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Assessing the Effectiveness of Textile Wastewater Treatment Through Fish Acute Toxicity Studies and Water Quality Evaluation

Akeredolu O. E. [1], Adegboro, A.O.[1]; Adebanjo O. G. [1] and Oluwatosin Dada[2]
[1] Department of Zoology, Faculty of Science, University of Lagos.
[2] Department of Wildlife and Ecotourism, University of Ibadan.
*E-mail: eakeredolu@unilag.edu.ng

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ABSTRACT

The UN Decade for Safe Water underscores the importance of evaluating the toxicities of industrial wastewater discharges to protect aquatic ecosystems. This study assessed the influent and effluent toxicities from a textile industrial establishment in Lagos State, Nigeria, using a 96-hour acute non-renewal bioassay system with juvenile *Oreochromis niloticus.* Various parameters, including pH, conductivity, color, total suspended solids (TSS), total dissolved solids (TDS), total alkalinity, total acidity, biological oxygen demand (BOD), chemical oxygen demand (COD), turbidity, and heavy metals, were analyzed in the textile industrial wastewater samples. The results indicated that most of the effluent parameters met the standards set by the Federal Environmental Protection Agency (FEPA) for industrial effluent discharge, including heavy metal concentrations. Mortality rates were recorded based on the wastewater concentrations (v/v), and the fish exhibited uptake of certain heavy metals from the wastewater. The derived toxicity indices revealed that the 96-hour LC50 values for the influent and effluent against *O. niloticus* were 49.46v/v and 325.43v/v, respectively, indicating that the influent was 6.58 times more toxic than the effluent. Test organisms displayed symptoms of toxicosis, including loss of equilibrium, erratic swimming, weakness, periods of quiescence, and death. This study emphasizes the importance of incorporating active biomonitoring of industrial effluent treatments at all stages to confirm treatment efficiency and ensure compliance with environmental safety limits in order to promote the UN Decade for Safe Water objectives.

INTRODUCTION

Industrial activities inevitably produce waste, and the composition of these residues depends on factors such as the industrial processes, raw materials used, and technological methods employed. In Nigeria, the textile industry and other industrial sectors contribute to the indiscriminate discharge of effluents into nearby water bodies. These effluents contain various environmental pollutants that can accumulate in organisms and persist in the environment due to their chemical stability and poor biodegradability (Chukwu, 1991). Numerous cases have been reported of fish mortalities resulting from the discharge of industrial effluents into receiving water bodies (Das, 2003; Adewoye and Lateef, 2004; Adewoye *et al.,* 2005).The introduction of these effluents into aquatic systems disrupts

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aquatic productivity and leads to physiological dysfunction in resident organisms. Improper disposal of industrial wastes is considered a primary cause of carcinogenic and mutagenic chemicals in water bodies (Chandra *et al.,* 2006). Ogundiran *et al.* (2010) highlighted that the accumulation of pollutants in the food chain leads to adverse effects and eventual death of aquatic organisms (Ogundiran *et al.,* 2010).

Water pollution has a range of impacts, including overburdening the self-purification processes of water, algal and phytoplankton blooms resulting from eutrophication, disruption of food chains and aquatic ecosystems, increased water turbidity, unpleasant odors from water bodies, contamination of shellfish and finfish, alterations in physicochemical water quality, and heavy siltation caused by suspended particulate matter (Odiete, 1999). Some of these effects pose health hazards by transferring pathogens to animals and humans alike.

Textile industries are significant sources of pollution due to their operations, which require large volumes of water, resulting in substantial wastewater generation (Nemerow, 1978). Different textile industries use distinct raw materials, which also influence the water volume consumed during production and the wastewater generated. Key activities in textile production, such as slashing, bleaching, mercerizing, and dyeing, generate wastewater and exert a strong influence on the potential impacts associated with these industrial processes. (Raji and Kamila 2018)

Although physicochemical parameters are commonly used to evaluate effluent quality, they alone cannot provide a quantitative measure of pollution impact. Toxicity evaluation serves as an essential and cost-effective tool in monitoring wastewater quality, as it provides a comprehensive response of test organisms to all compounds present (Somashekar *et al.,* 1985; Tisler and Koncan, 1999). The ultimate objective of toxicity evaluation is to determine acceptable levels of toxicants in the environment for biota. Therefore, these studies are invaluable in determining the safe concentration of wastewater to be discharged into aquatic ecosystems (Bobmanuel *et al.,* 2006).

The objective of this study is to establish the acute toxicity indices of the influent and effluent from a textile industry on Nile Tilapia (*Oreochromis niloticus).* By conducting these toxicity assessments, we aim to gain insights into the potential risks posed by the textile industry's wastewater discharge and its impact on aquatic organisms. The findings will contribute to the broader goals of the UN Decade for Safe Water by promoting sustainable practices in the textile industry and safeguarding water resources.

MATERIALS AND METHODS

Source of Fish and Test Media:

Four hundred healthy juveniles of *Oreochromis nilotic*us were sourced from a reputable fish farm in Abule Egba, Lagos. The fish had an average length of 7-8 cm and an average weight of 1.40 ± 0.01 g. They were transported to the Zoological laboratory at the University of Lagos, Akoka, and placed in a 20-liter aerated fiberglass tank, which served as the holding tank. The fish were acclimatized for 72 hours at a temperature of 28 ± 0.5°C and were fed a high-protein commercial diet twice daily. The commercial diet had an average particle size of 0.8 mm, and the water in the holding tank was replaced every 72 hours.

Test Compounds:

The influent and effluent from a textile industry located in Ogba, Lagos State, Nigeria, were used as the test compounds. Both the untreated influent (prior to processing in the waste treatment plant) and the treated effluent (after treatment in the waste treatment plant) were collected from different disposal tanks within the industrial complex.

Bioassays:

The acute toxicity test of the industrial influent and effluent on *Oreochromis niloticus* was conducted using the standard static non-renewal technique (APHA,2005). The test concentrations were prepared by diluting the influent and effluent with appropriate volumes of water to make a total volume of 1 liter in a 2 m by 2 m bioassay glass tank. The concentrations tested included 0, 50, 100, 200, 400, 600, and 800 ml (v/v). The test organisms were exposed to these concentrations in separate bioassay tanks. Ten fish were randomly selected and transferred from the holding tank to each bioassay tank after a four-day acclimatization period. The bioassay tanks were thoroughly cleaned prior to the experimental setup, and feeding was suspended 48 hours before the exposure period and throughout the experiment. Mortality assessments were made every 24 hours, and fish behavior was observed throughout the experiment. The experiment was conducted in two replicates and lasted for four days, with dead fish being removed as necessary using forceps. Physicochemical analyses, including temperature, Total Dissolved Solids (TDS), conductivity, and salinity, were performed at 12-hour intervals in each tank.

Physicochemical Analysis:

The influent and effluent samples collected were subjected to physicochemical analysis at the wastewater laboratory of the Lagos State Environmental Protection Agency (LASEPA) following standard procedures (APHA, 2005). The test compounds were stored at 4°C between experiments.

Statistical Analysis:

The means of the physicochemical variables were analyzed using Microsoft Excel (Microsoft Office, 2007), and graphs were plotted using the same application. Probit analysis was employed to determine the LC50 (lethal concentration that causes 50% mortality) of the influent and effluent, along with their corresponding 95% confidence intervals, using SPSS version 16.0 (SPSS, 2007). The safe dischargeable concentration was calculated by multiplying the LC50 values with an application factor of 0.1 (Bobmanuel et al., 2006). The acute toxic unit (TUa) and total efficiency (E) of effluent treatment were calculated according to USEPA (2000) using the following formulas:

TUa = 100/LC50% (v/v)

E = (TUai - TUae)/TUai * 100

Where TUai represents the influent TUa and TUae represents the effluent TUa.

RESULTS

Physico-chemical Properties:

The physicochemical parameters of the influent and effluent used for this study are shown in Table 1. The temperature of the influent and effluent measured 38ºC and 26ºC, respectively, while the alkaline values were 10.5 and 8.6, respectively. The dissolved oxygen content in the influent and effluent was 5.54 mg/l and 4.77 mg/l, respectively, which exceeded the FEPA set limit. Additionally, parameters such as BOD, COD, TSS, and TDS showed values higher than the set limits. The influent had total alkalinity and acidity below detectable limits, whereas the effluent exhibited values of 40 mg/l and 230 mg/l, respectively. Microbes were present in the effluent, indicating their action on the influent, but some were either absent or not detected in the influent's Coliform count (CFC). The oil and grease values in both samples were negative.

Table 1: Physicochemical characteristics of textile influent and effluent and FEPA standard.

Parameter	Influent	Effluent	FEPA Acceptable Limits
Appearance	Pinkish	Cloudy with particles	Clear
Turbidity	326FTU	111FTU	-
Temperature at collection (ºC)	38	26.2	29
pH	10.5	8.6	6 – 9
Conductivity	1712u*S*	740u*S*	-
Dissolved Oxygen (DO)	5.54mg/l	4.77mg/l	4.0mg/l
Total Acidity	0mg/l	40mg/l	-
Total Alkalinity	0mg/l	230mg/l	-
Chloride	1100mg/l	440mg/l	-
Nitrate	0mg/l	0.2mg/l	20mg/l
Phosphate	0.97mg/l	1.19mg/l	-
Sulphate	47mg/l	7mg/l	500mg/l
Chemical Oxygen Demand	328mg/l	137mg/l	80mg/l
Biochemical Oxygen Demand	82mg/l	34.25mg/l	20mg/l
Oil and grease	-1.7	-1.5	-
Total solid	1175	749	2000
Total Dissolved Solid	855	478	500 -1500
Total Suspended Solid	320	271	30
TPC	100	>150	-
CFC	Nil	+ve	-
TCC	+ve	+ve	-
Potassium	0.0928	0.1702	-
Cadmium	0.0049	0.0056	<1.0
Iron	0.0089	0.1080	20
Chromium	ND	ND	0.1
Zinc	0.0322	0.0066	<1.0
Copper	0.0172	0.0059	<1.0
Lead	0.0035	0.0020	<1.0
Silver	0.6928	0.0015	-

Heavy Metals Concentration in the Effluent:

The effluent showed minimal levels of heavy metals, with concentrations of Cd, Fe, Zn, Cu, Pb, and Ag being low and within acceptable limits (Table 2). While Ag had the highest concentration, it remained at a minute and negligible level. However, Cd was not detected (ND) in both textile samples.

Table 2: Heavy metal indices of textile influent and effluent before and after bioassay.

Heavy Metals	Influent	Effluent	Avg. After bioassay (Influent)	Avg. After bioassay (effluent)
Cadmium	0.0049	0.0056	ND	ND
Iron	0.0089	0.1080	ND	0.0745
Chromium	ND	ND	ND	ND
Zinc	0.0322	0.0066	ND	ND
Copper	0.0172	0.0059	0.0042	0.0008
Lead	0.0035	0.0020	ND	ND
Silver	0.6928	0.0015	ND	ND

Bioassay Results:

Mortality response of Nile Tilapia exposed to varying concentrations of Textile waste influent and effluent is shown in Table 3 with the lowest concentration of textile waste influent (25 v/v) causing 30% mortality after 96 hours exposure compared with 80% mortality percentage observed when fish were exposed for 96 hours at the highest concentration (800 v/v) of textile waste effluent.

Table 3: Mortality details of the Nile tilapia, *Oreochromis niloticus* exposed to different.

Conc. (v/v)	24hrs		48hrs		72hrs		96hrs	
	Mortality	% Mortality	Mortality	% Mortality	Mortality	% Mortality	Mortality	% Mortality
	INFLUENT							
0	0	**0**	0	**0**	0	**0**	0	**0**
25	0	**0**	4	**20**	4	**20**	6	**30**
50	5	**25**	9	**45**	10	**50**	11	**55**
100	8	**40**	11	**55**	13	**65**	14	**70**
200	8	**40**	13	**65**	16	**80**	16	**80**
400	8	**40**	12	**60**	15	**75**	17	**85**
800	19	**95**	19	**95**	20	**100**	20	**100**
	EFFLUENT							
0	0	**0**	0	**0**	0	**0**	0	**0**
25	0	**0**	0	**0**	0	**0**	0	**0**
50	0	**0**	0	**0**	1	**5**	1	**5**
100	0	**0**	0	**0**	5	**25**	6	**30**
200	1	**5**	4	**20**	5	**25**	7	**35**
400	4	**20**	6	**30**	9	**45**	9	**45**
800	5	**25**	9	**45**	13	**65**	16	**80**

Concentrations of textile influent and effluent

Lethal Concentration (LC_{50}):

The Lethal concentration (LC_{95}, LC_{50}, LC_{5}) and the associated 95% confidence interval (C. I) of the different ranges of textile influent and effluent for O. niloticus is shown on Table 4. LC_{50} is the concentration at which the test substances are enough kill 50 percent of the tested population

Table 4: LC_{95}, LC_{50} and LC_{5} and associated confidence intervals (C.I) of textile influent and effluent against *O. niloticus*.

Test Substance	Lethal Concentration (LC_x)	96hrsLC_x	df	Std Error	Equation of the line
Textile influent	LC_{95}	634.42 (335.69 – 2375.87)	4	0.603	Y=-2.515+5.603 x
	LC_{50}	49.46 (25.60– 75.12)			
	LC_{5}	3.86 (0.46 – 10.17)			
Textile effluent	LC_{95}	2684.14 (1303.39– 11314.43)	4	0.766	Y=-4.510+5.766 x
	LC_{50}	325.43 (230.30 – 516.99)			
	LC_{5}	39.46 (14.26 – 67.41)			

The 96-hour LC_{50} value of the influent against *O. niloticus* was determined to be 49.46 v/v, whereas the 96-hour LC_{50} value of the effluent was found to be 325.43 v/v. This indicates that the influent was approximately 6.58 times more toxic to the Tilapia species, O. niloticus, compared to the effluent. (Table 5)

Table 5: Relative Acute Toxicity indices (96 hrsLC_{50}) of textile influent and effluent on *O. niloticus* and efficiency of wastewater treatment

Test substance	96hrsLC_{50}	TF	TUa	Safe Dischargeable concentration	Total Efficiency of Treatment(%)
Textile influent	49.46	6.58	2.02	4.95	84
Textile effluent	325.43	1	0.31	32.54	

$$\text{Toxic Factor} = \frac{\text{LC50 of less toxic compound}}{\text{LC50 of more toxic compound}}$$

TUa: Acute toxic unit

Variation in the physicochemical parameters of the bioassay medium for *Oreochromis niloticus* in textile influent and effluent respectively at 12hrs interval.

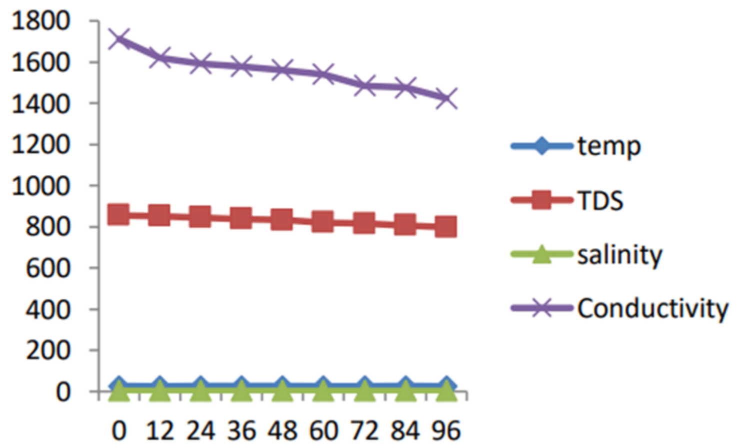

Fig. 1: Average variation in the physicochemical properties of the bioassay medium for *Oreochromis niloticus* in textile influent at 12hrs intervals.

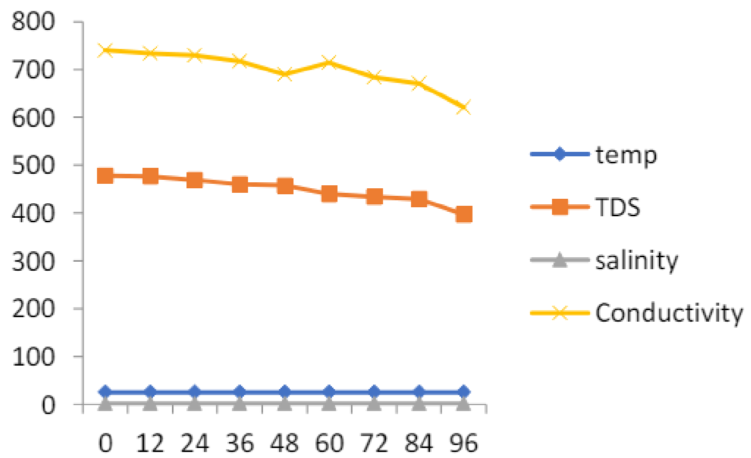

Fig. 2: Average variation in the physicochemical properties of the bioassay medium for *Oreochromis niloticus* in textile effluent at 12hrs intervals.

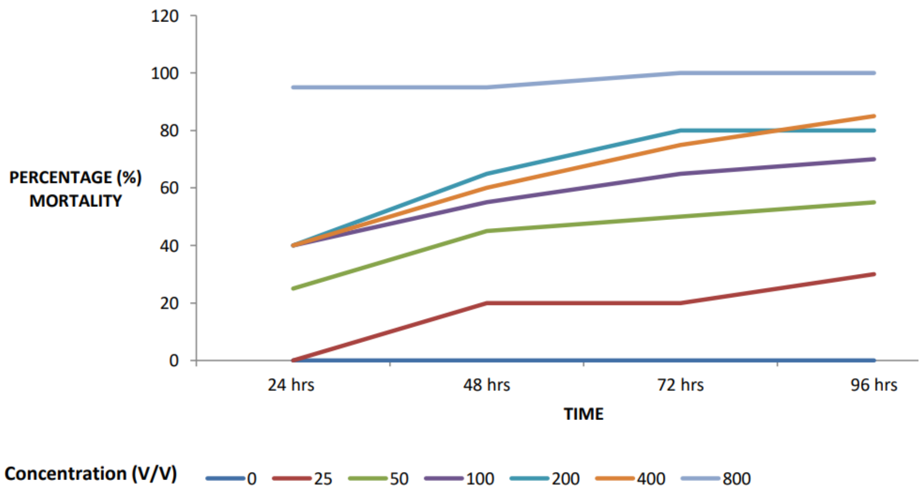

Fig. 3: Total % Mortality of *Oreochromis niloticus* with durations of exposure to textile influent at different concentrations.

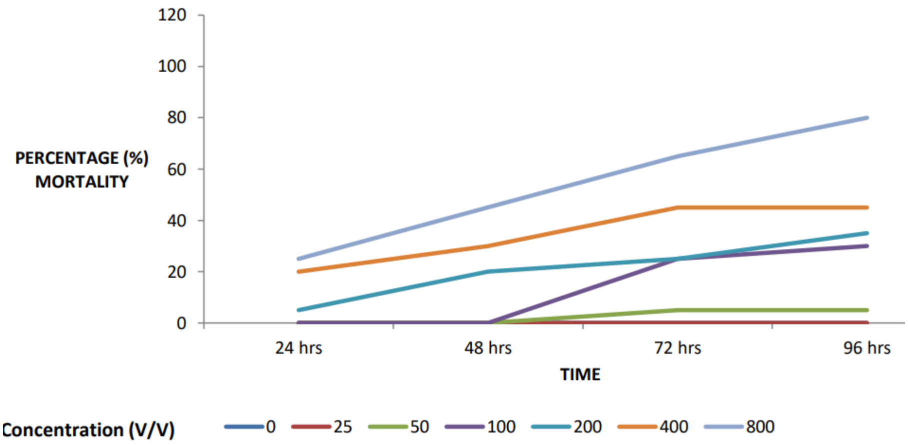

Fig. 4: Total % Mortality of *Oreochromis niloticus* with durations of exposure to textile effluent at different concentrations.

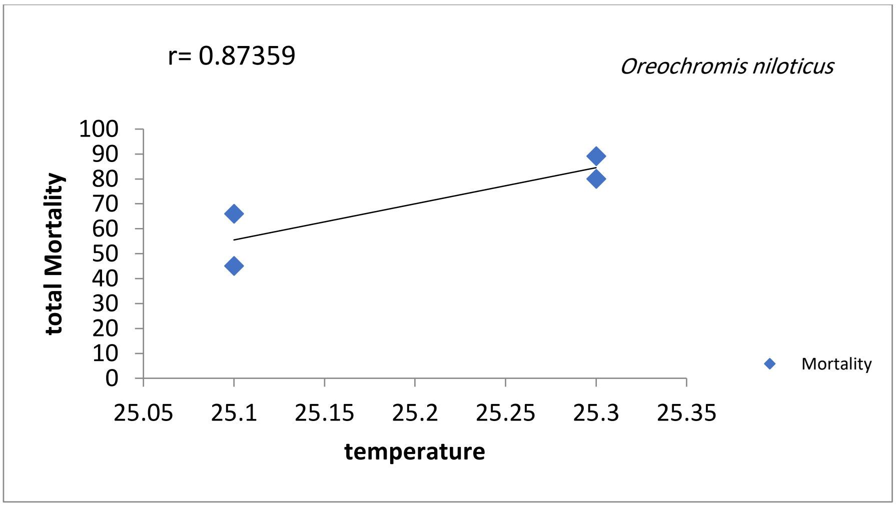

Fig. 5: A total mortality – temperature relationship in bioassay medium of *Oreochromis niloticus* in a textile influent at 24hrs interval

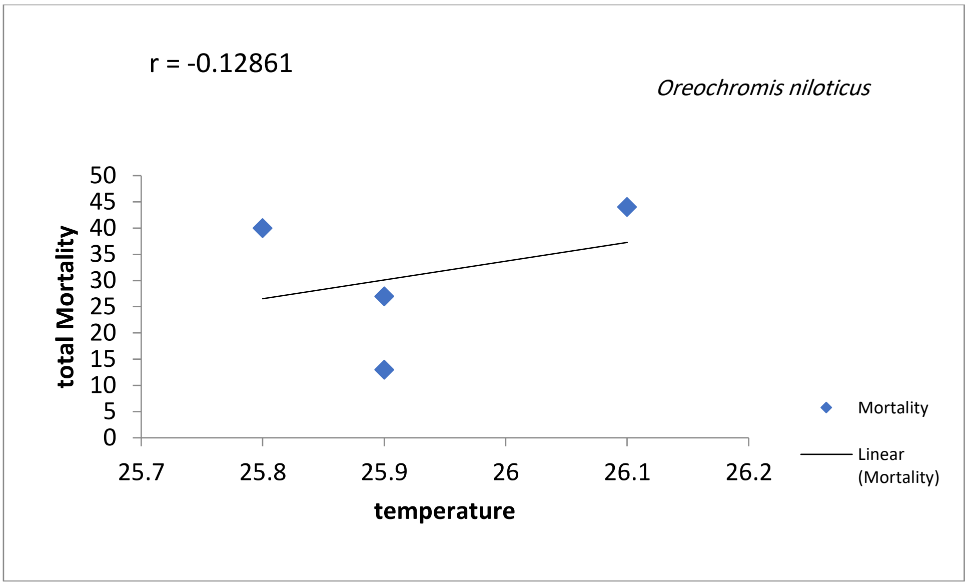

Fig. 6: A total mortality – temperature relationship in bioassay medium of *Oreochromis niloticus* in a textile effluent at 24hrs interval.

N.B: Figures 1 and 2 depict the average variations in the physicochemical properties of the bioassay medium for Oreochromis niloticus in the textile influent and effluent, respectively, at 12-hour intervals. Figures 3 and 4 present the total percentage of mortality of *Oreochromis niloticus* at different concentrations and durations of exposure to the textile effluent. Figures 5 and 6 illustrate the spatial relationship between total mortality and temperature during the bioassay study on O. niloticus at 24-hour intervals. These graphs provide insight into the potential correlation between temperature and the mortality rate observed during the study. In Figure 5, the relationship between total mortality and temperature is demonstrated for O. niloticus in the influent medium, while Figure 6 represents the same relationship for O. niloticus in the effluent medium. It was observed that the correlation between temperature and mortality was negative (r = -0.12861), indicating an inverse relationship. Notably, a strong correlation (0.87359) was observed between temperature and the total mortality of O. niloticus in the textile-influent medium, suggesting that the mortality rate is highly dependent on temperature. Specifically, as temperature increases, the mortality rate also increases.

DISCUSSION

Throughout the study, the temperature and salinity remained constant, indicating that the animals did not experience excessive physiological stress due to consistent laboratory conditions. However, there was a decline in total dissolved solids, attributed to biological degradation likely caused by microbial action. Conductivity also decreased over time.

After the bioassay, the concentration of heavy metals in the animals was lower compared to the levels before the experiment. This can be attributed to the uptake of heavy metals by the fish, leading to bioaccumulation. The animals exhibited normal behavior until they were exposed to toxicants. Their activity rate increased, as evidenced by agitated swimming, which later decreased along with the onset of symptoms such as loss of equilibrium, progressive weakness, mucus secretion, periods of inactivity, and quiescence. These anomalies were not observed in the control group under identical conditions, indicating that the observed behavioral responses were specific to the toxicant exposure. Fish behavior in response to toxicants and differences in reaction times are known to be influenced by the chemicals' effects, their concentrations, and specific environmental conditions.

Besch (1975) identified four main phases in fish responses to toxicants: the contact phase (a brief period of high excitability), exertion (visible avoidance characterized by fast swimming, leaping, and attempts to escape the toxicant), loss of equilibrium, and the lethal phase when opercular movement and responses to tactile stimuli cease. The observed bleeding and erosion of skin in O. niloticus align with a previous report by Oladimeji and Onwumere (1987), who demonstrated that refinery effluents treated to meet traditional physicochemical standards at sub-lethal concentrations resulted in fin hemorrhage, erosion of caudal fins, reduced growth, and gill damage in O. niloticus.

There was a consistent trend of increasing mortality with higher concentrations of both influent and effluent. During the early stage of toxicant introduction, the fish exhibited a higher lethal response in the influent compared to the effluent. The relationship between the lethal concentrations (LC50) of the influent (49.46) and the effluent (325.43) indicates that the influent was more toxic than the effluent. The toxicity factor (TF) of the textile wastewaters suggests that the influent was 6.58 times more toxic than the effluent. O. niloticus mortality remained directly proportional to the duration of exposure and concentration, as observed in a hybrid catfish study by Gabriel and Okey (2009). The treatment system exhibited an overall efficiency of 84%. The safe dischargeable concentration, which establishes acceptable limits for aquatic animals (Roopadevi & Somashekar, 2012), was calculated to be 4.95 for the textile influent and 32.54 for the effluent.

Conclusion:

In conclusion, this study confirms that untreated textile wastewater is highly toxic to the test animal, and treatment significantly reduces its toxicity. However, despite the 84% efficiency achieved by the textile factory's treatment system, the observed toxicity of the effluent to O. niloticus indicates that the current level of effluent treatment prior to discharge still requires improvement**.** The findings of this study thus contribute to the broader goals of the UN Decade for Safe Water by highlighting the importance of promoting sustainable practices in the textile industry and safeguarding water resources. The study reveals that untreated textile wastewater poses a significant threat to aquatic organisms, as evidenced by the high toxicity observed in O. niloticus. However, the treatment of wastewater significantly reduces its toxicity, indicating the potential for mitigating the negative impact on water quality and aquatic life. These efforts will contribute to the preservation of water resources, the protection of aquatic ecosystems, and the promotion of a more sustainable and environmentally conscious textile industry.

Recommendation:

To further advance the objectives of the UN Decade for Safe Water, it is crucial to recommend and implement measures that promote sustainable practices in the textile industry and enhance the treatment of wastewater:

1. Textile factories should invest in advanced treatment systems that effectively remove pollutants and minimize the toxicity of wastewater before discharge. Continuous monitoring and optimization of these treatment systems should be prioritized to ensure consistently high treatment efficiency.
2. Textile manufacturers should embrace cleaner production techniques that minimize the generation of hazardous substances and reduce water consumption. Implementing eco-friendly dyeing and finishing processes, optimizing chemical usage, and adopting water-efficient practices can significantly reduce the environmental impact of textile production.

3. Textile factories should explore opportunities for water recycling and reuse within their operations. Implementing closed-loop systems that treat and reuse water can significantly reduce the overall water demand of the industry and minimize the discharge of pollutants into natural water bodies.
4. Governments, regulatory bodies, and textile industry stakeholders should collaborate to establish and enforce stringent regulations and standards for wastewater treatment and effluent quality. Regular monitoring, inspections, and strict enforcement of compliance will ensure that textile factories adhere to sustainable practices and minimize their impact on water resources.
5. Raising awareness among consumers, policymakers, and the general public about the environmental impact of the textile industry is crucial. Educating stakeholders about the importance of sustainable textile production and the significance of water conservation can drive demand for eco-friendly products and encourage responsible consumption.

Declarations:

Ethical Approval: Not applicable.

Competing interests: The authors declare no conflict of interest.

Authors Contributions:I hereby verify that all authors mentioned on the title page have made substantial contributions to the conception and design of the study, have thoroughly reviewed the manuscript, confirm the accuracy and authenticity of the data and its interpretation, and consent to its submission.

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Availability of Data and Materials: All datasets analysed and described during the present study are available from the corresponding author upon reasonable request.

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