DEPENDABILITY STUDY OF AL-KERKH WASTEWATER TREATMENT PLANT

A Thesis

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By

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دراسة اعتمادية محطة الكرخ لمعالجـــة الميـاه الثقيلـة

رسالة

مقدمة إلى كلية الهندسة في جامعـــة بابـــل

كجزء من متطلبات نيل درجة الماجستير

في علوم الهندسة المدنيـــة

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إِنَّا كُلَّ شَيْءٍ خَلَقْنَاهُ بِقَدَرٍ

صدق الله العظيم

سورة القمر ، الاية ٤٩

الخلاصة

هذه الدراسة تتحرى اعتمادية محطة الكرخ لمعالجة المياه الثقيلة باستخدام النماذج الاحصائية المقدمة من قبل (Niku et al. ١٩٧٩) و (Niku et al. ١٩٨١) لتقييم معولية واستقرارية (اعتمادية) محطات معالجة المياه الثقيلة، ولتحقيق ذلك تم جمع المعلومات الخاصة بنوعية المياه الخارجة من محطة الكرخ لمعالجة المياه الثقيلة ، حيث شملت هذه المعلومات نتائج (٥٩٩٦) فحص مختبري اجري لمتغيرين هما طلب الاوكسجين البايوكيميائي (BOD_5) وتركيز المواد الصلبة العالقة (S.S) . وقد غطت هذه المعلومات فترة التشغيل للمشروع من سنة ١٩٨٩ ولغاية ١٩٩٧، باستثناء سنة ١٩٩١ حيث لم تتوفر أي معلومات بسبب تأثيرات الحرب وتوقف المشروع في تلك الفترة.

تم استخدام البرنامج الاحصائي الجاهز (STATISTICA) لغرض اجراء التحليلات الاحصائية المطلوبة للمعلومات المأخوذة للمتغيرين المذكورين اعلاه.

بعد اعتبار ان المعلومات المجموعة لكل متغير خلال فترة سنة تمثل عينة واجراء الفحص الاحصائي لها تبين ان قيمة معامل الانحراف (Coefficient of Skewness) موجبة ، أي ان العينة لا تتوزع بصورة متناظرة حول قيمة المعدل وانما تميل الى الانحراف الى يمين القيم الاكثر تكرار. تم استخدام اختبار (Chi-square) واختبار كولموكوروف – سيمرنوف (Kolmogorov – Smirnov) لغرض تحديد أي نوع من التوزيعات يكون أكثر ملائمة للعينة وشمل الاختبار كل من التوزيع الطبيعي (Normal Distribution) ، التوزيع اللوغاريتمي الطبيعي (Log-normal distribution) ، وتوزيع كاما (Gama distribution) وقد وجد ان التوزيع اللوغاريتمي الطبيعي هو الاكثر ملائمة لغرض وصف ودراسة العينات المأخوذة لكل من المتغيرين المذكورين اعلاه.

لغرض دراسة امكانية استخدام النموذج الاحصائي المقدم من قبل (Niku et al., ١٩٧٩) لايجاد معولية محطات معالجة المياه الثقيلة ، تم حساب النسبة المئوية للوقت التي كان فيها تركيز المتغير الخاص بالطلب البايوكيميائي للاوكسجين (BOD_5) اقل من ٤٠ (mg/l) ، وتركيز المواد الصلبة العالقة اقل من (mg/l) ٦٠ لكل عينة ، كذلك تم تخمين هذه النسبة بالاعتماد على النموذج الاحصائي المقترح على اساس ان العينة تخضع للتوزيع اللوغارتيمي وكانت النتائج متقاربة جدا.

كذلك لدراسة امكانية استخدام النموذج الاحصائي المقدم من قبل (Niku et al., ١٩٨١) لتقييم استقرارية محطات معالجة المياه الثقيلة، تم حساب الخصائص الاحصائية (Range, Mean, and Standard deviation) للمعلومات المأخوذة لكل متغير وتمثيل هذه الخصائص بأشكال بيانية ، وبفحص هذه الاشكال البيانية يمكن ملاحظة اختلاف واضح بين الخصائص الاحصائية للمعلومات المأخوذة لكلا المتغيرين حول قيمة معينة للانحراف المعياري ، تسمى قيمة الانحراف المعياري التي يظهر حولها الاختلاف بنقطة الاستقرارية. ان ظهور هذا الاختلاف في الخصائص الاحصائية للمعلومات المأخوذة حول نقطة الاستقرارية يؤيد صحة استخدام هذه النموذج لتقييم استقرارية محطة الكرخ لمعالجة المياه الثقيلة ، علما ان نقطة الاستقرارية التي وجدت في هذه الدراسة هي نفس القيمة التي حصل عليها (Niku et al. ١٩٨١) من تطبيق النموذج في الولايات المتحدة الامريكية.

تم تقييم اعتمادية مشروع الكرخ لمعالجة المياه الثقيلة للفترات قبل وبعد حرب عام ١٩٩١ ، وقد كان اداء المشروع في حالة تنازل ، فالعينات المأخوذة للمتغيرين (BOD_5) و (S.S) والتي عددها ١٦ عينة لكل متغير كانت هناك اربعة منها فقط ذات معالجة مستقرة وضمن حدود المواصفة العراقية التي تحدد الطلب البايوكيميائي للاوكسجين (BOD_5) بـ (mg/l) ٤٠ كحد أعلى ، والتركيز الاعلى للمواد الصلبة العالقة (S.S) بـ (mg/l) ٦٠ لـ ٩٥% من الوقت.

ان نتائج دراسة اعتمادية محطة الكرخ لمعالجة المياه الثقيلة تبين الحاجة الملحة لاعادة تأهيل وحدات هذه المحطة و تأهيل العاملين فيها لرفع مستوى ادائها.

APPENDIX A – ١

Table (A-١): The normal distribution
(Normal Table)

Z	F(z)	Z	F(z)	Z	F(z)
-٣.٠٠	٠.٠٠١٣٤٩ ٩٠	-٠.٩٠	٠.١٨٤٠٦٠ ١٣	١.٢٠	٠.٨٨٨٤٩٣ ٠٣٣
-٠.٢٩	٠.٠٠١٨٦٥ ٨١	-٠.٨٠	٠.٢١١٨٥٥ ٤٠	١.٣٠	٠.٩٠٣١٩٩ ٥٢
-٢.٨٠	٠.٠٠٢٥٥٥ ١٣	-٠.٧٠	٠.٢٤١٩٦٣ ٦٥	١.٤٠	٠.٩١٩٢٤٣ ٣٤
-٢.٧٠	٠.٠٠٣٤٦٦ ٩٧	-٠.٦٠	٠.٢٧٤٢٥٣ ١٢	١.٥٠	٠.٩٣٣١٩٢ ٨٠
-٢.٦٠	٠.٠٠٤٦٦١ ١٩	-٠.٥٠	٠.٣٠٨٥٣٧ ٥٤	١.٦٠	٠.٩٤٥٢٠٠ ٧١
-٢.٥٠	٠.٠٠٦٢٠٩ ٦٧	-٠.٤٠	٠.٣٤٤٥٧٨ ٢٦	١.٧٠	٠.٩٥٥٤٣٤ ٥٤
-٢.٤٠	٠.٠٠٨١٩٧ ٥٤	-٠.٣٠	٠.٣٨٢٠٨٨ ٥٨	١.٨٠	٠.٩٦٤٠٦٩ ٦٨
-٢.٣٠	٠.٠١٠٧٢٤ ١١	-٠.٢٠	٠.٤٢٠٧٤٠ ٢٩	١.٩٠	٠.٩٧١٢٨٣ ٤٤
-٢.٢٠	٠.٠١٣٩٠٣ ٤٥	-٠.١٠	٠.٤٦٠١٧٢ ١٦	٢.٠٠	٠.٩٧٧٢٤٩ ٨٧
-٢.١٠	٠.٠١٧٨٦٤ ٤٢	٠.٠٠	٠.٥٠٠٠٠٠ ٠٠	٢.١٠	٠.٩٨٢١٣٥ ٥٨
-٢.٠٠	٠.٠٢٢٧٥٠ ١٣	٠.١٠	٠.٥٣٩٨٢٧ ٨٤	٢.٢٠	٠.٩٨٦٠٩٦ ٥٥
-١.٩٠	٠.٠٢٨٧١٦ ٥٦	٠.٢٠	٠.٥٧٩٢٥٩ ٧١	٢.٣٠	٠.٩٨٩٢٧٥ ٨٩
-١.٨٠	٠.٠٣٥٩٣٠ ٣٢	٠.٣٠	٠.٦١٧٩١١ ٤٢	٢.٤٠	٠.٩٩١٨٠٢ ٤٦
-١.٧٠	٠.٠٤٤٥٦٥ ٤٦	٠.٤٠	٠.٦٥٥٤٢١ ٧٤	٢.٥٠	٠.٩٩٣٧٩٠ ٣٣
-١.٦٠	٠.٠٥٤٧٩٩ ٢٩	٠.٥٠	٠.٦٩١٤٦٢ ٤٦	٢.٦٠	٠.٩٩٥٣٣٨ ٨١
-١.٥٠	٠.٠٦٦٨٠٧ ٢٠	٠.٦٠	٠.٧٢٥٧٤٦ ٨٨	٢.٧٠	٠.٩٩٦٥٣٣ ٠٣
-١.٤٠	٠.٠٨٠٧٥٦ ٦٦	٠.٧٠	٠.٧٥٨٠٣٦ ٣٥	٢.٨٠	٠.٩٩٧٤٤٤ ٨٧
-١.٣٠	٠.٠٩٦٨٠٠ ٤٨	٠.٨٠	٠.٧٨٨١٤٤ ٦٠	٢.٩٠	٠.٩٩٨١٣٤ ١٩
-١.٢٠	٠.١١٥٠٦٩	٠.٩٠	٠.٨٢٥٩٣٩	٣.٠٠	٠.٩٩٨٦٥٠

	٦٧		٨٧		١٠
-١.١٠	٠.١٣٥٦٦٦ ٠٦	١.٠٠	٠.٨٤١٣٤٤ ٧٥		
-١.٠٠	٠.١٥٨٦٥٥ ٢٥	١.١٠	٠.٨٦٤٣٣٣ ٩٤		

After Little (١٩٨٣)

APPENDIX A – ٢

Table (A-٢): Critical statistics for the Kolmogorov-Smirnov test

Sample size	α=٠.١	α=٠.٠٥	α=٠.٠١
٥	٠.٥١	٠.٥٦	٠.٦٧
١٠	٠.٣٧	٠.٤١	٠.٤٩
١٥	٠.٣٠	٠.٣٤	٠.٤٠
٢٠	٠.٢٦	٠.٢٩	٠.٣٥
٢٥	٠.٢٤	٠.٢٦	٠.٣٢
٣٠	٠.٢٢	٠.٢٤	٠.٢٩
٤٠	٠.١٩	٠.٢١	٠.٢٥
Large n	١.٢٢/$\sqrt{n}$	١.٣٦/$\sqrt{n}$	١.٦٣/$\sqrt{n}$

After Mc Cuen (١٩٨٥)

APPENDIX A – ٣

Table (A-٣): Critical statistics for the Chi-square test

α	٠.٩٩٥	٠.٩٩	٠.٩٧٥	٠.٩٥	٠.٥٠	٠.٢٠	٠.١٠	٠.٠٥	٠.٠٢٥	٠.٠١	٠.٠٠٥
ν											
١	٠.٠٠٠	٠.٠٠٠٠٢	٠.٠٠١	٠.٠٠٣٩	٠.٤٥	١.٦٤	٢.٧١	٣.٤٨	٥.٠٢	٦.٦٣	٧.٨٨
٢	٠.٠١٠	٠.٠٢٠	٠.٠٥١	٠.١٥٣	١.٣٩	٣.٢٢	٤.٦١	٥.٩٩	٧.٣٨	٩.٢١	١٠.٦٠
٣	٠.٠٧٢	٠.١١٥	٠.٢١٦	٠.٣٥٢	٢.٣٧	٤.٦٤	٦.٢٥	٧.٨١	٩.٣٥	١١.٣٤	١٢.٨٤
٤	٠.٢٠٧	٠.٣٠	٠.٤٨٤	٠.٧١	٣.٣٦	٥.٩٩	٧.٧٨	٩.٤٩	١١.١٤	١٣.٢٨	١٤.٨٦
٥	٠.٤١٢	٠.٥٥	٠.٨٣١	١.١٥	٤.٣٥	٧.٢٩	٩.٢٤	١١.٧	١٢.٨٤	١٥.٩	١٦.٧٥
٦	٠.٦٧٦	٠.٨٧	١.٢٤	١.٦٤	٥.٣٥	٨.٥٦	١٠.٨٤	١٢.٥٩	١٤.٤٥	١٦.٨١	١٨.٥٥
٧	٠.٩٨٩	١.٢٤	١.٦٩	٢.١٧	٦.٣٥	٩.٨٠	١٢.٠٢	١٤.٠٧	١٦.٠١	١٨.٤٨	٢٠.٢٨
٨	١.٣٤	١.٦٥	٢.١٨	٢.٧٣	٧.٣٤	١١.٠٣	١٣.٣٦	١٥.٥١	١٧.٥٣	٢٠.٠٩	٢١.٩٥
٩	١.٧٣	٢.٠٩	٢.٧٠	٣.٣٣	٨.٣٤	١٢.٢٤	١٤.٦٨	١٦.٩٢	١٩.٠٢	٢١.٦٧	٢٣.٥٩
١٠	٢.١٦	٢.٥٦	٣.٢٥	٣.٩٤	٩.٣٤	١٣.٤٤	١٥.٩٩	١٨.٣١	٢٠.٤٨	٢٣.٢١	٢٥.١٩
١١	٢.٦٠	٣.٠٥	٣.٨٢	٤.٥٧	١٠.٣٤	١٤.٦٣	١٧.٢٨	١٩.٦٨	٢١.٩٢	٢٤.٧٢	٢٦.٧٦
١٢	٣.٠٧	٣.٥٧	٤.٤٠	٥.٢٣	١١.٣٤	١٥.٨١	١٨.٥٥	٢١.٠٣	٢٣.٣٤	٢٦.٢٢	٢٨.٣٠
١٣	٣.٥٧	٤.١١	٥.٠١	٥.٨٩	١٢.٣٤	١٦.٩٨	١٩.٨١	٢٢.٣٦	٢٤.٧٤	٢٧.٦٩	٢٩.٨٢
١٤	٤.٠٧	٤.٦٨	٥.٦٣	٦.٥٧	١٣.٣٤	١٨.١٥	٢١.٠٨	٢٣.٦٨	٢٦.١٢	٢٩.١٤	٣١.٣٢
١٥	٤.٦٠	٥.٢٣	٦.٢٦	٧.٢٦	١٤.٣٤	١٩.٣١	٢٢.٣١	٢٥.٠٠	٢٧.٤٩	٣٠.٥٨	٣٢.٨٠
١٦	٥.١٤	٥.٨١	٦.٩١	٧.٩٦	١٥.٣٤	٢٠.٤٧	٢٣.٥٤	٢٦.٣٠	٢٨.٨٥	٣٢.٠٠	٣٤.٢٧
١٧	٥.٧٠	٦.٤١	٧.٥٦	٨.٦٧	١٦.٣٤	٢١.٦١	٢٤.٧٧	٢٧.٥٩	٣٠.١٩	٣٣.٤١	٣٥.٧٢
١٨	٦.٢٦	٧.٠٢	٨.٢٣	٩.٣٩	١٧.٣٤	٢٢.٧٦	٢٥.٩٩	٢٨.٨٧	٣١.٥٣	٣٤.٨١	٣٧.١٦
١٩	٦.٨٤	٧.٨٣	٨.٩١	١٠.١٢	١٨.٣٤	٢٣.٩٠	٢٧.٢٠	٣٠.١٤	٣٢.٨٥	٣٦.١٩	٣٨.٥٨
٢٠	٧.٤٣	٨.٢٦	٩.٥٩	١٠.٨٥	١٩.٣٤	٢٥.٠٤	٢٨.٤١	٣١.٤١	٣٤.١٧	٣٧.٥٧	٤٠.٠٠
٢١	٨.٠٣	٨.٩٠	١٠.٢٨	١١.٥٩	٢٠.٣٤	٢٦.١٧	٢٩.٦٢	٣٢.٦٧	٣٥.٤٨	٣٨.٩٣	٤١.٤٠
٢٢	٨.٦٤	٩.٥٤	١٠.٩	١٢.٣	٢١.٣	٢٧.٣	٣٠.٨	٣٣.٩	٣٦.٧	٤٠.٢	٤٢.٨

			٨	٤	٤	٠	١	٢	٨	٩	٠
٢٣	٩.٢٦	١٠.٢٠	١١.٦٩	١٣.٠٩	٢٣.٣٤	٢٨.٤٣	٣٢.٠١	٣٥.١٧	٣٨.٠٨	٤١.٨٤	٤٤.١٨
٢٤	٩.٨٩	١٠.٨٦	١٢.٤٠	١٣.٨٥	٢٣.٣٤	٢٩.٠٥	٣٣.٢٠	٣٦.٤٢	٣٩.٣٦	٤٢.٩٨	٤٥.٥٨
٢٥	١٠.٥٢	١١.٥٢	١٣.١٢	١٤.٦١	٢٤.٣٤	٣٠.٨٨	٣٤.٣٨	٣٧.٨٥	٤٠.٦٥	٤٤.٣١	٤٦.٩٣
٢٦	١١.١٦	١٢.٢٠	١٣.٨٤	١٥.٣٨	٢٥.٣٤	٣١.٧٩	٣٥.٠٨	٣٨.٨٩	٤١.٩٢	٤٥.٦٤	٤٨.٢٩
٢٧	١١.٨١	١٢.٨٨	١٤.٥٧	١٦.١٥	٢٦.٣٤	٣٢.٩١	٣٦.٧٤	٤٠.١١	٤٣.١٩	٤٦.٩٦	٤٩.٦٤
٢٨	١٢.٤٦	١٣.٥٧	١٥.٣١	١٦.٩٣	٢٧.٣٤	٣٤.٠٣	٣٧.٩٢	٤١.٣٤	٤٤.٤٦	٤٨.٢٨	٥٠.٩٩
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After Lawrence(١٩٦٣)

إلى

أئمة الهدى وأعلام التقى

آل بيت النبي (ص)

إلى

الشمعتين اللتين احترقتا لتضيئا طريق حياتي

أمي وأبي

إلى

ذخري في الحياة

أخوتي وأخواتي

وإلى

كل من يحبون لي الخير.

إليهم جميعا ، أهدي ثمرة ما وفقني الله اليه

خالد

ABSTRACT

This study investigates the dependability of AL-Kerkh wastewater treatment plant through the application of reliability and stability models which developed by (Niku et al., ١٩٧٩) and (Niku et al., ١٩٨١) ,respectively. Data of effluent biochemical oxygen demand (BOD_5) and suspended solids (S.S) concentrations (٥٩٩٦ readings) were taken from the records of AL-Kerkh wastewater treatment plant. This data covered eight years of operation started in January, ١٩٨٩ and ended in November, ١٩٩٧.The data of year ١٩٩١ was missed because of the war of ١٩٩١. Each set of data represents an operation period of one year.

STATISTICA program has been used to perform the required statistical analysis for the data.

It was found that data were generally not symmetrical and were skewed to the right of most frequent values, as measured by the skewness coefficient .The candidate distribution functions that can be fitted to the skewed data include Normal, Log-normal, and Gama distributions .These distributions were tested by Chi-square and Kolmogorov-Smirnov tests(quantitative goodness-of-fit tests) to examine whether the data of effluent concentrations follow any one of the above mentioned distributions. Effluent BOD_5 and S.S data were found to fit a Log-normal distribution.

To support the validity of the reliability model in predicting the effluent quality, the percents of the time that effluent concentrations exceeded ٤٠ (mg/l) for BOD_5 and ٦٠ (mg/l) for S.S were computed. These percents of exceedance were also predicted by using the reliability

model based on log-normal assumption . In most cases the results were comparable with a little difference.

The validity of stability model had been also investigated by determining the statistical properties (Range, Mean, and Standard deviation) of effluent BOD٥ and S.S data and representing these properties graphically in two figures for effluent BOD٥ and S.S , respectively .Examination of these descriptive shows a distinct difference exists between the statistical properties of the data above and below the value of (١٠ mg/l) of the standard deviation (this value of standard deviation called stability cutoff point). As recommended by Niku et al. (١٩٨١), the appearance of this distinct difference between the statistical properties of the data gives the validity for this model to be used for stability assessment. The value of stability cutoff point that obtained in this study was the same value of stability cutoff point, (١٠ mg/l), that obtained in the U.S.A by Niku et al.١٩٨١.

Dependability study of AL-Kerkh wastewater treatment plant for the periods before and after the war of ١٩٩١indicates that the performance

Of this plant dropping down. For both of BOD٥ and S.S , in sixteen sets of data , only four of them were stable and within the Iraqi effluent standards of ٤٠ (mg/l) for effluent BOD٥ and ٦٠ (mg/l٠) for effluent S.S the results of Dependability study of AL- Kerkh wastewater treatment plant show the urgent need to rehabilitate the treatment units and the operators of this plant to increase its treatment efficiency.

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to Dr. Riyad H. AL-Anbari and Mr. Jabbar H. AL-Baidhani, my supervisors, for their advice and readiness to discuss the problems I came across in my work.

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Khalid Safa'a Al-Khalidi

٢٠٠٣

CERTIFICATE

We certify that the preparation of this thesis entitled ***"Dependability study of AL-Kerkh wastewater treatment plant "*** was prepared by ***"Khalid Safa'a Hashime"*** under our supervision at Babylon University, College of Engineering in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering.

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Mr. Jabbar H. AL-Baidhani
(Supervisor)
Date: / /٢٠٠٣

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LIST OF SYMBOLS

Symbol	***Description***
A	Regression coefficient.
B	Regression coefficient.
b	Microbial decay coefficient & process stability indicator $T^{-١}$.
BOD_{sec}	Biochemical Oxygen demand after secondary treatment, (mg/l).
$BOD_{٥}$	Biochemical Oxygen demand after ٥ days, (mg/l).
COR	Coefficient of reliability.
COS	Coefficient of stability.
$C_{٧}$ dam	Seven days arithmetic mean value.
$C_{٣٠}$ dam	Thirty days arithmetic mean value.
D_{max}	The largest difference cumulative distribution function.
D_{α}	Critical value of Kolmogorov-Smirnov test.
$E(X^{r})$	Moment about the origin for the normal distribution.
$E(\theta)$	Process stability indicator (function of θ).
F_i	Actual frequency value at mid-interval of each category.
$\hat{F}_i$	Expected frequency value at mid-interval of each category.
F(x)	Density function.
Fx(x)	Cumulative distribution function.
$F(x^{i})$	Observed cumulative histogram at i.
$G(\theta_c)$	Process stability indicator (function of θ_c). $T^{-١}$.
H_o	Null hypothesis.
i	Class interval.
k	Maximum rate of substrate utilization, $T^{-١}$.
k_s	Substrate concentration at which rate of substrate utilization is one-half of the maximum rate, $ML^{-٣}$.
MLSS	Mixed liquid suspended solids concentration, (mg/l).
m_{lnx}	Mean of natural logarithm of x.
mx	Mean of x.
$\bar{m}x$	Median of x.
n	Sample size.
OUR	Oxygen uptake rate, (mg/l).
p.d.f	Probability density function.
r	Sludge recycle ratio.
RWL	Raw waste load.
S	Influent substrate concentration, (mg/l).
S.D	Standard deviation.

Symbol	***Description***
S_o	Transient influent substrate concentration, (mg/l).
S.S	Suspended solids.
S(t)	Substrate concentration at time t, (mg/l).
$S.S_{sec}$	Substrate concentration after secondary clarifier, (mg/l).
SVI	Sludge volume index.
$SX^{٢}$	Variance of x.
$V_{BOD_٥}$	Coefficient of variation for $BOD_٥$ data.
$V_{S.S}$	Coefficient of variation for S.S data.
V_X	Coefficient of variation.
X_-	Quality parameter of sewage treatment effluent, (mg/l).
$\bar{X}$	Mean of observations values.
Xg	Log of quality parameter of sewage treatment effluent, (mg/l).
Xi	Observation values.
Xr	Clarifier underflow organism concentration, $ML^{-٣}$.
Xs	A fixed standard.
X%	Concentration exceeded ١٠٠-X% of the time, (mg/l).
Y	The predicted concentration, (mg/l).
y	Growth yield coefficient, $T^{-١}$.
Z	Standard normal unite.
$Z_{١-\alpha}$	Percentile of normal distribution.
α	Significance level and probability of failure.
θ	Solids retention time, T.
θ_c	Hydraulic detention time, T.
μ	Mean of the normal distribution and specific growth rate, $T^{-١}$.
μg	Geometric mean (based on log normal distribution).
σg	Geometric standard deviation(based on log normal distribution).
σ_{lnx}	Standard deviation of the natural logarithm of x.
$\sigma^{٢}_{lnx}$	Variance of the natural logarithm of x.
σ_X	Standard deviation of the sample.
$\chi^{٢}$	Chi-square test value.
$\chi^{٢}\alpha$	Critical value of Chi-square test.

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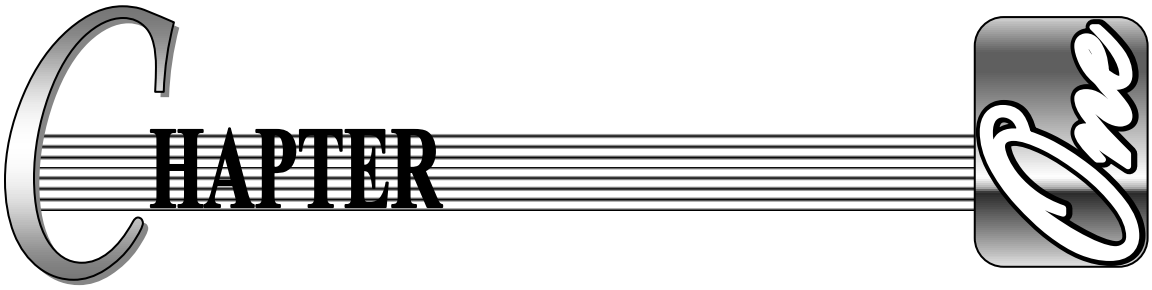


INTRODUCTION

١-١ Introduction

Since ١٩٧٠ explicit performance standards have been placed on most of wastewater treatment plants to restore the quality of receiving waters. These standards vary from plant to plant, but generally are require very high average treatment efficiencies and also restrict variations from the allowable average concentration.

Obviously, the average effluent concentration discharged must be designed below the standards because there will be a variations above and below the average.

To produce a high effluent quality and to meet the standards at a minimum cost, design engineers must be able to estimate the expected effluent quality and its variations for a given treatment process (ability to estimate the reliability and stability for a given treatment process).

Reliability of a system can be defined as “the ability to perform the specified requirements free from failure” or “the probability of adequate performance for at least a specified period of time under specified conditions”,(Niku et al. ١٩٨٢). While stability of a system can be defined as “measure of adherence to the annual mean constituent concentration”. (Niku et al. ١٩٨١)

Estimation of reliability and stability (which will called dependability) requires statistical evaluation of a system’s performance

over a time period long enough to establish typical operating patterns (the minimum required period is one year). (Niku et al. ١٩٧٩)

Dependability principles have been applied to a set of data which taken from the records A-Kerkh waste water treatment plant. The data included the final effluent concentrations for both of biochemical oxygen demand ($BOD_٥$) and suspended solids (S.S) for period of eight years of operation.

١-٢ Background for AL-Kerkh Wastewater Treatment Plant

AL-Kerkh wastewater treatment plant is one of the most important activated sludge treatment plants in Iraq. It lays in Baghdad city and discharges its effluents into Tigris river.

AL-Kerkh wastewater treatment plant consists of nine lines, final effluents of each three lines mixed together in one lines. Thus, it can be said that AL-Kerkh wastewater treatment plant consists of three lines .One of these three lines (line no. three) is not completely yet finished because of the war of ١٩٩١. Final effluent data that used in this research were collected from the records of the other two lines (lines one and two).

The basic design data of this treatment plant as given by Digremond company (the designer company) are:

a- Type of sewage to be treated : combined.

b- Population to be served : ١.٨ million inhabitants.

c- Expected average sewage flow : ٢٠٠ l/cap./day.

d- Expected daily sewage flow : ٣٦٠.٠٠٠ $m^٣$/day.

e-$BOD_٥$ concentration in raw sewage flow : ٦٠ g/cap./day.

f- S.S concentration in raw sewage flow : ٩٠ g/cap./day.

h-Treated effluent standards :

١- $BOD_٥$: ٤٠ mg/l.

٢- S.S :٦٠ mg/l.

j- Normal daily operation of the treatment plant : ٢٤ hours/day.

It is clear that Iraqi standards are differ from EPA standards (Effluent

$BOD_5 \leq ٢٠$ mg/l and S.S ≤ ٦٠ mg/l.)

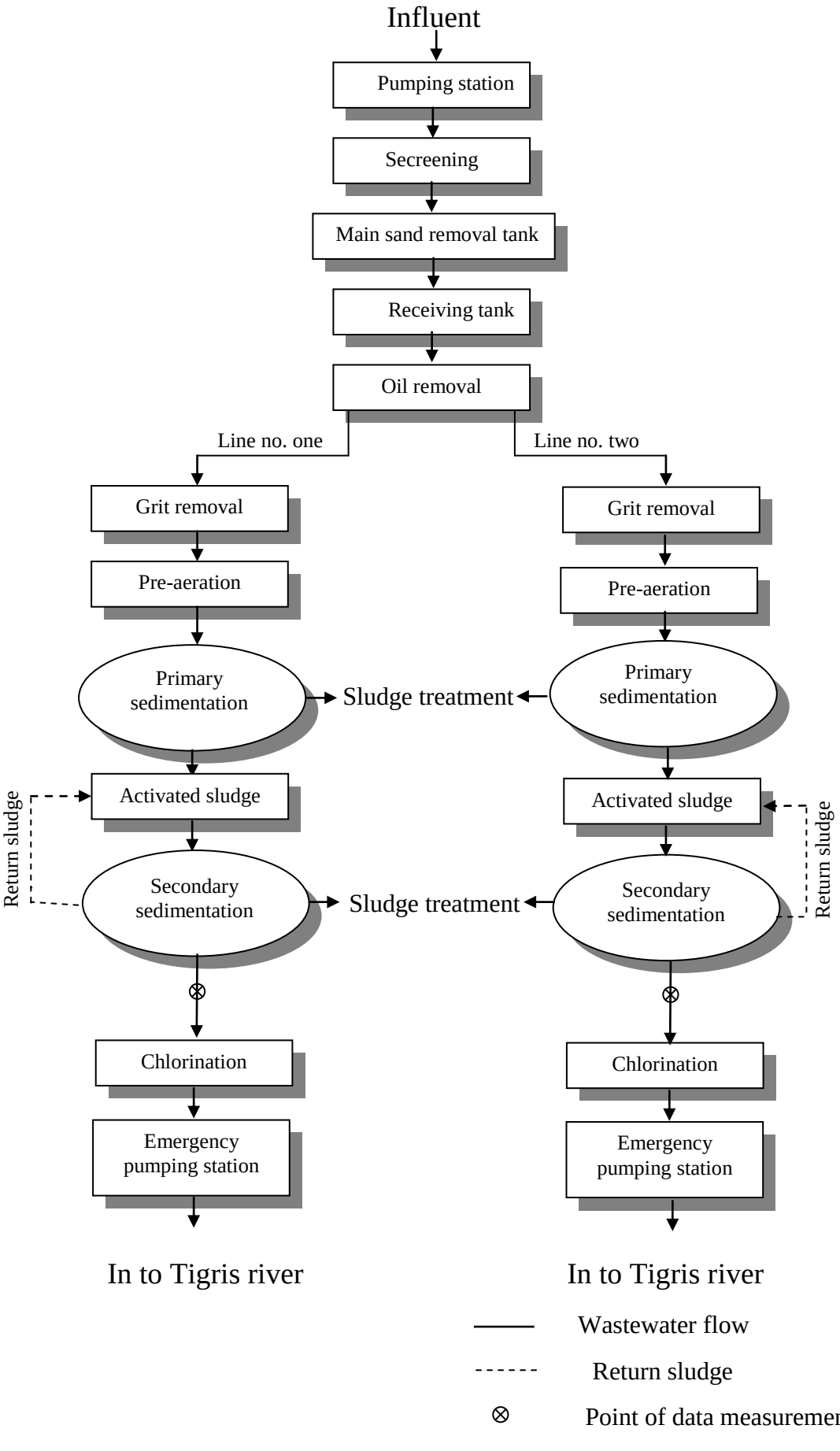


Figure (١-١): Flow chart sequence for AL-Kerkh wastewater treatment plant.

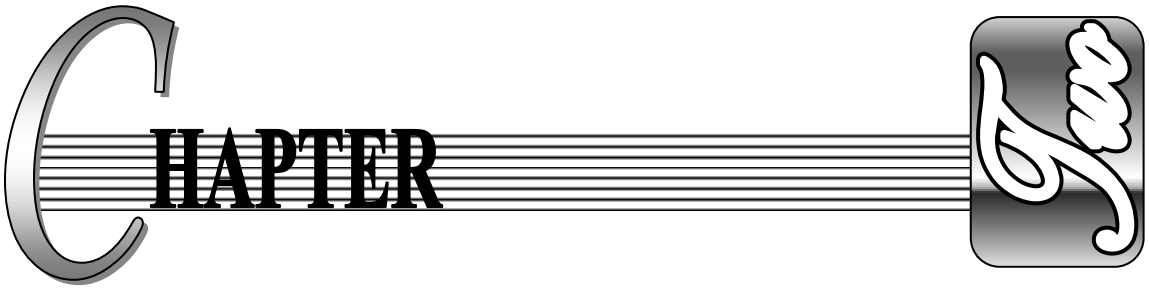
١.٣ Research Significance

The objective of the work presented here is to investigate the dependability of AL-Kerkh wastewater treatment plant by using reliability and stability models which were developed by Niku et al. (١٩٧٩) and Niku et al.(١٩٨١), respectively. As well as this study aims to develop a probabilistic model that can be used in predicting of future performance of AL-Kerkh wastewater treatment plant and in designing of new wastewater treatment plants that similar to AL-Kerkh wastewater treatment plant.

١.٤ Research Layout

In this research there are five chapters:

- Chapter One provides a general introduction.
- Chapter Two presents a review of both early and recent studies, including the factors that affecting dependability of wastewater treatment plants.
- Chapter Three provides a theoretical background for the models that will be used in this research. This chapter contains the required equations, tables, and figures for dependability prediction.
- Chapter Four includes analysis of results and their discussion.
- Chapter Five contains conclusions obtained from the analysis of the results and some possible recommendations for future works.



LITERATURE REVIEW

٢.١ Introduction

Activated sludge process is the most commonly used system for treating municipal wastewater. However, this process is affected by several factors such as fluctuation in input loads, environmental conditions, characteristics of wastewater, and inplant biological variations. Thus, to obtain the highest efficiency, activated sludge process should be analysed for each one of the affecting factors.

Many researchers studied the performance of activated sludge process. In this chapter the main factors that affected the dependability of activated sludge treatment plants will be discussed, as well as some of the researches that investigate the dependability of wastewater treatment plants will be review.

٢.٢ Causes of Effluent Variability

Variation of effluent quality may be affected by several factors such as temperature fluctuation, wastewater flow and composition of the wastewater to be treated. The followings are the main causes of effluent variability.

٢-٢-١ Variation in Raw Waste Load (RWL)

Variation in raw waste load, such as flow rate, organic concentration and presence of toxic materials, may affects effluent quality directly (Edward and Robert, ١٩٧٩).

Robert and Stanley (١٩٧٦), studied the response of activated sludge process to shock organic load. They found a quick response, quick increase in effluent (BOD_5) and (S.S) concentrations, of activated sludge process to input organic concentration changes. The effectiveness of flow rate on this process had been investigated by (Joseph and Alonozo, ١٩٧٥), (Singh and Joh, ١٩٧٦) and (Krishnan and Gaudy, ١٩٧٦). They found that an increase in influent flow will decrease the retention time, this will causes turbulence and a high over flow rate in the final clarifier which will result in a high effluent solids concentration.

James (١٩٩٨) and Pinheiro et al. (٢٠٠٢) refer to the effects of variation in influent composition (especially presence of toxic materials), significant results were found of toxic materials on performance of activated sludge process. These materials, even in low concentration, will kill the bacterial mass which results in upset in the performance of activated sludge process.

Many researchers, such as (Andrea, ١٩٨٢), (Jan and Edson, ١٩٨٦), (Chau-Chen et al., ١٩٩٨), (James, ١٩٩٩) and (Young, ١٩٩٩), were recommend for using oxygen up-take rate as an indicator for monitoring of (RWL) variation. Oxygen up-take rate (OUR) commonly used as a monitoring indicator because it is extremely sensitive to change in reactor soluble (BOD) concentration resulting from load variations.

٢-٢-٢ Variation in Temperature

The effect of temperature on biodegradation rates has long been investigated and is generally well documented. Temperature decreasing may result in a significant decreasing in the soluble (BOD) removing rate (Davis, ١٩٧٦).

In addition to the effect of temperature on removing rate of soluble (BOD). Metcalf and Eddy, (١٩٧٠), reported that a decrease in temperature will result in a poor setting of the flocs and the flocs tend to break more easily because of the increasing of water viscosity during the low temperature period. Fig.(٢-١) illustrated the effect of temperature on wastewater treatability.

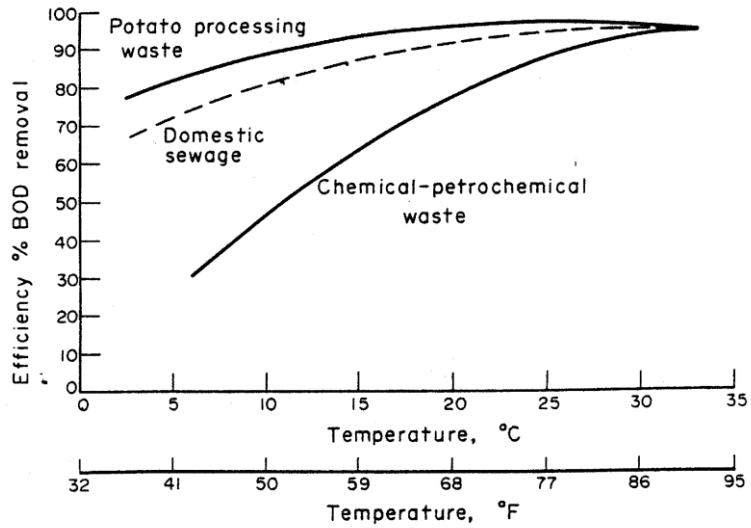


Figure (٢-١): Effect of Temperature on wastewater treatability, (After Davis, ١٩٧٨)

٢-٢-٣ Sludge Characteristics

Bulking sludge is the main cause of effluent variability, bulking of sludge results from presence of a significant numbers of filamentous bacteria in the flocs, such flocs have low density and high compactability and therefore do not settle well. Thus, such phenomenon will decrease settleability and results in a high effluent solids concentration. Phenomenon

of sludge bulking can be monitored through the parameter of sludge volume index (SVI). (Niku et al., ١٩٨١).

(SVI) is an empirical indication of the settling characteristics of the sludge. Values of the SVI vary with the characteristics and concentration of the MLSS ,thus, observed SVI values at a given plant can not be compared with other plants. In general, if (SVI) greater than normal value (usually about ١٠٠), then the sludge will not settle well. (Metcalf and Eddy, ١٩٧٠).

٢-٢-٤ Process Type

Activated sludge processes are flexible systems and have been adopted to a number of different flow schematics. The most appropriate process design reduces the variability ofeffluent quality significantly. In conventional plug flow activated sludge process, because both influent and return sludge enter the tank at the head end, the effects of flow and concentration variations or of the introduction of toxic substances are maximized and may result in upsets. However, longitudinal mixing tends to smooth out fluctuations in these variables. (Dowing, ١٩٧٦)

Step aeration, or step feed, process is a modification of the conventional activated sludge process that evens out the organic load or the oxygen demand in a treatment process. This modification may result in reduction of the effluent (BOD) and (S.S) concentration and, thus, in a more stable process, since it will reduce effluent variation and also will reduce the effect of shock loads to the plant.(Niku et al.,١٩٨١)

In complete mix systems the influent wastewater and return activated sludge flow are introduced at several points in the aeration tank and mixed virtually instantaneously throughout the system. In this case, any input fluctuations or toxic concentrations are diluted instantaneously with the entire contents of the aeration unit. This kind of process can thus be expected to be more stable. (Niku et al., ١٩٨١).

٢-٢-٥ Plant Size

It is usually assumed that larger treatment plants produced better-quality effluents than smaller plants. This assumption was based on the idea that larger plants tend to be more sophisticated and they have more highly trained operators. But, in fact, there is a poor (and possibly negative) correlation between plant size and mean effluent concentration. Hovey et al. (١٩٧٧)

٢-٢-٦ Inherent Variability

The term "inherent variability" as applied herein can be defined as: that variability in effluent quality from a properly designed and operated biological treatment system which is attributable to the basic nature of the treatment process. Simply stated, it is the minimum variability which can be practically obtained assuming proper system design, management and operational control. There are many factors which cause "inherent variability", such as geographical conditions, the nature of biota in the treatment process and wastewater characteristics. (Davis, ١٩٧٦).

Variation of effluent quality can be reduced by various means directed, for example, towards increasing the uniformity of flow and composition of the sewage to be treated and of the operating conditions prevailing in the works, restriction of release from industrial premises of substances which would interfere with treatment at works, and use of automatic control systems which permit the treatment given to be accurately matched to that ideally required. (Dowing, ١٩٧٦)

٢-٢-٧ Miscellaneous Factors

There are several miscellaneous factors which cause effluent variability, such as changes in pH, nutrient deficiency, loss of dissolved oxygen, or the presence of substances in aeration basin at toxic or inhibitory concentrations. These factors can be controlled, however, in design and operational functions of a biological treatment plant (Davis, ١٩٧٦).

٢.٣ Historical Background

Dependability of wastewater treatment plants has been investigated by many researchers through final effluent data of biochemical oxygen demand (BOD) and suspended solids (S.S) concentrations.

Thomann (١٩٧٠), studied daily data of effluent BOD_5 of eight wastewater treatment plants over one year period of operation. He used this data for studying the variability in performance of wastewater treatment plants, through the use of time series analysis. Probability histograms for data range from normal to log-normal. The results indicated a high degree of variability in the final effluent of biochemical oxygen demand (BOD_5) as measured by the coefficient of variation.

Wheatland (١٩٧٣), developed percentile-mean relations which can be used to predict effluent biochemical oxygen demand (BOD_5) and suspended solids (S.S) concentrations. **Wheatland** analyzed the daily data of effluent (BOD_5) and (S.S), for one year period, from fourteen large wastewater treatment plants in river Trent area.

Calculations were made by wheatland for:

١. The overall annual mean for each treatment plant.

٢. The concentration which was exceeded on;

a. ٥ percent of the days (the ٩٥ percentile).

b. ٥٠ percent of the days (the ٥٠ percentile).

c. ٩٥ percent of the days (the ٥ percentile).

A linear relationship was recognized after plotting annual mean and corresponding percentiles. Regression models relating these percentile to means are given in Table (٢-١).

The following relation related the predicted concentration, **Y** (mg/l), which corresponds to a given percentile to the mean concentration, **X** (mg/l), for both (BOD_5) and (S.S).

$$Y = mX + C$$

where *m* & *C* are coefficients depend on effluent characteristics.

Table (٢-١): Coefficients for equations of the form $Y = mX + C$ (After Whetland, ١٩٧٣).

Parameter of Effluent quality	Percentile	Coefficient for equation		Correlation coefficient
		M	C	
BOD	٥	٠.٤٤	٠.٢٣	٠.٨٩
	٥٠	٠.٨٩	٠.٢	٠.٩٨
	٩٥	١.٧٦	١.٥	٠.٩٦
S.S	٥	٠.٦٤	٤	٠.٩٥
	٥٠	١.٠٥٤	١.٩	٠.٩٩٧
	٩٥	١.٥	٥.٢	٠.٩٦

Porter (١٩٧٥), carried out a statistical technique, by using percentiles as a measure of variability, for specifying standards and establishing criteria for treatment design. He proposed that standards should be set on a probability basis. The corresponding mean (design value) can be obtained from a graph, which describes the effluent variability for a particular wastewater. This estimation of a mean concentration of a substance in an effluent will provide information about expected extreme concentration which is expected to be associated with mean.

Figure (٢-٢) shows the relationships between mean concentrations of a substance and the corresponding percentiles.

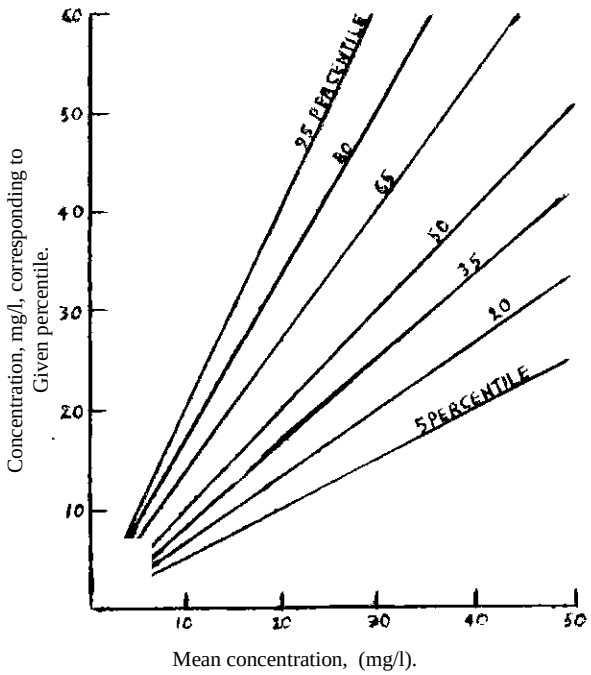


Figure (٢-٢): Relationships between mean concentration of a substance and corresponding percentile. (After Porter, ١٩٧٥).

Popel (١٩٧٦), constructed a realistic effluent standards concept and he evaluated its basic parameters by means of data from a number of wastewater treatment plants (activated sludge plants and trickling filters). **Popel** suggested that the normal distribution should be used because it is the simplest one and it will facilitate the later application of the results of frequency distribution analysis. But, through the analysis in many cases effluent data were positively skewed. This sheweness eliminated by applying the log-normal distributions. Tables (٢-٢) and (٢-٣) show the type of frequency distribution for effluent daily and monthly samples of data, obtained from a significant test on skeweness and kurtosis on a ٥٪ level. **Popel** concluded that a fixed standards for an effluent quality parameter will not be an appropriate measure for effluent quality control, because it will always be exceeded and the probability of such exceedance decreases with increasing magnitude of the standards.

A combined standard consisting of a standard value x_s, and a permissible probability of exceeding it, $P(x>x_s)$, will be more realistic and appropriate to understand variability of wastewater treatment plants. Depending on the type of data distribution, the probability of exceedance of the combined standards can be determined by using the following equations:

For normal distribution

$$P\left(x > x_s\right) = 1 - \phi\left(\frac{x_s - \mu}{\sigma}\right) \qquad .....(٢\text{-}١)$$

For log-normal distribution

$$P\left(x > x_s\right) = 1 - \phi\left(\frac{\log\left(x_s / \mu g\right)}{\log\left(\sigma_g\right)}\right) \qquad .....(٢\text{-}٢)$$

where

x_s : standards,

x : quality parameter of sewage treatment plant effluent,

x_g : log of quality parameter of sewage of treatment plant effluent,

μ : mean of normally distribution parameter,

σ : standard deviation of a normally distributed parameter,

μ_g : geometric mean (based on log-normal distribution),

σ_g : geometric standard deviation (based on log-normal distribution),

ϕ : represents the area under the normal curve (Appendix A-١).

Table (٢-٢) Frequency analysis of daily data. (After Popel, ١٩٧٦).

Plant	Parameters	Dimensions	Mean	Variance & S.D.	Correct frequency distribution	
					Normal	Log-normal
Heilborm	BOD	g/m^{٣}	١٥.٨	٥٩.٦	-	-
			١٣.٤	١.٧٧٤	-	X
Maple	BOD	g/m^{٣}	١٦.٨	٣٩.١	-	-
			١٥.٤	١.٤٦٨	-	X
Slough	BOD	g/m^{٣}	٨٠.٥	٣٣.٢	-	-
			٧٨.٥	١.٤١٩	-	X
	S.S	g/m^{٣}	١٨.٤	٤٣.٢	-	-
			١٦.٩	١.٤٩٤		X

First row: Results on the basis of the normal frequency distribution (mean & variance).

Second row: Results on the basis of the log-normal frequency distribution (mean and S.D.).

X : represent connect frequency distribution

Table (٢-٣) Frequency analysis of monthly data. (After Popel, ١٩٧٦).

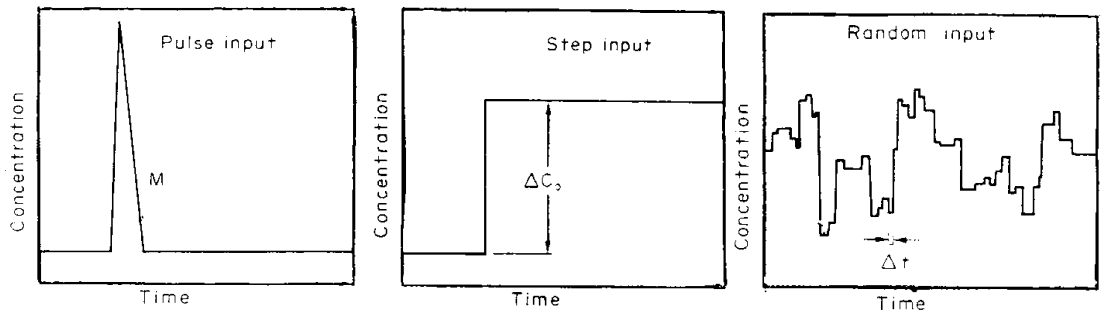
Plant	Parameters	Dimensions	Mean	Variance & S.D.	Correct frequency distribution	
					Normal	Log-normal
Clevlant	BOD	g/m^{٣}	١١.٥	٣٦	X	-
			١٠.٦	١.٥٢٩	-	-
Cranston	BOD	g/m^{٣}	٢٦.٩	٥٢.١	-	-
			٢٣.٣	١.٧	-	X
Gray	BOD	g/m^{٣}	١٢.٨	٦٤.٩	-	-
			١٠.٧	١.٨٠٦	-	X
Maples lodge	BOD	g/m^{٣}	١٦.٢	٤٢.٢	-	-
			١٤.٨	١.٦٣٦	-	X
Marion	BOD	g/m^{٣}	٨.٤	٤٢.٤	-	-
			٧.٥	١.٦٢٦	-	X
Slough	BOD	g/m^{٣}	٢٣.٥	٢٠.٨	-	-
			٢٣.٠	١.٢٣٢	-	X

First row: Results on the basis of the normal frequency distribution (mean & variance).

Second row: Results on the basis of the log-normal frequency distribution (mean and S.D.).
X : represent connect frequency distribution

Ropert and Stanley (١٩٧٦), introduced a statistical model for long-term reliability of advanced wastewater treatment plants based on normal statistics. Daily operation data, which covered six years of continuous operation, was obtained from south lake Tahoo (Nevada, USA) plants. The analysed data includes biochemical oxygen demand, suspended solids , and phosphate as final effluent. **Robert and Stanley**, indicated that the long-reliability of any process must be described by, at least, two numbers. If the distribution of the results is normal then it can be completely described by the average and the standard deviation.

Englande and Praviz (١٩٧٦), introduced a study, in which the application of a frequency response solution and spectral analysis of input-output data to estimate effluent variability from complete – mix activated sludge systems was verified by bench-scale studies. Experimental and theoretical results were compared for random, pulse, and step function inputs. Puls input into treatment system is very common and can be caused by a batch discharge or sudden spill of a substance into treatment process, as shown in Figure (٢-٣a). While step function is characterized by a sudden lasting change in concentration. Start-up or shut-down of a process, for example, could results in a step function nature, as appeared in Figure (٢-٣b). Random input might be approached by an industry with diversified processes contributing batch discharges with no rigid periodicity, as shown in Figure (٢-٣c).



(a) (b) (c)

Fig.(٢-٣): Basic wastewater time varying input. (After Englande and Praviz ,١٩٧٦).

Cheng (١٩٧٧), developed indicators for process stability and considered the importance of these indicators to completely mixed activated sludge process, specifically, to determine the relative influence of solids retention time θ_c, and hydraulic detention time θ, on process stability. These indicators enable the design engineers to evaluate the effect of various designs on process stability.

Monod kinetic equation was first employed by **Cheng**, and then he presented a summary for other kinetic rate equations (Table ٢-٤). **Cheng** introduced the following indicators:

- Process stability indicator (function of θ_c and θ , T^{-1})

$$B=\left(\frac{1}{\theta}\right).\left(1+\frac{k.x.\theta}{k_s+s}\right) \qquad .....(٢-٣)$$

- Process stability indicator (function of θ, T^{-1})

$$E(\theta)=\frac{1}{\theta} \qquad .....(٢-٤)$$

- Process stability indicator (function of θ_c, T^{-1})

$$G(\theta_c)=1+\frac{k.x.\theta}{k_s+s} \qquad .....(٢-٥)$$

The rate of change of process response with respect to (θ) is

$$\frac{\partial B}{\partial \theta}=-\frac{G(\theta_c)}{\theta^2} \qquad .....(٢-٦)$$

The rate of change of process response with respect to (θ_c) is

$$\frac{\partial B}{\partial \theta_c}=\left(\frac{1}{\theta}\right).\left[\frac{k.Y.(s_\sigma-s)}{(k_s+s)(1+b.\theta_c)^2}\right] \qquad .....(٢-٧)$$

Where;

b : microbial decay coefficient, T^{-1}.

k : maximum rate of substrate untilization, T^{-1}.

k_s : substrate concentration at which rate of substrate utilization is one-half the maximum rate, ML^{-3}.

s, s_o : influent and transient influent substrate concentration respectively.

x : organism concentration, ML^{-3}.

y : growth – yield coefficient, T^{-1}.

Figure (٢-٤) shows typical graphs of process response.

Table (٢-٤): Process stability indictors for various kinetic equations

(After Cheng, ١٩٧٧)

Kinetic equations for substrate utilization	E(θ)	$G(\theta_c)$	B	Transient effluent substrate concentration
Monod $\frac{dF}{dt}=\frac{k\times s}{k_s+s}$	١/θ	$1+\frac{k.x.\theta}{k_{s+s}}$	$E(\theta).G(\theta_c)$	$S_o/G(\theta_c)$
First – order: $k_s>>s$ $k_1=\frac{k}{k_s}$	١/θ	$1+k_1.x.\theta$	$E(\theta).G(\theta_c)$	$S_o/G(\theta_c)$
Gaud and Dohanyos, $K_s>>s$ $\frac{df}{dt}=\frac{k_2.x.s}{s_o}$	١/θ	$1+\frac{k_2.x.\theta}{s_o}$	$E(\theta).G(\theta)$	$S_o/G(\theta_c)$
zero-order, $s>>k_o$ $\frac{df}{dt}=k\,x$	١/θ	$1+\frac{k.x.\theta}{s}$	$E(\theta).G(\theta)$	$S_o/G(\theta_c)$

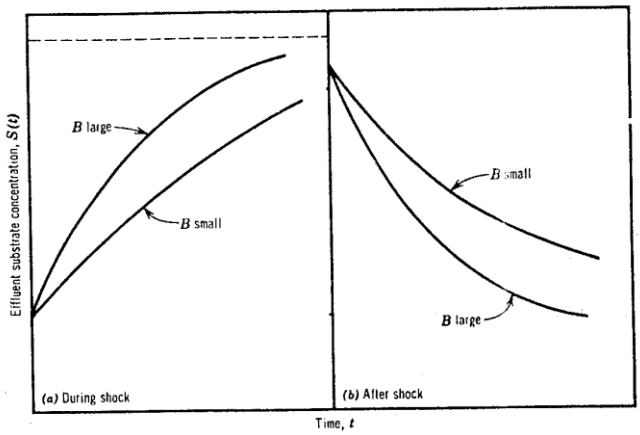


Fig.(٢-٤): Characteristics of process response, (After Cheng, ١٩٧٧).

Ely Ouano (١٩٧٨), made a discussion about the study that made by **Cheng** (١٩٧٧). **Ely** has recorded serious a doubt on the qualitative results from **Cheng's** indicators and their applicability to the stability analysis of the activated sludge process because of the following errors:

١- In the integration of the following equation;

$$\frac{dx}{dt} = -\left[\left(\frac{1}{\theta}\right).\left(1 + r - r.\frac{x_r}{x}\right) - \mu\right] x \qquad .....(٢-٨)$$

Cheng assumed (x_r/x) as a constant. This assumption is erroneous because it is to difficult to maintain this parameter constant.

٢- The term $\frac{k.x.\theta}{k_s + s}$ is a constant only at steady state, since (x) and (s) are variables whose values change in opposite direction during transient state (i.e., $\frac{ds}{dt} = -\frac{1}{y}.\frac{dx}{dt}$) then the following equation, which developed by **Cheng** on the basis of ds/dt=٠, helds true only during steady state;

$$X.\theta = \frac{y.(s_o - s).\theta_c}{1 + b.\theta_c} \qquad .....(٢-٩)$$

Where;

μ : specific growth rate, $T^{-١}$.

r : sludge recycle ratio.

x_r : clarifier underflow organism concentration, $ML^{-٣}$.

Thus, **Cheng's** indictors do not describe the process stability during dynamic conditions of activated sludge process.

Forde et al. (١٩٧٨), discussed the study of **Cheng** (١٩٧٧) as well. They appointed the following errors:

The first important error is the author's statement that $\mu = ١/\theta_c$. This is true only for completely mixed plants at steady state. The generalized equation (in **Cheng's** study) for completely mixed plants with no cells in the influent is;

$$\mu = \frac{1}{x}.\frac{dx}{dt} + \frac{1}{\theta} \cdot \left[(1 + r) - r.\frac{x_r}{x} \right] \qquad .....(٢-١٠)$$

Clearly, *dx/dt* is not zero under shock loading conditions. In addition, (*x*) is changing also. Thus, the term $\left(\frac{1}{\theta}\right)\left[(1+r) - r\left(\frac{x_r}{x}\right)\right]$ is also changing during the shock. The author uses the erroneous assumption that $\left(\mu = \theta_c^{-1}\right)$ and $\left(\frac{x}{x_r}\right)$ is constant in setting the following equation:

$$\frac{dx}{dt} = -\left[\left(\frac{1}{\theta}\right).\left(1 + r - r.\frac{x_r}{x}\right) - \frac{1}{\theta_c}\right].x \qquad .....(٢-١١)$$

and its integral

$$x(t) = x_o . Exp\left[-\left(\frac{1}{\theta}\right).\left(1 + r - r.\frac{x_r}{x}\right) - \frac{1}{\theta_c} \right].t \qquad .....(٢\text{-}١٢)$$

Then the results of these equations will be mislead:

The second error, in the developed model was in the assumption that the cell and substrate balances are independent equations.

In fact, these two parameters are couple and their coupling is defined by reaction stoichiometry. Unfortunately, Cheng ignored the stoichimetry of the reaction**.**

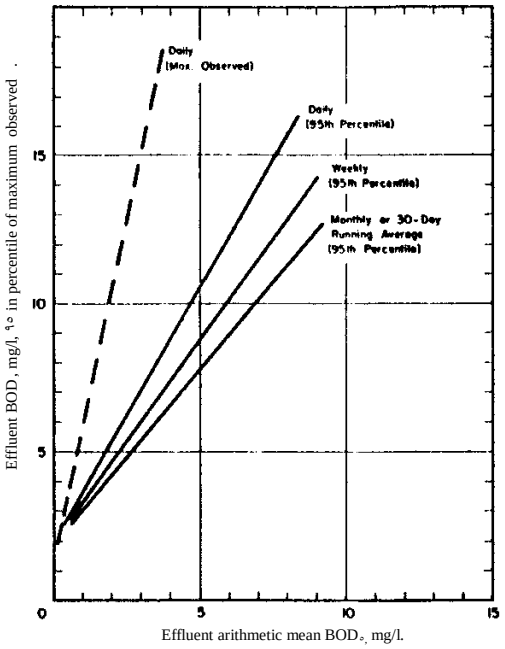
In the developing of the following equation;

$$S(t) = S_o . Exp.\left[-\frac{1}{\theta}.\left(1 + \frac{k.x.\theta}{k_s + S}\right).t \right] + \frac{S_o}{1 + \dfrac{R.x.\theta}{k_s + S}}.\left[1 - Exp\left(-\frac{1}{\theta}.\left(1 + \frac{k.x.\theta}{k_s + S}\right).t \right) \right] .....(٢\text{-}١٣)$$

The author also made a third error due to assuming that the term $(k.x.\theta/(k_s + s))$ remains relatively constant. However, during transient period, effluent substrate concentration (s) varies with the time and the rate, *ds/dt*, is a function of (s). Then, the preceding assumption does not hold. As a result, this equation is not generally applicable. Equation (٢-١٣) is the basic equation that used throughout the rest of **Cheng's** study. Thus, results and conclusions developed by Cheng were erroneous.

Finally, **Forde et al.** mentioned that the process response indicator, *B*, could not be available indication of process stability for several reasons. First, (B) is not sensitive to change in (s). Second, (B) does not include the effect of non-soluble effluent substrate. Both of the variables (s) and non-soluble effluent concentration are the most important variables used in process control. A third factor is that in the development of the model. The author presumed that (θ) was a constant. Thus, $E(\theta)$ does not change as a result of the shock. The interpretation of $(\partial B/\partial\theta)$ is therefore questionable.

Ralph et al. (١٩٧٩), presented a work to determine the applicability of percentile – mean relations, such as those of **Weatland** (١٩٧٣) and **Porter** (١٩٧٥), to estimate effluent constituents concentrations. The authors used effluent data from ten secondary and nine advanced treatment plants in their study. **Ralph et al.** found that the percentile – mean relationships are applicable. They were submitted Fig.(٢-٤ and ٢-٥) for prediction effluent (BOD) and (S.S) concentrations, respectively, for daily, weekly and monthly running average with (٩٥) percentile.



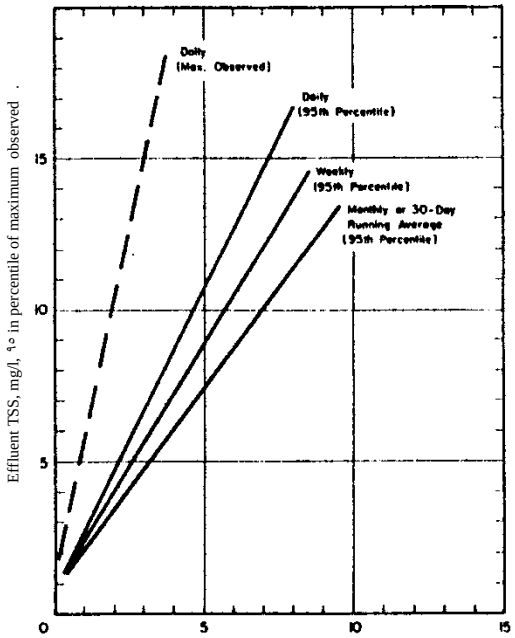


Fig.(٢-٥): BOD٥ percentile-mean relations(After Ralph et al., ١٩٧٩)

Fig.(٢-٦): S.S percentile-mean relations (After Ralph et al., ١٩٧٩)

Hovey et al. (١٩٧٩), examined statistically final effluent data of biochemical oxygen demand (BOD) and suspended solids (S.S) from ٢٨ activated sludge wastewater treatment plants over a period of one year of continuous operation. The main purpose of that examination was the study of variability of wastewater treatment plants performance, and to estimate steady-state effluent design values that should be selected to assure an effluent quality better than discharge requirements most of the time. The authors found that no single probability density function could be used to describe all the twenty sets of (BOD) and (S.S) data. Thus, simple linear regression analysis methods were used to relate (BOD) and (S.S) concentrations with the exceeded concentrations at various percentages of the time. **Hovey *et al.*** presented the following equations (models) for daily, ٧-day, and ٣٠-day arithmetic mean values.

Effluent arithmetic mean TSS, mg/l.

$$X\%\ ile\ S.S_{sec} = A + B\ (mean\ S.S_{sec}) \quad .....(٢-١٤)$$

$$X\%\ ile\ BOD_{sec} = A + B\ (mean\ BOD_{sec}) \quad .....(٢-١٥)$$

$$X\%\ ile\ C_{٧}dam\ S.S_{sec} = A + B\ (mean\ S.S_{sec}) \quad .....(٢\text{-}١٦)$$

$$X\%\ ile\ C_{٧}dam\ BOD_{sec} = A + B\ (mean\ BOD_{sec}) \quad .....(٢\text{-}١٧)$$

$$X\%\ ile\ ٣٠\ dam\ S.S_{sec} = A + B\ (mean\ S.S_{sec}) \quad .....(٢\text{-}١٨)$$

$$X\%\ ile\ ٣٠\ dam\ BOD_{sec} = A + B\ (mean\ BOD_{sec}) \quad .....(٢\text{-}١٩)$$

Where;

X% ile = concentration exceeded ١٠٠-X% of the time in (mg/l).
A and *B* = regression coefficients.

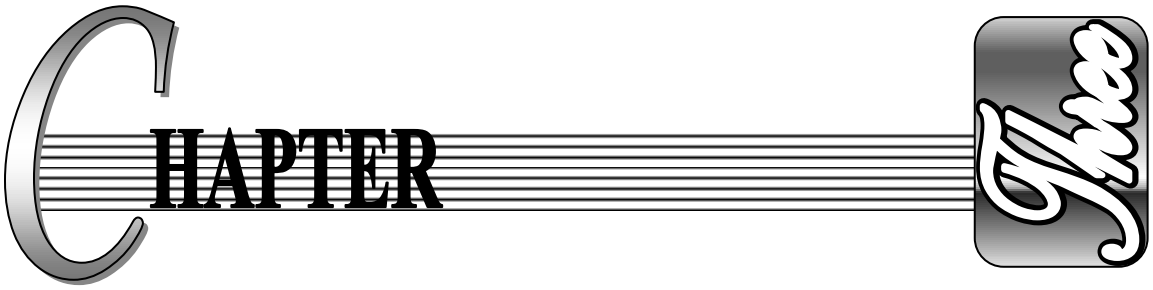
Niku et al. (١٩٧٩), proposed a reliability model based on log-normal assumption, and presented a simple graphical and tabulated devices that can be used to predict process performance of plants under design or currently under operation. **Niku et al.** developed their model by examine statistically effluent data of (BOD٥) and (S.S) which obtained from the records of (٣٧) activated sludge treatment plants across the U.S.A. The authors noted that in all plants effluent data were not symmetrically distributed. Generally the distributions were skewed to the right. It was found that the log-normal distribution consistently fits best to the observed effluent (BOD) and (S.S) data and consequently the log-normal distribution may be used to predict effluent quality.

Niku et al. (١٩٨١), introduced a model, based on statistical measurements, that can be used to define and compare the stability of activated sludge wastewater treatment plants. Through the statistical analysis of effluent (BOD٥) and (S.S) data of (٤٣) activated sludge treatment plants, **Niku et al.** concluded that plants having a standard deviation of less than ١٠ (mg/l) for both effluent (BOD٥) and (S.S) data may be statistically considered as stable plants. While, plants having standard deviation greater than ١٠ (mg/l) for both effluent (BOD٥) and (S.S) may be considered as unstable plants.

Niku et al. (١٩٨٢), presented a study determines applicability to trickling filters processes of the reliability and stability models that

developed for activated sludge processes. They found that the probabilistic model already developed for a activated sludge process for predicting achievable effluent ($BOD_٥$) and (S.S) concentrations and estimating the reliability of plants under operation could be used for trickling filters as well, also the stability of trickling filters follows the same patterns as activated sludge plants was. Trickling filters with standard deviation of less than (١٠ $g/m^٣$) may be statistically considered as stable, whereas these with a standard deviation of more than ١٠ (mg/l) may be considered unstable.

Tariq (١٩٩٨), Studied the reliability of AL-Rustamiyah wastewater treatment plant through the application of the reliability model that introduced by Niku et al. (١٩٧٩). To evaluate the reliability of this plant **Tariq** analyzed effluent data, which obtained from the records of AL-Rustamiyah wastewater treatment plant, of $BOD_٥$ and S.S for nine years of operation. The author had found that the overall reliability(of AL-Rustamiyah wastewater treatment plant) for effluent $BOD_٥$ was =٧٠.٩٢٪ and ٦٦.٠٩٪for effluent S.S.



THEORETICAL BACKGROUND

٣.١ Introduction

This chapter gives a theoretical background on the statistical models, (that used in this study); and their application on the final effluent ($BOD_٥$) and (S.S) data of Al-Kerkh wastewater treatment plant. As well as it will review the methods of finding the appropriate probability density function (p.d.f), goodness of fit tests, that fits the final effluent ($BOD_٥$) and (S.S) data.

٣.٢ Reliability Concept

Reliability is expressed in probability terms and it can be defined as "the probability of adequate performance"-that it is the percent of the time that effluent concentrations meet requirements. (Chorafas, ١٩٦٩).

$$Failure = effluent\ \ concentration > effluent\ \ requirements \quad .....(٣\text{-}١)$$

The probability of failure is extremely sensitive to the distribution function of effluent concentration. Thus, to develop a reliability model, first the distribution of effluent concentration should be modeled. Assuming the distribution of effluent concentration is known, then, the reliability of the plant could easily be computed. If an expression can be found that gives the fraction of the time that given concentration has been exceeded in the past,

the future performance of the plant can be predicted, provided process variables remain the same. (Robert and stanley, ١٩٧٦).

Reliability figures can not be interpreted until common criteria of performance judgment are established. Regulatory agencies establish these criteria based on adverse effects that performance failure may cause on the environment. (Chorfas, ١٩٦٠)

٣.٣ Effluent Concentration Distribution

Effluent variability can be shown and analyzed by determining the histogram and probability density function (p.d.f) of the data, Fig.(٣-١).

The discontinuous curve of the histogram may be approximated by a superimposed continuos curve, a scaled version of which is called the probability density function. (Benjamin and cornell, ١٩٧٠).

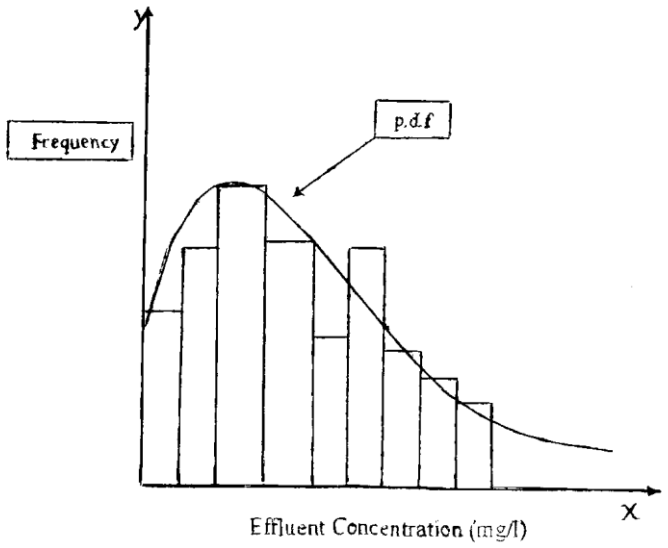


Fig.(٣-١): Histogram and its p.d.f. (After McCuen, ١٩٨٥).

Theoretically, positive skewness (distribution toward higher values) is very expected in wastewater treatment plant data since there is usually a lower bound on effluent concentration (no negative values for effluent concentration), but there are no upper limits. (Niku et al, ١٩٧٩).

Of particular concern to the designer engineers is the type of distribution to be used for reliability study, the type of distribution of effluent concentration can be examined as follows;

٣-٣-١ Kolmogorov-Smirnov Test

Kolmogorov-Smirnov test is one of the most commonly used tests for the selecting of the suitable type of distribution for a given histogram. This test involves the examination of random sample from an unknown continuous distribution to test the hypothesis that the unknown distribution function is the specified known continuous distribution function. The conventional null hypothesis is that the distribution functions are identical. The test is based on the difference between the empirical cumulative distribution function (C.D.F) (Observed cumulative histogram) and the known cumulative distribution function at each data point. The largest of these differences, *Dmax*, is used with sample size to test the hypothesis (Ho). (Nie et al., ١٩٧٥).

If the hypothesis cumulative distribution function Fx(x) and the empirical C.D.F (observed cumulative histograms) is:

$$F\left(x^i\right)=\frac{i}{n} \qquad \text{.....(٣-٢)}$$

where;

x^i : the largest observed value in the random sample.

n : size of the random sample.

i : class interval.

Then (*Dmax*) can be determined as follows: (Benjamin and Cornell, ١٩٧٠)

$$D_{\max}=\max_{i=1}^{n}\left[\left|F\left(x^i\right)-Fx\left(x^i\right)\right|\right] \qquad \text{.....(٣-٣)}$$

or

$$D_{\max}=\max_{i=1}^{n}\left[\left|\frac{i}{n}-Fx\left(x^i\right)\right|\right] \qquad \text{.....(٣-٤)}$$

Then (*Dmax*) will be compared with critical valued (Dα) from Table (A-٢) in Appendix A to take decision about the rejection or acceptance of the null hypothesis.

If $D_{\max} \le D\alpha$ accept H_o

If $D_{max} > D\alpha$ reject H_o

McCuen (١٩٨٥) proposed the following steps for running the Kolmogorov-Smirnov test.

١- State the null and the alternative hypotheses in terms of the proposed probability density function and its parameters.

٢- The test statistic, *Dmax* is the maximum absolute difference between the cumulative function of the sample and the cumulative function of the probability function specified in the null hypothesis.

٣- The level of significance should be set; values of ٠.٠١, ٠.٠٥ and ٠.١ are usually used.

٤- A random sample should be obtained and the cumulative probability function derived. After computing the cumulative probability function for the population, the value of the test statistics should be computed.

٥- The critical value, *Dα*, of the test statistic should be obtained from Table (A-٢) in Appendix A. The values of Dα is a function of (α) and the sample size (n).

٦- If the computed D_{max} is greater than Dα, the null hypothesis should be rejected.

٣-٣-٢ Chi-Square Test (χ^2)

Chi-square test is another test which can be used to help in using or rejecting a certain distribution toward which we have a certain predilection. This test is based on the difference between actual frequencies, *fi*, and the

expected frequencies, $\hat{fi}$, of a known distribution function at mid-interval of each category.

Chi-square statistics for a goodness-of-fit test is given by the following model; (Hays, ١٩٦٣).

$$\chi^2 = \sum \frac{\left(fi - \hat{fi}\right)^2}{\hat{fi}} \qquad .....(٣-٥)$$

where;

fi : actual frequency value at mid-interval of each category.

$\hat{f}_i$: expected frequency value at mid-interval of each category.

i : class interval.

χ^2 value will be compared with critical value (χ^2_α) from Table (A-٣) in Appendix A to take decision about rejection or acceptance of the proposed distribution (null hypothesis, H_o).

If $\chi^2 \le \chi^2_\alpha$ accept H_o.

If $\chi^2 > \chi^2_\alpha$ reject H_o.

Lawrence (١٩٨٣), proposed the following steps for running the Chi-square test:

١- Formulate the null hypothesis (*Ho*), for example the sample data represent a normal distribution.

٢- Establish the significance level, degree of freedom, and the acceptance and rejection rejoins for the decision rule. For example, A ٥٪ significance level and (٤) degree of freedom will result with critical value $\chi^2 = 9.488$ (from Table (A-٣) in Appendix A). Degree of freedom may be calculated as follows: (Lawrence, ١٩٨٣)

Degree of freedom = Number of categories – Number of the estimated parameters – ١ .....(٣-٦)

٣- Compute the test statistics, this step includes the finding of the actual and expected frequencies and computing χ^2 value.

٤- Make the decision of rejecting or accepting of the null hypothesis (*Ho*), by comparing (χ^2) value with ($\chi^2{}_\alpha$) value.

٣.٤ Log-Normal Distribution as the Candidate Distribution

Usually final effluent data from wastewater treatment plants have a positive skewness (distribution toward higher values). This skewed data can be fitted by using log-normal or gama distribution, (Niku et al, ١٩٧٩). But the log-normal distribution is the most candidate distribution function to eliminate this skewness, as recommended by Benjamin and Cornell (١٩٧٠), Popel (١٩٧٦), and Niku et al. (١٩٧٩).

The log-normal probability law is one commonly used in civil engineering practice and seems to have been adopted originally to produce a better fit to skewed data by using this simple transformation of the familiar normal distribution. (Benjamin and Cornell, ١٩٧٠).

The log-normal distribution has the following probability density function; (Benjamin and Cornell, ١٩٧٠).

$$f_x(x)=\frac{1}{x.\sqrt{2\pi}\,\sigma \ln x}\exp.\left[-\frac{1}{2}\left[\frac{1}{\sigma \ln x}.\ln\left(\frac{x}{m\bar{x}}\right)\right]^2\right] \quad x\geq 0 \quad .....(٣\text{-}٧)$$

where;

x : represents effluent variable concentration.

$\sigma \ln x$: standard deviation of the logarithm of *x*.

$m\bar{x}$: median of *x*.

From the properties of the moment-generating function of the normal distribution, the rth moment about the origin as denoted by $E(X^r)$ is given by; (Benjamin and Cornell, ١٩٧٠).

$$E\left(x^r\right)=\left(m\bar{x}\right)^r.\exp\left(\frac{1}{2}r^2,\sigma^2_{\ln x}\right) \quad .....(٣-٨)$$

In particular,

$$mx=m\bar{x}.\exp\left(\frac{1}{2}\delta^2_{\ln x}\right) \quad .....(٣-٩)$$

$$\sigma x^2=mx^2.\left[\exp\left(\sigma^2_{\ln x}\right)-1\right] \quad .....(٣-١٠)$$

where;

mx : mean of data.

σx^2 : variance of data.

From Equations (٣-٩) and (٣-١٠), the relationships for the parameters of probability density function of the log-normal distribution in terms of the moments of variable *x* are; (Benjamin and Cornell, ١٩٧٠).

$$m_{\ln x}=\ln\left(\frac{\sigma_x^2}{mx^2}+1\right) \quad .....(٣-١١)$$

and

$$\sigma^2_{\ln x}=\ln mx-\frac{1}{2}\sigma^2_{\ln x} \quad .....(٣-١٢)$$

where

$m\ln x$: mean of the natural logarithm of *x*.

$\sigma^2_{\ln x}$: variance of the logarithm of x.

٣.٥ Development of the Reliability Model

Niku et al. (١٩٧٩), constructed a statistical model for predicting the mean constituent value under a certain level of reliability. This model can be used for designing of wastewater treatment plants, and for estimating of reliability of the plants under operation.

Niku et al., constructed their model on the basis that effluent concentration distribution for the ($BOD_٥$) and (S.S) data fit a log-normal distribution.

Statistical models, which constructed for designing of wastewater treatment plants, should be designed to produce an average effluent concentration below the discharge standards because of the variations in effluent quality. Popel (١٩٧٦), Roper et al. (١٩٧٩), and Niku et al. (١٩٧٩).

The question is, what mean value guarantees effluent concentration consistently less than a standard with a certain reliability?. The coefficient of reliability may be introduced that relates mean constituent values (that is, the design values) to the standard that must be achieved on probability basis. The mean constituent value, *mx*, is then obtained from the following equation; (Niku et al, ١٩٧٩).

$$mx = (COR) * X_s \qquad \text{.....(٣-١٣)}$$

where;

X_s : a fixed standard.

COR : coefficient of reliability.

The problem of interest to the designer engineer is to develop an expression for the coefficient of reliability from which one may compute the necessary mean value of the process that guarantees the reliability level ($١-\alpha$).

Suppose that, for some probability of failure α between (٠) and (١), but presumably this value of α is near zero, the designer engineer wish to

design the treatment process for which the observed log-normal variable X has the property that;

$$P(x \le x_s) = 1 - \alpha \qquad \text{.....(٣-١٤)}$$

This equation is equivalent to choosing the parameters of the log-normal, so that:

$$P\left(Z \le \frac{\ln x_s - m_{\ln x}}{\sigma_{\ln x}} \right) = 1 - \alpha \qquad \text{.....(٣-١٥)}$$

where Z is a standardized normal variable. If $Z_{١-\alpha}$ defined to be the number with the property that:

$$P(Z \le Z_{1-\alpha}) = 1 - \alpha \qquad \text{.....(٣-١٦)}$$

then $Z_{١-\alpha}$ may be obtained from the standard normal tables.

Substituting the properties of log-normal distribution (Equations (٣-١١) and (٣-١٢)) in equation (٣-١٥) results in the following; (Niku et al, ١٩٧٩).

$$\frac{\ln x_s - \left[\ln mx - \frac{1}{2}\left(v_x^2 + 1\right) \right]}{\left[\ln\left(v_x^2 + 1\right)\right]^{1/2}} = Z_{١-\alpha}$$

where $Vx = \sigma_x / m_x$ .....(٣-١٧)

this equation can be manipulated as follows;

$$\ln x_s - \left[\ln mx - \frac{1}{2}\ln\left(v_x^2 + 1\right) \right] = z_{1-\alpha}\left[\ln\left(v_x^2 + 1\right)\right]^{1/2}$$

$$\ln x_s - \ln mx + \frac{1}{2}\ln\left(v_x^2 + 1\right) = z_{1-\alpha}\left[\ln\left(v_x^2 + 1\right)\right]^{1/2}$$

$$-\ln x_s + \ln mx - \ln\left(v_x^2 + 1\right)^{1/2} = -z_{1-\alpha}\left[\ln\left(v_x^2 + 1\right)\right]^{1/2}$$

$$\ln\left[\frac{mx}{x_s.\left(v_x^2+1\right)^{1/2}}\right]=-z_{1-\alpha}\left[\ln\left(v_x^2+1\right)\right]^{1/2}$$

$$\frac{mx}{x_{s.}\left(v_x^2+1\right)^{1/2}}=\exp.\left(-z_{1-\alpha}\left[\ln\left(v_x^2+1\right)\right]^{1/2}\right)$$

$$\frac{mx}{x_s}=\left(v_x^2+1\right)^{1/2}.\exp\left[-z_{r\alpha}\left(\ln\left(v_x^2+1\right)\right)^{1/2}\right]$$

we have $COR=\frac{mx}{x_s}$, then

$$COR=\frac{mx}{x_s}=\left(v_x^2+1\right)^{1/2}.\exp\left[-z_{1-\alpha}\left(\ln\left(v_x^2+1\right)\right)^{1/2}\right] \qquad .....(٣-١٨)$$

where;

Vx : coefficient of variation.

The COR (Equation (٣-١٨)) relates the mean constituent value, *mx*, to the standard, X_S, for reliability level ١-α.

Two statistical parameters are used in ratability determinations:

* The first parameter is the coefficient of variation, Vx, which is the ratio of the standard deviation, σ_x, and the mean value, mx; (Niku et al., ١٩٧٩).

$$Vx=\frac{\sigma_x}{mx} \qquad .....(٣-١٩)$$

* The second parameter is the percentiles $Z_{١-\alpha}$, of the standard normal distribution; that is the number of standard deviations by which *X* differs from the mean.

Values of the COR for effluent concentrations for different coefficients of variation at different levels of reliability are given in Table (٣-١). In Table (٣-٢), the fractional reliability for effluent

concentrations is presented as a function of *Vx* and *COR*. The results of Table (٣-٢) have been shown graphically in Figure (٣-٢).

Table (٣-١): COR as a function of (Vx) and reliability. (After Niku et al., ١٩٧٩).

Reliability	٥٠٪	٨٠٪	٩٠%	٩٢٪	٩٥٪	٩٨٪	٩٩٪	٩٩.٩٪
Vx								
٠.٣	١.٠٤	٠.٨١	٠.٧١	٠.٦٩	٠.٦٤	٠.٥٧	٠.٥٣	٠.٤١
٠.٤	١.٠٨	٠.٧٨	٠.٦٦	٠.٦٣	٠.٥٧	٠.٤٩	٠.٤٤	٠.٣٣
٠.٥	١.١٢	٠.٧٥	٠.٦١	٠.٥٨	٠.٥١	٠.٤٢	٠.٣٧	٠.٢٦
٠.٦	١.١٧	٠.٧٣	٠.٥٧	٠.٥٤	٠.٤٧	٠.٣٧	٠.٣٢	٠.٢١
٠.٧	١.٢٢	٠.٧٢	٠.٥٤	٠.٥٠	٠.٤٣	٠.٣٣	٠.٢٨	٠.١٨
٠.٨	١.٢٨	٠.٧١	٠.٥٢	٠.٤٨	٠.٤٠	٠.٣٠	٠.٢٥	٠.١٦
٠.٩	١.٣٥	٠.٧٠	٠.٥٠	٠.٤٦	٠.٣٨	٠.٢٨	٠.٢٢	٠.١٤
١.٠	١.٤١	٠.٧٠	٠.٤٩	٠.٤٤	٠.٣٦	٠.٢٦	٠.٢٠	٠.١٣

Table (٣-٢): Reliability as a function of normalized mean, and Vx of effluent concentration. (After Niku et al., ١٩٧٩).

COR	٠.١	٠.٢	٠.٣	٠.٤	٠.٥	٠.٦	٠.٧	٠.٨	٠.٩	١.٠	١.٢٥	١.٥
	Vx											
	٠.٣	٠.٩٩٩٩	٠.٩٩٩٩	٠.٩٩٩٥	٠.٩٩٣٩	٠.٩٧٠٦	٠.٩١٣٤	٠.٨١٧٩	٠.٦٩٣٢	٠.٥٥٨٣	٠.٢٦٩٨	٠.١٠٨٣
	٠.٤	٠.٩٩٩٩	٠.٩٩٩٩	٠.٩٩٩٥	٠.٩٩٥٠	٠.٩٧٦٧	٠.٩٣٥٣	٠.٨٦٨١	٠.٧٧٩٩	٠.٦٧٩٣	٠.٥٧٦٣	٠.٣٥٠٧	٠.١٩٥٠
	٠.٥	٠.٩٩٩٩	٠.٩٩٩٩	٠.٩٩٧٣	٠.٩٨٥٢	٠.٩٥٥٧	٠.٩٠٦٢	٠.٨٣٩١	٠.٧٦٠٧	٠.٦٧٧٠	٠.٥٩٣٤	٠.٤٠٦٤	٠.٢٦٦٩
	٠.٦	٠.٩٩٩٩	٠.٩٩٩٣	٠.٩٩٢٨	٠.٩٧٣٢	٠.٩٣٦٦	٠.٨٨٤٦	٠.٨٢١٢	٠.٧٥١٦	٠.٦٧٩٨	٠.٦٠٩٢	٠.٤٥٠٢	٠.٣٢٥١
	٠.٧	٠.٩٩٩٩	٠.٩٩٧٩	٠.٩٨٦٩	٠.٩٦١٠	٠.٩٢١٢	٠.٨٦٧٥	٠.٨١٠٧	٠.٧٤٨٣	٠.٦٨٥٣	٠.٦٢٣٩	٠.٤٨٥٠	٠.٣٧٢١
	٠.٨	٠.٩٩٩٩	٠.٩٩٥٩	٠.٩٨٠٥	٠.٩٥٠٩	٠.٩٠٨٧	٠.٨٥٩٤	٠.٨٠٤٧	٠.٧٤٨٢	٠.٦٩٢٠	٠.٦٣٧٣	٠.٥١٣٧	٠.٤١١٠
	٠.٩	٠.٩٩٩٦	٠.٩٩٣٢	٠.٩٧٤٣	٠.٩٤٣٢	٠.٩٠٠٦	٠.٨٢٧٠	٠.٨٠١٨	٠.٧٥٣٩	٠.٦٩٩٢	٠.٦٤٩٩	٠.٥٣٨٠	٠.٤٤٣٩
	١.٠	٠.٩٩٩٣	٠.٩٩٠٥	٠.٩٦٨٨	٠.٩٣٥٣	٠.٨٩٤١	٠.٨٤٨٥	٠.٨٠٠٩	٠.٧٥٣٠	٠.٧٠٦٥	٠.٦٦١٤	٠.٥٥٨٩	٠.٤٧١٨
	١.٢	٠.٩٩٨٢	٠.٩٨٥١	٠.٩٥٩٧	٠.٩٢٥٤	٠.٨٨٦٠	٠.٨٤٤٥	٠.٨٠٢٣	٠.٧٦٠٤	٠.٧٢٠١	٠.٦٨١٦	٠.٥٩٣٦	٠.٤٨٢٨
	١.٥	٠.٩٩٦١	٠.٩٧٨٥	٠.٩٥٠٧	٠.٩١٧٢	٠.٨٨١٢	٠.٨٤٤٦	٠.٧٧٥٤	٠.٧٧٢٨	٠.٧٣٨٩	٠.٧٠٧٥	٠.٥٦١٢	٠.٥٦٧٥

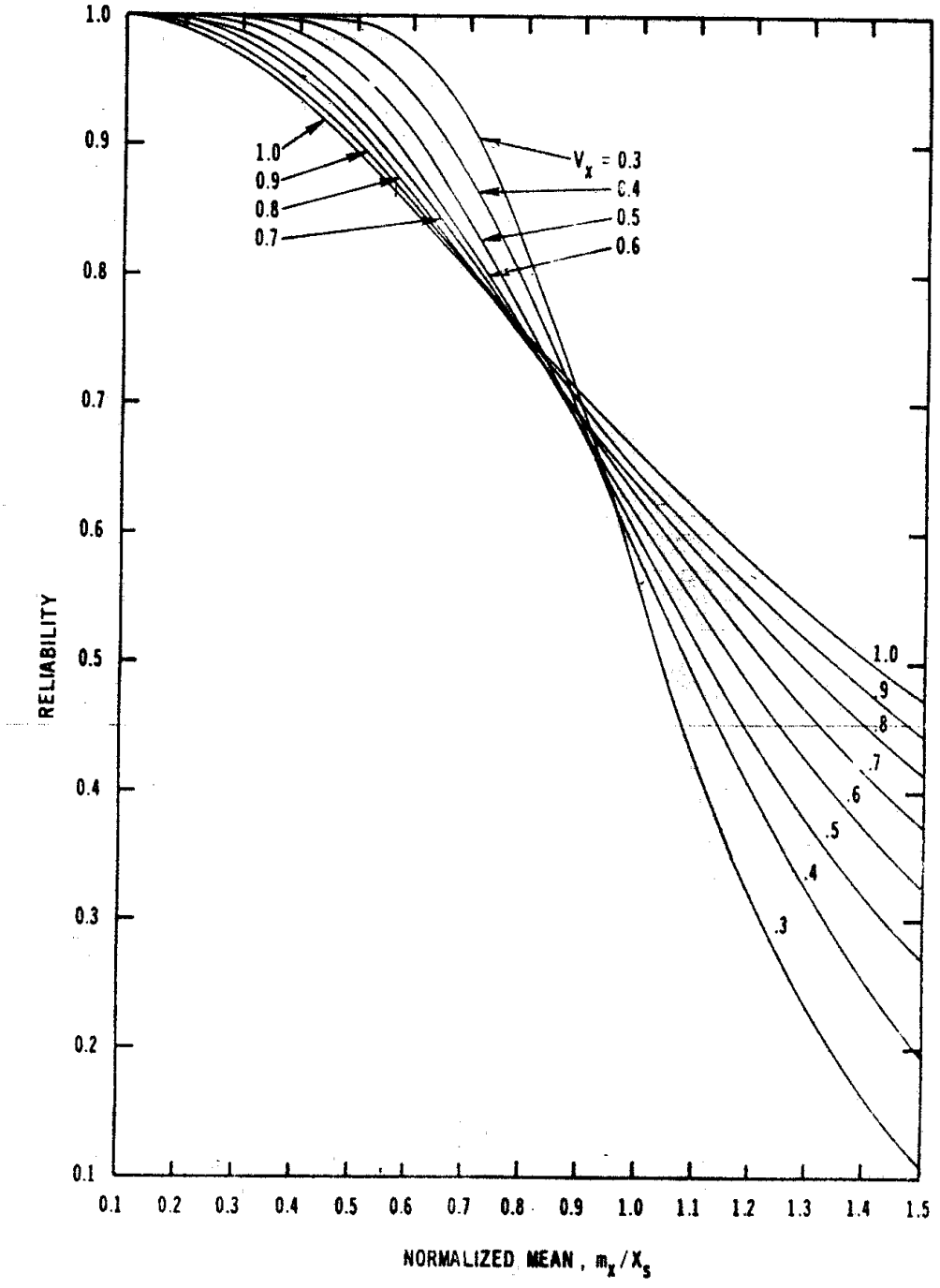


Figure (٣.٢): Reliability versus normalized mean for different coefficient of variation (After Niku et al., ١٩٧٩).

٣.٦ Reliability Model Applications

Niku et al. (١٩٧٩), developed their model for the purpose of the design of wastewater treatment plants and the estimation of reliability of the plants under operation.

٣-٦-١ Using the Model in Designing of Treatment Plants

The results of Table (٣-١) have a significant potential application in design. Values of COR given in the table may be used in design of a treatment plant expected to perform a certain reliability. The coefficient of variation for effluent concentration should be estimated. Selection of the appropriate design value of the coefficient of variation, Vx, must be based on reasonable expectation of performance (that is, experience). This may be done from past experience or using the results from other similar treatment plants. (Niku et al., ١٩٧٩).

Values of coefficient of variation for effluent BOD٥and S.S for some treatment plants are given in Table (٣-٣) as given by Niku et al.(١٩٨٢).

Applications of the results of Table (٣-١) in designing process are described by the following example; (Niku et al., ١٩٧٩).

To have ٩٥٪ reliability that effluent BOD٥ concentration is equal or less than a certain standard, X_S, when *Vx* for the plant is estimated to be ٠.٧, by using the results of Table (٣-١), the plant should be designed for the mean value equal to or less than ٠.٤٣ X_S. (If X_S = ٣٠ mg/l then average BOD٥=٠.٤٣*٣٠=١٢.٩ mg/l or less. Similarly, for a less stringent standard of X_S= ٤٠ mg/l; average BOD٥= ٠.٤٣*٤٠=١٧.٢ mg/l or less).

Table (٣-٣): Estimated coefficient of variations (V_s) of various process types (After Niku et al. ١٩٨١)

Process type	Coefficient of variability
BOD	
Step feed / aeration	٠.٦٨
Conventional	٠.٦٩
Complete-mix	٠.٧٧
Contact-stabilization	٠.٧٦
Trickling filters	٠.٤٦
S.S.	
Step feed /aeration	٠.٨٣
Conventional	٠.٨٦
Complete-mix	١.٠٠
Contact-stabilization	٠.٩٠
Tricking filters	٠.٥٢

٣-٦-٢ Using of the Model in Reliability Prediction

Results from Table (٣-٢) or Fig.(٣-٢) may be used to estimate the reliability of a treatment plant under operation if the mean and standard deviation for the plant are known. For example, there is ٨٧٪ reliability in a plant operating with COR = ٠.٦ and a Vx=٠.٧. (Niku et al., ١٩٧٩).

٣.٧ Process Stability

The term "process stability" has often been used without a formal definition to describe plants with consistent performance. Stability may be defined in terms of the magnitude of the perturbations of effluent quality characteristics from the mean values. For example, a process may be considered stable when fluctuations exist in input loading but large variations will not appear in the effluent quality characteristics. Process stability may be analyzed by three approaches: experiment studies under laboratory conditions, mathematical modeling and simulation techniques, and statistical measures. (Niku et al, ١٩٨١).

usually experimental studies under laboratory conditions are performed under favorable laboratory conditions permitting investigation of individual variables and thus don't reflect the variations encountered in full-scale operations. Therefore, working with full-scale plant data is preferable where the objective is to develop a measure of actual system stability. (Niku et al., ١٩٨١).

Mathematical modeling and simulation techniques are another techniques occasionally used for quantitative description of waste treatment process performance. The results of these techniques should be used with caution in stability studies, because these techniques are based on the assumption of steady-state conditions, whereas the concern in stability studies is non-steady – state conditions. (Andrews, ١٩٧٤).

Because of the intricate nature of the stability problem and the fact that many of the parameters affecting effluent quality are inherently stochastic, an obvious approach to analyzing process stability is through statistical analysis. Statistical examination techniques can be used to identify and quantify numerical characteristics exiting in the data. Dealing with data from full-scale plants, the stability of a process may be evaluated

both qualitatively and quantitatively. In this case, all variables affecting the process variation are considered, regardless of their cause and effect relationships. (Niku et al, ١٩٨١).

٣.٨ Stability Measurement

Stability may be thought of as the property of adherence to a reference or norm. In the case of wastewater treatment, the best reference value for stability appears to be the annual mean of constituent concentration. One complete cycle of weather and a monitoring period long enough to damp the effects of short-term variations is reflected in the annual mean value. Variations from the mean on a day-to day, week – to – week, or month-to-month basis then provided a measure of stability (Niku et al., ١٩٨٢).

Since stability is a measure of variations from the mean, for comparison purposes a standard quantitative measure of variation (stability indicator) is of special interest. The stability indicator may be used as a tool for evaluating different plants statistically and comparing their relative stability and for examining the effects of various design and operation procedures have on process stability. The indicators available are variance and standard deviation, coefficient of variation, and coefficient of stability. (Niku et al., ١٩٨١).

٣-٨-١ Variance and Standard Deviation

The most common measure of dispersion are variance and standard deviation. Variance ($Sx^{٢}$) is defined as the weighted average of the squared deviations from the mean (Benjamin and Cornell, ١٩٧٠).

$$S x^2 = \frac{1}{1-n} \sum_{i=1}^{n} (x_i - \bar{x})^2 \qquad .....(٣-٢٠)$$

where:

n : number of observations.

x_i : observation value.

$\bar{x}$: mean of observations values.

i : class interval.

In practice the positive square root of the variance, called standard deviation (Sx) is given more importance than the variance because this value has the same units as the variable.

Standard deviation may be used as a logical indicator for stability comparison of plants. Smaller standard deviations generally imply tighter distributions, less widely spread about the mean, and therefore a more stable situation. This has been shown schematically in Fig.(٣-٣), where probability density functions of the same basic shape but having different means or standard deviations are shown. The curves in sections (a) and (b) of the figure differ only in their mean, while the curves in sections(b) and (c) differ only in their standard deviation. The curve in section (c), which has a wide spread – corresponds to less stable situation than the curve shown in section (b). (Niku et al., ١٩٨١).

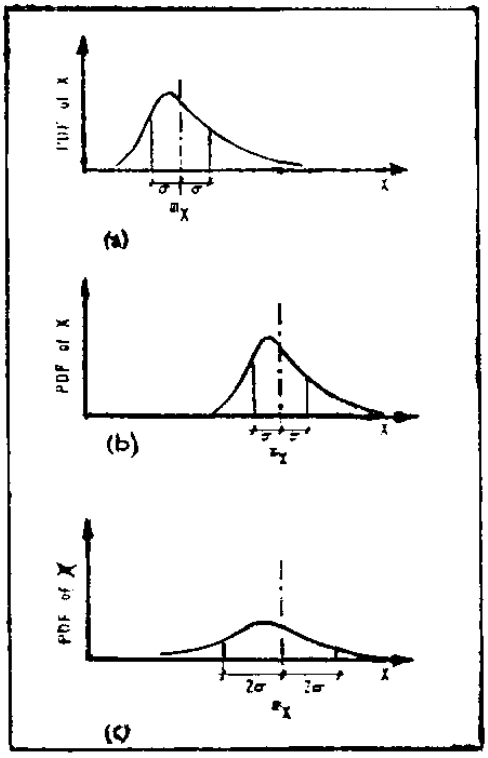


Fig.(٣-٣): Changes in probability density function (P.D.F), with changes in the mean and in the standard deviation (After Niku et al, ١٩٨١).

٣-٨-٢ Coefficient of Variation (VX)

The coefficient of variation, *Vx*, is another common measure of relative dispersion. This coefficient is defined as the ratio of the standard deviation to the mean. (Benjamin and Cornell, ١٩٧٠).

$$Vx = \frac{Sx}{\bar{x}} \qquad \text{.....(٣-٢١)}$$

The coefficient of variation is not a good or logical measure of stability. For example, two plants may have the same coefficient of variation, say (٠.٧), where one plant has a mean of (٥٠) mg/l and standard deviation of (٣٥) mg/l and the other plant has a mean of (١٠) mg/l and a standard deviation of (٧) mg/l. Obviously the latter plant has less variation and thus is more stable than the former. (Niku et al., ١٩٨١).

٣-٨-٣ Coefficient of Stability (COS)

Forsthl (١٩٣٢) has proposed the coefficient of stability (COS), defined as the ratio of variance over the mean, for stability analysis.

$$COS = \frac{Sx^2}{\bar{x}} \qquad .....(٣-٢٢)$$

This coefficient is a far better measure of stability than the coefficient of variation, because it gives more weighted to the variations while taking the mean into account. In other words, plants that are operating at higher mean concentrations are allowed to have more variation than those operating at lower mean concentrations with same measure of stability.

٣.٩ Selection of the Most Appropriate Indicator of Stability

Niku et al. (١٩٨١), selected the standard deviation as the most appropriate indicator of wastewater treatment plant stability, because theoretically it is the measure of dispersion and practically it is the most familiar and simplest term among the measures of stability.

٣.١٠ Stability Cutoff Point

The stability cutoff point may be defined as a standard deviation value below which plants are considered stable and above which plants are considered unstable. (Niku et al., ١٩٨١).

In Fig.(٣-٤), which was constructed by Niku et al., (١٩٨٢) by using effluent ($BOD_٥$) data from (١١) treatment plants, the mean, standard deviation, and range of effluent ($BOD_٥$) data are shown. Examination of the these descriptive statistics leads to the conclusion that plants having standard deviation of less than (١٠) mg/l for effluent ($BOD_٥$) may statistically be considered stable. The (١٠) mg/l has been selected as the

stability cutoff point because distinct difference exists between the statistical characteristics of the plants operating below and above this value.

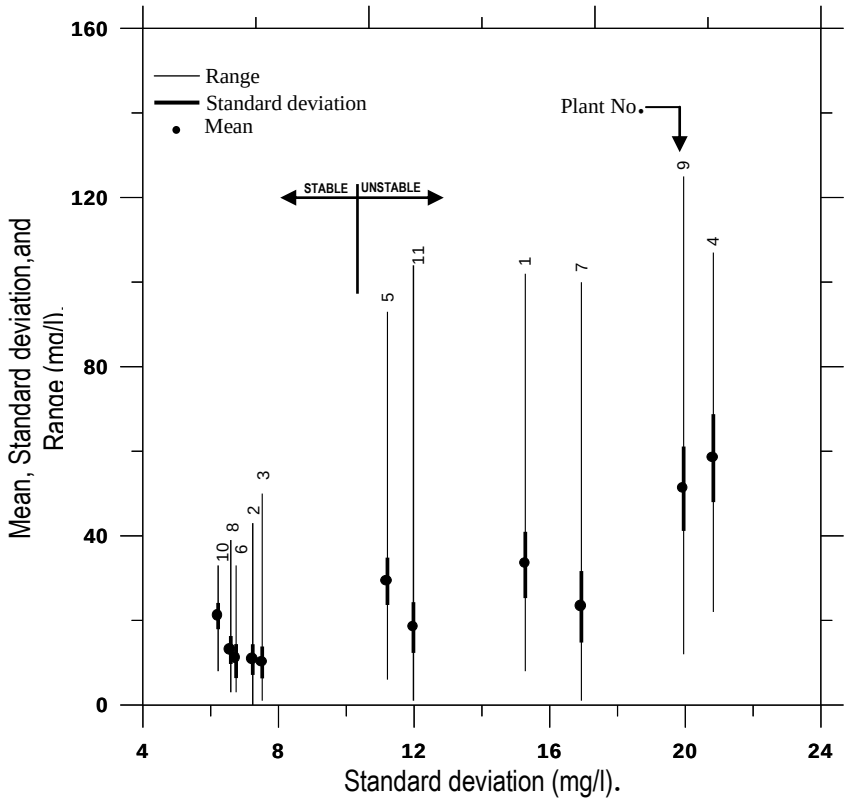


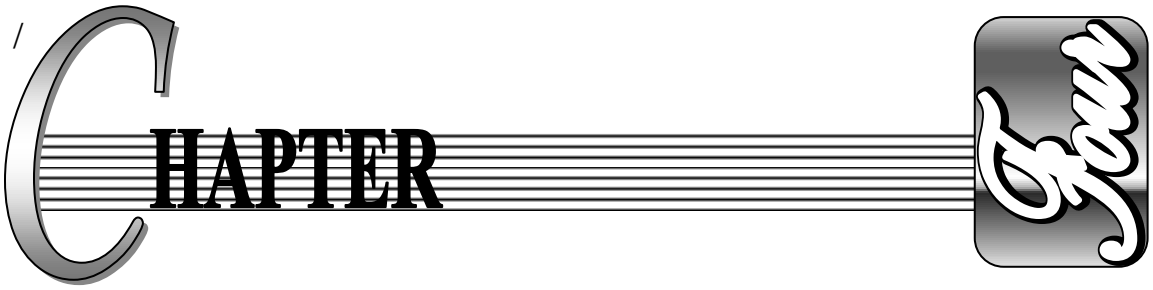
Fig.(٣-٤): Mean, standard deviation, and ranges of effluent (BOD_5) concentration in

different plants. (After Niku et al., ١٩٨٢)

Table (٤-٥): Chi-square test for final effluent (S.S) data of Al-Kerkh wastewater treatment plant.

Year	Line	χ^2 Normal	χ^2 Log-normal	χ^2 Gama	$\chi^2 \alpha = .05$			Normal	Log-normal	Gama
					Normal	Log-normal	Gama			
١٩٨٩	١	٥٥.٥٦	٩.٣٠	٧.٢٩	٥.٩٩	٩.٤٩	٧.٨١	-	X	X
	٢	٣٨.٩٤	٧.٥١	٧.٠٠	٥.٩٩	٩.٤٩	٧.٨١	-	X	X
١٩٩٠	١	٢٣.٧٨	٣.٤٥	٧.٣٥	٥.٩٩	٩.٤٩	٧.٨١	-	X	X
	٢	٢٢.٨٦	٢.٤٧	٧.٧٦	٥.٩٩	٩.٤٩	٧.٨١	-	X	X
١٩٩٢	١	٣٢.١١	٣.٥٩	٧.٠٢	٥.٩٩	٣.٨٤	٧.٨١	-	X	X
	٢	١٤.٧١	٥.١٥	٢.٨٨	٥.٩٩	٥.٩٩	٧.٨١	-	X	X
١٩٩٣	١	٢٣.٦٢	٣.٠٩	١٠.٣٣	٧.٨١	٣.٨٤	٣.٨٤	-	X	-
	٢	٢٠.٨٦	٣.٥٠	٨.٨٦	٣.٨٤	٣.٨٤	٥.٩٩	-	X	-
١٩٩٤	١	٩.٦٦	٥.٦٠	٧.٧٢	٥.٩٩	٧.٨١	٧.٨١	-	X	X
	٢	٩.٣٧	٦.١٥	٤.٧٥	٥.٩٩	٥.٩٩	٥.٩٩	-	-	X
١٩٩٥	١	٤٩.٤٦	٣.٩٧	١٢.٤٧	٣.٨٤	٣.٨٤	٣.٨٤	-	-	-
	٢	٤٧.٧٢	٩.٤٣	٨.٥٤	١١.٠٧	١١.٠٧	١٢.٥٩	-	X	X
١٩٩٦	١	٥٨.٠٧	١٢.٢١	٨.٩٢	١١.٠٧	١١.٠٧	١٢.٥٩	-	X	X
	٢	٦٤.١٧	٩.٧٣	٩.٦١	٩.٤٩	٩.٤٩	١١.٠٧	-	X	X
١٩٩٧	١	٣١.٤٤	٧.٣٢	٧.٧٢	٧.٨١	٧.٨١	٧.٨١	-	X	X
	٢	٤١.٤٢	٩.٤٠	٨.٠٣	٧.٨١	٧.٨١	٩.٤٩	-	X	X

X: Represent the acceptance of distribution type.



ANALYSIS OF THE RESULTS

٤.١ Introduction

This chapter provides the statistical analysis of effluent data of biochemical oxygen demand ($BOD_٥$) and suspended solids (S.S) for lines one and two of Al-Kerkh wastewater treatment plant, in order to investigate the dependability of this plant.

To evaluate the dependability of the above mentioned plant, it is necessary to model the distribution of effluent data. The knowledgement of the probability distribution function makes the reliability of plant easy to compute. As well as it is necessary to establish the common criteria that concerns the performance of the plant.

In this study, the statistical analysis are based on criteria of Iraqi effluent standards of ٤٠ (mg/l) for $BOD_٥$ and ٦٠ (mg/l) of S.S for the treated wastewater disposed into rivers. These criteria are based on the adverse effects that the performance failure may cause on the environment.(Tariq, ١٩٩٨)

٤.٢ Reliability Estimation

Reliability of Al-Kerkh wastewater treatment plant has estimated by using of effluent data of BOD٥ and S.S for eight years of operation (٥٩٩٦ readings).

٤-٢-١ Selection of Distribution Type.

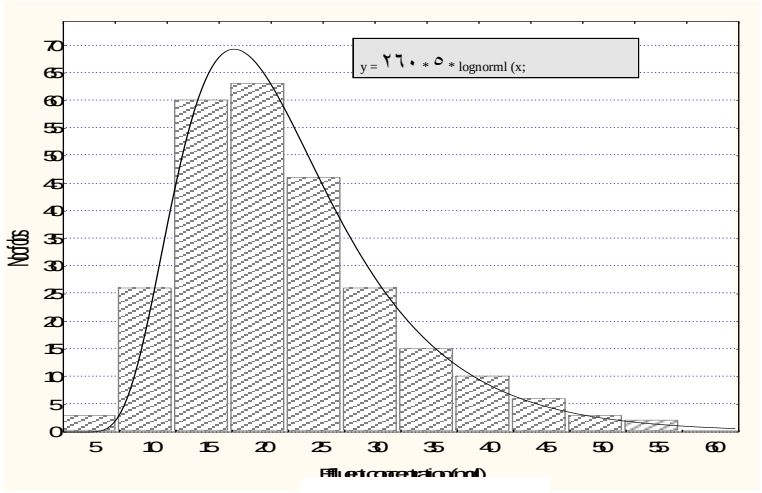
Effluent variability can be shown and analyzed by determining the histogram and probability density function(p.d.f). Figures (٤-١) through (٤-٨) are typical histograms of the final effluent (BOD٥) and (S.S) concentrations of Al-Kerkh wastewater treatment plant (lines one and two).Each figure represents the data of one year. The data of year ١٩٩١ were missing as a result of the war.

The data were not symmetrical and skewed to right of most frequent values, as measured by the skewers coefficient (Table ٤-١).

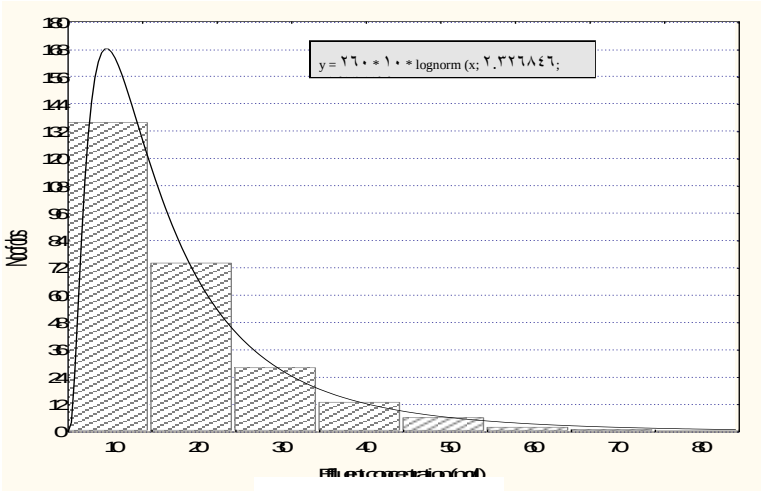
The candidate distribution functions that can be fitted to the skewed data include log-normal and gamma distributions (Benjamin and Cornell, ١٩٧٠), as well as the normal distribution may be suitable for large data (Lawrence, ١٩٨٣). By using Kolmogrov-Simironov test, Tables (٤-٢ and ٤-٣) for effluent BOD٥ and S.S data respectively, and Chi-Square test, Tables (٤-٤ and ٤-٥) for effluent BOD٥ and S.S data respectively. It has been found that the hypothesized log-normal distribution function should not be rejected for both lines at different levels of significance, as shown in these tables. Thus, the discontinuous curve of the histogram can be approximated by superimposed of log-normal probability density function (p.d.f.) as shown in the above mentioned figures.

Table (٤-١): Statistics for final effluent BOD_5 and S.S data of Al-Kerkh wastewater treatment plant.

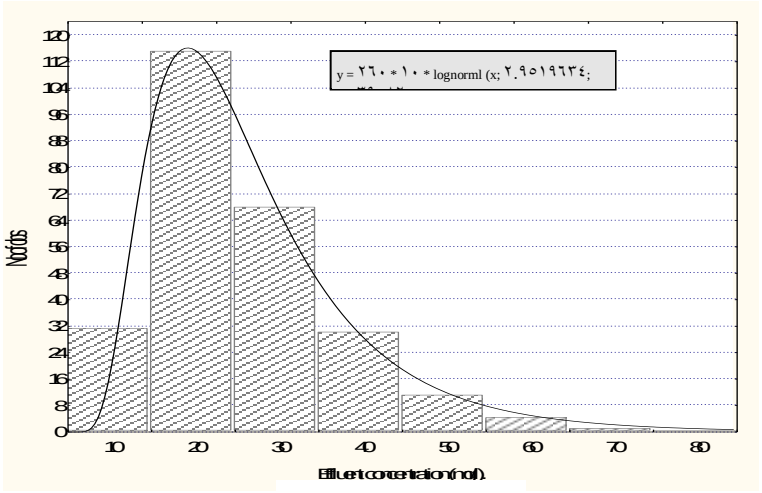
Year	Line	Effluent BOD_5					Effluent S.S				
		Valid Obs.	Mean	S.D.	Vx	Skew-ness	Valid Obs.	Mean	S.D.	Vx	Skew-ness
١٩٨٩	١	٢٦٠	٢٠.٣٠	٨.٤٦	٠.٤٢	١.١١	٢٦٠	١٣.٦٩	٩.٤٥	٠.٦٩	١.٧٤
	٢	٢٦٠	٢١.٣٠	٨.٨٨	٠.٤٢	١.٠٨	٢٥٨	١٧.٧١	٩.٥٧	٠.٥٤	١.٣٢
١٩٩٠	١	٢٤٠	١٨.٤٤	٩.٧٩	٠.٥٣	١.٠٦	٢٤٠	١٩.٤٠	٩.٢٢	٠.٤٨	١.٣٤
	٢	٢٤٠	١٦.٦٠	٩.٤٣	٠.٥٧	٠.٩٧	٢٣٩	١٩.٤١	٩.٨٥	٠.٥١	١.٢٦
١٩٩٢	١	٨٨	٦٠.٥٥	٤٨.٦٠	٠.٨٠	١.٨٢	٩٢	٧٩.٢٢	٦٧.٧٥	٠.٨٦	١.٢٩
	٢	٨٧	٨٩.٢٣	٦٩.٢٢	٠.٧٨	١.٢٦	٩٤	٩٠.٦٦	٨١.٢٥	٠.٩٠	١.٣٨
١٩٩٣	١	١٨٠	٦٣.٠٩	٤٢.٦٠	٠.٦٨	١.٠٩	١٨٠	٦٩.٦٠	٣٧.٤٠	٠.٥٤	٢.٧١
	٢	١٨٠	٧٢.٢٢	٦٣.١٠	٠.٧٧	١.٤٦	١٨٠	٧٤.٨٠	٣٩.١٠	٠.٥٣	٢.٠٢
١٩٩٤	١	١٨٠	٧٢.٨٠	٥٩.٨٠	٠.٨٢	٢.٥٨	١٨٤	٧٦.٠٠	٤٨.٨٠	٠.٦٤	١.٦٨
	٢	١٨٢	٨٣.٣٠	٦٨.٨٠	٠.٨٣	٢.٣٠	١٨٤	٧٦.٠٠	٥١.٧٠	٠.٦٨	١.٤٤
١٩٩٥	١	١٨٠	٤٣.٠٠	٣٥.٠٠	٠.٨١	١.٨٠	١٨٠	٥٧.٥٠	٢٨.٨٠	٠.٥٠	٢.٧٨
	٢	١٨٠	٤٥.٧٠	٣٧.٩٠	٠.٨٣	١.٤٣	١٨١	٥٤.٠٠	٣٦.٢٠	٠.٦٧	١.٠٥
١٩٩٦	١	١٨٥	٣٢.٠٠	٢٦.٢٠	٠.٨٢	٢.٠٢	١٨٣	٤٧.٢	٤٠.٨٠	٠.٨٦	١.٣٦
	٢	١٨٥	٢٩.٣٠	٢١.٣٠	٠.٧٣	٢.٢٠	١٨٣	٤٦.٢٠	٣٦.١٠	٠.٧٩	١.٠٨
١٩٩٧	١	١٨١	٢٨.٨٢	١٧.٨٢	٠.٦٢	١.٦٣	١٨٤	٣٥.٦٠	٢٤.٣٢	٠.٦٨	١.١١
	٢	١٨٢	٢٨.١٥	١٦.٨٤	٠.٧٠	١.٢٤	١٨٤	٣٧.٦٠	٢٤.٥٠	٠.٦٣	١.٣٤



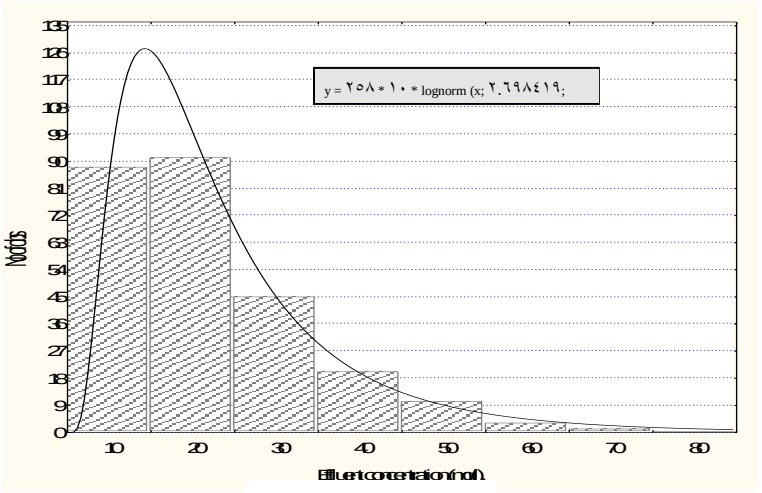
LINE ١- BOD٥



LINE ١- S.S

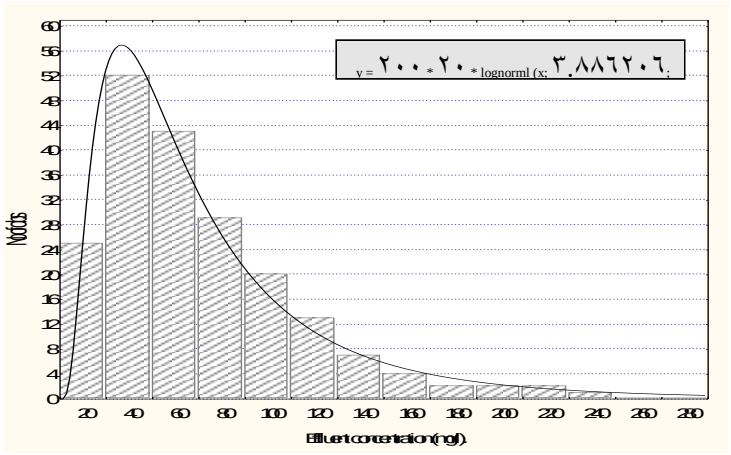


LINE ٢- BOD٥

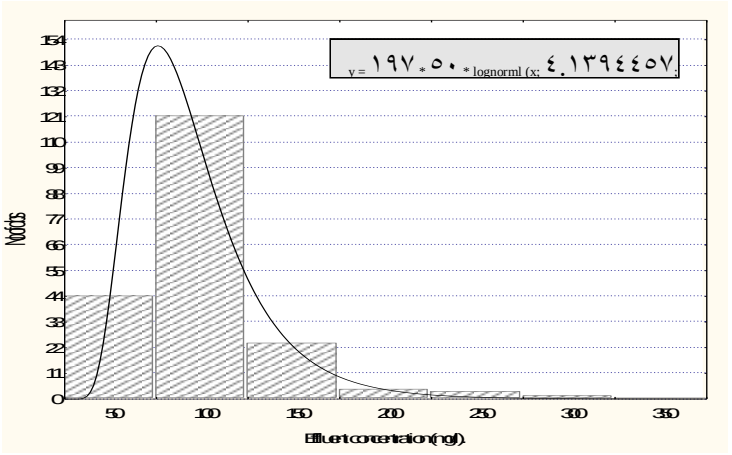


LINE ٢- S.S

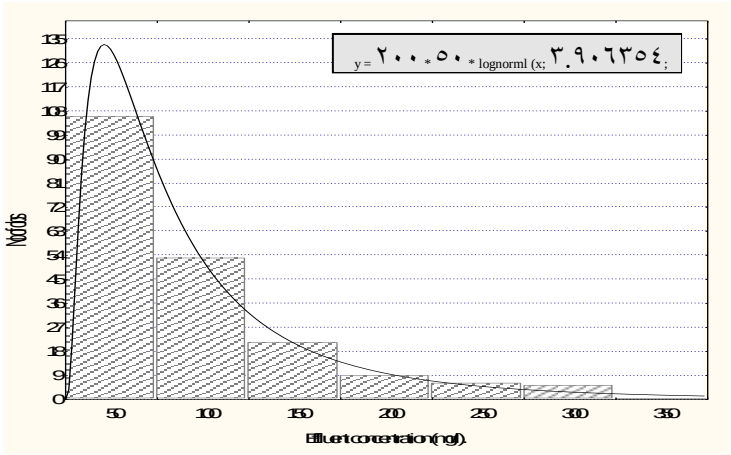
FIGURE (٤-١): Histogram and its p.d.f for final effluent BOD٥ and S.S data (Year١٩٨٩),AL-Kerkh wastewater treatment plant.



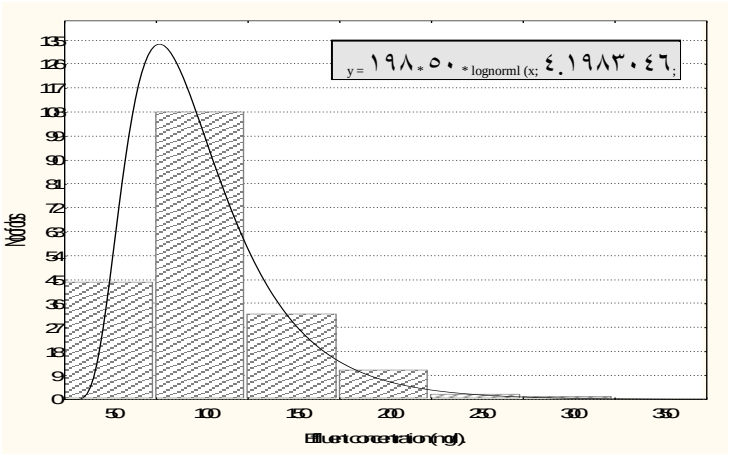
LINE ١- BOD٥



LINE ١- S.S

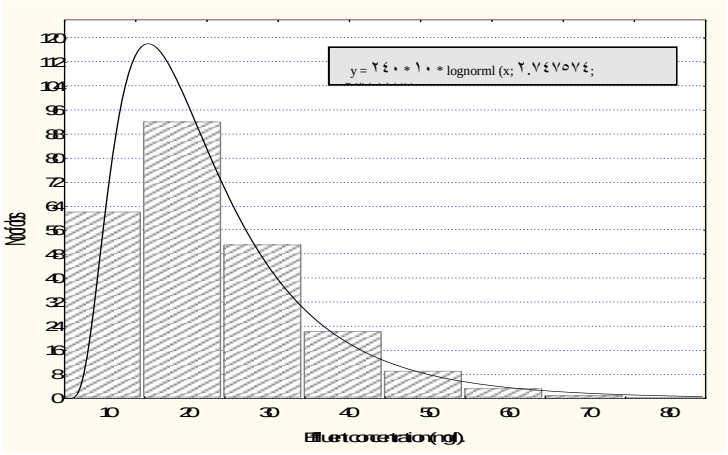


LINE ٢- BOD٥

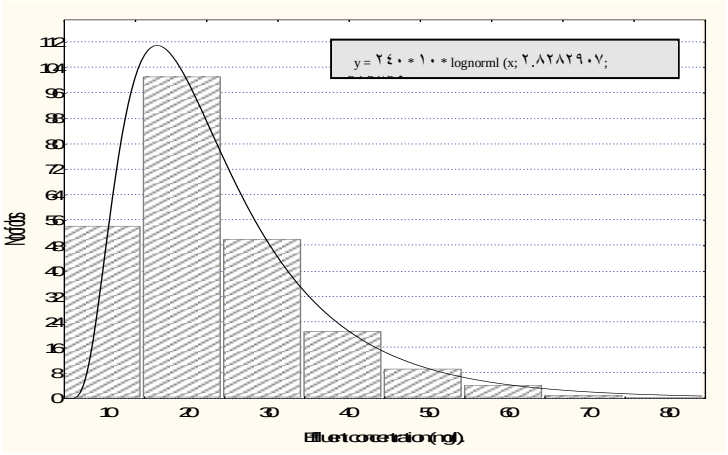


LINE ٢- S.S

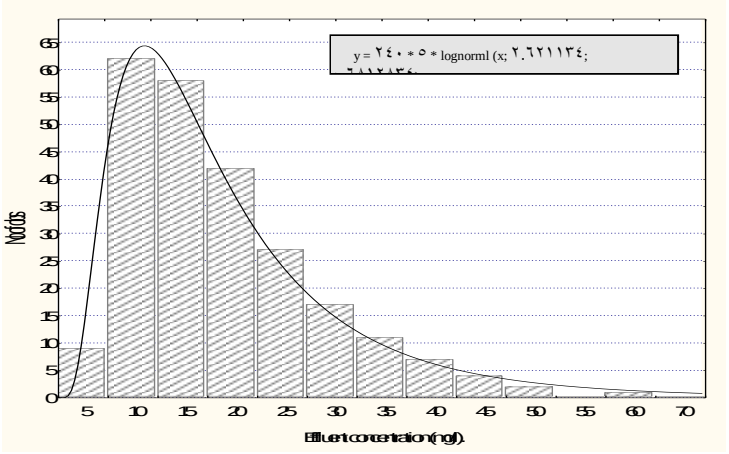
FIGURE (٤-٤): Histogram and its p.d.f for final effluent BOD٥ and S.S data (Year١٩٩٣) ,AL-Kerkh wastewater treatment plant.



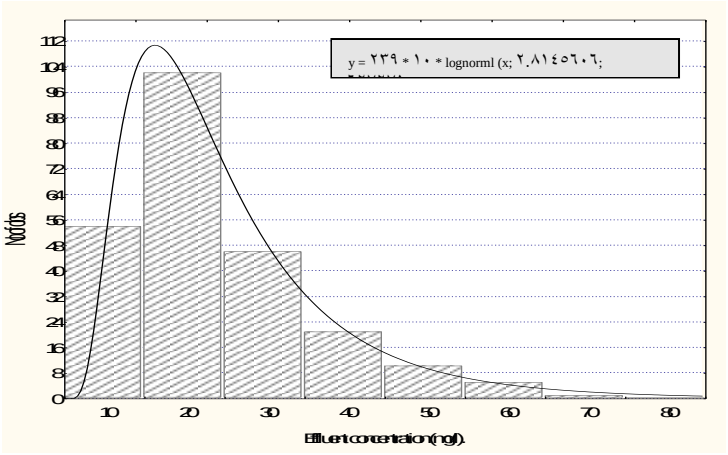
LINE ١- BOD٥



LINE ١- S.S

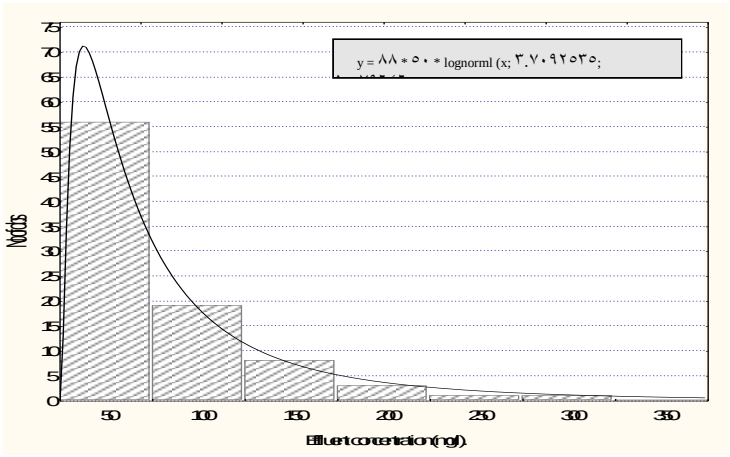


LINE ٢- BOD٥

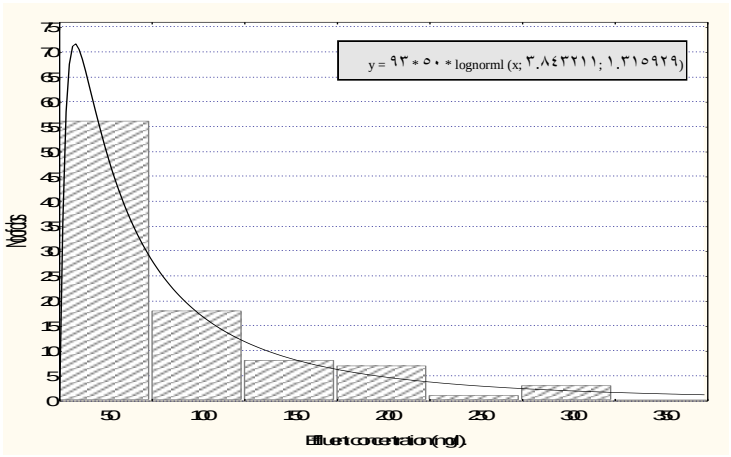


LINE ٢- S.S

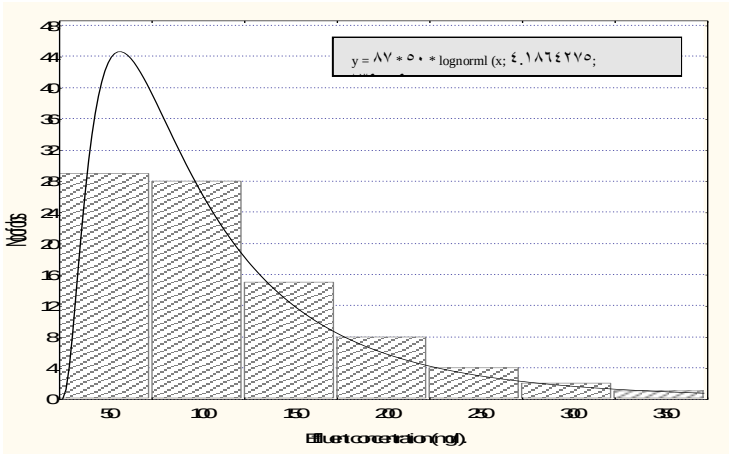
FIGURE (٤-٢): Histogram and its p.d.f for final effluent BOD٥ and S.S data (Year١٩٩٠),AL-Kerkh wastewater treatment plant.



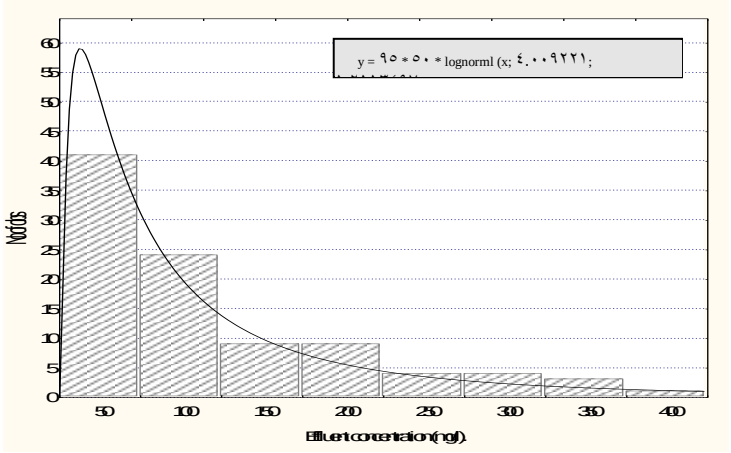
LINE ١- BOD٥



LINE ١- S.S

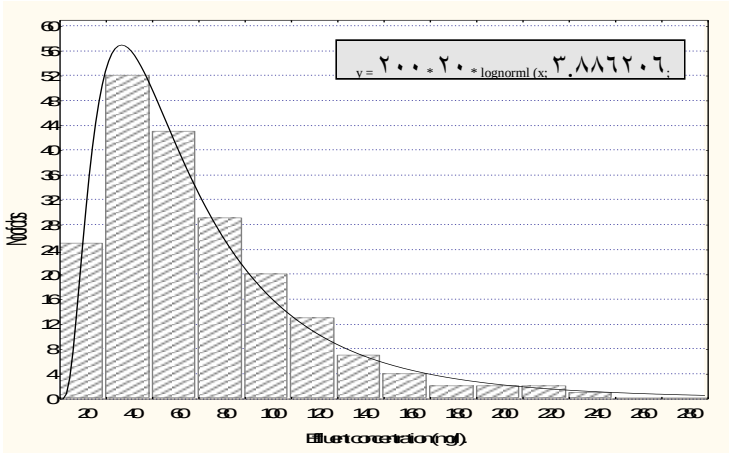


LINE ٢- BOD٥

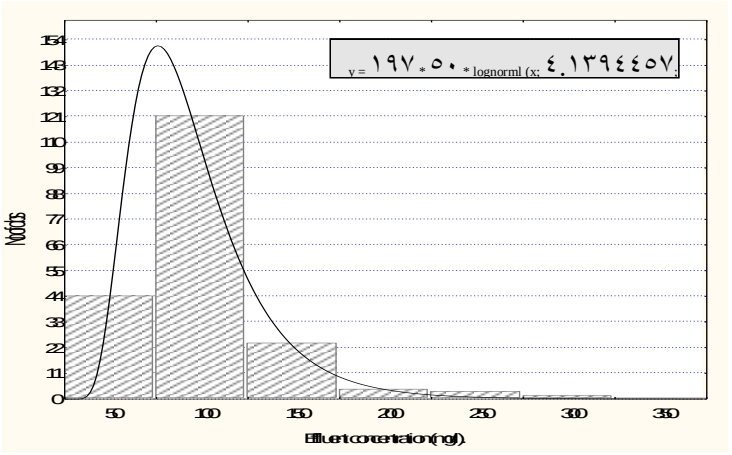


LINE ٢- S.S

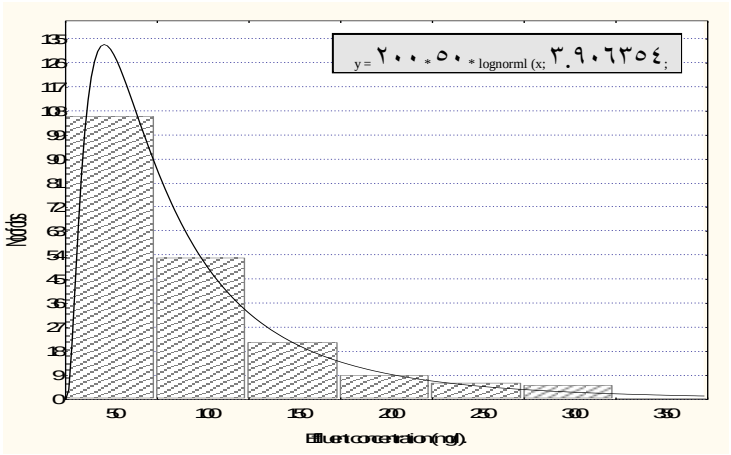
FIGURE (٤-٣): Histogram and its p.d.f for final effluent BOD٥ and S.S data (Year١٩٩٢),AL-Kerkh wastewater treatment plant.



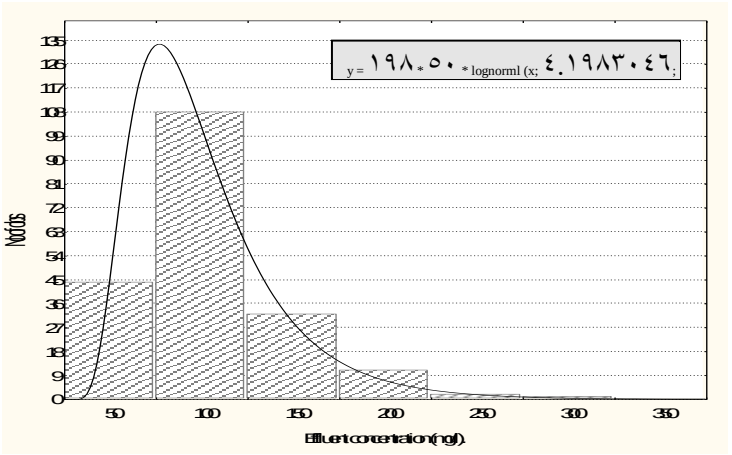
LINE ١- BOD٥



LINE ١- S.S

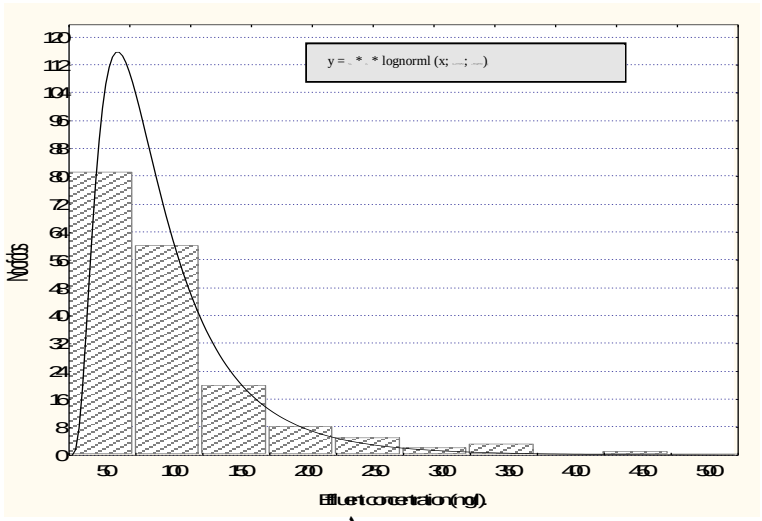


LINE ٢- BOD٥

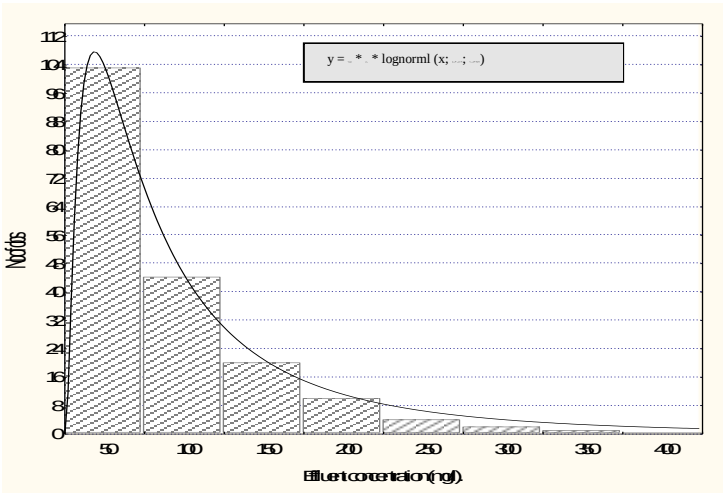


LINE ٢- S.S

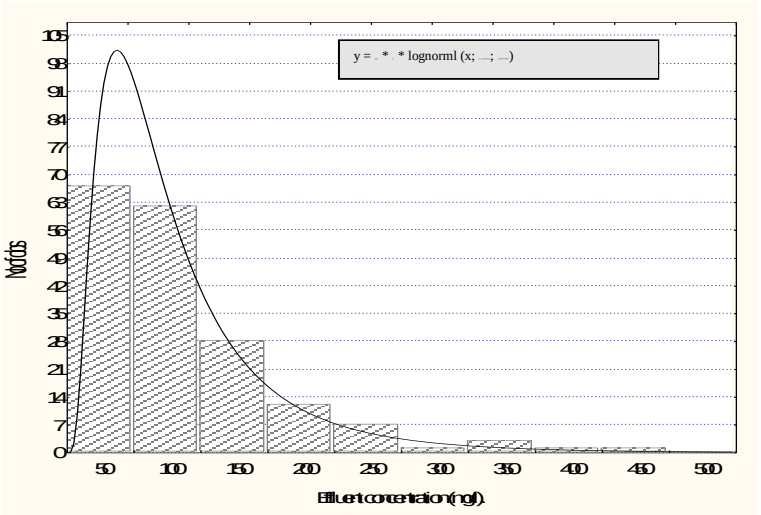
FIGURE (٤-٤): Histogram and its p.d.f for final effluent BOD٥ and S.S data (Year١٩٩٣) ,AL-Kerkh wastewater treatment plant.



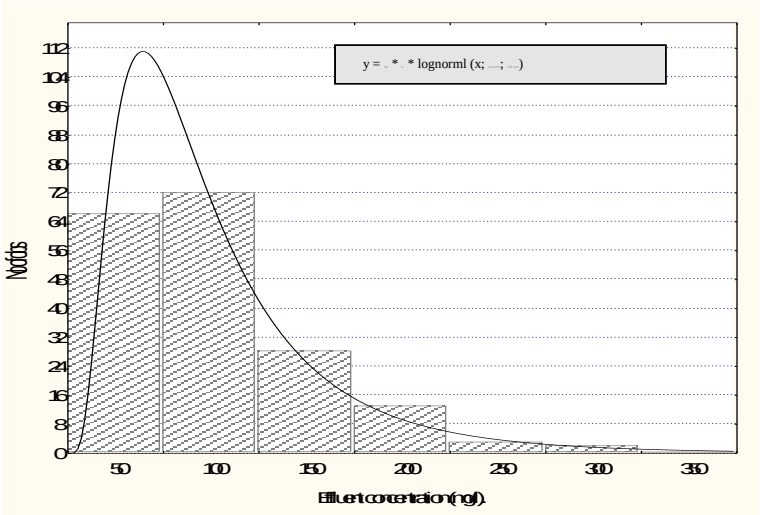
LINE ١- BOD٥



LINE ١- S.S

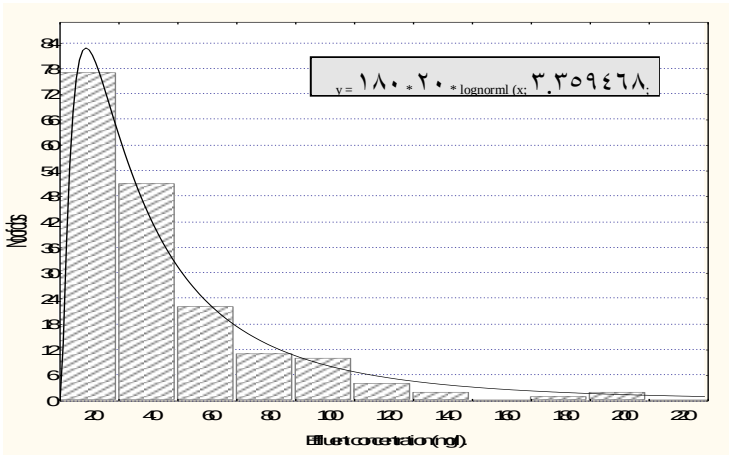


LINE ٢- BOD٥

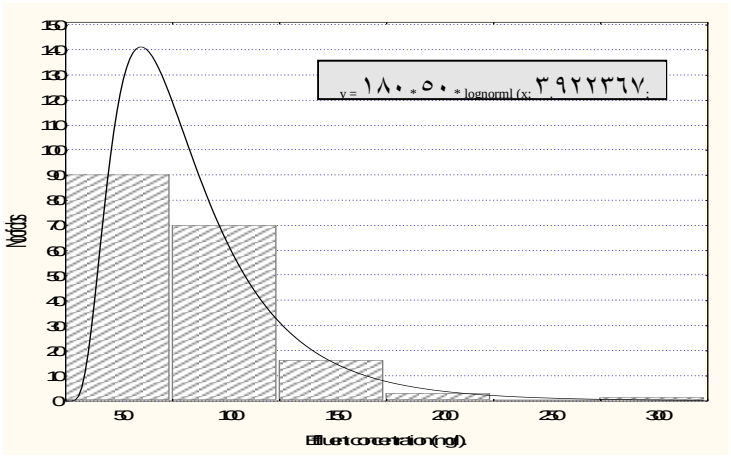


LINE ٢- S.S

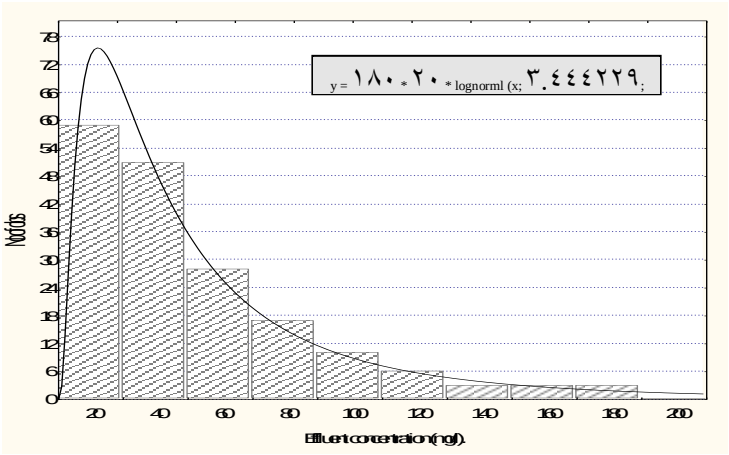
FIGURE (٤-٥): Histogram and its p.d.f for final effluent BOD٥ and S.S data (Year١٩٩٤) , AL-Kerkh wastewater treatment plant.



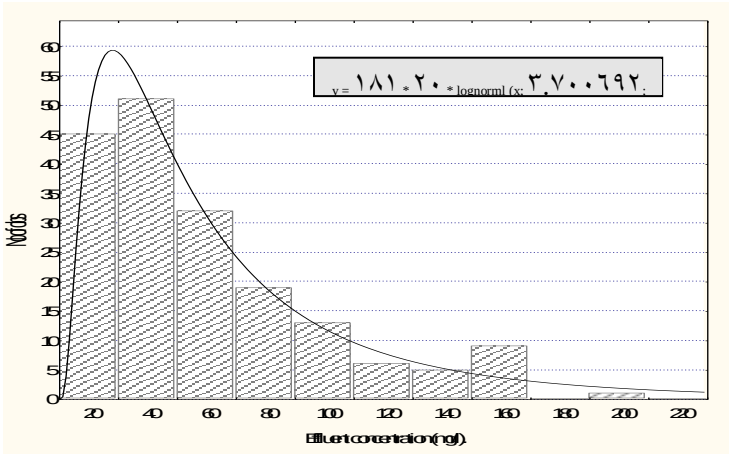
LINE ١- BOD٥



LINE ١- S.S

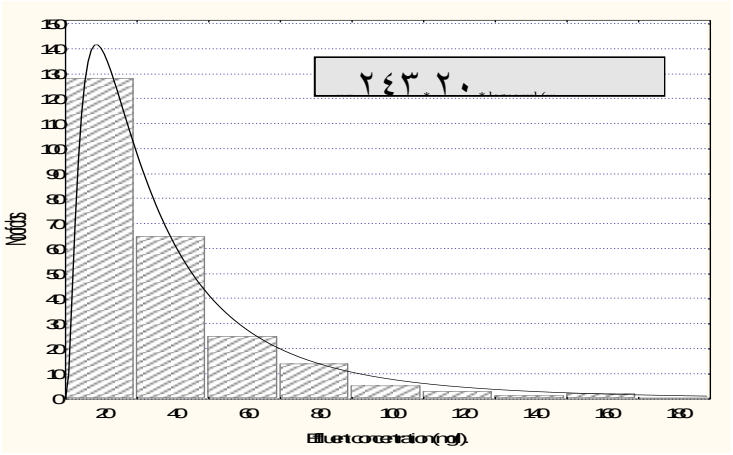


LINE ٢- BOD٥

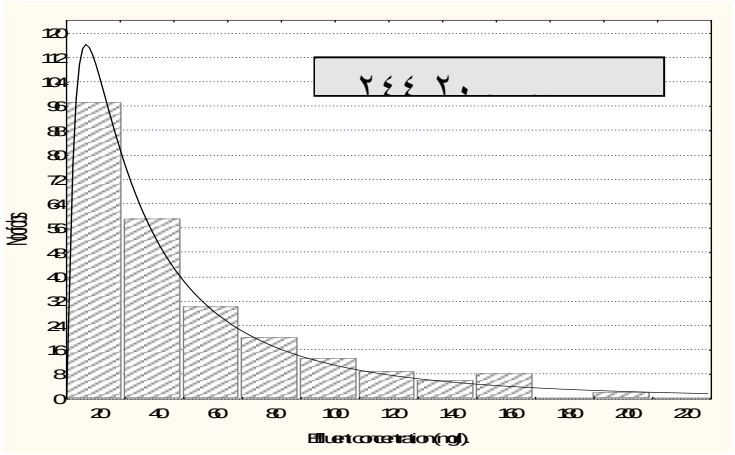


LINE ٢- S.S

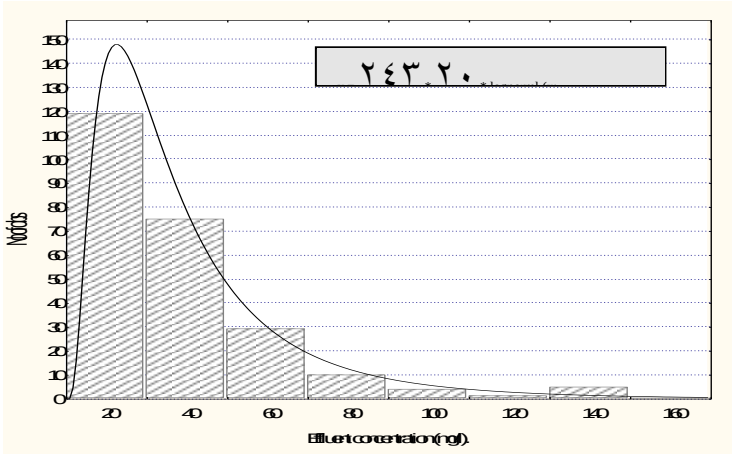
FIGURE (٤-٦): Histogram and its p.d.f for final effluent BOD٥ and S.S data (Year١٩٩٥) ,AL-Kerkh wastewater treatment plant.



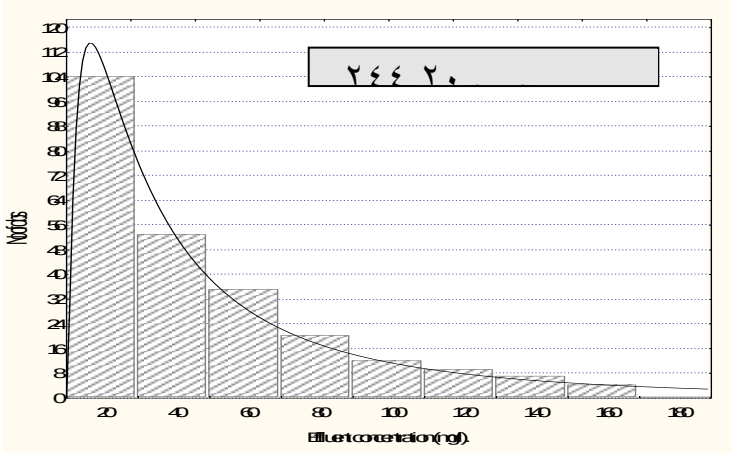
LINE ١- BOD٥



LINE ١- S.S

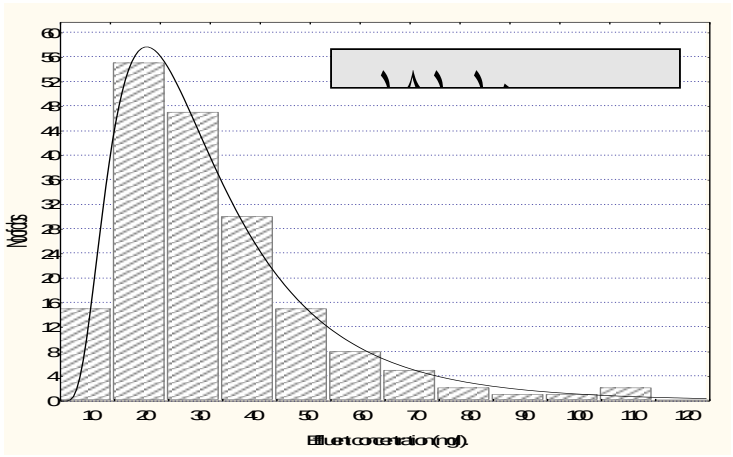


LINE ٢- BOD٥

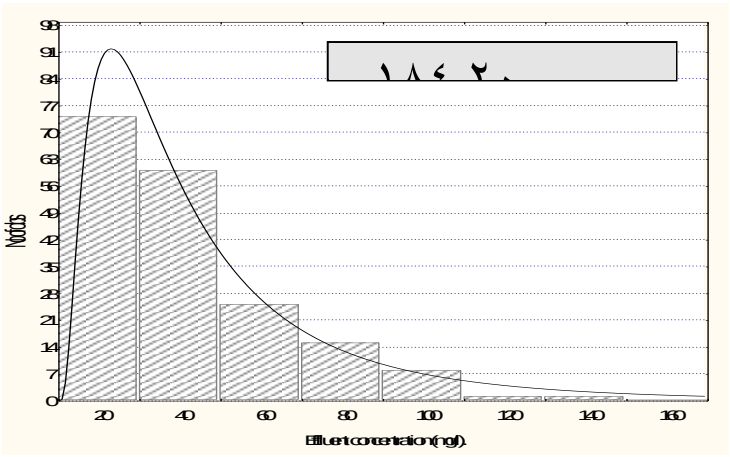


LINE ٢- S.S

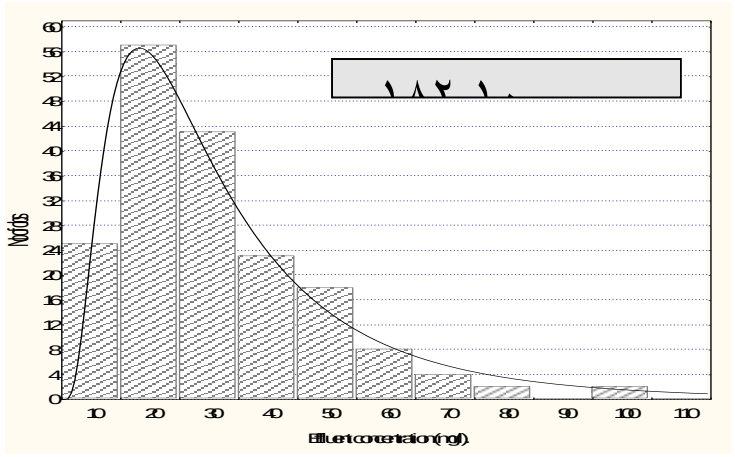
FIGURE (٤-٧): Histogram and its p.d.f for final effluent BOD٥ and S.S data (Year١٩٩٦), AL-Kerkh wastewater treatment plant.



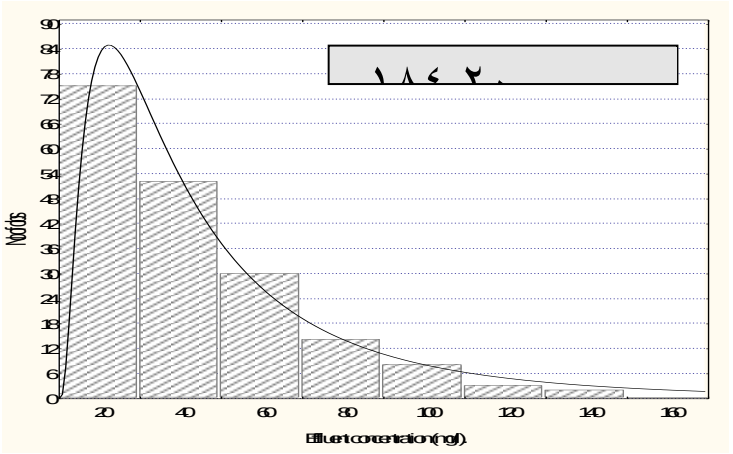
LINE ١- BOD٥



LINE ١- S.S



LINE ٢- BOD٥



LINE ٢- S.S

FIGURE (٤-٨): Histogram and its p.d.f for final effluent BOD٥ and S.S data (Year١٩٩٧) ,AL-Kerkh wastewater treatment plant.

Table (٤-٢): Kolmogorov-Smirnov test for final effluent (BOD_5) data of Al-Kerkh wastewater treatment plant

Year	Line	Dmax Normal (١)	Dmax Log-normal (٢)	Dmax Gama (٣)	Dα ١٪	Dα ٥٪	Dα ١٠٪	Normal	Log-normal	Gama
١٩٨٩	١	٠.٠٩٣٩	٠.٠٢٧٥	٠.٠٥٠١	٠.١٠١١	٠.٠٨٤٣	٠.٠٧٥٧	١	١-٢-٣	١-٢-٣
	٢	٠.١٢١٠	٠.٠٢٩٢	٠.٠٨٥٧	٠.١٠١١	٠.٠٨٤٣	٠.٠٧٥٧	-	١-٢-٣	
١٩٩٠	١	٠.٠٩٨٥	٠.٠١٦٨	٠.٠٤٣٢	٠.١٠٥٢	٠.٠٨٧٨	٠.٠٧٨٨	١	١-٢-٣	١-٢-٣
	٢	٠.١٤٠٩	٠.٠٣١٣	٠.٠٣٤١	٠.١٠٥٢	٠.٠٨٧٨	٠.٠٧٨٨	١	١-٢-٣	١-٢-٣
١٩٩٢	١	٠.٢٢٢٠	٠.١٠٦١	٠.١١٠٥	٠.١٧٣٨	٠.١٤٥٠	٠.١٣٠١	-	١-٢-٣	١-٢-٣
	٢	٠.١٩٣٤	٠.١٤٣٥	٠.١١٣٩	٠.١٧٤٨	٠.١٤٥٨	٠.١٣٠٨	-	١-٢-٣	١-٢-٣
١٩٩٣	١	٠.١٢٨٩	٠.٠٣٣٢	٠.٠٣٥٨	٠.٠٨٩٧	٠.١٠٠٠	٠.١١٩٨	-	١-٢-٣	١-٢-٣
	٢	٠.١٦٧٠	٠.٠٢٧٦	٠.٠٨٥١	٠.٠٨٩٧	٠.١٠٠٠	٠.١١٩٨	-	١-٢-٣	١-٢-٣
١٩٩٤	١	٠.١٠٨٠	٠.١٠٣١	٠.١٠٩٤	٠.١٢١٥	٠.١٠١٤	٠.٠٩٠٩	١	-	١
	٢	٠.١١٣٦	٠.٠٩٠٠	٠.٠٩٢٤	٠.١٢٠٨	٠.١٠٠٨	٠.٠٩٠٤	١	١-٢-٣	١-٢-٣
١٩٩٥	١	٠.٢٤٤٦	٠.٠٩٢٢	٠.١٣٠١	٠.١٢١٥	٠.١٠١٤	٠.٠٩٠٩	-	١-٢-٣	-
	٢	٠.١٧١٠	٠.٠٣٦٤	٠.٠٦٢٣	٠.١٢١٥	٠.١٠١٤	٠.٠٩٠٩	-	١-٢-٣	١-٢-٣
١٩٩٦	١	٠.٢٠٣٤	٠.١٠٠٢	٠.١٠٠٢	٠.١١٩٦	٠.١٠٠١	٠.٠٨٩٧	-	١	١
	٢	٠.١٥٨٥	٠.٠٥٥٥	٠.٠٨٢٧	٠.١١٩٦	٠.١٠٠١	٠.٠٨٩٧	-	١-٢-٣	١-٢-٣
١٩٩٧	١	٠.١٢٠٠	٠.٠٢٤٣	٠.٠٤١٧	٠.١٢١٢	٠.١٠١١	٠.٠٩٠٧	١	-	-
	٢	٠.١٤٣٠	٠.٠٥٦٣	٠.٠٦٦٦	٠.١٢٠٨	٠.١٠٨٨	٠.٠٩٠٤	-	-	-

Table (٤-٣): Kolmogorov-Smirnov test for final effluent (S.S) data of Al-Kerkh wastewater treatment plant.

Year	Line	Dmax Normal (١)	Dmax Log-normal (٢)	Dmax Gama (٣)	Dα			Normal	Log-normal	Gama
					١٪	٥٪	١٠٪			
١٩٨٩	١	٠.١٧٥٠	٠.٠٨٢٦	٠.٠٨٣٦	٠.١٠١١	٠.٠٨٤٣	٠.٠٧٥٧	-	١-٢	١-٢
	٢	٠.١٣٠٨	٠.٠٥٨٣	٠.٠٨٠٣	٠.١٠١٥	٠.٠٨٧٨	٠.٠٧٦٠	-	١-٢-٣	١-٢
١٩٩٠	١	٠.١١٩٠	٠.٠٣٨٨	٠.٠٧٢٧	٠.١٠٥٢	٠.٠٨٧٨	٠.٠٧٨٨	-	١-٢-٣	١-٢-٣
	٢	٠.١٢٩٠	٠.٠٣٩١	٠.٠٧٢٧	٠.١٠٥٤	٠.٠٨٨٠	٠.٠٧٨٩	-	١-٢-٣	١-٢-٣
١٩٩٢	١	٠.٢٦٩٠	٠.٠٩١٤	٠.١٤٠٢	٠.١٦٩٠	٠.١٤١٠	٠.١٢٦٥	-	١-٢-٣	١-٢
	٢	٠.١٣٨٢	٠.٠٥٢٦	٠.٠٣٥٨	٠.١٦٧٢	٠.١٣٨٥	٠.١٢٥٢	١	١-٢-٣	١-٢-٣
١٩٩٣	١	٠.١٠٢٦	٠.٠٨٦٨	٠.١٠٨٧	٠.١١٩٨	٠.١٠٠٠	٠.٠٨٢٧	١	١-٢-٣	١
	٢	٠.١٠٠١	٠.٠٦٢٦	٠.١٠٠٩	٠.١١٩٨	٠.١٠٠٠	٠.٠٨٢٧	١	١-٢-٣	١
١٩٩٤	١	٠.٢٦٢٠	٠.٠٩٤٧	٠.٠٧٨٨٠	٠.١٢٠٢	٠.١٠٠٣	٠.٠٨٩٩	-	١-٢	١-٢-٣
	٢	٠.٢٢٧٠	٠.١٠١٩	٠.٠٦٢٨	٠.١٢٠٢	٠.١٠٠٣	٠.٠٨٩٩	-	١	١-٢-٣
١٩٩٥	١	٠.١٠٣١	٠.١٠٧٥	٠.١٠١٨	٠.١٢١٥	٠.١٠١٤	٠.٠٩٠٩	١	١	١
	٢	٠.١٨٠٩	٠.٠٥٨٢	٠.٠٨٦٨	٠.١٢١٢	٠.١٠١١	٠.٠٩٠٧	-	١-٢-٣	١-٢-٣
١٩٩٦	١	٠.٢٠٩٦	٠.٠٧٠٠	٠.٠٨١٤	٠.١٢٠٥	٠.١٠٠٥	٠.٠٩٠٢	-	١-٢-٣	١-٢

	٢	٠.٢٠٨٧	٠.٠٨١٦	٠.٠٨٥٦	٠.١٢٠٨	٠.١٠٠٨	٠.٠٩٠٤	-	١-٢-٣	١-٢-٣
١٩٩٧	١	٠.١٥٦٣	٠.٠٥٢٠	٠.٠٨٦٦	٠.١٢٠٢	٠.١٠٠٣	٠.٠٨٩٩	-	١-٢-٣	١-٢-٣
	٢	٠.١٧١٩	٠.٠٦٤٥	٠.٠٨٨٠	٠.١٢٠٢	٠.١٠٠٣	٠.٠٨٩٩	-	١-٢-٣	١-٢-٣

Table (٤-٤): Chi-square test for final effluent (BOD_5) data of Al-Kerkh wastewater treatment plant.

Year	Line	χ^2 Normal	χ^2 Log-normal	χ^2 Gama	$\chi^2_{\alpha} = ٠.٠٥$			Normal	Log-normal	Gama
					Normal	Log-normal	Gama			
١٩٨٩	١	٤٦.٧٤	٥.٤١	٦.٥٦	١٢.٥٩	١١.٠٧	١٢.٥٩	-	X	X
	٢	٢٠.٩١	٢.٩٤	١٠.٦٨	٥.٩٩	٧.٨١	٧.٨١	-	X	-
١٩٩٠	١	١٥.٠٣	٣.٢٨	٤.٥٨	٥.٩٩	٧.٨١	٧.٨١	-	X	X
	٢	٢٥.٩٧	٩.٩٨	٧.٣٤	١٢.٥٩	١٢.٥٩	١٤.٠٧	-	X	X
١٩٩٢	١	١٣.٨٧	٣.٠٩	٣.٣٦	٣.٨٤	٣.٨٤	٥.٩٩	-	X	X
	٢	٨.٥٠	١.٤٨	٣.٤٥	٧.٨١	٥.٩٩	٧.٨١	-	X	X
١٩٩٣	١	٣٥.٩٧	٤.٠٢	٣.٦٨	١٢.٥٩	١٢.٥٩	١٤.٠٧	-	X	X
	٢	٢٩.٠٤	١.٨٢	٧.٥٠	٥.٩٩	٥.٩٩	٧.٨١	-	X	X
١٩٩٤	١	١٥.٦٣	٦.٠٠	٨.٧٣	٥.٩٩	٥.٩٩	٥.٩٩	-	-	-
	٢	١٦.٨٣	٢.٩٢	٤.٠٩	٧.٨١	٧.٨١	٧.٢٧	-	X	X
١٩٩٥	١	٤٨.١٦	١٢.٤٠	١٣.٥٠	٩.٤٩	٩.٤٩	١١.٠٧	-	X	-
	٢	٢٥.٤١	٣.٩٩	١٢.٤٧	٩.٤٩	٩.٤٩	١١.٠٧	-	X	X
١٩٩٦	١	٥٧.٢٢	٩.١٨	١٠.٥٧	٥.٨١	٩.٤٩	٩.٤٩	-	-	-
	٢	٣٣.٨٩	٣.٧٠	٧.٥٢	٥.٩٩	٧.٨١	٧.٨١	-	X	X
١٩٩٧	١	٣٨.٩٤	١.٢٦	٣.٤٦	١١.٠٧	١١.٠٧	١١.٠٧	-	X	X
	٢	١٨.٩٢	٦.٤٢	٣.٦٥	٩.٤٩	١١.٠٧	١١.٠٧	-	X	X

X: Represent the acceptance of distribution type.

٤-٢-٢ Verification of the Result.

Daily operation data of effluent BOD٥ and S.S concentrations have been collected from the records of Al-Kerkh wastewater treatment plant. The percentile values of effluent BOD٥ and S.S data have been computed and given in Tables (٤-٥ and ٤-٦) respectively. These percentiles have normalized by deducting mean from each value and dividing it by its standard deviation. Then, the average of the normalized values at each percentile was computed, as given in the same tables.

The COR based on the data has been computed by using the averages of normalized percentiles, and given Tables (٤-٨ and ٤-٩) for different coefficients of variation of effluent BOD٥ and S.S data at different levels of reliability. These tables are constructed exactly like Table (٣-١), but on the basis of the results of pooled plant data from Tables (٤-٦ and ٤-٧).

The coefficient of reliability COR based on data is computed as follows;

$$P\left(x \le x_s\right) = P\left(z \le \frac{x_s - x}{s_x}\right) = 1 - \alpha$$

$$\frac{x_s - \bar{x}}{s_x} = z_{1-\alpha}$$

$$\bar{x} = \frac{1}{z_{1-\alpha} V_x + 1}$$

and

$$COR_{(data)} = \frac{1}{z_{1-\alpha} V_x + 1} \qquad .....(١-٤)$$

where the percentile $Z_{١-\alpha}$ is calculated from data.

Table (٤-٨) :COR as a function of Vx and reliability from pooled plant data (BOD_5).

Reliability	٥٠٪	٦٠٪	٧٠٪	٨٠%	٩٠%	٩٥%	٩٩%	١٠٠٪

Vx								
٠.٣	١.٠٧	١.٠٠	٠.٩٤	٠.٨٥	٠.٧٤	٠.٦٣	٠.٤٩	٠.٤٢
٠.٤	١.٠٩	١.٠٠	٠.٩٣	٠.٨١	٠.٦٨	٠.٥٦	٠.٤٢	٠.٣٥
٠.٥	١.١٢	١.٠١	٠.٩١	٠.٧٧	٠.٦٣	٠.٥١	٠.٣٧	٠.٣٠
٠.٦	١.١٤	١.٠١	٠.٨٩	٠.٧٣	٠.٥٩	٠.٤٦	٠.٣٣	٠.٢٦
٠.٧	١.١٧	١.٠١	٠.٨٨	٠.٧٠	٠.٥٥	٠.٤٢	٠.٢٩	٠.٢٣
٠.٨	١.٢٠	١.٠١	٠.٨٦	٠.٦٨	٠.٥٢	٠.٣٩	٠.٢٧	٠.٢١
٠.٩	١.٢٣	١.٠١	٠.٨٥	٠.٦٥	٠.٤٩	٠.٣٦	٠.٢٥	٠.١٩
١.٠	١.٢٦	١.٠١	٠.٨٣	٠.٦٣	٠.٤٦	٠.٣٤	٠.٢٣	٠.١٧

Table(٤-٩) :COR as a function of Vx and reliability from pooled plant data S.S.

Reliability	٥٠٪	٦٠٪	٧٠٪	٨٠%	٩٠%	٩٥%	٩٩%	١٠٠٪
Vx								
٠.٣	١.٠٩	١.٠٥	٠.٩٤	٠.٨٤	٠.٧٢	٠.٦٤	٠.٥٢	٠.٤٢
٠.٤	١.١٢	١.٠٧	٠.٩٢	٠.٨٠	٠.٦٦	٠.٥٧	٠.٤٥	٠.٣٥
٠.٥	١.١٦	١.٠٩	٠.٩٠	٠.٧٦	٠.٦١	٠.٥٢	٠.٣٩	٠.٣٠
٠.٦	١.١٩	١.١١	٠.٨٨	٠.٧٢	٠.٥٦	٠.٤٧	٠.٣٥	٠.٢٧
٠.٧	١.٢٣	١.١٤	٠.٨٦	٠.٦٩	٠.٥٣	٠.٤٣	٠.٣٢	٠.٢٤
٠.٨	١.٢٨	١.١٦	٠.٨٥	٠.٦٦	٠.٤٩	٠.٤٠	٠.٢٩	٠.٢١
٠.٩	١.٣٢	١.١٨	٠.٨٣	٠.٦٥	٠.٤٦	٠.٣٧	٠.٢٧	٠.١٩
١.٠	١.٣٧	١.٢١	٠.٨١	٠.٦٣	٠.٤٤	٠.٣٥	٠.٢٥	٠.١٨

The results of Tables (٤-٨ and ٤-٩) are highly comparable with the theoretical results based on a log-normal distribution assumption (see Table(٣-١)). In most cases, the results are the same or comparable with a difference less than ٥٪, usually, the log-normal assumption is conservative.

To support the validity of the model in the prediction of effluent performance, the percent of the time that effluent concentrations has not exceeded ٤٠ (mg/l) for $BOD_٥$ and ٦٠ (mg/l) for S.S has been computed for each year of data for both lines, as shown Tables (٤-١٠ and ٤-١١). This percent has also been predicted using the reliability model, (Table (٣-٢) or Figure (٣-٤)), based on the log-normal assumption. The predicted values were very comparable with the measured values.

Table (٤-١٠) : Comparison of predicted and measured reliability ,($BOD_٥$), of Al-Kerkh wastewater treatment plant

Year	Line	Mean	S.D	Vx	COR	Predicted reliability %	Measured reliability %
١٩٨٩	١	٢٠.٣٠	٨.٤٦	٠.٤٢	٠.٥١	٩٦.٩٤	٩٧.٣٠
	٢	٢١.٣٠	٨.٨٨	٠.٤٢	٠.٥٣	٩٦.٢٢	٩٨.٤٦
١٩٩٠	١	١٨.٤٤	٩.٧٩	٠.٥٣	٠.٤٦	٩٦.٤٨	٩٧.٠٨
	٢	١٦.٦٠	٩.٤٣	٠.٥٧	٠.٤٢	٩٧.١٣	٩٨.٤٥
١٩٩٢	١	٦٠.٥٥	٤٨.٦٠	٠.٨٠	١.٥١	٤٠.٨٠	٣٩.٧٧
	٢	٨٩.٢٣	٦٩.٢٢	٠.٧٨	٢.٢٣	٢٠.٦٤	٢٢.٩٩
١٩٩٣	١	٦٣.٠٩	٤٢.٦٠	٠.٦٨	١.٥٨	٣٣.٧٨	٣٠.٠٠
	٢	٧٢.٢٢	٦٣.١٠	٠.٧٧	١.٨١	٣٤.٥٥	٣١.٦٦
١٩٩٤	١	٧٢.٨٠	٥٩.٨٠	٠.٨٢	١.٨٢	٣١.٦٧	٢٨.٨٩
	٢	٨٣.٣٠	٦٨.٨٠	٠.٨٣	٢.٠٨	٢٥.٨١	٢٦.٣٧
١٩٩٥	١	٤٣.٠٠	٣٥.٠٠	٠.٨١	١.٠٨	٥٩.٧٥	٥٦.٦٧
	٢	٤٥.٧٠	٣٧.٩٠	٠.٨٣	١.١٤	٥٧.١٨	٥٣.٣٣
١٩٩٦	١	٣٢.٠٠	٢٦.٢٠	٠.٨٢	٠.٨٠	٧٤.٨٢	٧١.٣٥
	٢	٢٩.٣٠	٢١.٣٠	٠.٧٣	٠.٧٣	٧٩.٠٤	٧٧.٨٤
١٩٩٧	١	٢٨.٨٢	١٧.٨٢	٠.٦٢	٠.٧٢	٨٠.٥٤	٨٢.٣٢
	٢	٢٨.١٥	١٦.٨٤	٠.٧٠	٠.٦٠	٨٦.٩٧	٨٤.٦٢

Table (٤-١١): Comparison of predicted and measured reliability ,(S.S), of Al-Kerkh wastewater treatment plant

Year	Line	Mean	S.D	Vx	COR	Predicted Reliability %	Measured reliability %
١٩٨٩	١	١٣.٦٩	٩.٤٥	٠.٦٩	٠.٢٣	٩٩.٦٢	٩٨.٠٨
	٢	١٧.٧١	٩.٥٧	٠.٥٤	٠.٣٠	٩٩.٥٨	٩٧.٦٧
١٩٩٠	١	١٩.٤٠	٩.٢٢	٠.٤٨	٠.٣٢	٩٩.٦٨	٩٨.٣٣
	٢	١٩.٤١	٩.٨٥	٠.٥١	٠.٣٢	٩٩.٥٥	٩٧.٤٩
١٩٩٢	١	٧٩.٢٢	٦٧.٧٥	٠.٨٦	١.٣٢	٤٩.٦٤	٥١.٠٩
	٢	٩٠.٦٦	٨١.٢٥	٠.٩٠	١.٥١	٤٤.٠٤	٤٢.٥٥
١٩٩٣	١	٦٩.٦٠	٣٧.٤٠	٠.٥٤	١.١٦	٤٨.٣٦	٥١.٦٧
	٢	٧٤.٨٠	٣٩.١٠	٠.٥٣	١.٢٥	٤٢.٠٧	٤٣.٨٩
١٩٩٤	١	٧٦.٠٠	٤٨.٨٠	٠.٦٤	١.٢٧	٤٥.٤٢	٤٧.٢٨
	٢	٧٦.٠٠	٥١.٧٠	٠.٦٨	١.٢٧	٤٦.٨٥	٤٦.٧٤
١٩٩٥	١	٥٧.٥٠	٢٨.٨٠	٠.٥٠	٠.٩٦	٦٢.٦٣	٦٥.٥٦
	٢	٥٤.٠٠	٣٦.٢٠	٠.٦٧	٠.٩٠	٦٨.٣٧	٧٠.١٧
١٩٩٦	١	٤٧.٢٠	٤٠.٨٠	٠.٨٦	٠.٧٩	٧٥.٤٦	٧٢.٦٨
	٢	٤٦.٠٠	٣٦.١٠	٠.٧٩	٠.٧٧	٧٦.٥٤	٧٣.٠٨
١٩٩٧	١	٣٥.٦٠	٢٤.٣٢	٠.٦٨	٠.٥٩	٨٧.٧٨	٨٦.٤١
	٢	٣٧.٦٠	٢٤.٥٠	٠.٦٣	٠.٦٥	٨٤.٩٤	٨٢.٠٧

Figures (٤-٩ and ٤-١٠) show the predicted versus measured reliability for effluent BOD_5 and S.S data, respectively. These figures indicate that the model of Niku et al., (١٩٧٩) is conservative.

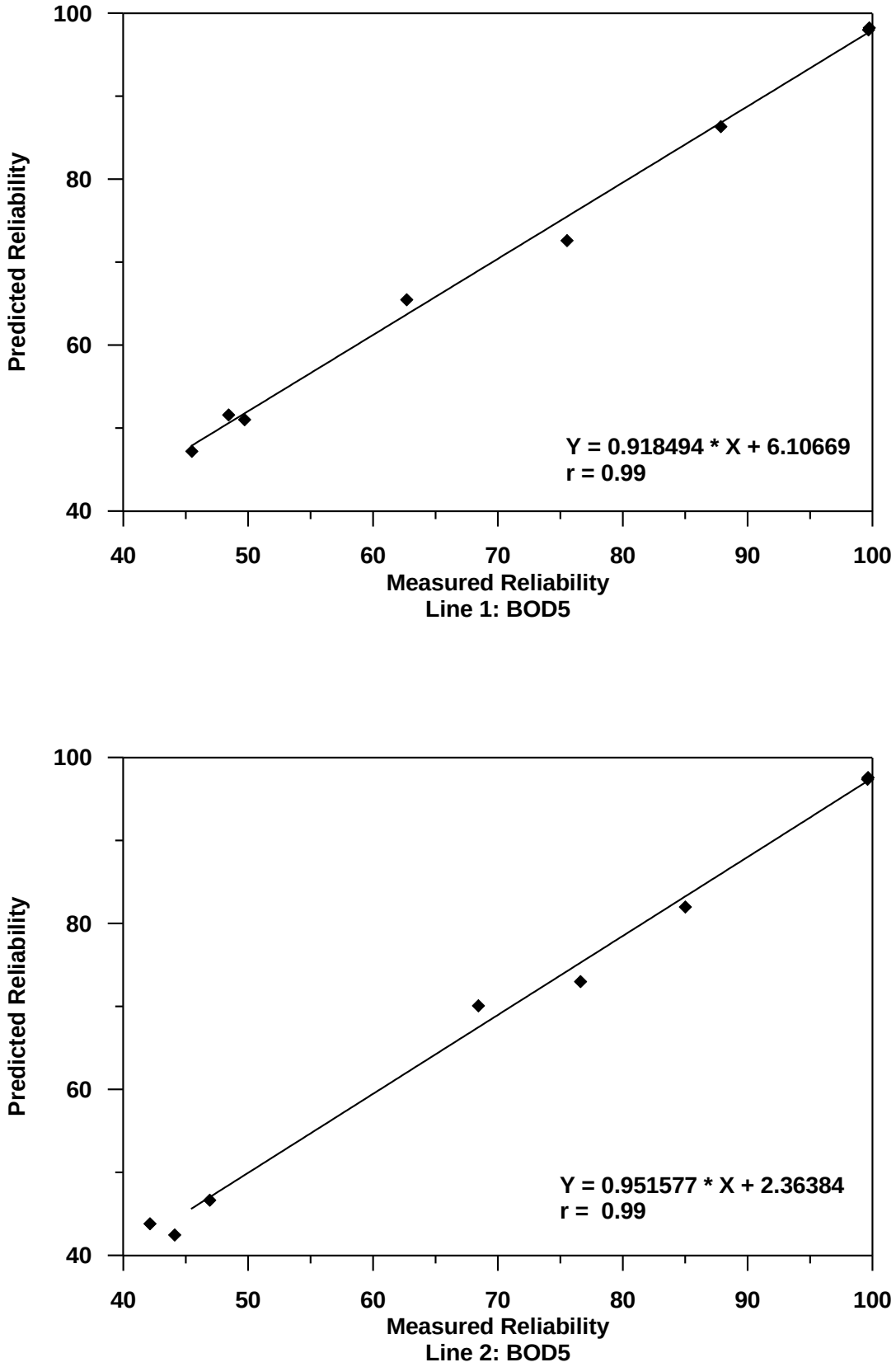


Fig.(٤-٩): predicted versus measured reliability (Lines ١ and ٢-$BOD_٥$).

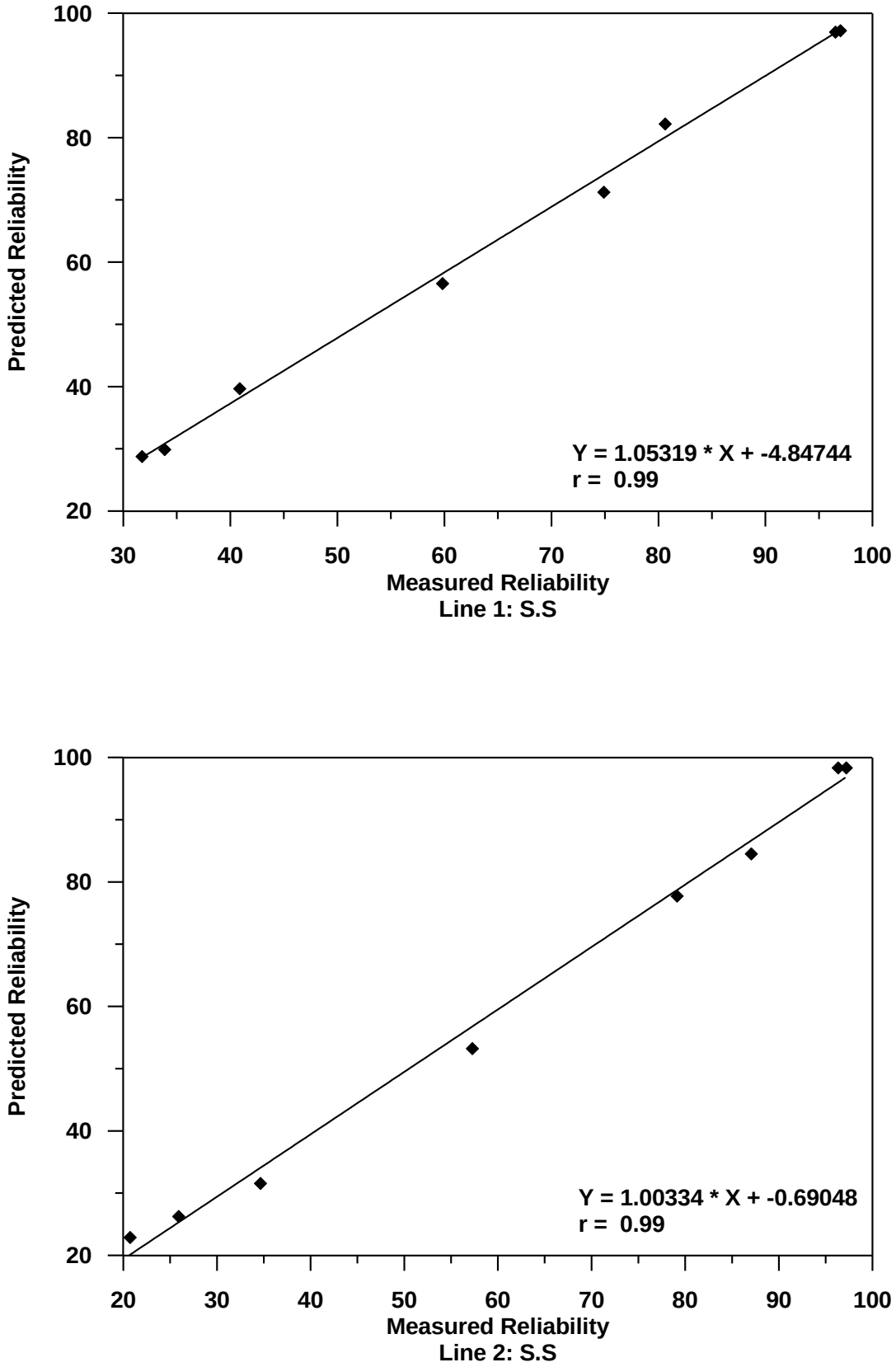


Fig.(٤-١٠): predicted versus measured reliability (Lines ١ and ٢-S.S).

Table(٤-٦): Percentile values of final effluent BOD٥ data of Al-Kerkh wastewater treatment plant.

Year	Line	Percentiles								Normalized Percentiles							
		٥٠٪	٦٠٪	٧٠٪	٨٠٪	٩٠٪	٩٥٪	٩٩٪	١٠٠٪	٥٠٪	٦٠٪	٧٠٪	٨٠٪	٩٠٪	٩٥٪	٩٩٪	١٠٠٪
١٩٨٩	١	٢٠	٢١	٢١	٢٦	٣١	٣٦	٤٦	٦٠	-٠.٠٤	٠.٠٨	٠.٠٨	٠.٦٧	١.٢٦	١.٢٦	٣.٠٤	٤.٧٨
	٢	٢٠	٢١.١	٢١.٢	٢٧.٢	٣١.١	٤١	٥١	٦٤	-٠.١٥	-٠.٠٣	-٠.٠٣	٠.٦٦	١.٠٩	٢.٢٢	٣.٣٥	٤.٨١
١٩٩٠	١	١٨	١٩	٢٠.٩	٢١	٣	٤٠.٩	٥٠.٨	٦٥	-٠.٠٥	٠.٠٦	٠.٢٦	٠.٢٦	١.٢٨	٢.٣٠	٣.٣٣	٤.٧٦
	٢	١٥	٢٠	٢٠	٢١.١	٣٠.٩	٣٦	٤٤.٠٥	٥٦	-٠.١٧	٠.٣٦	٠.٣٦	٠.٤٧	١.٥٣	٢.٠٦	٢.٩١	٤.١٨
١٩٩٢	١	٤٦.٥	٥٠	٦٢.٩	٩٩.٦	١١٦.٤	١٥٠.٦	٢١٠.٦	٢٧٥	-٠.٢٩	-٠.٢٢	-٠.٠٥	٠.٨٠	١.١٥	١.٨٥	٣.٠٩	٤.٤١
	٢	٦٢	٩٤.٤	١٠٣.٦	١٤٠.٦	١٨٧.٢	٢٢٨	٢٩٠.٣	٣٠٩	-٠.٣٩	٠.٠٨	٠.٢١	٠.٧٤	١.٤٢	٢.٠٠	٢.٩١	٥.١٨
١٩٩٣	١	٦٠	٦٨	٨٠	٩٥	١٠٥.٣	١٤١	٢٠٢	٢٣٩	-٠.٠٧	٠.١٢	٠.٠٤	٠.٧٥	٠.٩٩	١.٨٣	٣.٢٦	٤.١٣
	٢	٥٠	٥١.١	١٠٠	١٠٠.٨	١٥٠.١	٢٣٢.١	٢٥١.١٥	٢٧٨	-٠.٣٥	-٠.٣٤	٠.٤٤	٠.٤٦	١.٢٣	٢.٥٣	٢.٢٤	٣.٢٦
١٩٩٤	١	٥٠.٩	٥١	٦٨	١٢٢	١٥١	٠١ ٢	٣٠١	٤٥٠	-٠.٣٦	-٠.٣٦	-٠.٠٨	٠.٨٢	١.٣١	٢.١٤	٣.٨٢	٦.٣١
	٢	٥١	١٠٠	١٠٠.١	١٠١.١	١٥١	٢٢ ٢	٣٣٢.٤٥	٤٤٤	-٠.٤٧	٠.٢٤	٠.٢٤	٠.٢٦	٠.٩٨	٢.٠٢	٣.٦٢	٥.٢٤
١٩٩٥	١	٤٠	٤٠	٤٠.١	٦٠	٨٨	٥ ١٠٠.٠	١٨٣.٥٧	١٩٧	-٠.٠٩	-٠.٠٩	-٠.٠٩	٠.٤٩	١.٢٩	١.٦٣	٤.٠٢	٤.٤٠
	٢	٣٣.٥	٤٠	٦٠.١	٨٠	٨١	١٢١	١٧٦.٦٣	١٨٠	-٠.٣٢	-٠.١٥	٠.٣٨	٠.٩١	٠.٩٣	١.٩٩	٣.٤٥	٥.٥٤
١٩٩٦	١	٢٠	٣٠.١	٣٥	٥٥.٦	٦١.١	٨. ٧٩	١٣١.٦	١٦٠	-٠.٤٥	-٠.٠٨	٠.١٢	٠.٩٠	١.١٣	١.٨٢	٣.٨٠	٤.٨٩
	٢	٣٠	٣٠	٤٠	٤٠.٦	٤١	٦١	١٢١	١٣٧	٠.٠٣	٠.٠٣	٠.٥	٠.٥٣	٠.٥٥	١.٤٩	٤.٣١	٥.٠٦
١٩٩٧	١	٢٦	٢٩	٣٥	٣٥	٥١	٦١	٩٦.٢	١٠٣	-٠.١٦	٠.٠١	٠.٣٥	٠.٣٥	١.٢٥	١.٨١	٣.٧٨	٤.١٦
	٢	٢٩	٣٠	٣١	٣٦	٥٠	٦٠	٨٢.٠٠	٩٦	٠.٠٥	٠.١١	٠.٧	٠.٤٧	١.٣٠	١.٨٩	٣٢.٢٠	٤.٠٣
								Average		-١.٢٠٦	-٠.٠١٠	٠.٢٠٠	٠.٦٠٠	١.١٧٠	١.٩٧٠	٣.٤٢٠	٤.٧٠٠

Table(٤-٧): Percentile values of final effluent S.S data of Al-Kerkh wastewater treatment plant.

Year	Line	Percentiles								Normalized Percentiles							
		٥٠٪	٦٠٪	٧٠٪	٨٠٪	٩٠٪	٩٥٪	٩٩٪	١٠٠٪	٥٠٪	٦٠٪	٧٠٪	٨٠٪	٩٠٪	٩٥٪	٩٩٪	١٠٠٪
١٩٨٩	١	١٠	١٦	١٦.١	١٦.١	٢٠	٣١	٤٥.١	٦٦	-٠.٣٩	٠.٢٤	٠.٢٤	٠.٢٤	٠.٧٧	١.٨٣	٣.٣٢	٥.٥٠
	٢	١٨	١٨.١	٢١	٢١	٣٠	٤١	٥٢	٦٥	٠.٣٠	٠.٣١	٠.٣٤	٠.٣٤	١.٢٢	٢.٤٤	٣.٥٨	٤.٩٤
١٩٩٠	١	١٨	٢٠	٢٢	٢٢.١	٣١	٤٠	٥٢	٦٤	-٠.١٥	٠.٠٧	٠.٢٨	٠.٢٨	١.٢٦	٢.٢٣	٣.٥٤	٤.٨٤
	٢	١٩	١٩.١	٢١	٢٣	٣٠	٤٢	٥٠	٦٦	-٠.٠٤	-٠.٠٤	٠.٢٩	٠.٧٤	١.٧٧	١.٧٨	٣.٠٨	٣.١٠
١٩٩٢	١	٤٩	٤٩.٤	٩٩	١٢٩	١٩٩	٢٠٠	٢٨٨	٢٨٥	-٠.٤٥	-٠.٤٤	٠.٢٩	٠.٧٤	١.٧٧	١.٧٨	٣.٠٨	٣.١٠
	٢	٦٦	٩١.٦	١٠١	١٥١	٢١٩	٢٧٢	٣٠٤.١	٣٥٢	-٠.٠٣	٠.٠١	٠.١٣	٠.٧٤	١.٥٨	٢.٢٣	٢.٦٣	٣.٢٢
١٩٩٣	١	٥١	٥١.٥	٥٣	١٠٠	١٠١	١١٠.٨	٢٠٣	٢٨٨	-٠.٥٠	-٠.٤٨	-٠.٤٤	٠.٨١	٠.٨٤	١.١٠	٣.٥٧	٥.٨٤
	٢	٥١.١	٥١	١٠٠	١٠١	١٠٧.٣	١٥١	٢٠٢.٥	٢٩٨	-٠.٦١	-٠.٦١	٠.٦٥	٠.٦٧	٠.٨٣	١.٩٥	٣.٢٧	٥.٧١
١٩٩٤	١	٥٠	٥١	١٠٠	١٠٠.٥	١٤٩	١٥١	٢٥٢	٣٢٦	-٠.٥٣	-٠.٥١	٠.٤٩	٠.٥٠	١.٥٠	١.٥٤	٣.٦١	٥.٦٢
	٢	٥١	٥٥	٧٨.١	١٣٣	١٥٠	١٧٧.٩	٢٢٥.٩	٢٩٨	-٠.٤٨	-٠.٤١	٠.٠٤	١.١٠	١.٤٣	١.٩٧	٢.٩٠	٤.٢٩
١٩٩٥	١	٥٠.٥	٥١	٦٢.٣	٧٠	١٠١	١٠١	١٥١.٦	٢٦٦	-٠.٢٤	-٠.٢٣	٠.١٧	٠.٤٣	١.٥١	١.٥٢	٣.٢٧	٧.٢٤
	٢	٤٠	٦٠	٦٠	٨٠.١	١٢٠	١٤١	١٤٢	١٨٤	-٠.٣٩	٠.١٧	٠.١٧	٠.٧٢	١.٨٢	٢.٤٠	٢.٤٣	٣.٥٩
١٩٩٦	١	٤٠	٤٠	٦٠	٨٠.١	٩٥	١٤٠	١٦٠	٢٠٠	-٠.٤٨	-.١٨	٠.٣١	٠.٨٠	١.١٧	٢.٢٧	٢.٧٦	٣.٧٥
	٢	٤٠.١	٤٠	٥٩.٩	٨٠	١٠٠	١٢٠	١٥٠	١٥١	-٠.١٧	-٠.١٧	٠.٣٩	٠.٩٤	١.٥	٢.٠٥	٢.٨٨	٣.٩١
١٩٩٧	١	٣٠	٣٠.١	٤٠	٥٠	٧٠	٨٨.٥	١٠٠	١٢٩	-٠.٢٣	-٠.٢٣	٠.١٨	٠.٥٩	١.٤١	٢.١٨	٢.٦٥	٣.٨٤
	٢	٤٠	٤١	٤٣	٦٠	٦١	٩٩.٩	١٠٥.٨	١٣٢	٠.١٠	٠.١٤	٠.٢٢	٠.٩١	٠.٩٦	٢.٥٤	٢.٧٨	٣.٨٥
								Average		-٠.٢٧	-٠.١٧	٠.٢٣	٠.٦٤	١.٢٥	١.٨٦	٣٠٩	٤٦٠

٤-٢-٣ Effects of outliers on reliability.

In ordinary operation data of wastewater treatment plants, it may be found that there are some days (١→ ٣ days), in each year of operation, in which the effluent BOD٥ or S.S concentration is much higher than the rest of the year. This situation will strongly affect the results of both the annual mean and the variance, (Niku et al., ١٩٨١). Thus, reliability evaluation from such data will be misleading, because it is dominated by a few (one to three) samples (called outliers) that have extremely high values. The plant may be classified as unreliable because of a few outliers although if the outliers were neglected the plant might be classified as reliable. These outliers may be caused by a mechanical failure of a part of the system, stormy weather and strong wind over the clarifier errors in sampling measurements, or any other unexpected cause.

To examine the effects of outliers on plant reliability, remove ١٪ of the upper data for each year of operation for both BOD٥ and S.S data. Then, calculate the statistical properties of the rest of data(٩٩٪ of the data) and repeat the evaluation of reliability by following the same procedures used in reliability evaluation (Niku et al., ١٩٨١). Tables (٤-١٢ and ٤-١٣) give the reliability of Al-Kerkh wastewater treatment plant after the removing of outliers.

Comparison of the results of Tables (٤-١٢ and ٤-١٣) with those of Tables (٤-١٠ and ٤-١١), shows slight effect of outliers on the data set and reliability evaluation. The effect of outliers on plant reliability was insignificant because of two reasons. The first reason, Al-Kerkh wastewater treatment plant before the war of ١٩٩١ was a new treatment project and it was controlled by good operators. Thus, no mechanical or operational failure had occured. The second reason, that there was a whole deficit in the treatment processes after the war of ١٩٩١, because of the shortage in the required chemical materials for treatment processes as well as the shortage in controlling and monitoring devices, the absence of the trained operators and the neglecting of the third line. Due to these reasons, the magnitudes of effluent concentrations have the same tendancy for both low and high values.

TABLE(٤-١٢): Comparisons of predicted and measured reliability of ٩٩ percentile data of effluent BOD_5.

Year	Line	Vx	COR	Predicted reliability %	Measured reliability %
١٩٨٩	١	٠.٤٠	٠.٥٠	٩٧.٦٧	٩٨.٤٤
	٢	٠.٣٩	٠.٥٢	٩٧.٣٠	٩٩.٦١
١٩٩٠	١	٠.٤٩	٠.٤٥	٩٧.٤٦	٩٨.٣١
	٢	٠.٥٤	٠.٤١	٩٧.٨٣	٩٩.٥٨
١٩٩٢	١	٠.٧٤	١.٤٤	٤٠.٩٥	٤٠.٢٣
	٢	٠.٧٥	٢.١٥	٢٠.٩٤	٢٣.٢٦
١٩٩٣	١	٠.٦٥	١.٥٢	٣٤.٢٣	٣٠.٣٤
	٢	٠.٨٦	١.٧٦	٣٤.٩٠	٣٢.٠٢
١٩٩٤	١	٠.٧٤	١.٧٤	٣٢.٦٨	٢٩.٢١
	٢	٠.٧٥	١.٩١	٢٦.٧٤	٢٦.٦٧
١٩٩٥	١	٠.٧٦	١.٠٣	٦١.٥٢	٥٧.٣٠
	٢	٠.٨٠	١.١١	٥٨.٠٥	٥٣.٩٣
١٩٩٦	١	٠.٧٤	٠.٧٦	٧٧.٢٠	٧٢.١٣
	٢	٠.٦٦	٠.٧٠	٨١.٤٣	٧٨.٦٩
١٩٩٧	١	٠.٥٨	٠.٧٠	٨٢.٤٣	٨٣.٢٤
	٢	٠.٥٦	٠.٦١	٨٧.١٧	٨٥.٥٦

Figure (-): Comparison of predicted and measured reliability of percentile data of effluent (S.S).

Year	Line	Vx	COR	Predicted reliability %	Measured reliability %
١٩٨٩	١	٠.٦٣	٠.٢٢	٩٩.٨٢	٩٩.٢٢
	٢	٠.٥٠	٠.٢٩	٩٩.٧٩	٩٨.٨٢
١٩٩٠	١	٠.٤٤	٠.٣٢	٩٩.٨٢	٩٩.٥٨
	٢	٠.٤٧	٠.٣٢	٩٩.٧٢	٩٨.٧٣
١٩٩٢	١	٠.٨٤	١.٢٨	٥١.١٢	٥٢.٢٢
	٢	٠.٨٨	١.٤٧	٤٤.٨٣	٤٣.٤٨
١٩٩٣	١	٠.٥٠	١.١٣	٤٩.٦٢	٥٢.٢٥
	٢	٠.٤٦	١.٢٠	٤٢.٤٦	٤٤.٣٨
١٩٩٤	١	٠.٥٩	١.٢٣	٤٥.٧٨	٤٧.٨٠
	٢	٠.٦٤	١.٢٣	٤٧.٦١	٤٧.٢٥
١٩٩٥	١	٠.٤٢	٠.٩٣	٦٤.٨٧	٦٦.٣٠
	٢	٠.٦٥	٠.٨٨	٦٩.٥٧	٧٠.٩٥
١٩٩٦	١	٠.٨٣	٠.٧٦	٧٧.٠٧	٧٣.٤٨
	٢	٠.٧٧	٠.٧٤	٧٨.٢٩	٧٣.٨٨
١٩٩٧	١	٠.٦٦	٠.٥٨	٨٨.٦٩	٨٧.٣٦
	٢	٠.٦٢	٠.٦١	٨٧.٥٥	٨٢.٩٧

٤-٣ Process Stability

Examination of stability of treatment processes required statistical analysis of data that obtained from plant operation. The scope of this study included collection and analysis of daily operation data from Al-Kerkh wastewater treatment plant.

٤-٣-١ Stability Evaluation

The required statistical properties to evaluate the stability of both lines (one and two) of Al-Kerkh wastewater treatment plant are given in Table (٤-١٤).

Table (٤-١٤): Statistics of effluent BOD_5 and S.S data of Al-Kerkh wastewater treatment plant.

Year	Line	BOD٥					S.S				
		Mean	S.D	Max.	Min.	Valid Obs.	Mean	S.D	Max.	Min.	Valid Obs.
١٩٨٩	١	٢٠.٣٠	٨.٤٦	٦٠.٠٠	١	٢٦٠	١٣.٦٩	٩.٤٥	٦٦	١	٢٦٠
	٢	٢١.٣٠	٨.٨٨	٦٤.٠٠	١	٢٦٠	١٧.٧١	٩.٥٧	٦٥	١	٢٥٨
١٩٩٠	١	١٨.٤٤	٩.٧٩	٦٥.٠٠	٢	٢٤٠	١٩.٤٠	٩.٢٢	٦٤	١	٢٤٠
	٢	١٦.٦٠	٩.٤٣	٥٦.٠٠	١	٢٤٠	١٩.٤١	٩.٨٥	٦٦	١	٢٣٩
١٩٩٢	١	٦٠.٥٥	٤٨.٦٠	٢٥٧	٢	٨٨	٧٩.٢٢	٦٧.٧٥	٢٨٩	١	٩٢
	٢	٨٩.٢٣	٦٩.٢٢	٣٠٩	٢	٨٧	٩٠.٦٦	٨١.٢٥	٣٥٢	١	٩٤
١٩٩٣	١	٦٣.٠٩	٤٢.٦٠	٢٣٩	٢	١٨٠	٦٩.٦٠	٣٧.٤٠	٢٨٨	٢	١٨٠
	٢	٧٢.٢٢	٦٣.١٠	٢٧٨	١	١٨٠	٧٤.٨٠	٣٩.١٠	٢٩٨	٢	١٨٠
١٩٩٤	١	٧٢.٨٠	٥٩.٨٠	٤٥٠	٣	١٨٠	٧٦.٠٠	٤٨.٨٠	٣٢٦	١	١٨٤
	٢	٨٣.٣٠	٦٨.٨٠	٤٤٠	٤	١٨٢	٧٦.٠٠	٥١.٧٠	٢٩٨	٢	١٨٤
١٩٩٥	١	٤٣.٠٠	٣٥.٠٠	١٩٧	١	١٨٠	٥٧.٥٠	٢٨.٨٠	٢٦٦	٢	١٨٠
	٢	٤٥.٧٠	٣٧.٩٠	١٨٠	١	١٨٠	٥٤.٠٠	٣٦.٢٠	١٨٤	٢	١٨١
١٩٩٦	١	٣٢.٠٠	٢٦.٢٠	١٦٠	١	١٨٥	٤٧.٢٠	٤٠.٨٠	٢٠٠	١	١٨٣
	٢	٢٩.٣٠	٢١.٣٠	١٣٧	١	١٨٥	٤٦.٠٠	٣٦.١	١٥١	١	١٨٢
١٩٩٧	١	٢٨.٨٢	١٧.٨٢	١٠٣	٢	١٨١	٣٥.٦٠	٢٤.٣٢	١٢٩	١	١٨٤
	٢	٢٨.١٥	١٦.٨٤	٩٦	٢	١٨٢	٣٧.٦٠	٢٤.٥٠	١٣٢	١	١٨٤

The results of Table (٤-١٤) are shown graphically in Figures (٤-١١and ٤-١٢) for effluent BOD_5 and S.S data, respectively.

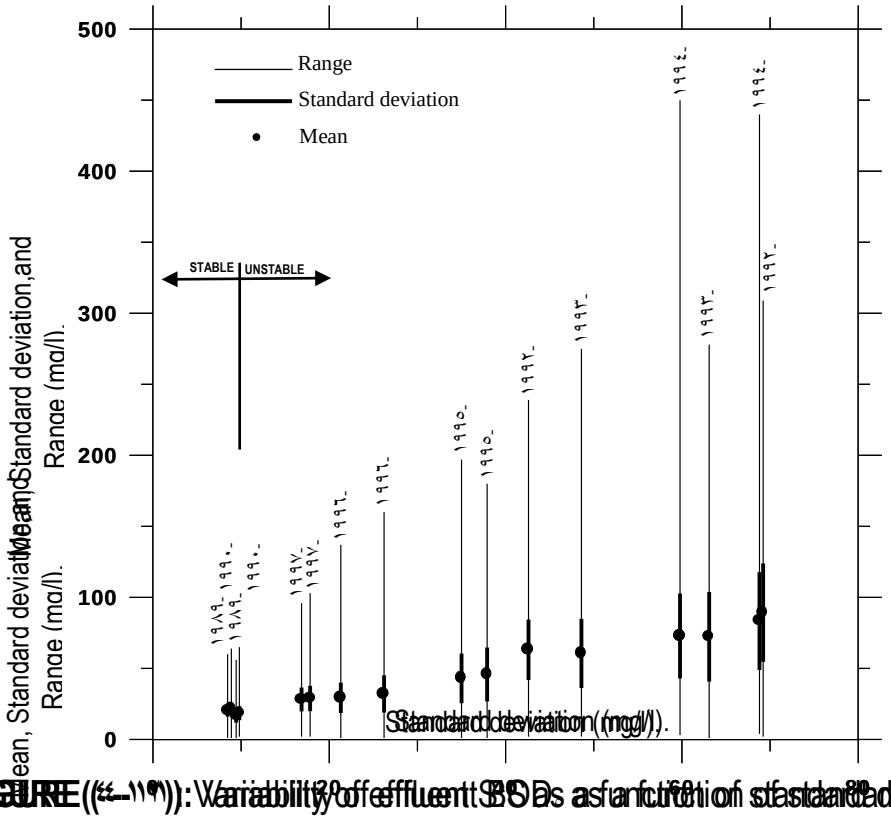
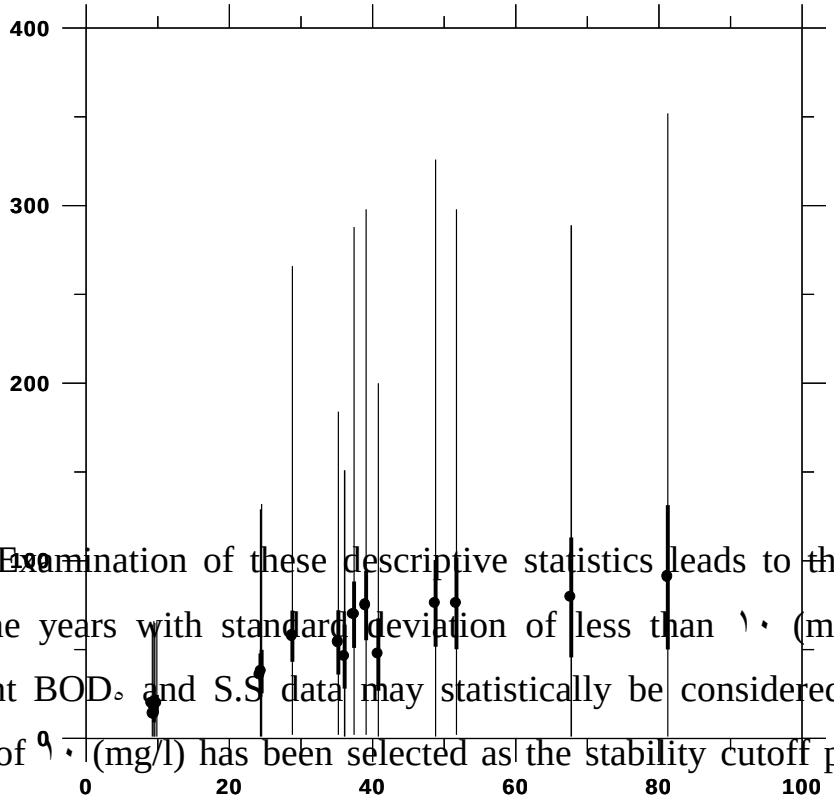


FIGURE (٤-١١): Variability of effluent BOD as a function of standard deviation.



Examination of these descriptive statistics leads to the conclusion that the years with standard deviation of less than ١٠ (mg/l) for both effluent BOD_5 and S.S data may statistically be considered stable. The value of ١٠ (mg/l) has been selected as the stability cutoff point because distinct difference exists between the statistical characteristics of the plant operating below and above this value. This cutoff point can be visualized clearly by examining Figures (٤-١١ and ٤-١٢).

It is worth noting to mention, that the stability cutoff point, (١٠ mg/l), that obtained in this study is the same cutoff point that obtained in the U.S.A by Niku et al., (١٩٨١).

٤-٣-٢ Effects of outliers on stability evaluation

It has been mentioned that, the statistical properties of effluent data may be strongly affected by a few (one to three) samples (called outliers) that have extremely high values. Standard deviation from such data may be misleading when used as stability measured, because these outliers may dominate it.

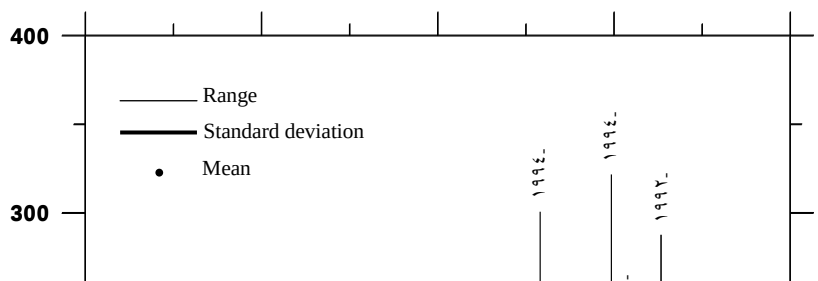
To examine the effects of outliners on plant stability, ١٪ of the upper data values (٤ days in ١ full year of operation) were removed from the data set and the statistical properties of the rest of the data (٩٩ percentile values) were calculated and given in Table (٤-١٥). Results of Table (٤-١٥) were shown graphically in Figures (٤-١٣ and ٤-١٤) for effluent BOD_5 and S.S data, respectively.

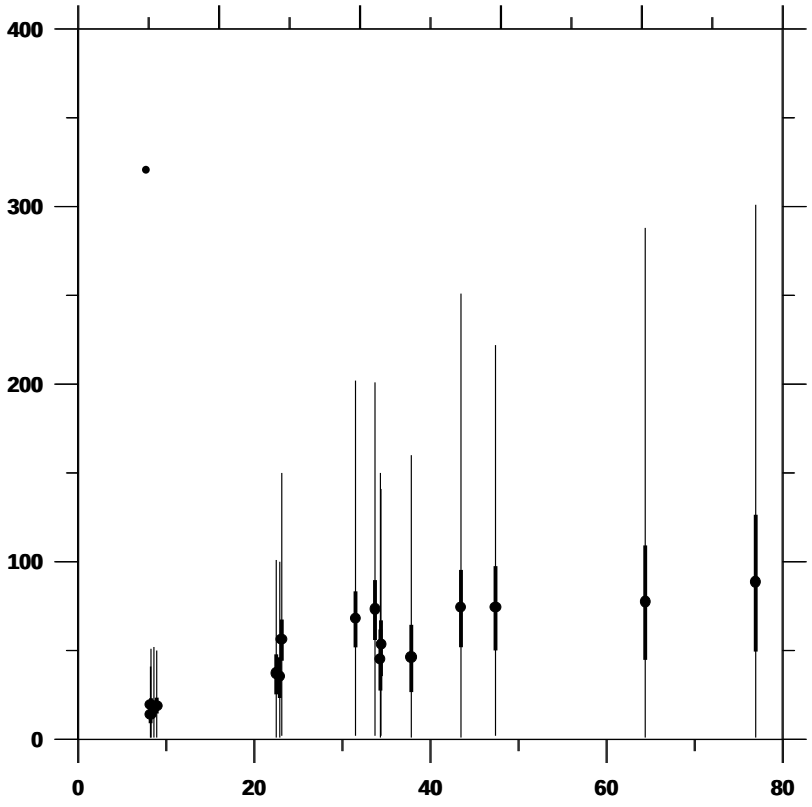
Table (٤-١٥): Statistics of ٩٩ percentile data of effluent BOD٥ and S.S of Al-Kerkh wastewater treatment plant .

Year	Line	Effluent BOD٥					Effluent S.S				
		Mean	S.D	Max.	Min.	Valid Obs.	Mean	S.D	Max.	Min.	Valid Obs.
١٩٨٩	١	١٩.٩٥	٧.٨٩	٤٦	١	٢٥٧	١٣.٢٠	٨.٢٨	٤١	١	٢٥٧
	٢	٢٠.٩٣	٨.١٠	٥١.٥	١	٢٥٧	١٧.٢٦	٨.٦٥	٥٢	١	٢٥٥
١٩٩٠	١	١٧.٩٧	٨.٨٧	٥١	٢	٢٣٧	١٨.٩٥	٨.٣١	٥١	١	٢٣٧
	٢	١٦.١٨	٨.٦٩	٤١	١	٢٣٧	١٨.٩٥	٨.٩٦	٥٠	١	٢٣٦
١٩٩٢	١	٥٨.٠٨	٤٢.٩٩	٢٠١	٢	٨٧	٧٦.٩٥	٦٤.٤٤	٢٨٨	١	٩١
	٢	٨٦.٦٧	٦٥.٣٧	٢٨٨	٢	٨٦	٨٧.٨٨	٧٧.٠٠	٣٠١	١	٩٣
١٩٩٣	١	٦١.٥٠	٣٩.٦٩	٢٠٢	١	١٧٨	٦٧.٥٦	٣١.٥٤	٢٠٢	٢	١٧٨
	٢	٧٠.٢٠	٦٠.٠٨	٢٥١	٣	١٧٨	٧٢.٧٥	٣٣.٧٦	٢٠١	٢	١٧٨
١٩٩٤	١	٦٩.٦٠	٥١.٦٣	٣٠١	٤	١٧٨	٧٣.٦٢	٤٣.٥٢	٢٥١	١	١٨٢
	٢	٧٩.٧٨	٥٩.٧٣	٣٢٢	١	١٨٠	٧٣.٧٦	٤٧.٤٥	٢٢٢	٢	١٨٢
١٩٩٥	١	٤١.٢١	٣١.١	١٨٠	١	١٧٨	٥٥.٨١	٢٣.١٧	١٥	٢	١٧٨
	٢	٤٤.٢١	٣٥.٣١	١٧٦	١	١٧٨	٥٢.٧٨	٣٤.٤٣	١٤١	٢	١٧٩
١٩٩٦	١	٣٠.٥٢	٢٢.٥٧	١٢٠	١	١٨٣	٤٥.٥٠	٣٧.٨٩	١٦٠	١	١٨١
	٢	٢٨.٠٩	١٨.٤٢	١٢١	١	١٨٣	٤٤.٦٣	٣٤.٣٦	١٥٠	١	١٨٠
١٩٩٧	١	٢٨.٠	١٦.١٤	٩٥	٢	١٧٩	٣٤.٧١	٢٢.٩٤	١٠٠	١	١٨٢
	٢	٢٧.٤٢	١٥.٤٤	٨٠	٢	١٨٠	٣٦.٥٩	٢٢.٥٤	١٠١	١	١٨٢

Comparison of the results of Table (٤-١٥), that shown graphically in Figures (٤-١٣ and ٤-١٤), with those of Table (٤-١٤), shows a slight effect of outliers on process stability, where the stability cutoff point still ١٠ (mg/l) for both effluent BOD٥ and S.S data. Removing of the upper ١٪ of the data resulted in an insignificant reduction in the maximum values, due to the same reasons that presented in the study of outliers effects on plant reliability.

Removing the ١٪ of the data set may not be convenient for operators or acceptable to regulatory agencies. Only if high-value data points can be proven to be true outliers, that is, the results of accidents or measurement errors, should their removal be considered because, these data observations may be true values of process performance and characteristics of effluent concentration distributions. The nature of these outliers is determinable only if the source and reason for each outliers is noted and documented properly by the plant operator (Niku et al, ١٩٨١).





٤.٤ Dependability of Al-Kerkh Wastewater Treatment Plant

Results of dependability analysis of final effluent BOD٥ and S.S data are summarized in Tables (٤-١٦ and ٤-١٧), respectively, for lines one and two of Al-Kerkh wastewater treatment plant. In addition, these tables give the results of the analysis of data for the periods before and after the war of ١٩٩١ and confirm the strong effects of the war on the performance of Al-Kerkh wastewater treatment plant. The results of these tables confirm the urgent need for more attention to the environmental impacts, which the war inflected upon the environment and consequently on the public health.

Results of Tables (٤-١٦ and ٤-١٧) show clearly the devastating effects of the war on the performance of Al-Kerkh wastewater plant. For instance, the overall reliability of Al-Kerkh wastewater treatment plant for the effluent BOD٥ has dropped from ٩٦.٦٩٪ before the war to ٥٢.١٣٪ after the war, while the same overall reliability for the effluent S.S has dropped from ٩٩.٦١٪ before the war to ٦١.٠٠٪ after the war.

Using of the Vx values listed in Tables (٤-١٦ and ٤-١٧) in combination with the limits of effluent BOD٥ and S.S concentrations as set by Iraqi standards on effluents into rivers (effluent BOD٥≤ ٤٠ mg/l and effluent S.S≤ ٦٠ mg/l) it can be stated that Al-Kerkh wastewater treatment plant should be designed on the basis of;

١- Stability;

Average of effluent concentration = S.D / Vx

And

Standard deviation, S.D, for stable plant ≤ ١٠ mg/l

Then

Average of effluent BOD٥ concentration=١٠/٠.٦٩=١٤.٣ mg/l≈١٤ mg/l

Average of effluent S.S concentration = ١٠/٠.٦٦=١٥.٢٢ mg/l≈١٥ mg/l

٢- Reliability

Average of effluent concentration = COR*X_s

Using of results of Table (٣-١) or Tables (٤-٨ and ٤-٩) with Vx_{BOD_5} = ٠.٦٩ and

$Vx_{s.s}$ = ٠.٦٦, at reliability level ٩٥٪, we can find;

COR_{BOD_5} = ٠.٤٢

$COR_{S.S}$ = ٠.٤٥

Then

Average of effluent BOD_5 concentration = ٠.٤٢ * ٤٠ = ١٦.٨ mg/l ≈١٦ mg/l
Average of effluent S.S concentration = ٠.٤٥ * ٦٠ = ٢٧ mg/l

The designer engineer selects the smallest values of the above values to produce a stable and a reliable wastewater treatment plant. Thus, Al-Kerkh wastewater treatment plant should be designed on the basis of;

Average of effluent BOD_5 concentration =١٤ mg/l.

Average of effluent S.S concentration = ١٥ mg/l.

It is worth noting that these design values of Al-Kerkh wastewater treatment plant are very comparable with those suggested by Niku et al., (١٩٨١). They suggested the following values;

Average of effluent BOD_5 concentration ≤ ١٣ to ١٥ (mg/l)

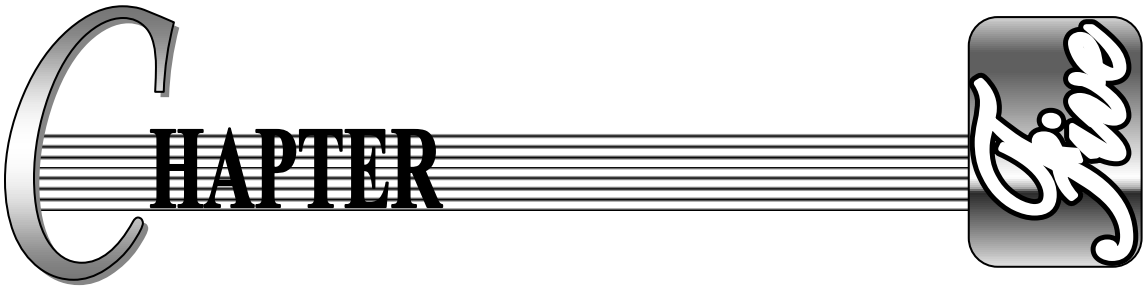
Average of effluent S.S concentration ≤ ١٠ to ١٤ (mg/l)

Table (٤-١٦) : Results of Al-Kerkh wastewater treatment plant dependability analysis for final effluent BOD٥.

	Mean	S.D.	Vx	Reliability %	Stability
Pre-war					
Line-١	١٩.٣٧	٩.١٢	٠.٤٨	٩٦.٧١	Stable
Line-٢	١٨.٩٥	٩.١٥	٠.٥٠	٩٦.٦٨	Stable
Overall	١٩.١٦	٩.١٤	٠.٤٨	٩٦.٦٩	
Post-war					
Line-١	٥٠.٠٤	٣٨.٣٤	٠.٧٦	٥٣.٥٦	Unstable
Line-٢	٦٠.٧٥	٤٦.١٩	٠.٧٧	٥٠.٧٠	Unstable
Overall	٥٣.٤٩	٤٢.٢٦	٠.٧٧	٥٢.١٣	
Overall	٤٥.٣٤	٣٤.٥٥	٠.٦٩	٦٣.٢٧	

Table (٤-١٧) : Results of Al-Kerkh wastewater treatment plant dependability analysis for final effluent S.S.

	Mean	S.D.	Vx	Reliability%	Stability
Pre-war					
Line-١	١٦.٥٥	٩.٣٤	٠.٨٥	٩٩.٦٥	Stable
Line-٢	١٨.٥٦	٩.٧١	٠.٥٢	٩٩.٥٦	Stable
Overall	١٧.٥٥	٩.٥٣	٠.٥٦	٩٩.٦١	
Post-war					
Line-١	٦٠.٩٠	٤١.٣١	٠.٦٨	٦١.٥٣	Unstable
Line-٢	٦٣.١٨	٤٤.٨١	٠.٧٠	٦٠.٤٧	Unstable
Overall	٦٢.٠٤	٤٣.٠٦	٠.٦٩	٦١.٠٠	
Overall	٥٠.٩٢	٣٤.٦٨	٠.٦٦	٧٠.٦٥	



CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORKS

٥.١ Conclusions

Based on the results of the present study, the following conclusions can be drawn:

∂ The probabilistic models, that used in this study, are valid to be used to investigate the dependability of AL-Kerkh wastewater treatment plant.

- Dependability study of AL- Kerkh wastewater treatment plant shows that the performance of this plant before the war of ١٩٩١ was in an excellent state and within the Iraqi standards. Where the treatment process was stable during that period and the overall reliability was ٩٦.٦٩٪ for effluent BOD_5 and ٩٩.٦١٪ for effluent S.S, But, after the war of ١٩٩١, the plant became unstable and the overall reliability dropped to ٥٢.١٣٪ for effluent BOD_5 and to ٦١.٠٠٪ for effluent S.S.

÷ Study of outliers effects on the dependability of Al-Kerkh wastewater treatment plant shows that these effects may be neglected .It was found that after the removing of outliers the overall reliability

for effluent S.S increased only with ١.٠١٪ and with ٢.٧٩٪ for effluent BOD_5.

≠ Al-Kerkh wastewater treatment plant consists of three lines, one of them (line No.٣) is out of order. This leads to increase the waste-water load on the other two lines and consequently in lowering of treatment efficiency of the plant.

≡ The results of this study indicate that it is more better to take in consideration, for Al-Kerkh wastewater treatment plant, an effluent BOD_5 concentration ≤ ١٤ (mg/l) and ≤١٥ (mg/l) for an effluent S.S concentration in order to make this plant stable and reliable. These values seem to be in agreement with the design values that recommended by Niku et al. (١٩٨١), who recommended that activated sludge treatment plants should be designed for an effluent BOD_5 concentration ≤ ١٣ to ١٥ (mg/l) and an effluent S.S concentration ≤ ١٠ to ١٢ (mg/l).

≈ The results of stability study show an excellent agreement with the results that obtained in U.S.A by Niku et al. (١٩٨١), where it was found that the stability cutoff point of Al-Kerkh wastewater treatment plant can be taken at S.D. = ١٠ (mg/l), which was the same cutoff point that obtained by Niku et al. (١٩٨١).

٥.٢ Recommendations

The author would like to appoint the following recommendations for future studies:

∂ The results of this research may be helpful to study the possibility of introducing more stringent standards on effluents from Iraqi

wastewater treatment plants, like, BOD_5 = ٢٠ (mg/l) and S.S = ٣٠ (mg/l) to improve the aquatic environment of our rivers.

- The same analysis can be carried out on effluent data from other activated sludge plants in Iraq.

÷ Other effluent variables (such effluent Nitrogen and phosphor concentrations) can be used to perform this analysis.

≠ Dependability of individual processes within the plant can be evaluated by applying the same analysis.

≡ It is of great importance to follow a study about the population that served by Al-Kerkh wastewater treatment plant, because it is probable that Al-Kerkh wastewater treatment plant is serving more than its ability (١.٨ millions inhabitants) which results in increasing the wastewater load on the plant.

≈ An annual report about the performance of Iraqi wastewater treatment plants should be introduced to the Iraqi environmental agencies to monitor the performance of these plants. This can be done with the help of the results of this study.

… The third line of Al-Kerkh wastewater treatment plant should be constructed as quickly as possible in order to minimize the wastewater load on the other two lines and consequently to increase treatment efficiency of the plant.

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