for an average value equal to or less than 0.43xCs.If for example the Cs standard effluent concentration = 30mg/l, then the average BOD5 = 0.43x30 = 12.9 mg/l, even for a less strict standard Cs = 40mg/l, the average BOD5 must be lower than the following value (0.43 x 40 = 17.2 mg/l). As expected, the average value of the required effluent concentration varies inversely with the level of reliability and with the coefficient of variation (Cv) of the effluent concentration **(Niku et al., 1979)**.

3.6 Plant Reliability Assessment Cleanup Using Other Approaches

The stability of a treatment process has been used to describe compliance efficiency of a treatment plant based on the statistical measurements of the different wastewater quality parameters, it was found that the standard deviation is the most important indicator appropriate process stability. **Niku and Schroeder, (1981)** found a strong linear correlation between standard deviation and other stability indicators. The stability of a wastewater treatment plant was defined as the standard deviation value below of which a station is considered as statistically stable, exceeding this limit value, the station is considered statistically unstable. They concluded that the treatment plants with a standard deviation of less than 10 mg/l for $BOD_5$and 70 mg/l for SS can be statistically considered as stable stations **(Niku & Schroeder, 1981; Niku et al., 1982).** The instability of a station, or the excessive variability of the quality of the effluents at the entrance, can cause the treatment process to fail and no longer consistently meet standards rejection of BOD_5. Most violations of release standards can be linked to the absence of possibilities to regulate the excessive variabilities of the quality of wastewater brutes at the entrance to the station **(Ossenbruggen et al., 1987)**. The assessment of reliability and cleanup procedures for wastewater treatment plants has been extensively examined in several academic studies. In their study, **Padalkar and Kumar, (2018)** devised a model that leveraged machine learning algorithms to forecast the occurrence of water pump failure by analyzing sensor data. In their study, **Anwar et al., (2021)** conducted an analysis of the comprehensive functioning of a wastewater treatment plant. They also developed a monitoring system to oversee the equipment and processes involved, which encompassed the identification of failures and the evaluation of associated hazards. The approach proposed by **Khudair, et al., (2017**) aims to evaluate the dependability and robustness of a wastewater treatment facility by examining the factors contributing to non-compliance and analyzing several operational situations. In their study, **Padalkar and Kumar, (2018)** conducted an analysis on the reliability of pollution removal within a wastewater treatment plant. This analysis involved the calculation of effectiveness and reliability factors. **Taheriyoun and Moradinejad, (2015)** conducted a study on the dependability of the "WWTP-Receiver" system by employing probabilistic models and Monte Carlo simulations.The aforementioned studies offer valuable perspectives on diverse methodologies employed in the evaluation and enhancement of wastewater treatment plant dependability.

Chapter Four: Results and Discussion

4.1 Introudiction

In order to assess the efficiency of the Karbala wastewater treatment plant, the present study involves investigating information collected from the plant (reliability analysis and performance index evaluation), as mentioned in chapter four. The aim of the performance assessment of the Karbala wastewater treatment plant is to enhance the treated effluent's general quality.

4.2 Evaluation of the performance of the WWTP in Karbala

Based on the performance reliability assessment, the efficiency of the facility was assessed in the present study. To guarantee the facility's reliability, information relating to the four years of data operation (2020–2023) for effluents produced by A2/O systems were gathered from the Karbala wastewater treatment plant and examined. Throughout the present study process, the plant was visited multiple times in addition to collection information in order to assess the system performance indicator by filling out a checklist according to actual observations and conversations with plant staff. The following is a description of the analysis's findings:

4.2.1 Statistical analysis of data from Karbala wastewater treatment plant

This study is conducted on the basis of self-monitoring data for a period of four years. Biological oxygen demand (BOD_5), chemical oxygen demand (COD), and total suspended solids (TSS) in the effluent wastewater of Karbala WWTP were weekly collected for four years since 2020 to 2023 to complete this study successfully, a combination of computational programs Excel, Statistical graphics the Centurion XVII-X64 and MATLAB 2023 was used to conduct a statistical analysis of the collected data .Tests were conducted of each pollutant weeklyof each year from 2020 to 2023. To show the comprehensine information of the values of BOD5, COD, TSS are presented in Figures (4-1 to 4-4).

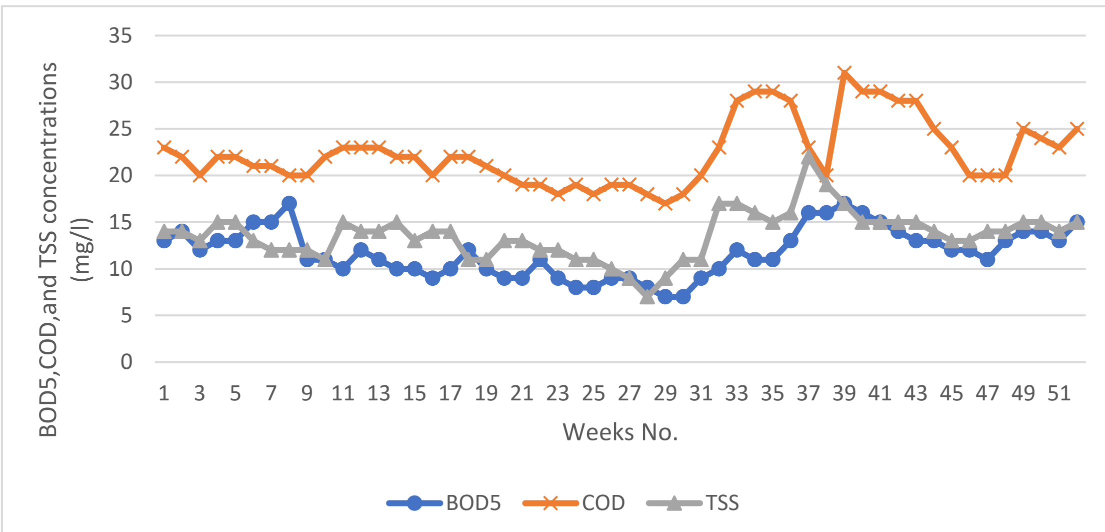


Figure 4-1. Collected data of Karbala WWTP treatment plant for the year 2020.

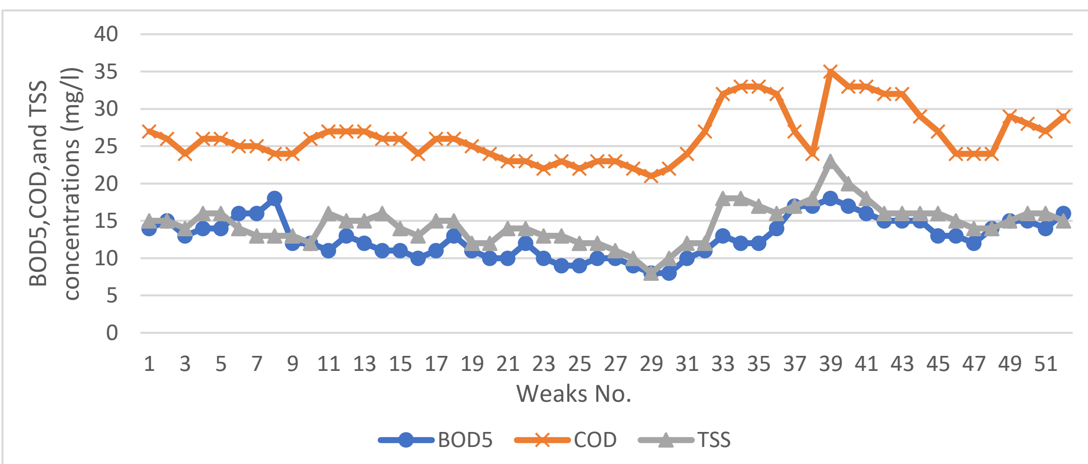


Figure 4-2. Collected data of Karbala WWTP treatment plant for the year 2021.

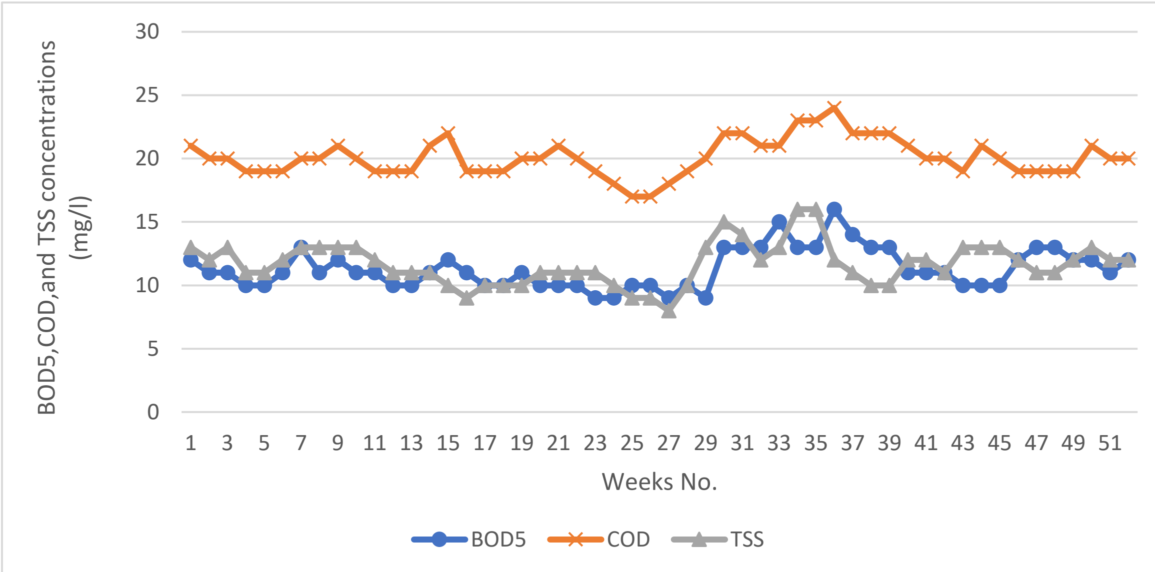


Figure 4-3. Collected data of Karbala WWTP treatment plant for the year 2022.

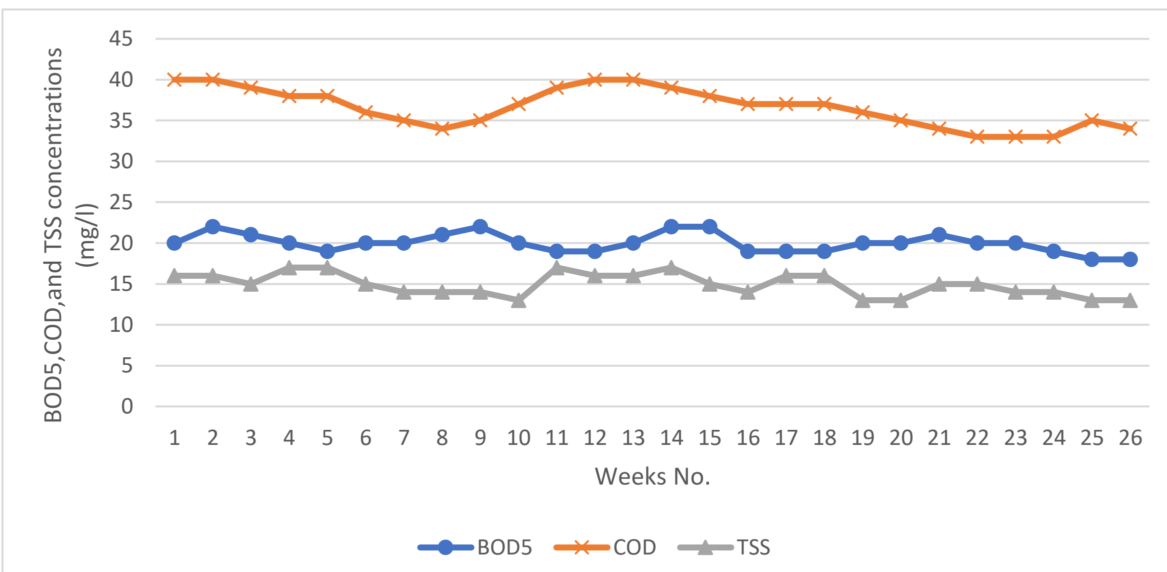


Figure 4-4. Collected data of Karbala WWTP treatment plant for the year 2023

4.2.2 Primary Data Analysis

Evaluating the efficiency of wastewater performance in Karbala treatment plant is established based on the percentage of pollutants that are removed. The average concentration of each pollutant parameter (BOD_5,COD, and TSS) was determined for the years (2020-2023). The removal efficiency of each pollutant parameter shown in Tables 4-1 to 4-4 was calculated by using equation (3-1).

Table 4-1. Summary of Karbala WWTP Removal efficiency for the year (2020).

Parameters	**Influent**	**Effluent**	**Removal efficiency (%)**
BOD_5 (mg/L)	115	11.769	89.77
COD (mg/L)	350	22.404	93.56
TSS (mg/L)	140	13.596	90.28

Table 4-2. Summary of Karbala WWTP Removal efficiency for the year (2021).

Parameters	**Influent**	**Effluent**	**Removal efficiency (%)**
BOD_5 (mg/L)	135	12.808	90.51
COD (mg/L)	400	26.404	93.39
TSS (mg/L)	160	14.596	90.87

Table 4-3.Summary of Karbala WWTP Removal efficiency for the year (2022).

Parameters	**Influent**	**Effluent**	**Removal efficiency (%)**
BOD_5 (mg/L)	140	11.308	91.9
COD (mg/L)	360	20.096	94.4
TSS (mg/L)	180	11.673	93.51

Table 4-4.Summary of Karbala WWTP Removal efficiency for the year (2023).

Parameters	**Influent**	**Effluent**	**Removal efficiency (%)**
BOD_5 (mg/L)	175	20.012	88.56
COD (mg/L)	400	36.615	90.8
TSS (mg/L)	180	14.923	91.7

According to the aforementioned Table, the organic matter (COD and BOD_5) was reduced with excepted efficiency, with removal rates fluctuating between 90% to 94%, respectively. The reason for this is explained by the fact that microorganisms, particularly heterotrophic bacteria, helped to remove organic matter once the necessary levels of dissolved oxygen that were present and there was sufficient mixing within the reactor to cause these compounds to break down and become fixed substances (Bankston et al., 2020). Roughly 90% to 98% of the suspended solids (TSS) were removed from secondary sedimentation basins with satisfactory outcomes

4.2.3 Verification of Selected Data Distribution

It is possible to use the reliability model of (Niku et al., 1979) with lognormally distributed data. It was used to monitor the treated effluent quality by using the weekly recorded concentrations of certain parameters. Finding the probability distribution function of the necessary treated effluent parameters was therefore the first step. The quality of the plant effluents was evaluated using three criteria's, Table (4.5) chemical oxygen demand (COD), total suspended solids (TSS), and biochemical oxygen demand (BOD_5) during a five-day period.

To perform an initial assessment on the symmetry of the collected information, the values for the coefficients of kurtosis and skewness for each parameter of treated effluents were found and displayed in Table (4.5) below. The observations were positively skewed and approximately symmetrical, as seen by the positive means and positive skewness values in the results. On the other hand, the values of the kurtosis coefficient did not deviate from the normal distribution. The pre-check so demonstrated that the data were normal.

Table 4-5.Statistics describing the parameters of the (A2/O) effluent during years from 2020 to 2023.

Parameter	**Year**	**Mean**	**Standard deviation**	**Coeff. of variation**	**Min.**	**Max.**	**Stand. skewness**	**Stand. kurtosis**	**Iraqi standards**
BOD_5 (mg/l)	2020	11.769	2.6093	0.2217	7	17	0.1616	2.2103	40
	2021	12.808	2.6349	0.2057	8	18	0.1327	2.1351	
	2022	11.308	1.5535	0.1374	9	16	0.7440	3.3100	
	2023	20.012	1.1662	0.05831	18	22	0.30864	2.3841	
COD (mg/l)	2020	22.404	3.5105	0.1567	17	31	0.7771	2.695	100
	2021	26.404	3.5105	0.1330	21	35	0.7771	2.695	
	2022	20.096	1.4587	0.0726	17	24	0.3677	3.1121	
	2023	36.615	2.3677	0.0646	33	40	0.0270	1.7386	
TSS (mg/l)	2020	13.596	2.5534	0.1878	7	22	0.3084	4.5435	60
	2021	14.596	2.5991	0.1781	8	16	0.3291	4.2925	
	2022	11.673	1.6535	0.1417	8	16	0.4011	3.4519	
	2023	14.923	1.3834	0.0927	13	17	0.0470	1.7631	

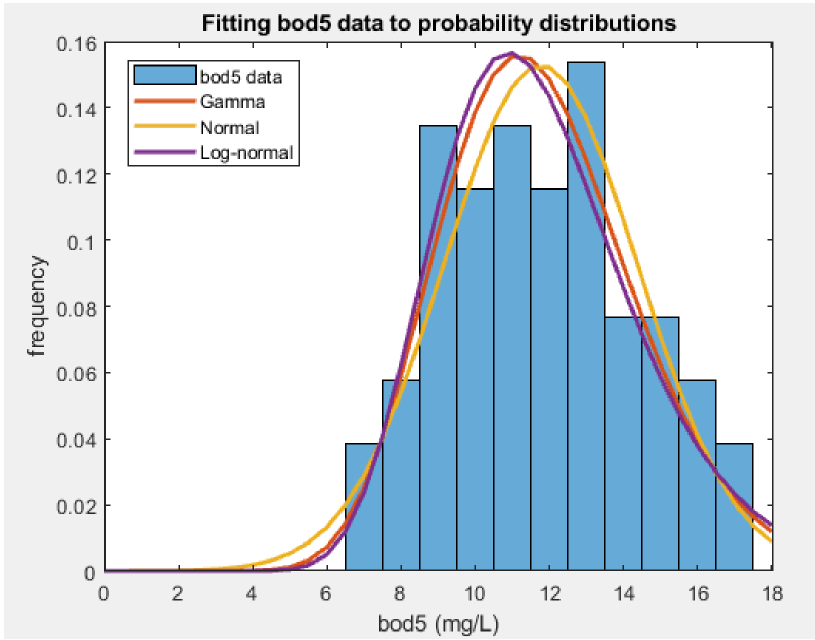
Finding the coefficients of skewness and kurtosis for the treated effluents parameters, as indicated in Table (4.5), allowed for a preliminary examination of the normality of the data. Stand. Kurtosis is projected to be three. A symmetric distribution is seen in this. Positive Kurtosis is denoted by a kurtosis more than 3. Additionally, a negative kurtosis is indicated by a kurtosis of fewer than three. The peak rises with increasing kurtosis values.

4.2.4 Probability Distribution of selected parameters

The histogram is a useful graphical tool for displaying the kurtosis and skewness of data collection. The variation of concentrations of selected parameters used to track effluent quality can be showned and analyzed by finding the histogram and probability density for each parameter concentration for different significant levels (0.01%, 0.05% and 0.1%). Figure 4-5 to 4-8 presents the histogram and the probability distribution function (PDF) of effluent concentrations of BOD_5, COD, and TSS in Karbala wastewater treatment plant.

The results of the study indicate that the lognormal distribution is the most appropriate model to characterize the patterns exhibited by the effluent parameters, (BOD_5), (COD), and (TSS), in the Karbala WWTPs for conventional activated sludge (CAS).

The resulting data are believed to be reliable based on the observations, which indicate that using lognormal distributions of effluent properties is a viable approach for assessing wastewater quality. Studies conducted by (Charles et al., 2005; Oliveira & Von Sperling, 2008) are relevant to the topic at hand. Given that the model that was used for the data followed lognormal distribution, it can be concluded that the data were appropriate for the purpose of performing reliability assessments.


Fitting bod5 data to probability distributions
bod5 data
Gamma
Normal
Log-normal
frequency
bod5 (mg/L)
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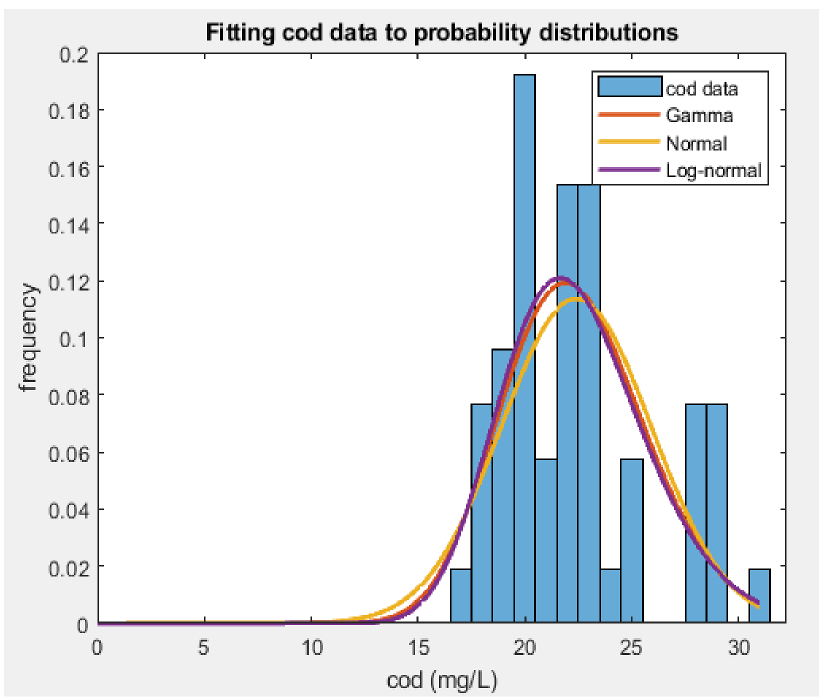
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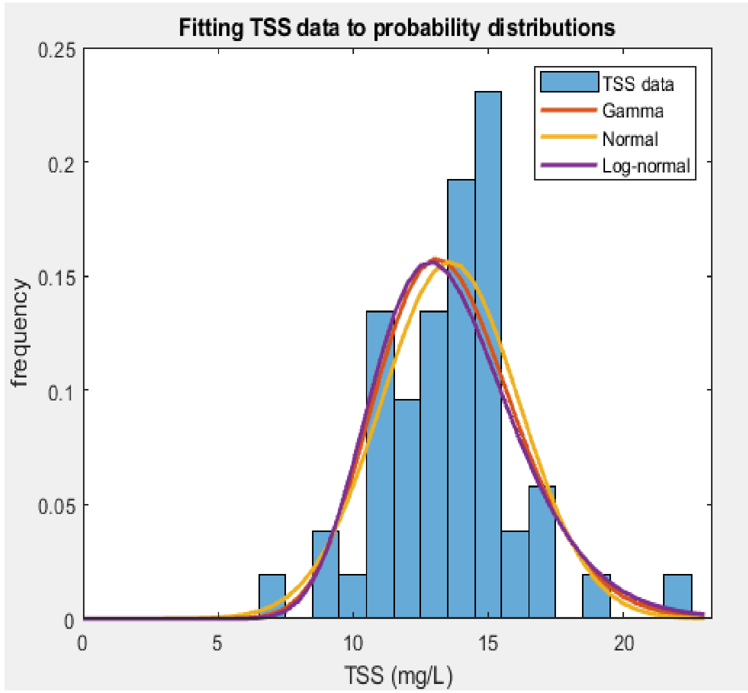
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TSS data
Gamma
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Log-normal
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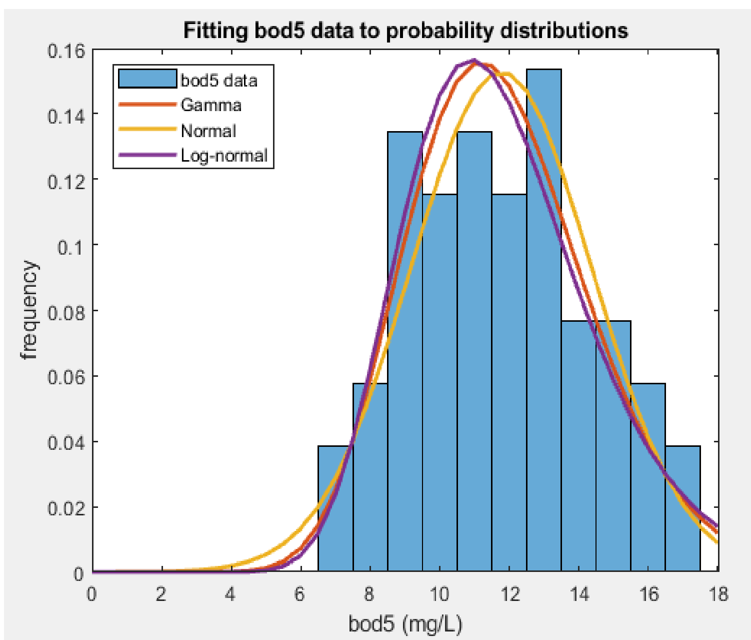
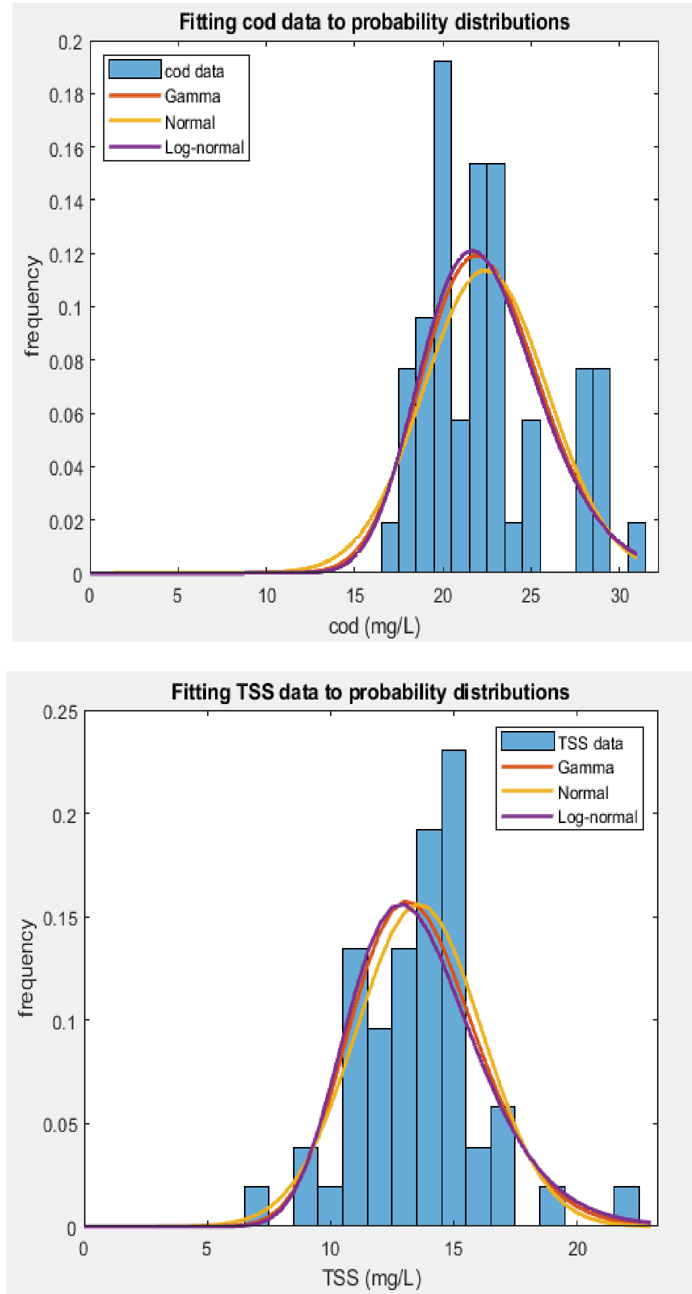
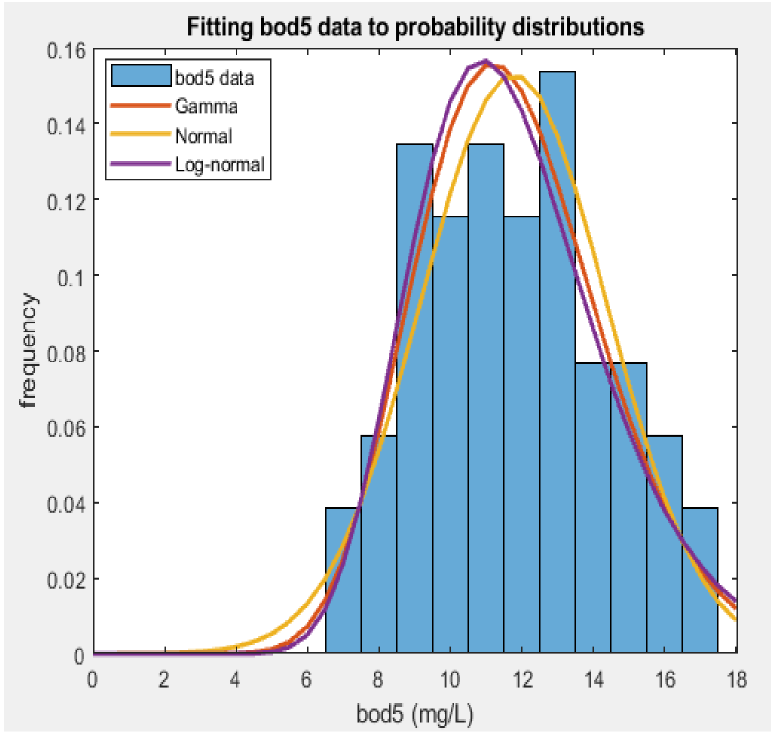
0.2
0.15
0.1
0.05
0
0
5
10
15
20
TSS (mg/L)

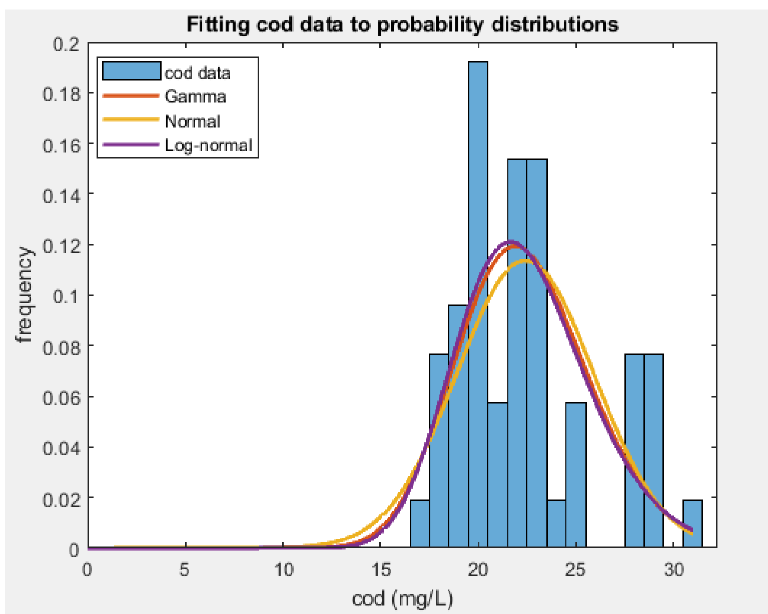
(a) α = 0.01

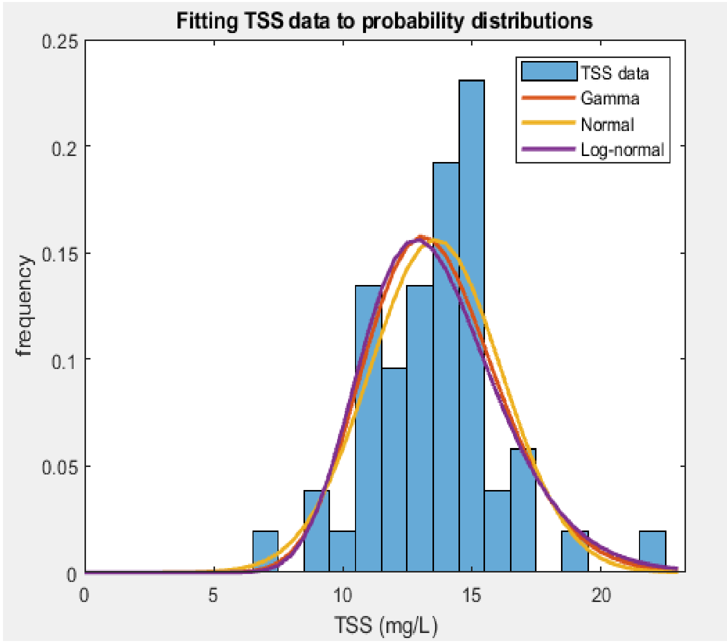

Fitting bod5 data to probability distributions
bod5 data
Gamma
Normal
Log-normal
frequency
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
2
4
6
8
10
12
14
16
18
bod5 (mg/L)


Fitting cod data to probability distributions
cod data
Gamma
Normal
Log-normal
frequency
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
5
10
15
20
25
30
cod (mg/L)
Fitting TSS data to probability distributions
TSS data
Gamma
Normal
Log-normal
frequency
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
TSS (mg/L)

(b) α = 0.05

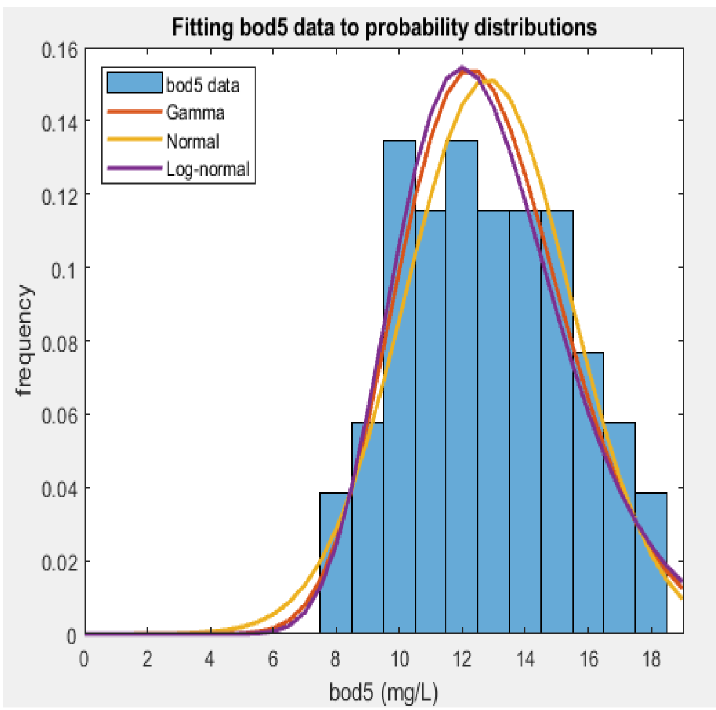

Fitting bod5 data to probability distributions
bod5 data
Gamma
Normal
Log-normal
frequency
bod5 (mg/L)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0
2
4
6
8
10
12
14
16
18

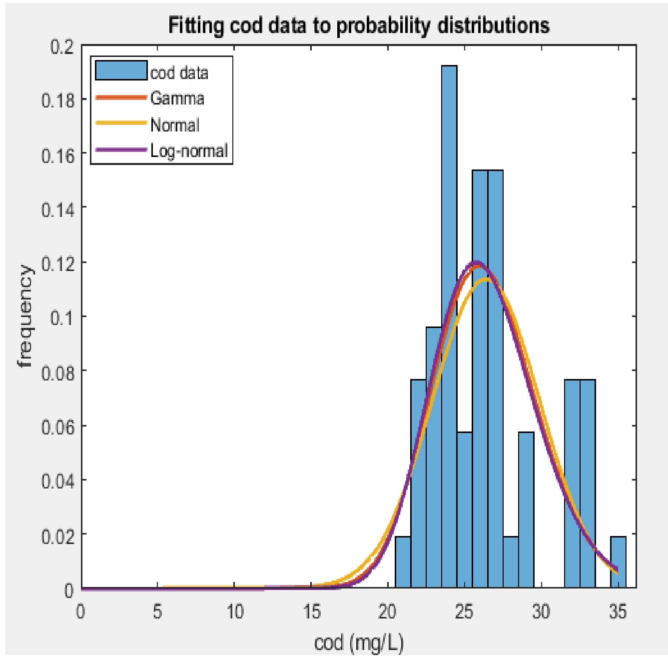

Fitting cod data to probability distributions
cod data
Gamma
Normal
Log-normal
frequency
cod (mg/L)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0
5
10
15
20
25
30

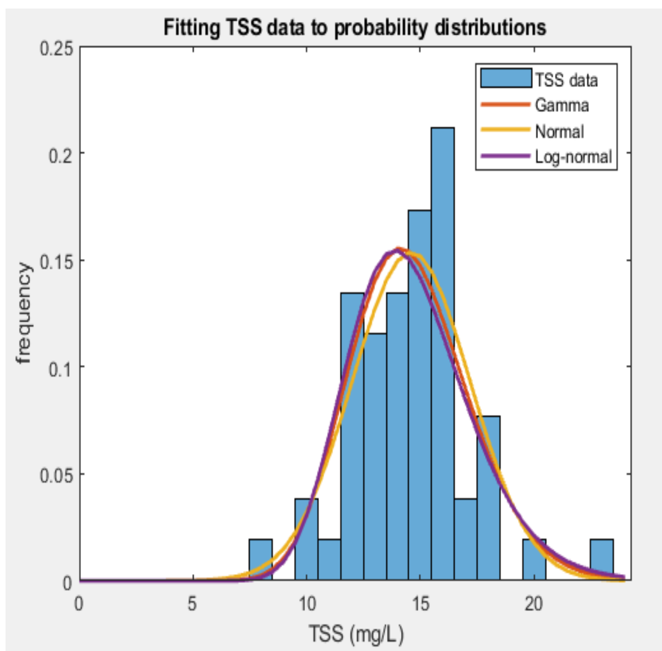


(c) α = 0.1

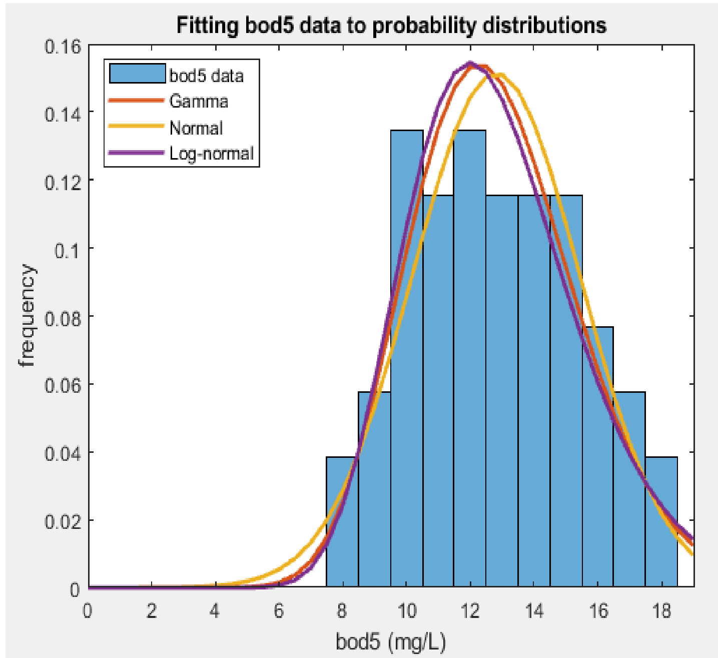
Figure 4-6. Histogram and PDF of BOD5, COD and TSS of 2020 with different significant level.

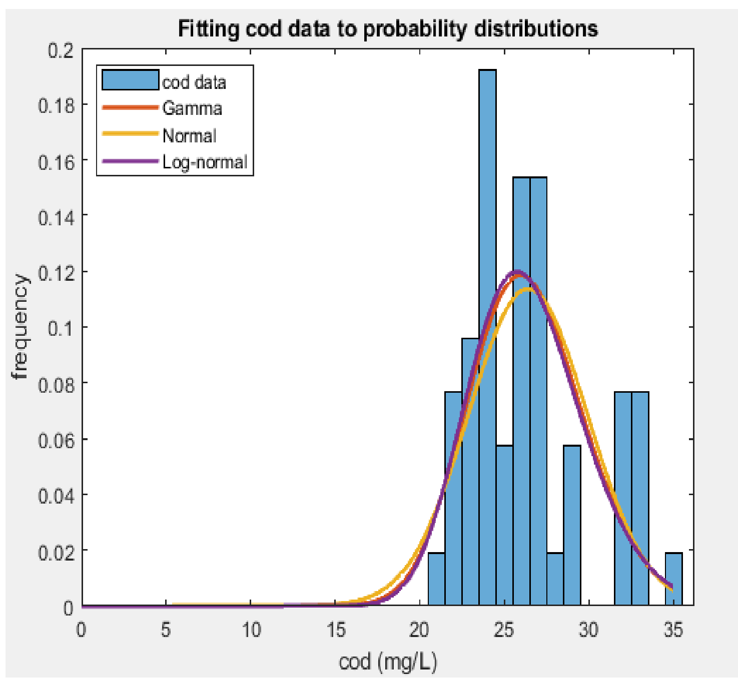


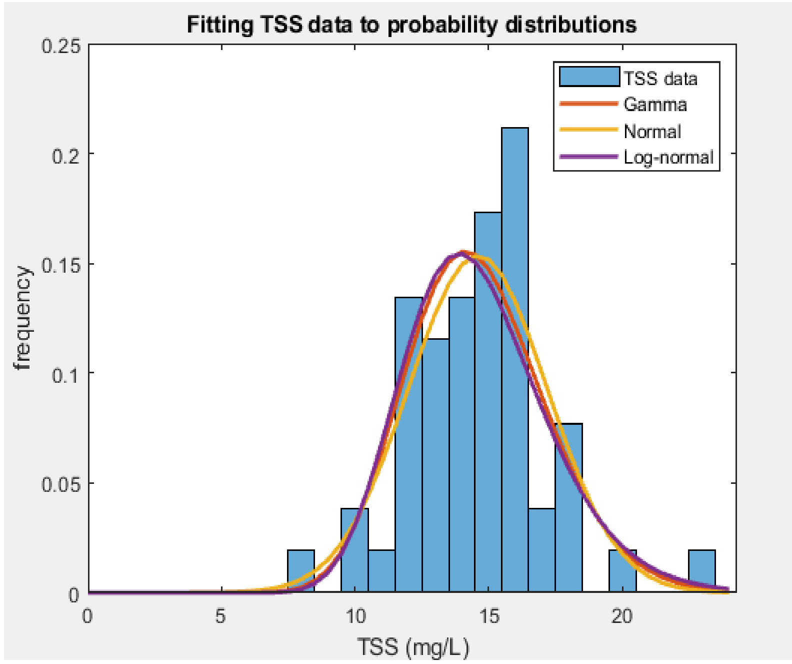

Fitting cod data to probability distributions
cod data
Gamma
Normal
Log-normal
frequency
cod (mg/L)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0
5
10
15
20
25
30
35


Fitting TSS data to probability distributions
TSS data
Gamma
Normal
Log-normal
frequency
TSS (mg/L)
0
0.05
0.1
0.15
0.2
0.25
0
5
10
15
20

(a) α = 0.01

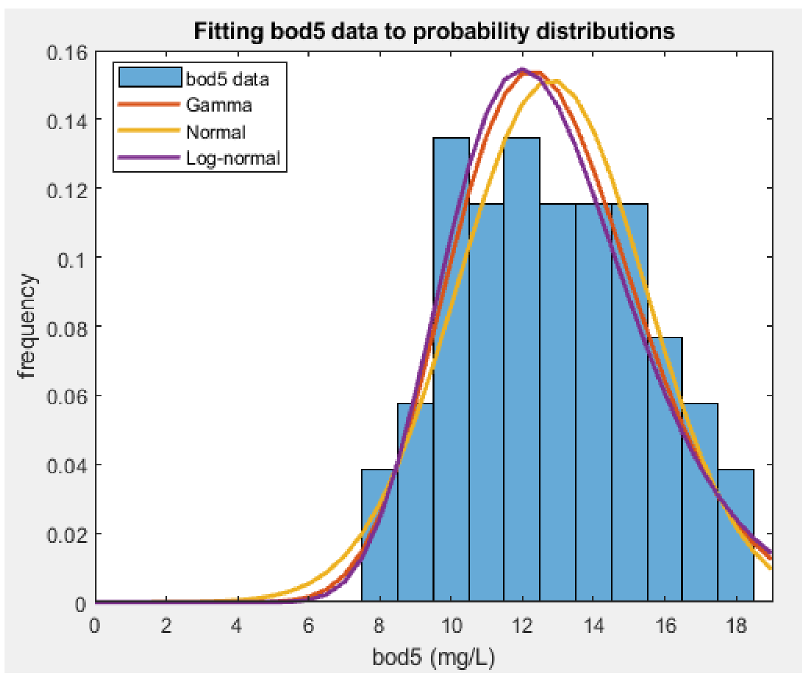

Fitting bod5 data to probability distributions
bod5 data
Gamma
Normal
Log-normal
frequency
bod5 (mg/L)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
2
4
6
8
10
12
14
16
18


Fitting cod data to probability distributions
cod data
Gamma
Normal
Log-normal
frequency
cod (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
5
10
15
20
25
30
35

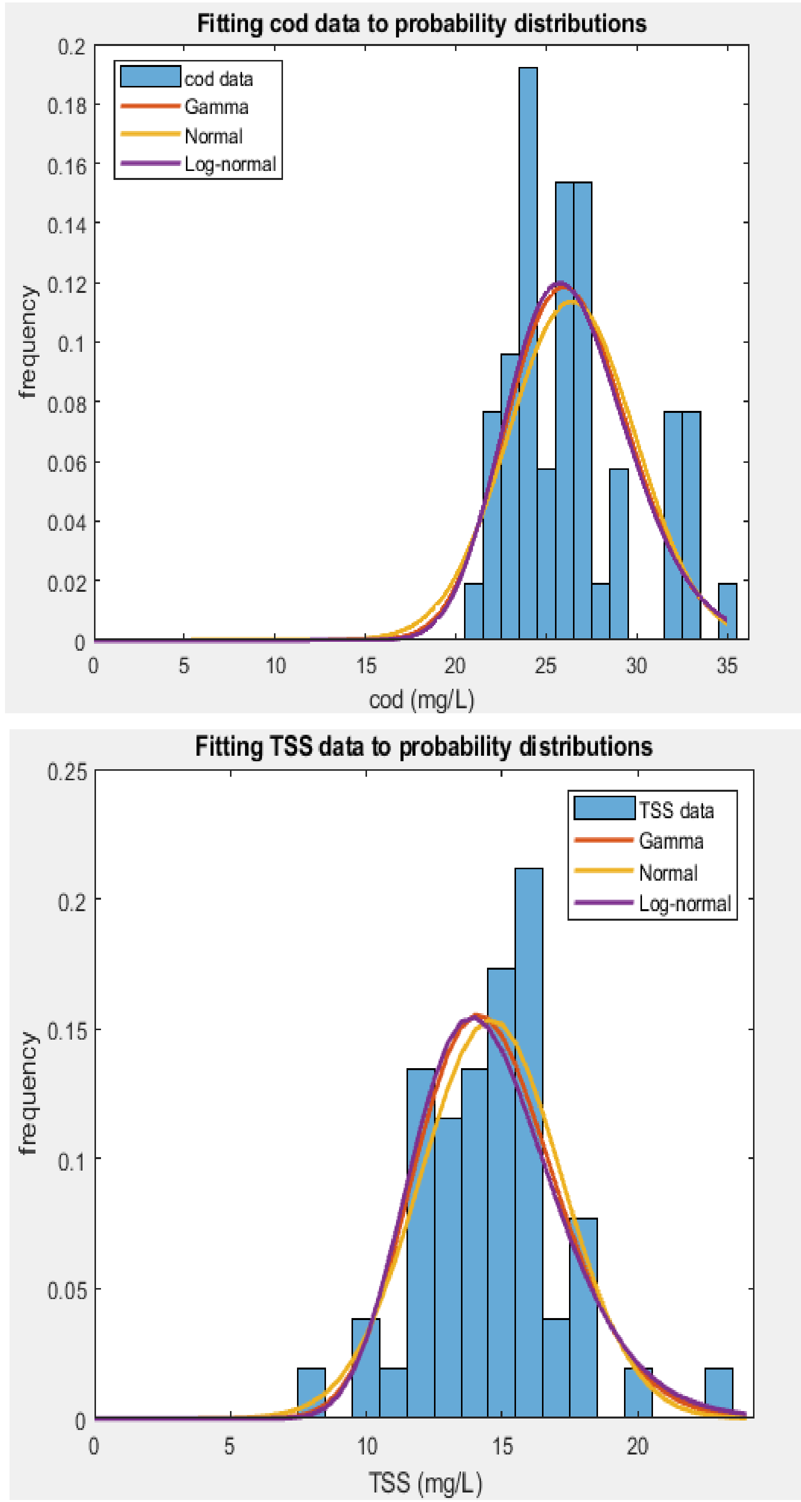


Fitting TSS data to probability distributions
TSS data
Gamma
Normal
Log-normal
frequency
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
TSS (mg/L)

(b) α = 0.05

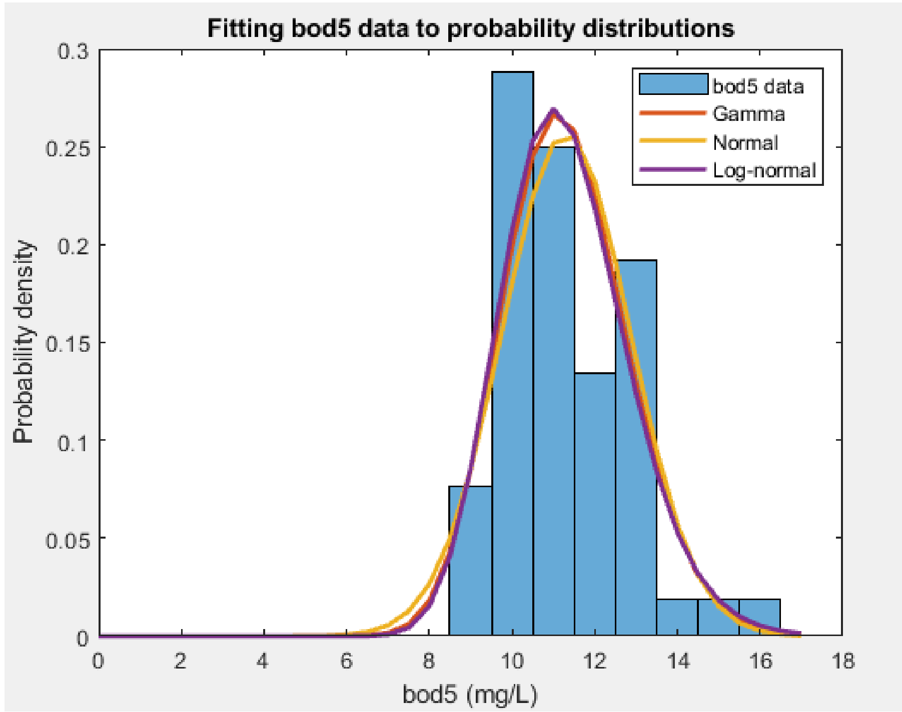


Fitting bod5 data to probability distributions
bod5 data
Gamma
Normal
Log-normal
frequency
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
2
4
6
8
10
12
14
16
18
bod5 (mg/L)

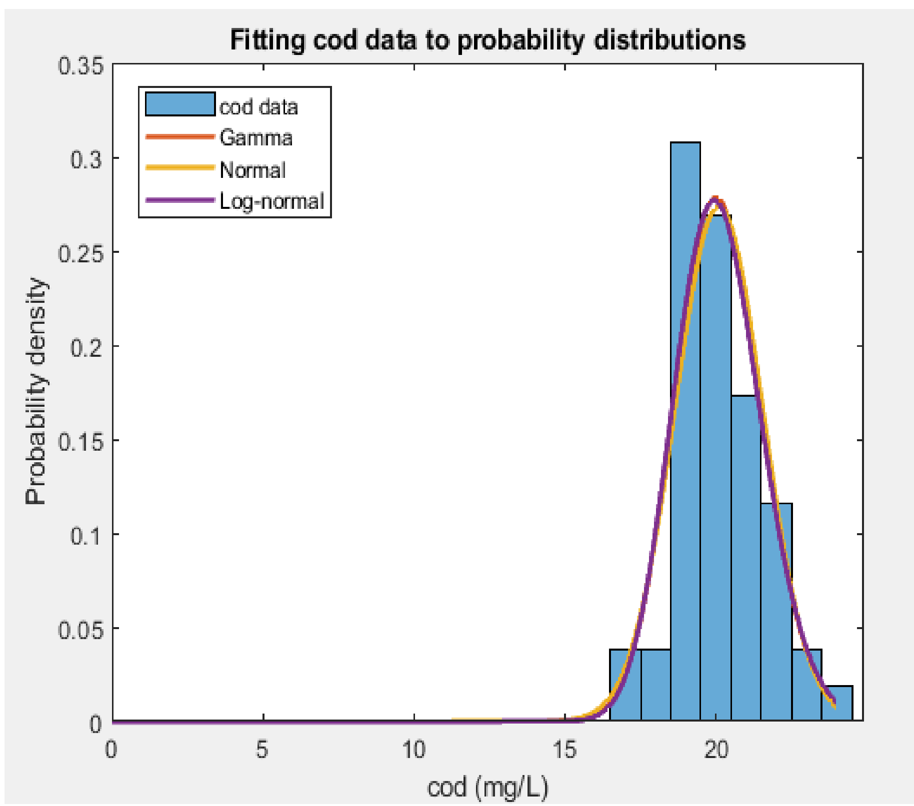


(c) α = 0.1

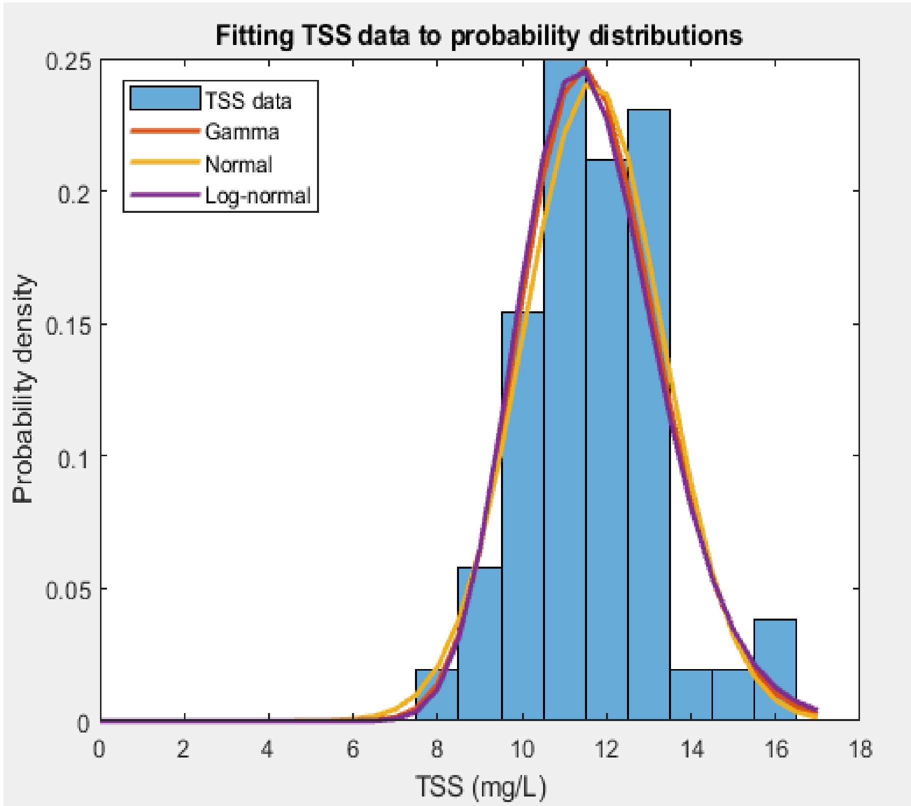
Figure 4-6. Histogram and PDF of BOD5, COD and TSS of 2021 with different significant levels.



Fitting bod5 data to probability distributions
bod5 data
Gamma
Normal
Log-normal
Probability density
0
0.05
0.1
0.15
0.2
0.25
0.3
0
2
4
6
8
10
12
14
16
18
bod5 (mg/L)

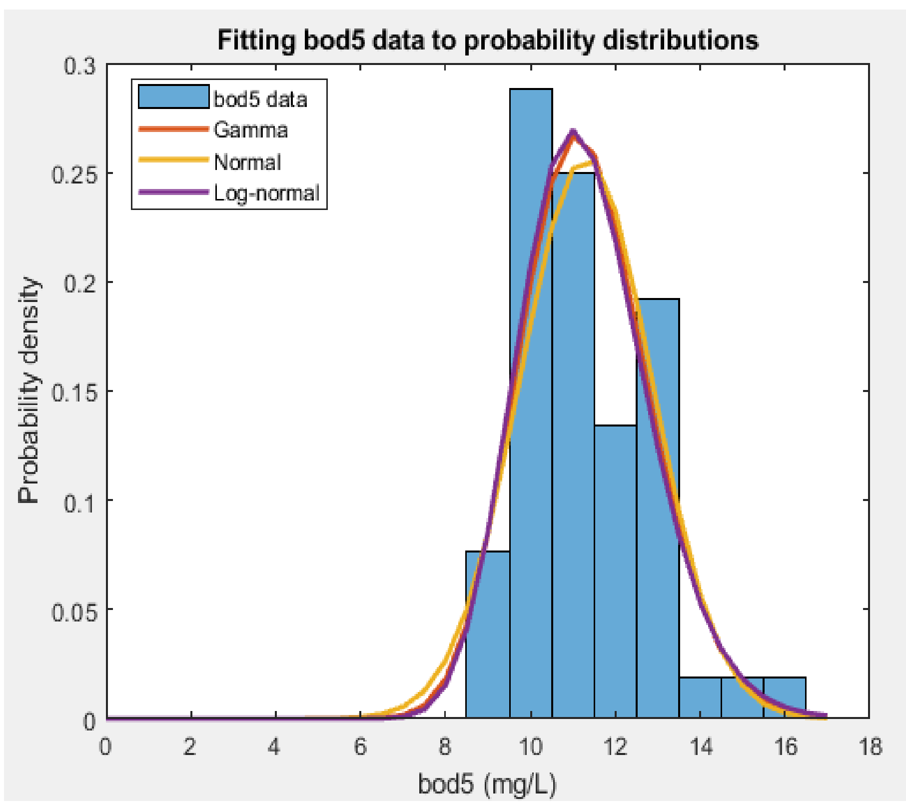


Fitting cod data to probability distributions
cod data
Gamma
Normal
Log-normal
Probability density
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0
5
10
15
20
cod (mg/L)

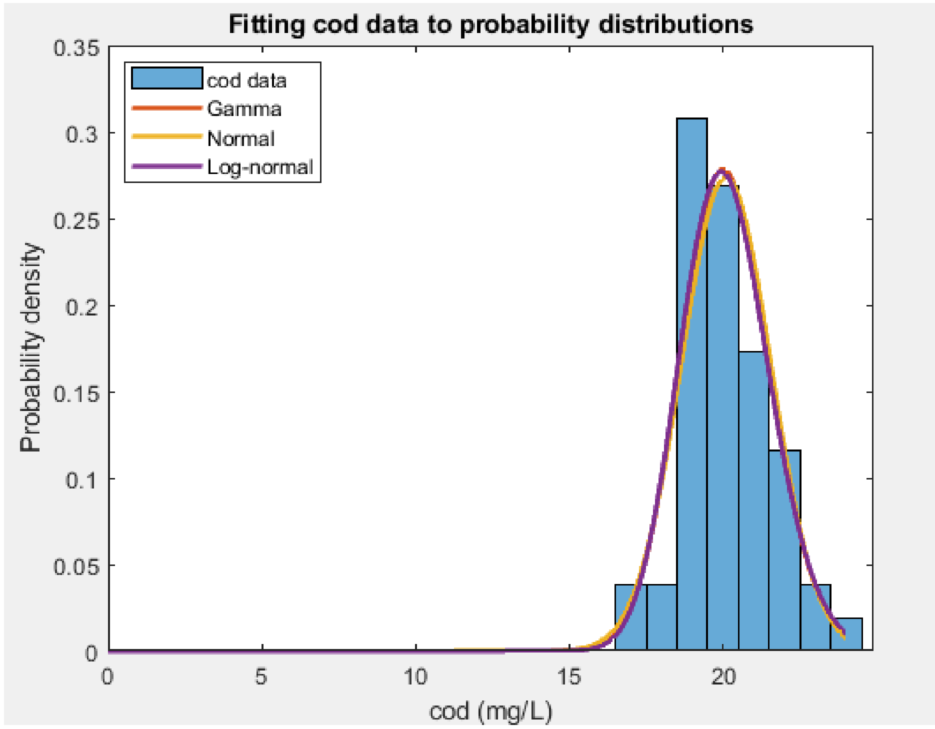


Fitting TSS data to probability distributions
TSS data
Gamma
Normal
Log-normal
Probability density
0.25
0.2
0.15
0.1
0.05
0
0
2
4
6
8
10
12
14
16
18
TSS (mg/L)

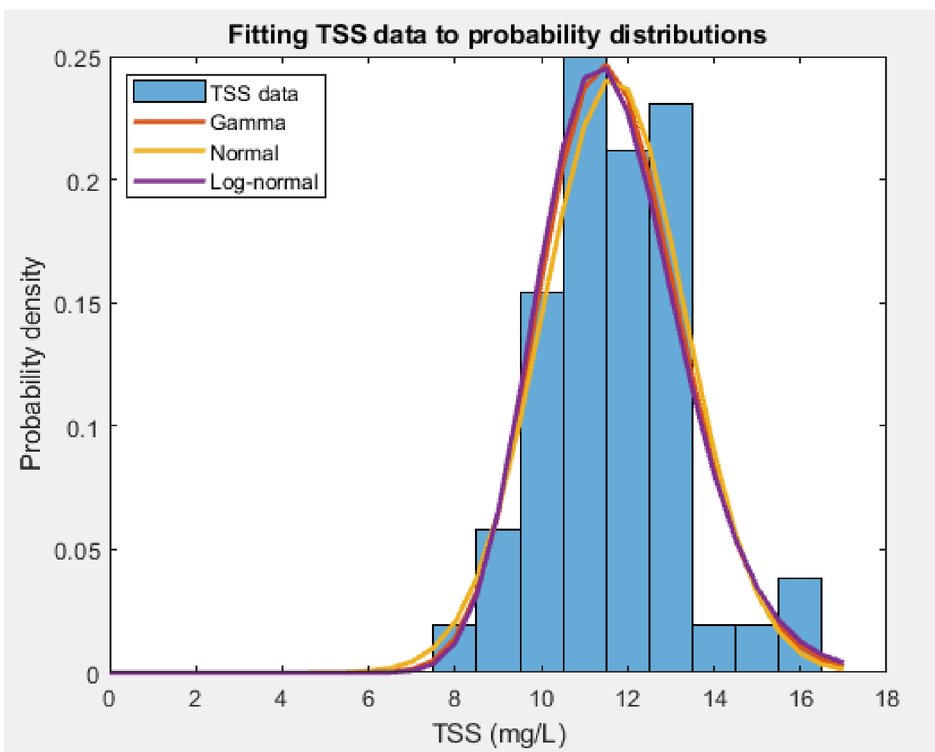
(a) α = 0.01



Fitting bod5 data to probability distributions
bod5 data
Gamma
Normal
Log-normal
Probability density
0.3
0.25
0.2
0.15
0.1
0.05
0
0
2
4
6
8
10
12
14
16
18
bod5 (mg/L)

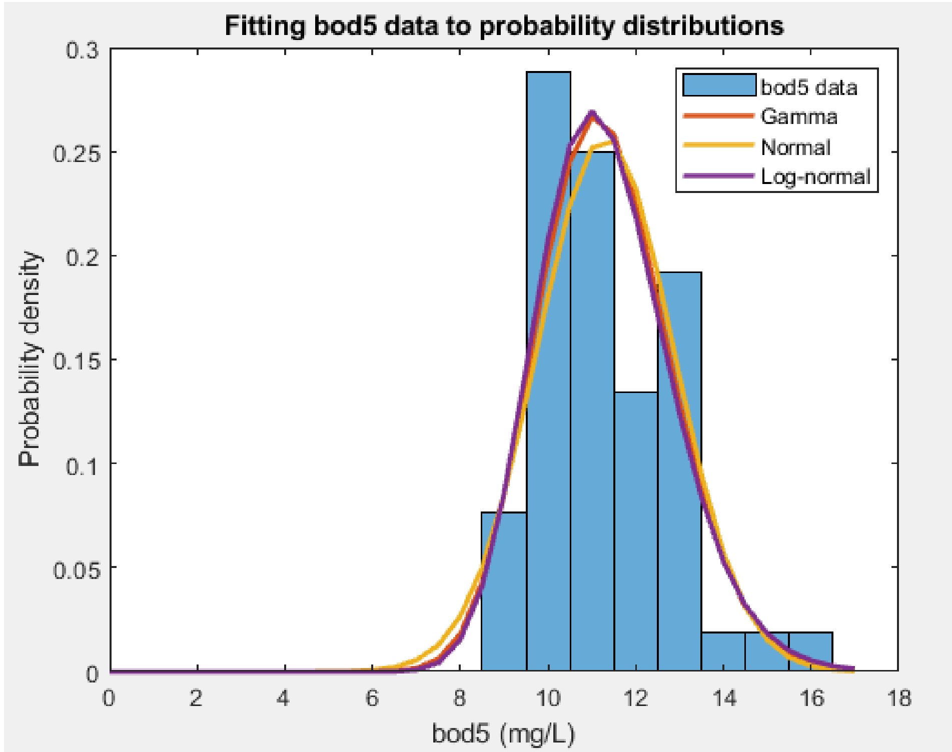


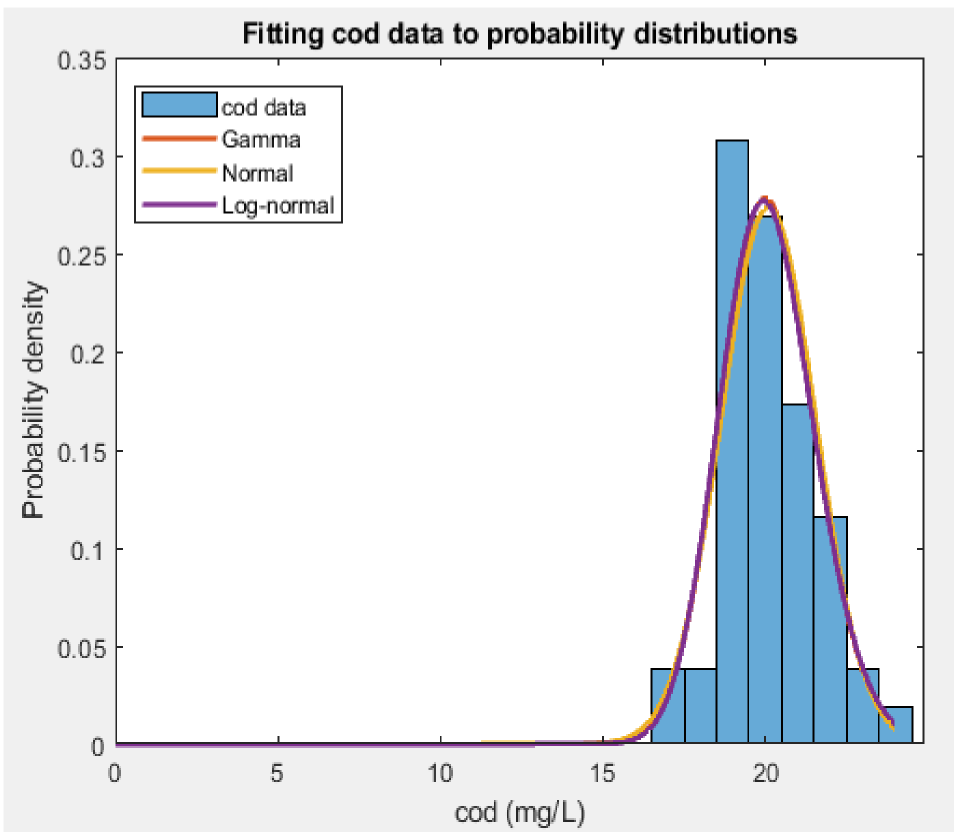
Fitting cod data to probability distributions
cod data
Gamma
Normal
Log-normal
Probability density
cod (mg/L)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0
5
10
15
20

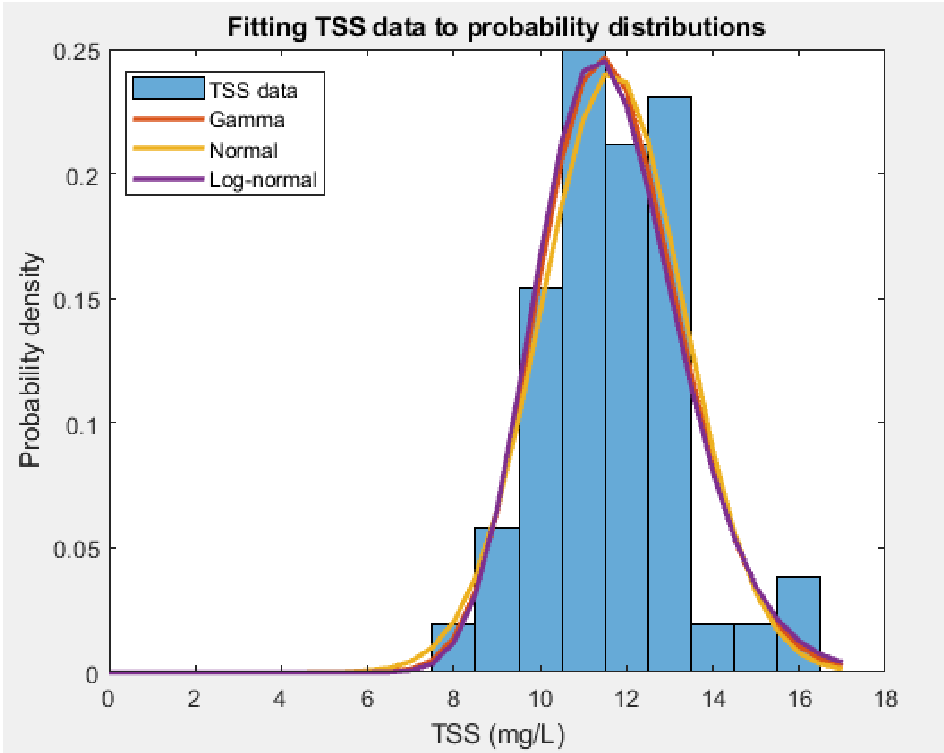


Fitting TSS data to probability distributions
TSS data
Gamma
Normal
Log-normal
Probability density
TSS (mg/L)
0
0.05
0.1
0.15
0.2
0.25
0
2
4
6
8
10
12
14
16
18

(b) α = 0.05

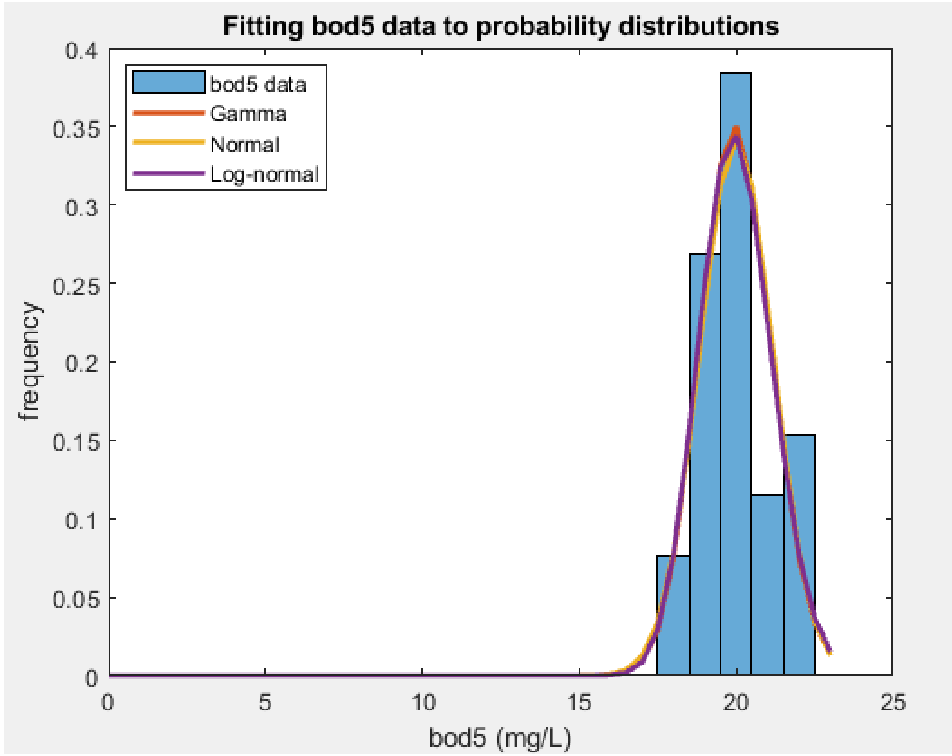

Fitting bod5 data to probability distributions
bod5 data
Gamma
Normal
Log-normal
Probability density
bod5 (mg/L)
0
0.05
0.1
0.15
0.2
0.25
0.3
0
2
4
6
8
10
12
14
16
18


Fitting cod data to probability distributions
cod data
Gamma
Normal
Log-normal
Probability density
cod (mg/L)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0
5
10
15
20

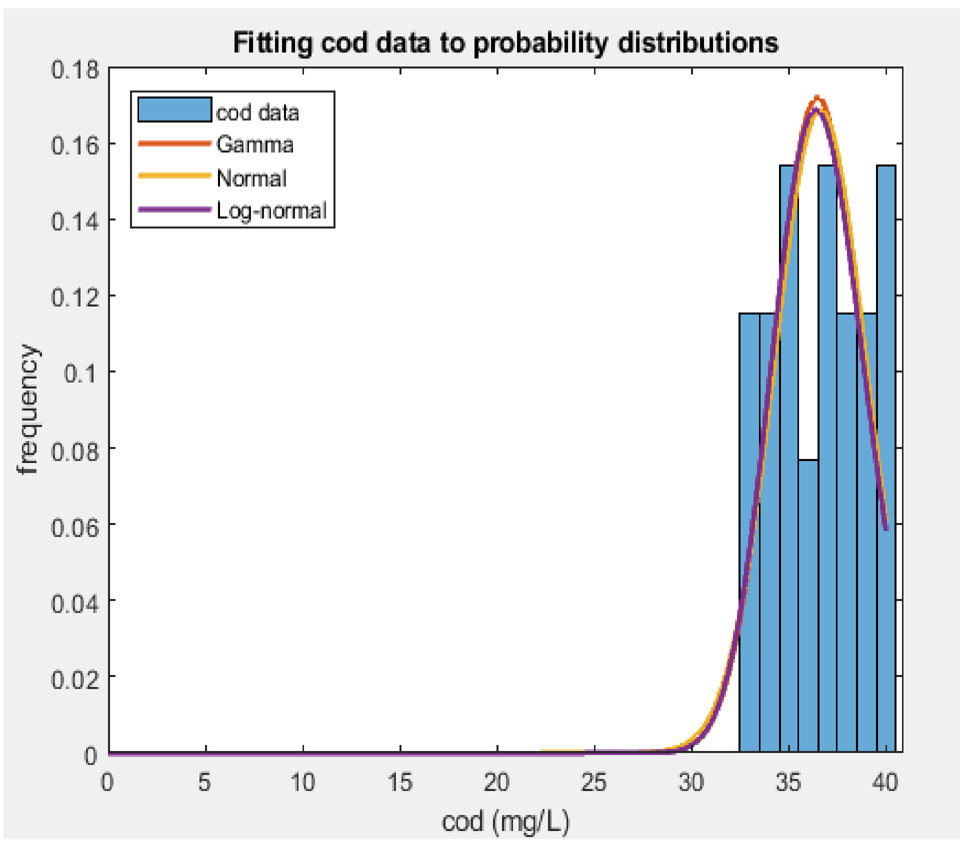


(c) α = 0.1

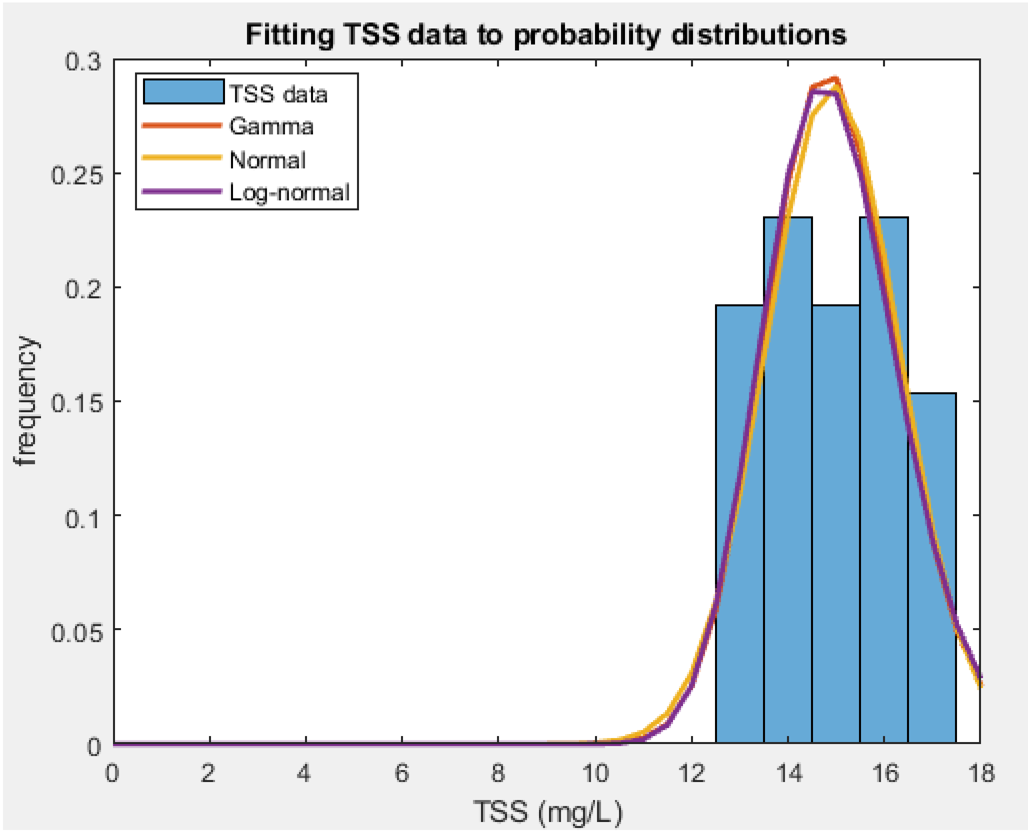
Figure 4-7. Histogram and PDF of BOD_5, COD and TSS of 2022 with different significant levels.



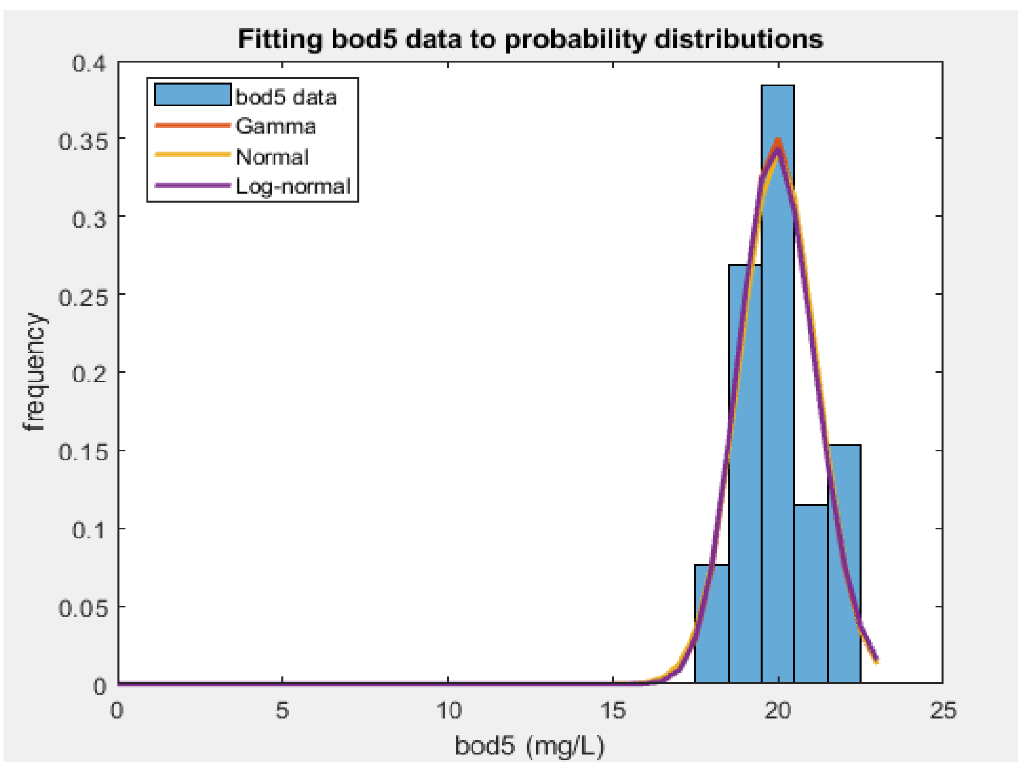
Fitting bod5 data to probability distributions
bod5 data
Gamma
Normal
Log-normal
frequency
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
bod5 (mg/L)

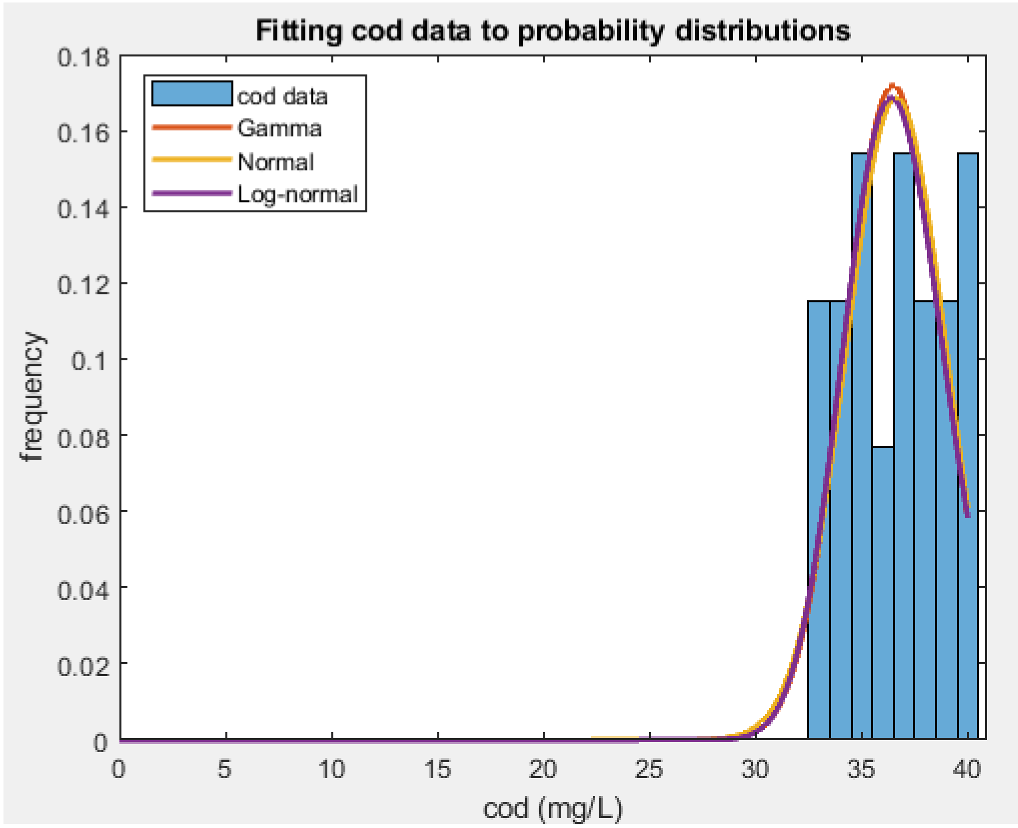


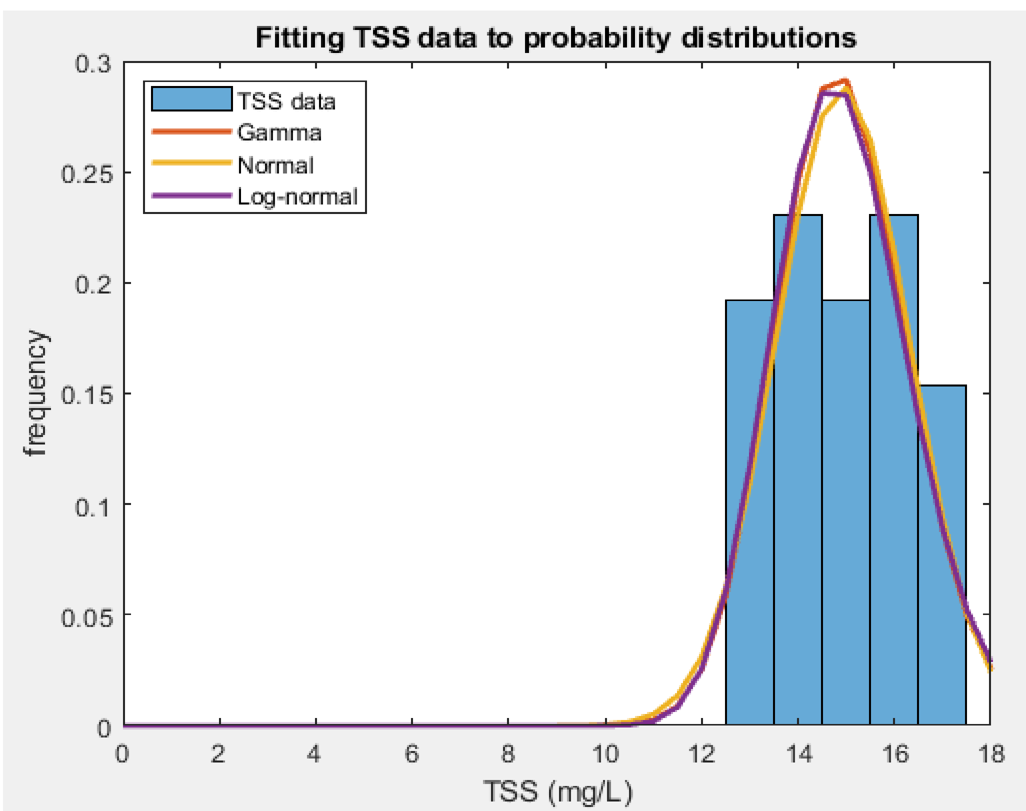
Fitting cod data to probability distributions
cod data
Gamma
Normal
Log-normal
frequency
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
5
10
15
20
25
30
35
40
cod (mg/L)


Fitting TSS data to probability distributions
TSS data
Gamma
Normal
Log-normal
frequency
TSS (mg/L)
0
0.05
0.1
0.15
0.2
0.25
0.3
2
4
6
8
10
12
14
16
18

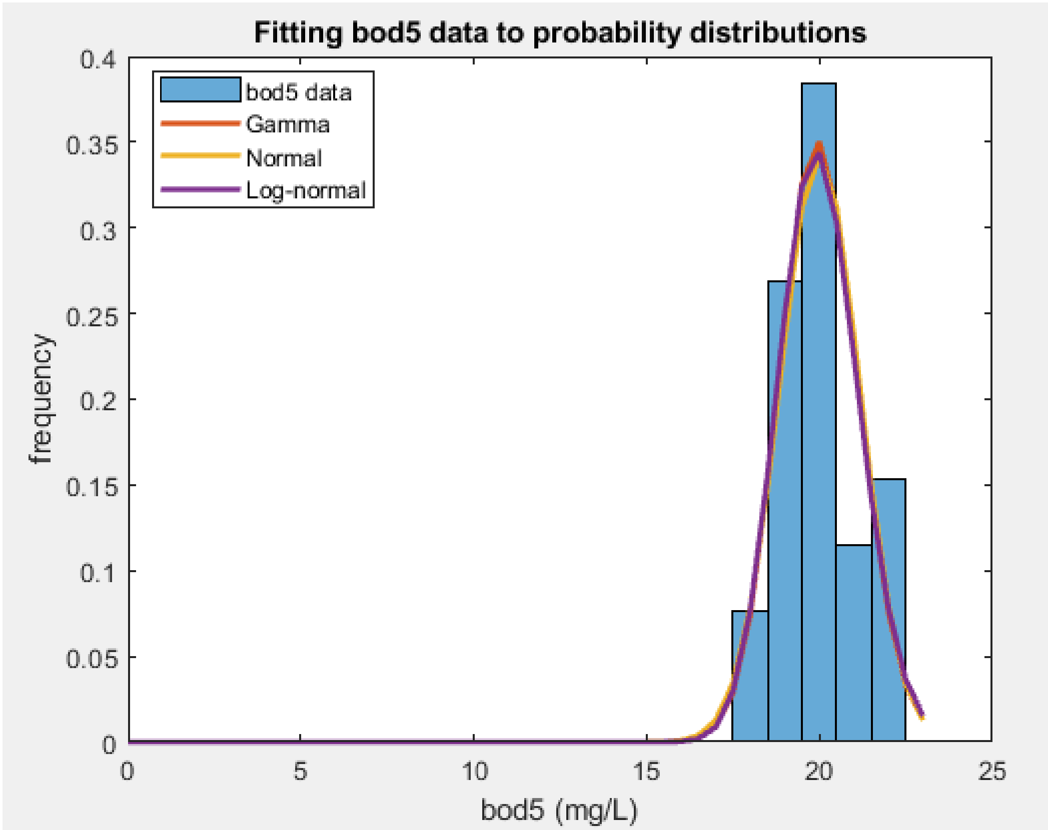
(a) α = 0.01

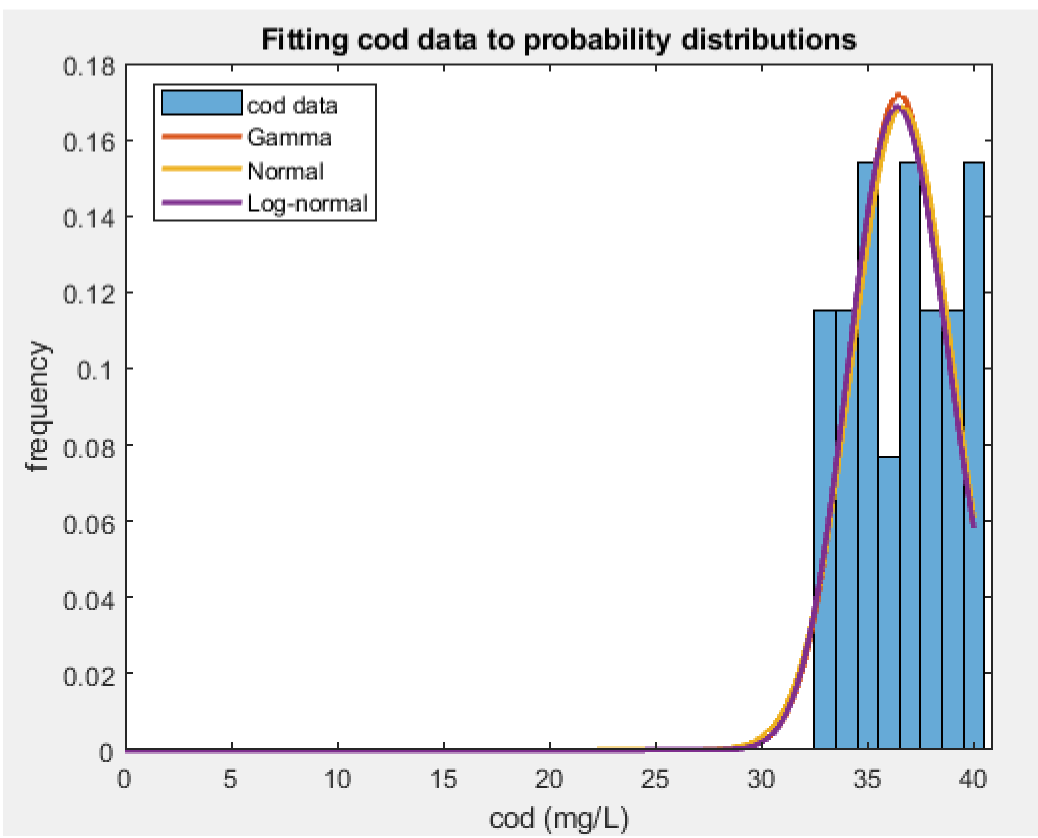

Fitting bod5 data to probability distributions
bod5 data
Gamma
Normal
Log-normal
frequency
bod5 (mg/L)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
5
10
15
20
25

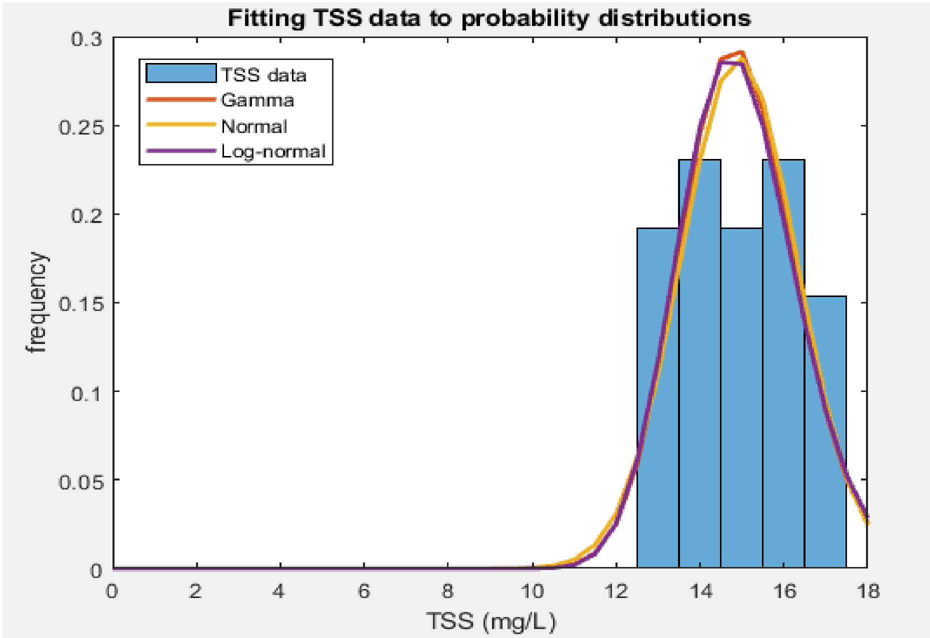

Fitting cod data to probability distributions
cod data
Gamma
Normal
Log-normal
frequency
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
5
10
15
20
25
30
35
40
cod (mg/L)


Fitting TSS data to probability distributions
TSS data
Gamma
Normal
Log-normal
frequency
0.3
0.25
0.2
0.15
0.1
0.05
0
0
2
4
6
8
10
12
14
16
18
TSS (mg/L)

(b) α = 0.05


Fitting bod5 data to probability distributions
bod5 data
Gamma
Normal
Log-normal
frequency
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
bod5 (mg/L)


Fitting cod data to probability distributions
cod data
Gamma
Normal
Log-normal
frequency
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
5
10
15
20
25
30
35
40
cod (mg/L)



(c) α = 0.1

Figure 4-8. Histogram and PDF of BOD_5, COD and TSS of 2023 with different significant levels.

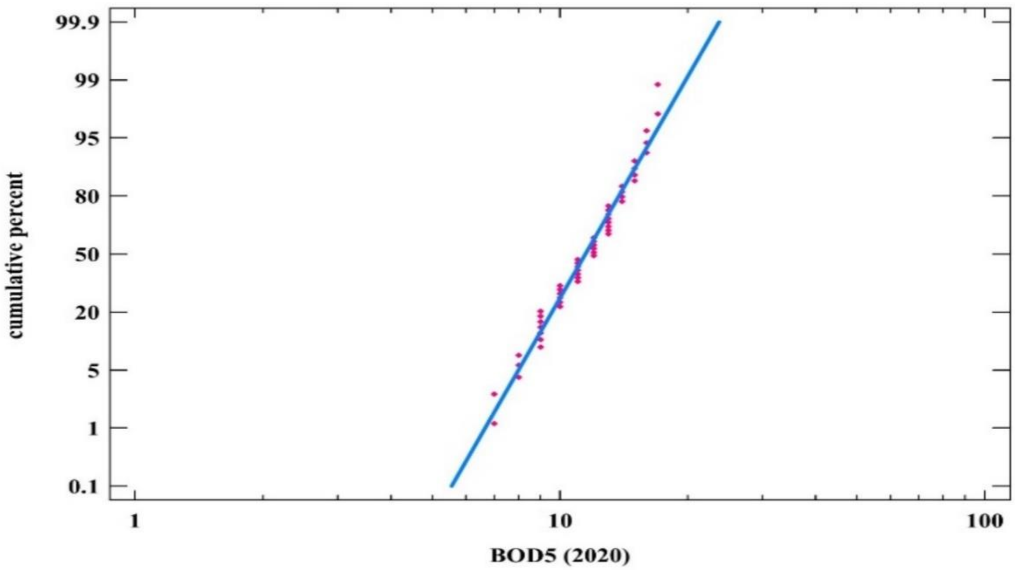
Statistical graphics the Centurion XVII-X64 “software” was used to implement the probabilistic plots. Based on the data, it can be concluded that the lognormal distribution best describes how the three effluent parameters BOD5, COD, and TSS behave. A normality test was conducted and the data were converted to its logarithmic value in order to validate the selection of this distribution. The outcomes are in agreement with the finding stated by (Dean & SL, 1976), (Niku & Schroeder, 1981) and (Olivera, 2008) .The lognormal distribution provides a good overall fit to effluent concentration values, according to a number of studies that were published about the distribution of the concentration data from WWTP (most of them taking BOD and TSS into consideration).

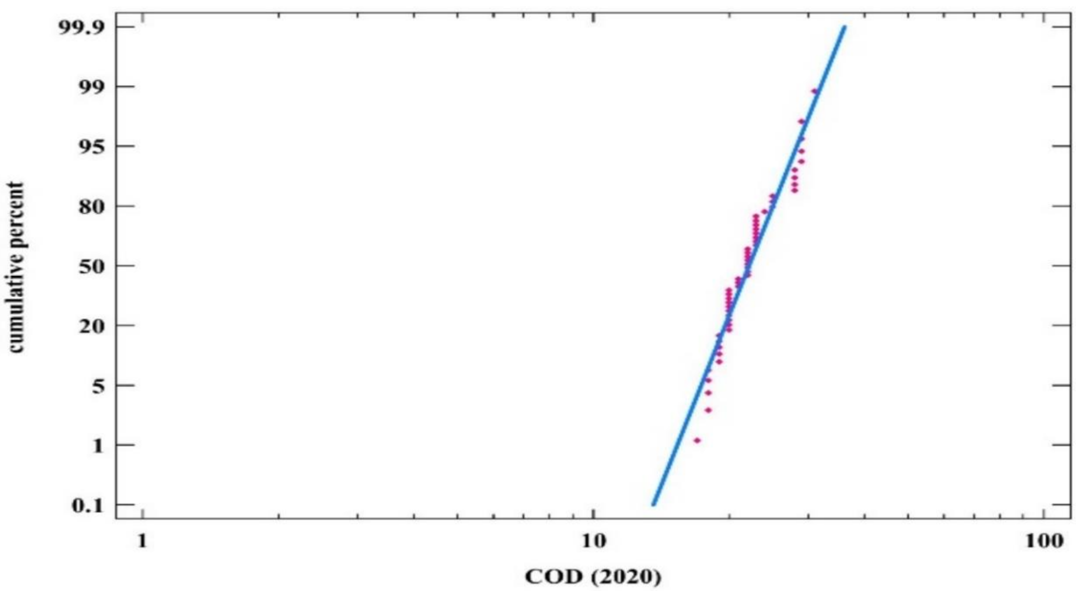
Additionally, the lognormal distribution of effluent concentrations agreed with earlier studies conducted by (Cohen et al., 1975; Kahn &

Rubin, 1989; Ossenbruggen et al., (1987) cited by (Loftis et al., (1983) who discovered that modeling wastewater quality with lognormal distributions for effluent concentrations is beneficial. (Loftis et al., (1983) imply that the most broadly applicable distributions for wastewater quality are the normal and lognormal distributions. Taking this into consideration, the lognormal distribution was used to the effluent BOD_5, COD, and TSS concentrations in the current investigation. Lognormal probability plots are graphical tools used in data analysis to assess the deviation of data from a lognormal distribution. In these plots, the natural logarithm of the data is plotted on the x-axis, while the actual data values are plotted on the y-axis. If the data closely follow a lognormal distribution, the plot will result in a straight line. However, if there is significant deviation from this line, it indicates that the data do not conform well to a lognormal distribution. These plots are commonly used in fields such as statistics and data science to analyze and evaluate the distribution of data and determine whether it follows the expected pattern or not. Lognormal probability plots offer several benefits and important uses in data analysis, including:

Distribution Assessment: They help determine whether data follow a lognormal distribution or not. If the plot shows a straight line, it indicates that the data follow a lognormal distribution, while deviations from the linear line may suggest another distribution.

Detection of Deviations: They enable the detection of deviations or outliers in data from the expected pattern of the lognormal distribution. This information can be used to scrutinize data to identify outliers or errors.


99.9
99
95
80
50
20
5
1
0.1
cumulative percent
1
10
100
BOD5 (2020)


99.9
99
95
80
50
20
5
1
0.1
cumulative percent
1
10
100
COD (2020)

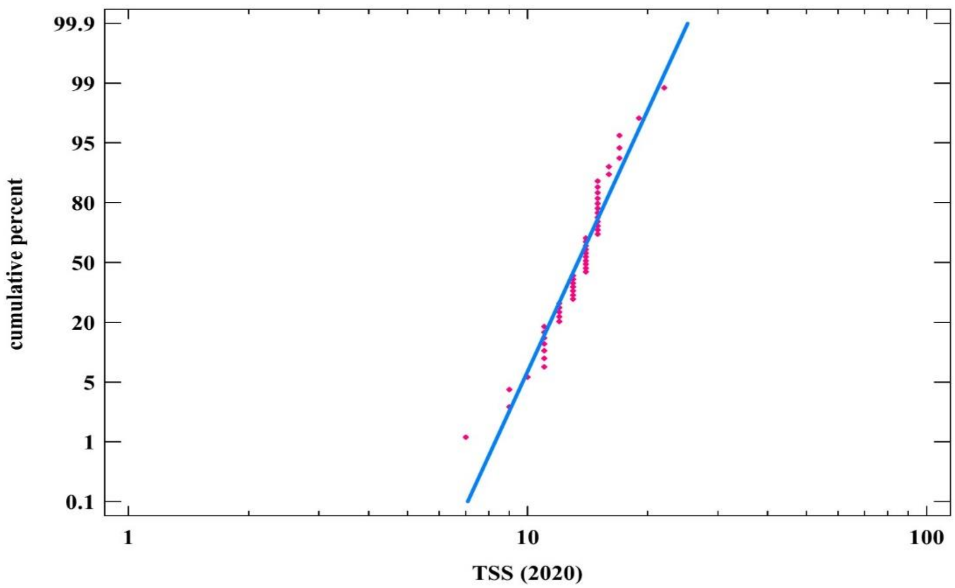
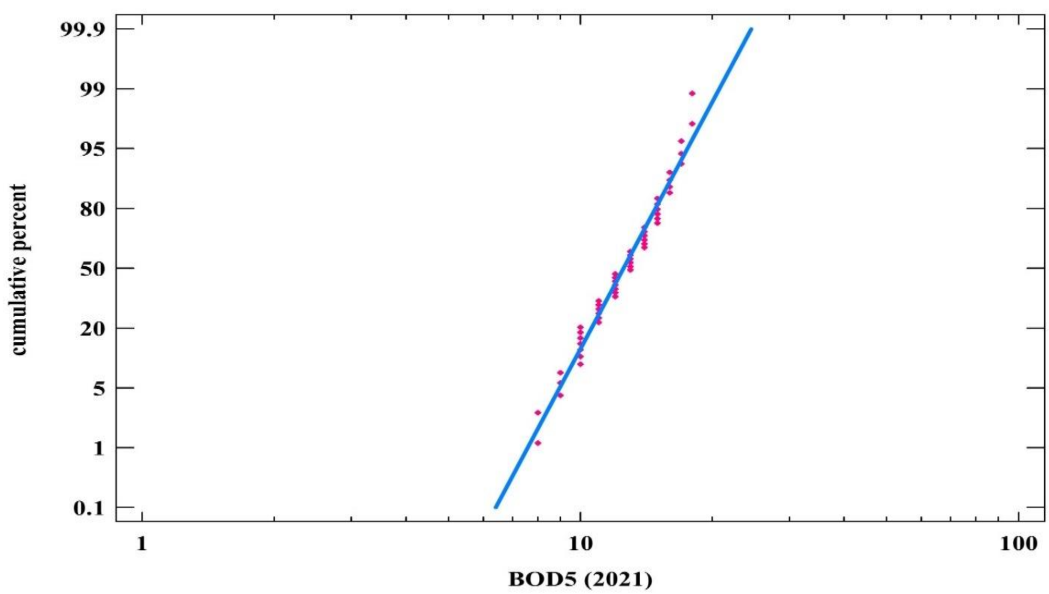


Figure 4-9. Lognormal probability plots with 95 % significance level of Karbala WWTP (2020).



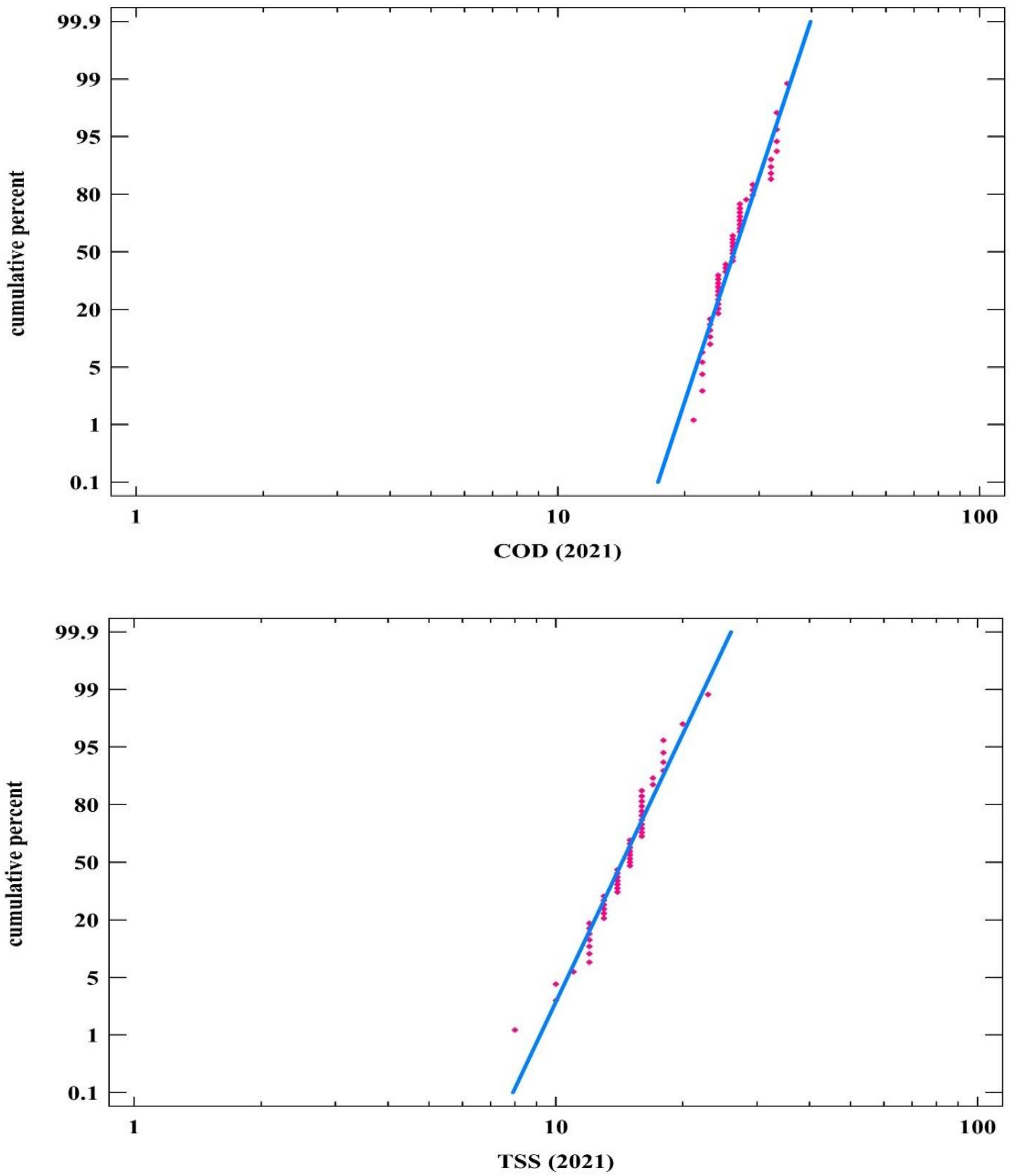
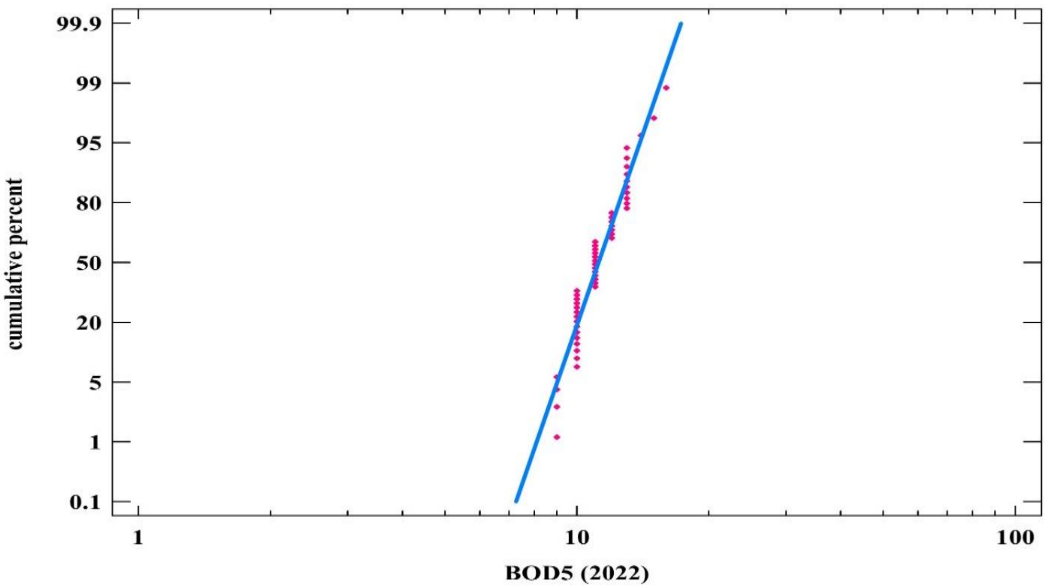
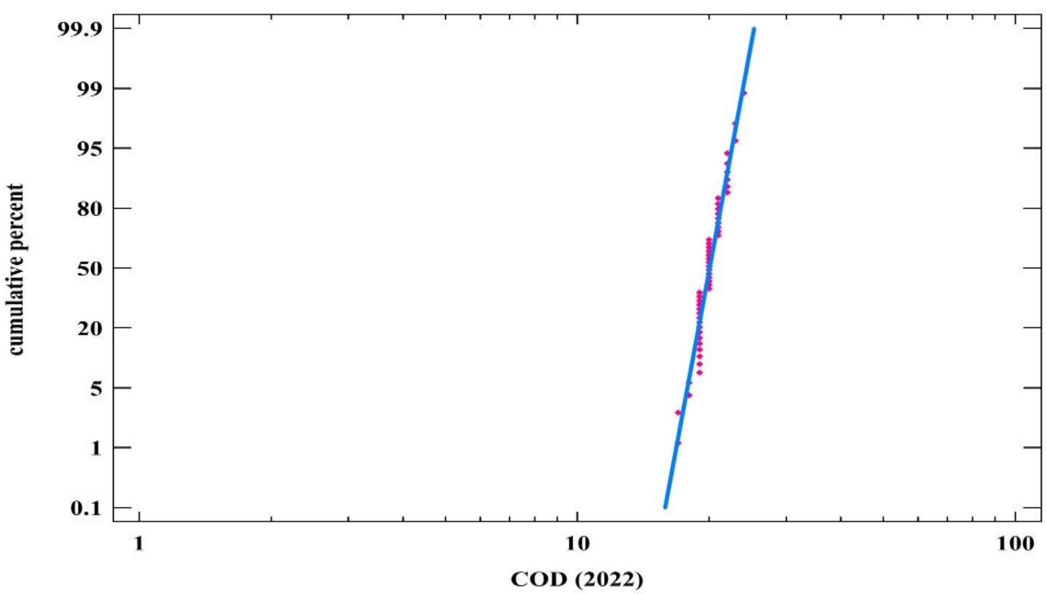


Figure 4-10. Lognormal probability plots with 95 % significance level of Karbala WWTP (2021).


99.9
99
95
80
50
20
5
1
0.1
cumulative percent
1
10
100
BOD5 (2022)


99.9
99
95
80
50
20
5
1
0.1
cumulative percent
1
10
100
COD (2022)

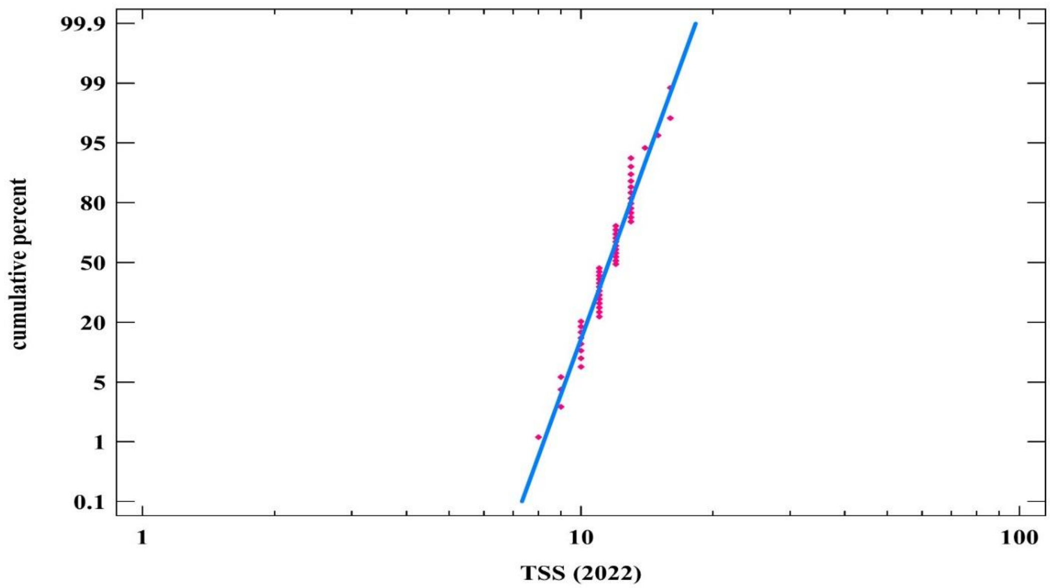
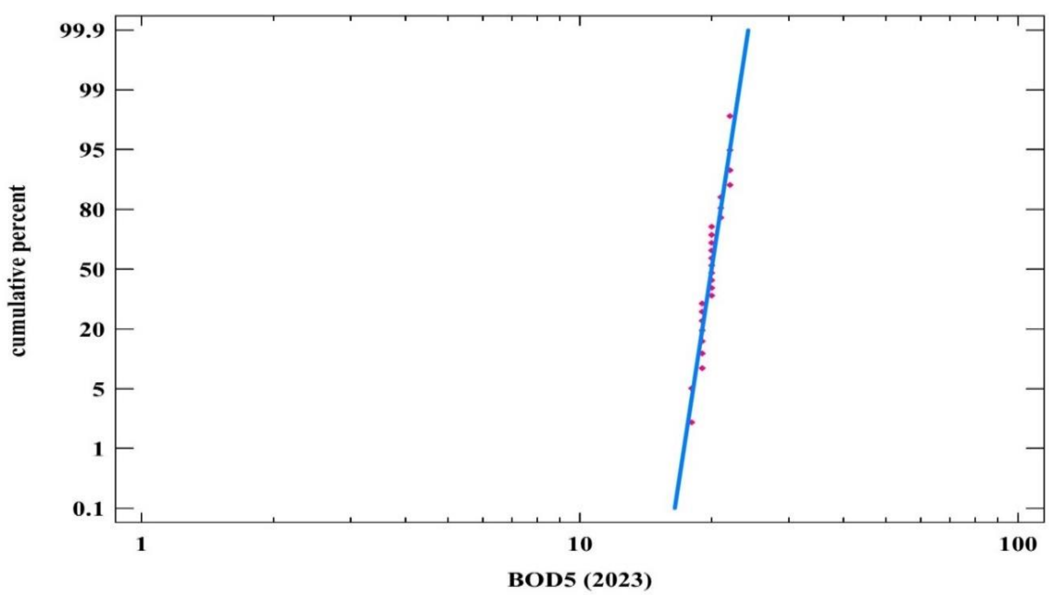


Figure 4-11. Lognormal probability plots with 95 % significance level of Karbala WWTP (2022).



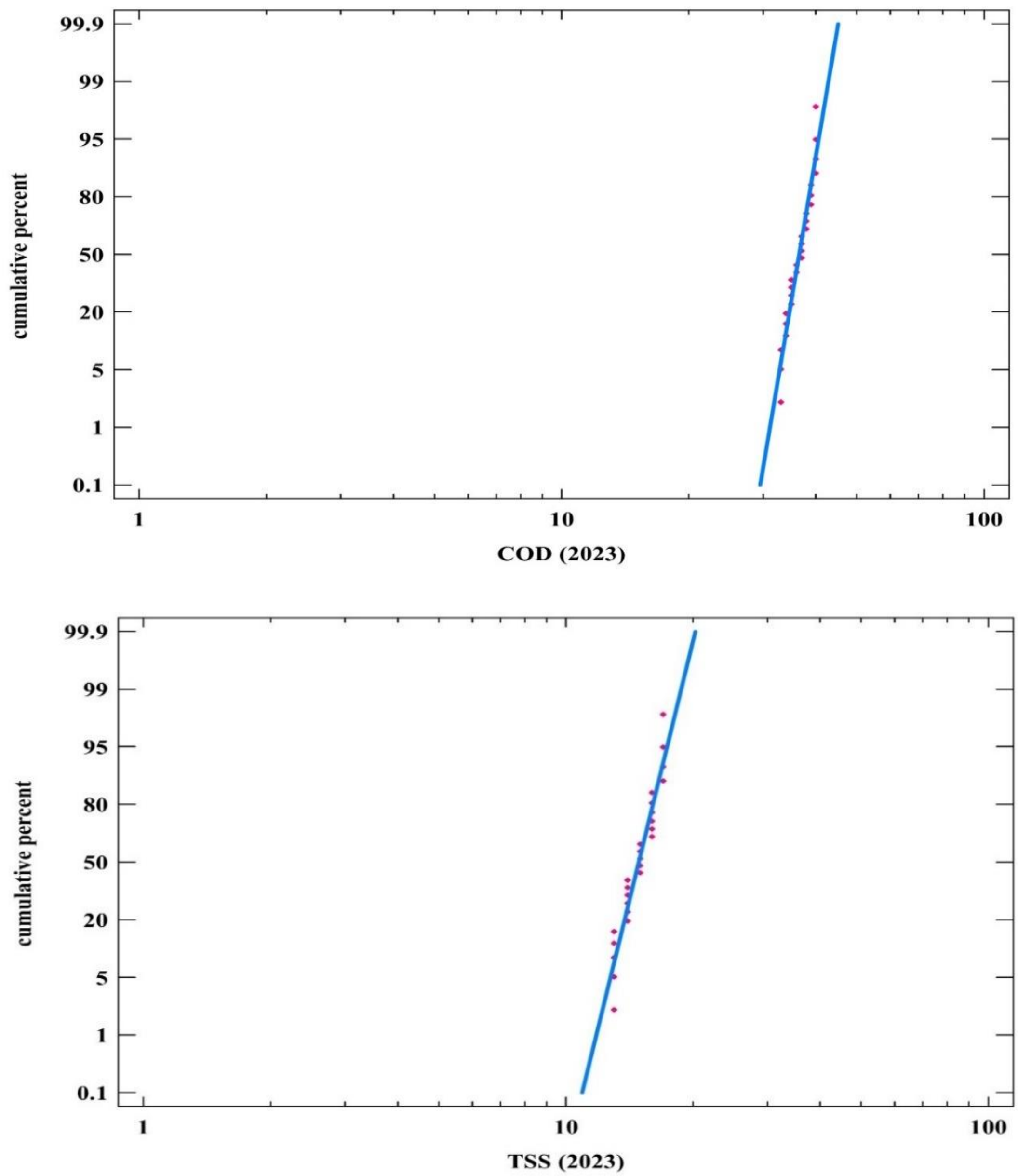


Figure 4-12. Lognormal probability plots with 95 % significance level of Karbala WWTP (2023).

Figure (4.12) reveals that data have histogram bars that are closely follow the lognormal distribution line well. In addition to that by visualizing. Figures (4.9), (4.10), and (4.11) of the lognormal probability plots to assess how closely the data points are following the fitted lognormal distribution line, it seems like the data points are following the line well. Accordingly, for WWTP, the lognormal distribution best describes the behavior of the chosen effluent parameters (BOD_5, COD, and TSS). The results obtained are in line with the observations that suggested using the lognormal distributions for effluent characteristics, which are the most widely applicable, to evaluate the water quality was beneficial. (Górka, 2015). The lognormal distribution of the model applied to the data meant that the data could be used for a reliability assessment.

4.2.5 Application of Coefficient of Reliability (COR)

The selected effluent quality parameters (BOD_5, COD, and TSS) for the WWTP were measured during a four-year period. The data were tabulated, and the monthly average and standard deviation were found and examined to get the monthly coefficient of variation (Cv) values for the years (2020-2023). Then, monthly corresponding values of coefficient of reliability (COR) were processed according to Eq. 3.6, for a confidence level equal to 90%, 95%, and 99% (α= 10%, 5%, and 1% significance levels). Setting values of significance level and corresponding (subsequently 1-α values) leads to the corresponding cumulative probability of the standard normal distribution (Z-distribution). Probability values were determined by NORMSDIST function in Excel, but were easily found in statistical textbooks where, Microsoft office Excel 2016 was used to perform the whole analysis. Setting Cv values yields COR values for a given confidence level (1-α). Results for Cv and COR are shown in Table (4-6), note that all calculations were based on the original data properties and not on the logarithms of the data.

Table 4-6.Average concentration COR,C_V Cv value for BOD_5, COD and TSS concentrations for 99%, 95% and 90% confidence levels for the year (2020-2023).

		Z (1- α)	**Cv**				**COR**			
			First year	Second year	Third year	fourth year	First year	Second year	Third year	Fourth year
BOD_5 (mg/l)	α = 0.01	2.3263	0.2217	0.2057	0.1374	0.05	0.6153	0.6358	0.7344	0.88
	α = 0.05	1.6449					0.7144	0.7304	0.8061	0.91
	α = 0.10	1.2816					0.7736	0.7865	0.8471	0.93
COD (mg/l)	α = 0.01	2.3263	0.1567	0.1330	0.0726	0.06	0.7046	0.7414	0.8470	0.90
	α = 0.05	1.6449					0.7834	0.8114	0.8899	0.93
	α = 0.10	1.2816					0.8291	0.8514	0.9137	0.95
TSS (mg/l)	α = 0.01	2.3263	0.1878	0.178121	0.1417	0.09	0.6598	0.6734	0.7276	0.86
	α = 0.05	1.6449					0.7491	0.7596	0.8010	0.91
	α = 0.10	1.2816					0.8015	0.8099	0.8431	0.95

Table (4-6) illustrates that as Cv values get increase as COR values decrease. Such result is consistent with a related study who set randomly values for Cv to yield COR values for a given confidence level (1-α) and found that as a given value of the Cv for same confidence level got increase as COR value got decrease and for the same given Cv, COR was getting decrease as the confidence level was increase as shown in Figure (4-13)

Table 4-7.The Coefficient of reliability (COR) for the different values of coefficients of variation (Cv) and high-reliability levels (Oliviera and Sperling, 2008).

Reliability Level	C_v										
	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
90%	1.00	0.79	0.66	0.57	0.52	0.49	0.47	0.45	0.45	0.44	0.44
95%	1.00	0.74	0.57	0.47	0.40	0.36	0.33	0.31	0.30	0.29	0.28
99%	1.00	0.64	0.44	0.32	0.25	0.20	0.17	0.15	0.14	0.13	0.12

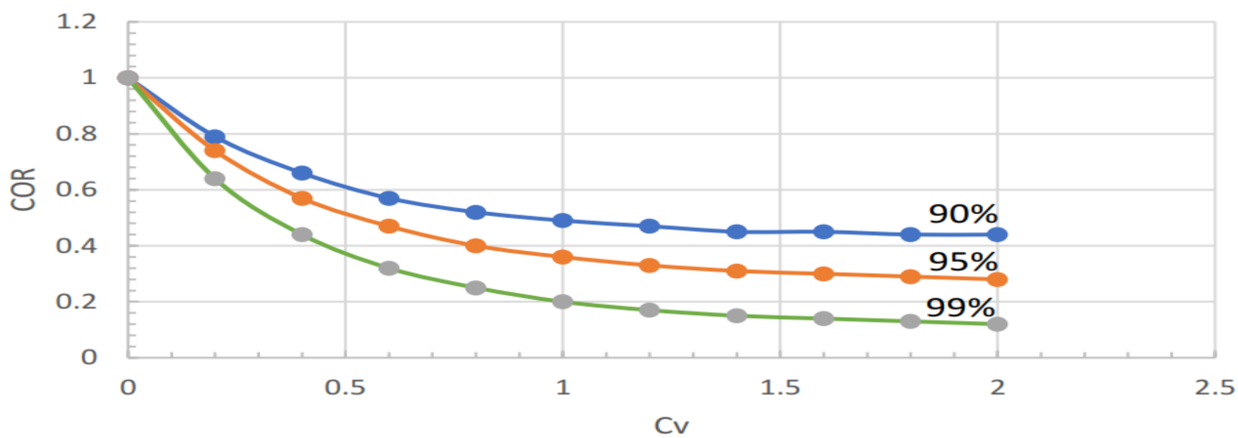


Figure 4-13. COR as a function of Cv and confidence level (Olivera, 2008).

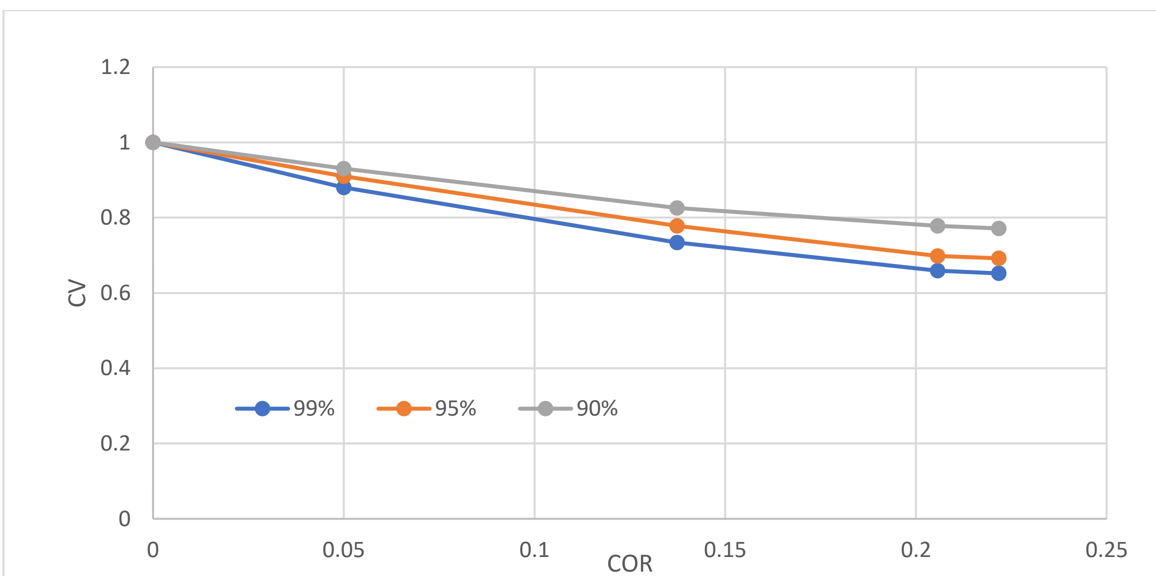


Figure 4-14.The variation of COR with Cv for 95% reliability level for the concentrations of BOD5 for the period (2020-2023).

The Cv and COR values were calculated for the concentrations of BOD_5, COD, and TSS in the effluent wastewater of Karbala WWTP for 90%, 95%, and 99% confidence intervals for the period from 2020 to 2023. Figure 4-14 shows an inverse relation between COR and Cv of BOD_5 concentrations for a 95% confidence interval for the above-mentioned period, and the same inverse relation between COR and Cv is found for COD and TSS concentrations in the effluent wastewater for 90% and 99% confidence intervals for the same time period. Accordingly, the present study is consistent with the study by Olivera, (2008) as mentioned above.

4.2.6 Application of Setting Operational Guidelines

The theoretical expressions mentioned in equation 3-5 leads to get average concentration value (mx) for selected parameters used for tracking the treated effluent quality. Equation (3-5) combines the average of parameters concentrations in the effluent with the standard values in the effluent and the probability of their occurrence. The values of the variable Cs were derived from the Iraqi standards for the year 1967, No. 25, which adopted at Karbala WWTP where: Cs of (BOD_5) = 40 mg/L; Cs of (TSS) = 60 mg/L; Cs of (COD) = 100 mg/L. Results of the numerical applications are presented in Table (4.8).

The operational guidelines are defined using a manner that produces more stringent limits than the current rule. Put another way, focusing on reliability should result in the design and operation of the plant such that the selected parameter's average concentration is set below the regulatory limits.The gap between the set value and the limit in force depends on the actual variation of the concentration (modelled and quantified by the coefficient of variation) and by the confidence level selected for processing.

As mentioned, a higher value of the Cv yields a lower COR and subsequently a lower average concentration of the effluent (mx) for the same level of reliability (95%). Accordingly, low COR values represent the need for lower treated effluent concentrations and thus the need to improve operational methods or maintenance of the WWTPs. Nevertheless, many of the effluent values were well consistent and within the target parameter limits resulted in some higher values of COR.

Table 4-8. Average coefficients and operational guidelines values of Karbala WWTP (2020-2023).

		2020	2021	2022	2023
BOD_5 (mg/l)	C_V	0.22	0.20	0.13	0.05
	COR	0.71	0.73	0.80	0.91
	m_x=COR×C_s	28.4	29.2	32.0	36.4
COD (mg/l)	C_V	0.15	0.13	0.07	0.06
	COR	0.78	0.81	0.88	0.90
	m_x=COR×C_s	78.0	81.0	88.0	90.0
TSS (mg/l)	C_V	0.18	0.17	0.14	0.09
	COR	0.74	0.75	0.80	0.86
	m_x=COR×C_s	44.4	45.0	48.0	51.6

4.2.7 Reliability Level Determination of Karbala WWTP

The collected data of the WWTP provides the ability for determining the probability of failure P (Ce > Cs=mx) after making a comprehensive analysis of data to collect all required statistics. Then, the reliability level was processed using equation (3-5). Results for the reliability level of BOD_5, COD and TSS by considering 95% confidence thresholds, for four years are shown in Table (4-9).

Table 4-9.The reliability level of BOD_5, COD and TSS.

	Reliability			
	2020	2021	2022	2023
BOD	0.9998211	0.99995051	0.9999845	0.99999814
COD	0.9999998	0.99996215	0.9999496	0.99994767
TSS	0.9999815	0.99997723	0.8307278	0.99999823

The obtained results show the high reliability of the WWTP. Considering that most of the BOD_5, COD, and TSS concentrations of the effluent are lower than the m_x values, therefore, high reliability values were expected. Thus, by the knowledge of the effluent concentration's behavior, it was possible to use a probabilistic model for determining thresholds for effluent BOD5, COD and TSS concentrations below which the effluent quality must be kept up to date to fulfill a specific requirement at the WWTP's intended level of reliability,where, such reliability is expressed as the probability of success or adequate performance as a function of mean values and effluent variability. The application of statistical concepts to the setting of wastewater discharges standards have been the subject of several articles (**Messaoud et al., 2013; Górka, 2015; Alderson et al., 2015**). The contribution of the study lies in the generation of reliable information that can be used by operators of WWTP to evaluate plant reliability level, and comprehend how biological treatment works, taking into account the effluent's quality to establish discharge limits that are practical, efficient, and technically feasible.

4.2.8 Removal Performance of Karbala WWTP

i. Biochemical Oxygen Demand BOD_5

Biochemical oxygen demand (BOD_5) was evaluated. From the first week of operation, high BOD_5removal efficiency was achieved. Despite the variation in $BOD_5$of raw wastewater, which may be due to the influence of rainy days and some contributions from industrial and commercial areas. The treatment efficiency was at the same level, reaching 91.2%, as shown in Figure (4.15). An average effluent BOD_5concentration of 14.5 mg/L was always reached, which corresponds to the initial average BOD_5 of 170 mg/L, and the BOD_5 was well below the standard discharge concentration according to Iraqi environmental standards of (40 mg/L).

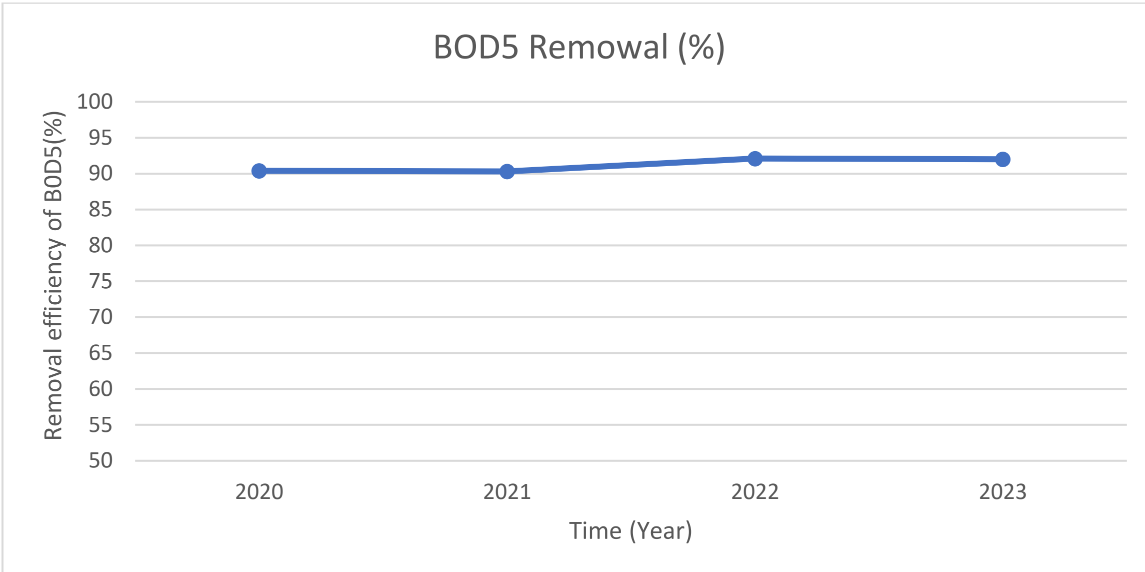


Figure 4-15. Removal efficiency of BOD_5 for years (2020-2023).

ii. Chemical Oxygen Demand (COD):

The amount of oxygen required to analyze or oxidize organic carbon. from the first week of operation, high COD removal efficiencies were achieved. In spite of COD variation of raw wastewater which might be resulted from the influence of rainy days, some contributions of industrial and commercial zones, treatment efficiency was on the same level reach up to 93% as shown in Figure (4-16). Effluent COD was always reached an average concentration of 27.0 mg/L, in correspondence to an average initial COD of 385 mg/L, effluent COD which was significantly lower than the standard discharge concentration according to environmental Iraqi standards (100 mg/L).

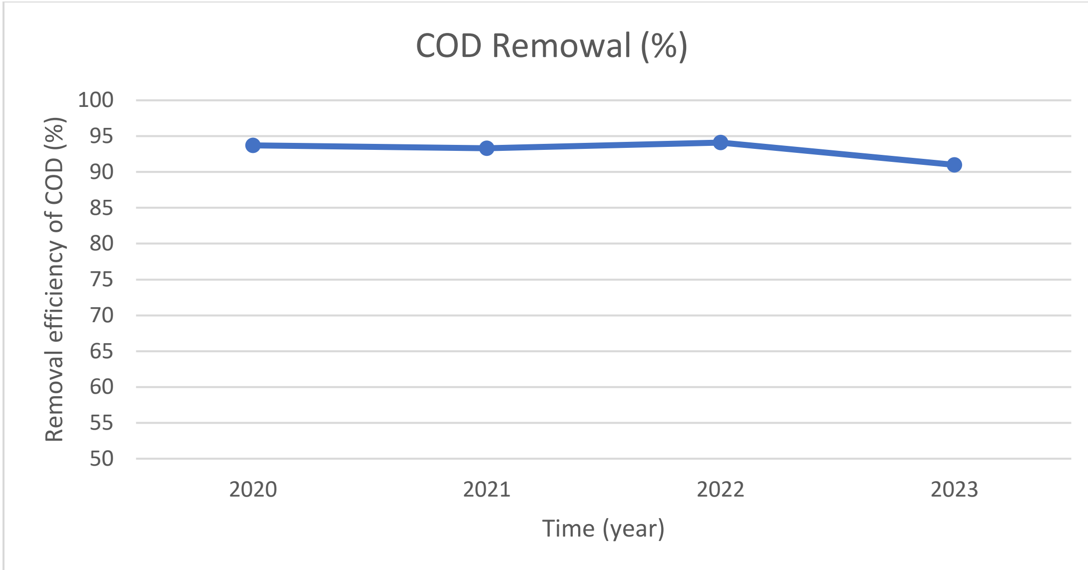


Figure 4-16.Removal efficiency of COD for years (2020-2023).

This result due to the fact that in this system at the feeding times with wastewater, the optimum growth conditions and the richness of substrate as well, microorganisms develop rapidly and use nutrients.

iii. Total Suspended Solids (TSS)

The total suspended solids (TSS) are one of the most important physical characteristics of wastewater that contained a variety of suspended and colloidal material **(Kutty et al., 2011)**. In addition to turbidity that often indicates the presence of dispersed and suspended solids like clay, organic matter, algae and other microorganisms. Also, soaps, detergents and emulsifying agents produce stable colloids that result in turbidity **(Nagwekar, 2014).** In spite of these facts, high TSS removal percentages were up to 92.7% as shown in Figure (4.17). these results indicated that the reactor had a suitable microorganisms' growth condition, a good ability to form flocs, good settling condition and for sure sufficient time for settling leading to low effluent TSS and turbidity concentrations. Average effluent concentration of 15 mg/L TSS in correspondence to an average initial of 170 mg/L of TSS

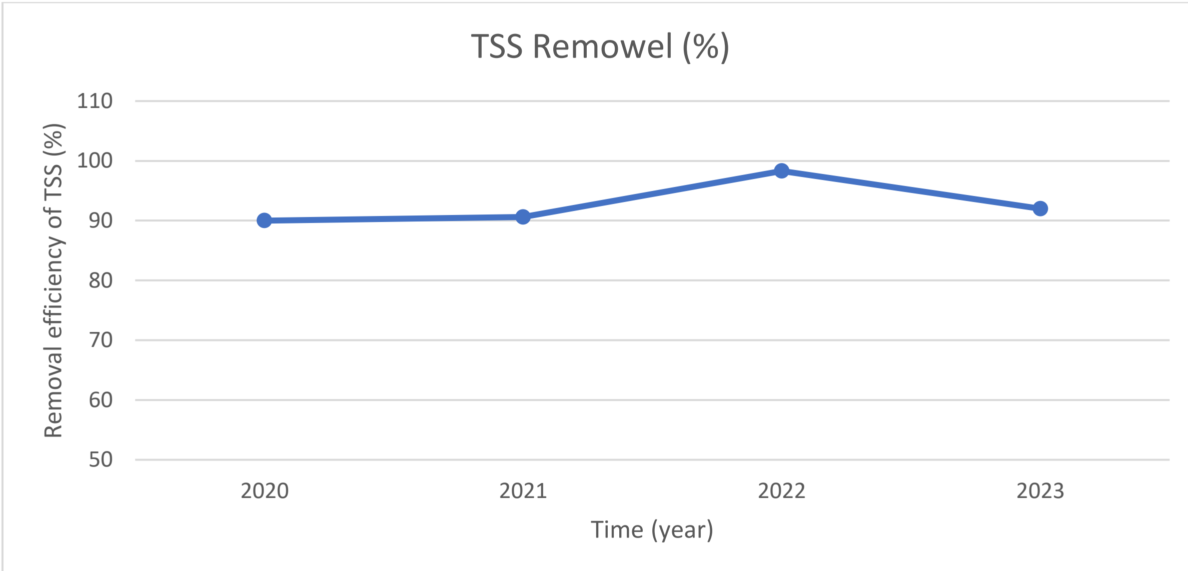


Figure 4-17. Removal efficiency of TSS for years (2020-2023).

Chapter Five: Conclusions and Recommendations

This chapter includes the most important results obtained from the present study, which was devoted to evaluating the wastewater treatment plant in the city of Karbala, with the necessary recommendations to improve the performance of the plant based on the results of the study.

5.1 Conclusions

The main conclusions can be summerized as follows:

1. For the studied period, the Karbala wastewater treatment plant provided acceptable reliability rates.
2. All contamination parameter (BOD_5,COD, and TSS) of the Karbala WWTP outlet follow the lognormal probability distribution.
3. In general, for the studied period (2020-2023), the effectiveness of the Karbala WWTP in treating major pollutions was good and reflect the gradual improvement in effluent quality.
4. The fluctuations of reliability rates of the Karbala WWTP were large. This is important because the plant is modern, and with time progress, the reliability becomes better. It was also affected by quantitative and qualitative fluctuations, especially for wastewater
5. Statistical analysis of the collected data shows that the values of the parameters of pollution differs significantly for wastewater at the entrance (Influent) to the plant extends between 350-420 mg/l for COD, 115-175 mg/l for BOD5, 120-220 mg/l for TSS. At the effluent the average concentrations of the pollution parameters range between 11-18 mg/l for COD, 22-32 mg/l for BOD5, 9-20 mg/l for TSS.

5.2 Recommendations for the Operating staff of wastewater treatment Karbala WWTP

1. The reliability model is suggested for use in future studies because the accuracy of the method was acceptable and the result was the true concentration of plant parameters.
2. It is necessary to carry out tests on a daily basis of effluent quality parameters to control the plant performance.
3. It is important to operate all units when the influent wastewater is increased as well as ensuring their good operation

5.3 Recommendations for future studies

1. It is suggested to use the neural networks for future studies because the research has shown that neural networks are a reliable option to consider Prediction of wastewater treatment plant performance.

2. Future research is required to evaluate the cost of the plant's ideal operation which suggested that energy and chemical use may be decreased.

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الخلاصة

تعد موثوقية وفعالية محطة معالجة مياه الصرف الصحي عوامل مهمه يجب أخذها في الاعتبار، خاصة إذا تم استرداد مياه الصرف الصحي المعالجة واستخدامها مرة أخرى في المستقبل. ومن الضروري ضمان حماية البيئة وسلامة الصحة العامة. هناك عدة عوامل تؤثر على أداء عملية المعالجة، مثل التغييرات النوعية والكمية في مياه الصرف الصحي. وهناك معايير لنوعية المياه المعالجة والتخلص منها تحددها المواصفات العراقية، ولذلك ينبغي أن يكون من الممكن تقييم أداء العمليات وموثوقية المرافق لضمان الامتثال. بناءً على تحليل الموثوقية، تم تقييم أداء محطة معالجة مياه الصرف الصحي في محافظة كربلاء. ومن بين البيانات التي تم فحصها وتقييمها إحصائيا معدلات تدفق المياه المستعملة وعدد قليل من المؤشرات الهامة لنوعية المياه، مثل إجمالي المواد الصلبة المعلقة، والطلب على الأكسجين الكيميائي، والطلب على الأكسجين الكيميائي الحيوي لمدة خمسة أيام (BOD_5). وباستخدام وظيفة اللوغاريتم العادي، تم تطوير نموذج موثوقية احتمالية ووجد أنه مناسب لأداء المحطة من الناحية الكمية. ومن السمات الهامة لهذا النموذج أن بارامترات النموذج تستند إلى خصائص البيانات الأصلية. إن تطوير نموذج الموثوقية هذا هو المساهمة الأولى لهذه الدراسة ؛ نموذج يمكن أن يوفر أداءً كميًا لمحطة معالجة مياه الصرف الصحي المدروسة، ويمكن استخدامه أيضًا لتقدير القيم المتوسطة لنوعية النفايات السائلة. ومن السمات الهامة لهذا النموذج أن المتغيرات النموذج تستند إلى خصائص البيانات الأصلية. إن تطوير نموذج الموثوقية هذا هو المساهمة الأولى لهذه الدراسة ؛ نموذج يمكن أن يوفر أداءً كميًا لمحطة معالجة مياه الصرف الصحي المدروسة، ويمكن استخدامه أيضًا لتقدير القيم المتوسطة لنوعية النفايات السائلة. تمت دراسة جودة تدفق مياه الصرف الصحي الخام ومياه الصرف الصحي المعالجة للسنوات (٢٠٢٠-٢٠٢٣) من أجل تقييم محطة معالجة مياه الصرف الصحي. يتم تقييم كفاءة أداء محطة معالجة مياه الصرف الصحي في كربلاء باستخدام الطلب البيولوجي على الأكسجين (BOD5)، والطلب على الأكسجين الكيميائي (COD)، وإجمالي المواد الصلبة المعلقة (TSS). وتحدد كفاءة إزالة كل معامل من مياه الصرف الصحي والصرف الصحي، ثم تقارنت النتائج بالمواصفات العراقية. تم استخدام نموذج الموثوقية لإنشاء نموذج النبات. أظهرت نتائج النموذج أن الدقة الكافية للنموذج المولد جعلته مناسبًا للاستخدام في الأبحاث اللاحقة. تظهر النتيجة الاحتمالية مستويات جيدة جدًا من الكفاءة. تشير معدلات الموثوقية المقدرة للمعايير الثلاثة، COD، و TSS إلى كفاءات إزالة جيدة تبلغ ٧٩٪ و ٨٤٪ و ٧٨,٨٪ على التوالي. في السنوات ٢٠٢٠ ٢٠٢١، كان المصنع غير مستقر لأنه كان في بداية تشغيله، مما يجعل قيم الموثوقية التي تشير إلى كفاءة الإزالة أعلاه.

ويبين التحليل الإحصائي للبيانات المجمعة أن قيم المتغيرات التلوث تختلف اختلافا كبيرا بالنسبة لمياه الصرف الصحي عند مدخل النبات (ال وتمتد بين ٣٥٠-٤٢٠ ملغم/لتر بالنسبة لمادة كود، و ١١٥-١٧٥ ملغم/لتر بالنسبة لمادة ١٢٠-٢٢٠ ملغم/لتر بالنسبة لمادة TSS. ويتراوح متوسط تركيزات بارامترات التلوث في النفايات السائلة بين ١١ و١٨ ملغم/لتر بالنسبة لكود، و٢٢-٣٢ ملغم/لتر بالنسبة لـ٩-٢٠ ملغم/لتر بالنسبة لـTSS. تم تطبيق طريقة حساب معامل موثوقية تركيزات النفايات السائلة COD و TSS (COR). أظهرت النتيجة أن قيم COR للنفايات السائلة و COD و TSS كانت قريبة من ١ لجميع السنوات، وهذا يشير إلى كفاءة إزالة جيدة للملوثات في محطة معالجة مياه الصرف الصحي في كربلاء.

جمهورية العراق
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قسم الهندسة المدنية

تقييم أداء محطة معالجة مياه الصرف الصحي في كربلاء باستخدام نموذج الموثوقية

رسالة مقدمة الى مجلس كلية الهندسة / جامعة كربلاء وهي جزء من متطلبات نيل درجة الماجستير في علوم الهندسة المدنية

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