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Tannery Effluents Quality Evaluation Using Principal Component Analysis for Challawa Industrial Estate, Kano, Nigeria

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Abstract: Physical and chemical parameters monitored at eight locations in Challawa Industrial Estate, Kano were analyzed. Principal component analysis (PCA) was used to extract the factors associated with the tannery effluents pollution variability and to obtain the spatial and temporal changes in the effluent quality. Temperature, total solids, total dissolved solids, total suspended solids, conductivity, chloride, sulphide, alkalinity, biochemical oxygen demands and chemical oxygen demands were the main patterns extracted. The spatial analysis isolated six sampling sites showing a possible point source of pollution. Six of the properties (temperature, total dissolved solids, total suspended solids, sulphide, biochemical oxygen demand and chemical oxygen demand) exceed apparent standard limit for industrial effluent discharge in Nigeria for most of the tanneries. Treatments of these effluents are also recommended before discharge.

Introduction

There has been an increasing rise of environmental pollution globally as a result of man's activities such as sewage disposal in rivers and ecosystem (Lake et al., 1984; Schmidt, 1997), inadequate treatment of waste water from industries (Ademoroti, 1996; Malek and Hachemi, 2008; Mu et al., 2003), discharges from agricultural activities (McBride, 1995), heavy metals and persistent organic pollutants and oil spills (Nwigwe, 1998). Out of all these, industrial waste discharge constitutes the largest source of pollution where industries are available (Oyewusi, 1994).

The pollutants from industries include all forms of chemical wastes, which are allowed as effluent out of the industries mainly into the rivers. This results in adverse effects on the water quality of the river and probably depletion of the living aquatic resources (Adewoye, 1998). The threat to human lives posed by industrial pollution cannot be dismissed with the wave of the hand. Direct contact with some of the chemicals used can cause disability, illness and in some cases death. Even relatively minor exposures, if they occur frequently, can eventually build up to toxic levels.

The increasing realization of the effect of industrial pollutants of both organic and inorganic origin and the historical records from the hospitals, of the devastating nature of epidemics due to industrial effluents has necessitated a careful and detailed analysis of tannery industrial effluent characteristics within Challawa industrial area of Kano State, Nigeria. The aim of this study is to use principal component analysis in environmental monitoring to better understand a complex tannery effluent quality. Environmental pollution standard was also used to confirm tannery industry sludge status.

Materials And Methods

The Study Area

Kano State is the centre of Nigeria's tanning industry. Challawa Industrial Estate in Kano metropolis (N 1159°

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981', E 008° 31.491') is one of three industrial estates in Kano that hold 70% of Nigeria's tanneries. In addition they contain large number of rubber and plastics, food, metallurgical and manufacturing industries. In Kano, most industrial effluents are channeled into drains and subsequently into the Challawa River.

Sampling and Sample Preservation

Eight tanneries from Challawa industrial estate (Figure 1) were chosen for their effluents analyses for four months. These tanneries studied were purposively selected on the basis that they were the only operational plants as at the time of this research work and can be viewed as representative enough of tannery industries in Challawa Industrial Estate, Kano, Nigeria.

The sampling was conducted bi-weekly to gain better idea on the physical and chemical characteristics of the effluents. Sample preservation followed APHA (1992) guidelines, which include cooling the samples to 4°C.

Field and Laboratory Analysis

The APHA (1992) procedure has been used to study the environmental pollution of eight tannery industries by physical and chemical methods using end of pipe discharges of chemical, organic and suspended pollution loads, based on field and laboratory studies.

Twelve tannery wastewater quality parameters (priority and non-priority pollutants) were determined for each tannery site. Appropriate procedures were followed with instruments standardized daily, and

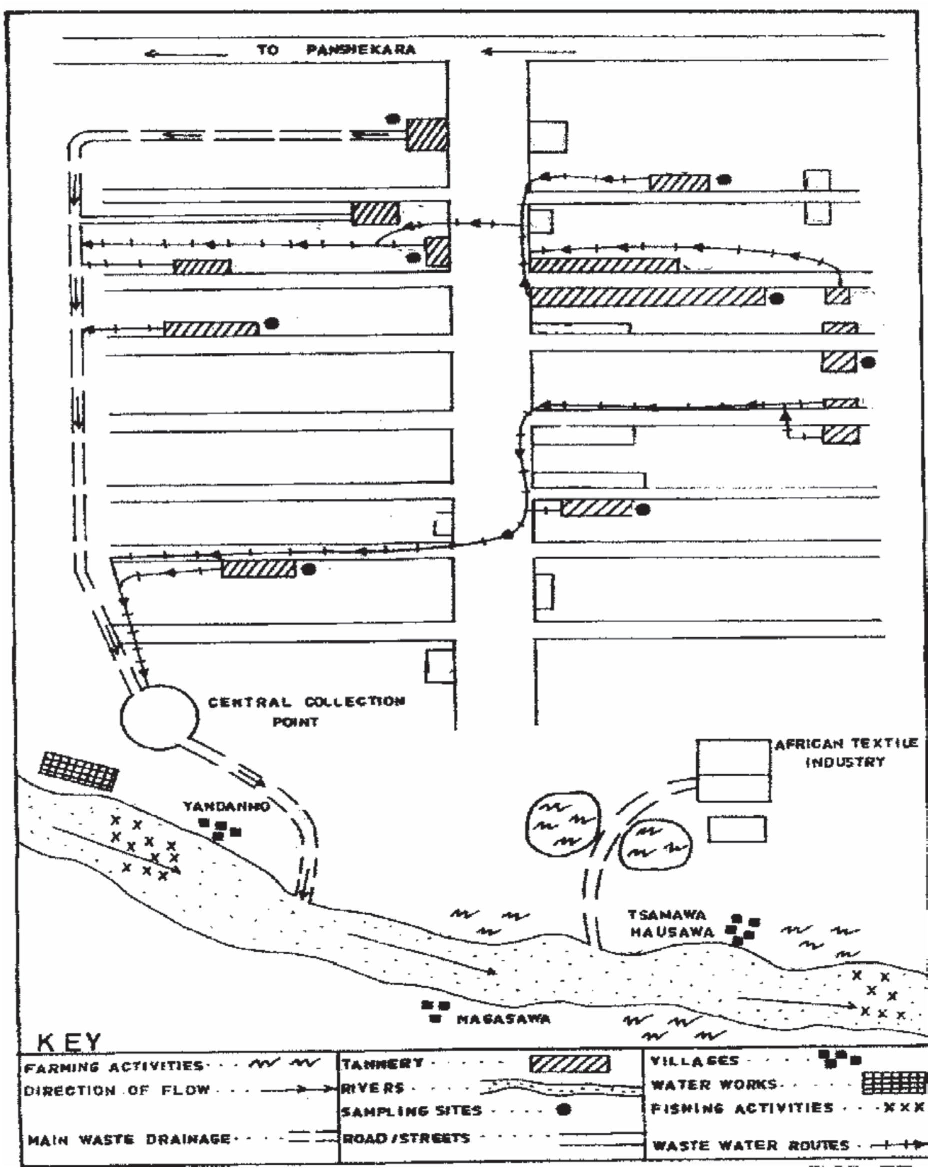

Figure 1: Sketch map of Challawa Industrial Estate showing the sampling sites.

appropriate blanks and standards run according to APHA, (1992). pH was measured with a Griffin pH meter model 60. The temperature was always determined at the source of the sample using thermometer in degree centigrade (°C). Other parameters investigated include alkalinity, total solids (TS), total dissolved solids (TDS), total suspended solids (TSS), conductivity, sulphide, chloride, biochemical oxygen demand (BOD), chemical oxygen demand (COD) and total Kjedahl nitrogen (TKN). Sample preservation followed APHA (1992) guidelines, which include cooling the samples to 4°C.

The statistical software package used for these analyses was SPSS for Windows: Release 10.

Results and Discussion

In the application of principal component analysis (PCA) to tannery effluent quality data (Table 1) from the Challawa monitoring stations, a correlation matrix was used. The reason was that variables were different in scale (as suggested by Karpuzcu and Senes, 1987) and equal in importance (as suggested by Chatfield and Collins, 1980). The results of principal components analysis of the data are presented in Table 2. The six subsequently derived components from this table were rotated according to varimax rotation in order to make interpretation easier (Table 3). Table 3 also yields six factors, which may be interpreted as having vital importance to the tannery effluent quality status.

In order to reduce the contribution of variables with minor significance, thus, we simplify the data structure. The number of principal components (PCs) considered for each situation was mainly decided on the basis of the percentage of explained variance. The decision of when to stop extracting factors basically depends on when there is only very little "random" variable left, which means that the extraction of a new factor does not significantly improve the overall information. We only have selected factors with eigenvalues higher than one. This was in agreement with Chatfield and Collins (1980), who stated that components with an eigenvalue of less than one should be eliminated so that fewer components are dealt with. That is unless a factor contributes to improve the overall information at least as much as the equivalent of one original variable, we drop it. This criterion is also similar to the Screen-test, which is a graphical method that plots the eigenvalues until the place where the smooth decrease of the eigenvalues appears to level off to the right of the plot (Chatfield and Collins, 1980).

Since all the communalities are larger than 0.67, it may be assumed that all the variables were described to an acceptable level. It can also be seen from Table 3 that these six principal components accounted for 84.94% of the total pollution variance of the effluents original data.

As a general guide in interpreting factor loadings, Comrey and Lee (1992) suggested a range of values to interpret the strength of the relation between variables and each factor. Loadings of 0.71 and higher are considered excellent, 0.60 very good, 0.55 good, 0.45 fair, and 0.32 poor. For this work, component loadings (correlation coefficients) larger than 0.60 was taken into consideration in the interpretation (as suggested by Mahloch, 1974). In other words, the most significant variables in the components represented by high loadings have been taken into consideration in evaluating the components. In addition to the significance of high

Table 1: Descriptive statistics for all tanneries sampling sites

	Median	*Maximum*	*Minimum*	*Mean*	*Std. deviation*	*Skewness*	*Kurtosis*
pH	8.11	12.92	4.21	8.39	2.17	0.03	-0.75
Temperature (^{o}C)	27.00	40.00	24.00	27.20	3.01	1.86	4.91
TS (mg/dm^3)	8019.50	23030.00	2766.50	8758.57	3663.16	1.61	4.68
TDS (mg/dm^3)	5258.50	11710.00	1280.00	5139.02	2524.14	0.33	-0.46
TSS (mg/dm^3)	2463.50	11573.00	104.60	3083.03	2140.10	2.30	6.40
Conductivity (μS/cm)	10454.00	22410.00	1970.00	10587.15	4156.06	0.37	0.34
Chloride (mg/dm^3)	1701.34	9489.00	0.00	2209.82	1961.99	1.52	2.73
Sulphide (mg/dm^3)	200.00	1140.00	14.00	274.79	235.88	1.78	3.82
TKN (mg/dm^3)	40.94	1526.53	2.10	133.48	223.28	4.29	24.16
Alkalinity (mg/dm^3)	30.00	1140.00	0.00	170.55	282.83	2.07	3.60
BOD (mg/dm^3)	3506.50	9500.00	742.95	3808.66	1971.44	0.80	0.34
COD (mg/dm^3)	5195.51	10177.65	965.55	5172.72	2324.27	0.25	-0.64

TS = Total Solids, TDS = Total Dissolved Solids, TSS = Total Suspended Solids, TKN = Total Kjedahl Nitrogen, BOD = Biochemical Oxygen Demand, COD = Chemical Oxygen Demand

Table 2: Latent roots (Eigenvalues or Variances) explained by principal components

	1	2	3	4	5	6	
	4.1	2.276	1.041	1.01	0.967	0.800	
Percent of Total Variance Explained							
	1	2	3	4	5	6	
	34.165	18.963	8.677	8.418	8.059	6.663	
Components Loadings							
	PC1	PC2	PC3	PC4	PC5	PC6	*C
pH	0.443	-0.418	-0.481	-0.253	-0.241	0.108	0.736
T	-0.275	0.217	-0.248	0.572	0.588	0.321	0.961
TS	0.916	0.100	-0.132	0.203	0.036	-0.231	0.961
TDS	0.839	0.145	-0.290	-0.061	0.194	0.038	0.853
TSS	0.728	-0.058	-0.048	0.459	-0.171	-0.281	0.854
CON	0.854	0.158	-0.121	-0.135	0.139	-0.068	0.810
Cl	0.601	-0.166	0.030	-0.183	-0.009	0.660	0.858
S	0.270	-0.420	0.282	0.502	-0.470	0.285	0.883
TKN	0.458	-0.398	0.486	-0.221	0.394	-0.030	0.809
ALK	0.403	-0.524	0.386	0.056	0.269	-0.099	0.671
BOD	0.304	0.799	0.362	0.001	-0.110	0.056	0.877
COD	0.357	0.848	0.182	-0.086	-0.124	0.128	0.919

*C = Communalities

T = Temperature, TS = Total Solids, TDS = Total Dissolved Solids, TSS = Total Suspended Solids, CON = Conductivity, TKN = Total Kjedahl Nitrogen, BOD = Biochemical Oxygen Demand, COD = Chemical Oxygen Demand

Table 3: Latent roots (Eigenvalues or Variances) explained by Varimax Rotated Component Matrix

	1	2	3	4	5	6	
	4.1	2.276	1.041	1.01	0.967	0.800	
Percent of Total Variance Explained							
	1	2	3	4	5	6	
	34.165	18.963	8.677	8.418	8.059	6.663	
Components Loadings							
	PC1	PC2	PC3	PC4	PC5	PC6 *C	
pH	0.394	-0.444	-0.108	0.505	0.033	-0.34	0.736
T	-0.052	-0.031	-0.139	-0.045	-0.059	0.966	0.961
TS	0.939	0.163	0.171	0.084	0.123	-0.048	0.961
TDS	0.801	0.141	0.114	0.395	-0.148	0.035	0.853
TSS	0.798	0.037	0.099	-0.111	0.438	-0.054	0.854
CON	0.765	0.231	0.216	0.306	-0.138	-0.110	0.810
Cl	0.199	0.107	0.241	0.844	0.193	-0.012	0.858
S	0.056	-0.085	0.119	0.158	0.911	-0.057	0.883
TKN	0.140	-0.022	0.865	0.169	-0.025	-0.109	0.809
ALK	0.198	-0.196	0.740	0.031	0.206	-0.043	0.671
BOD	0.166	0.920	-0.058	-0.022	-0.006	-0.018	0.877
COD	0.237	0.897	-0.184	0.119	-0.102	-0.027	0.919

*C = Communalities

T = Temperature, TS = Total Solids, TDS = Total Dissolved Solids, TSS = Total Suspended Solids, CON = Conductivity, TKN = Total Kjedahl Nitrogen, BOD = Biochemical Oxygen Demand, COD = Chemical Oxygen Demand loading values, there exists a difference between the components; the components with larger variances are more desirable since they give more information about the data. When the variances (eigenvalues) of the components are examined in the related tables, it can be seen that principal components are in decreasing order of importance with respect to their variances.

An interpretation of the rotated six principal components in Table 3 is made by examining the component loadings noting the relationship to the original variables. The first component gives pollution information about the variation in total solids, total dissolved solids, total suspended solids and electrical conductivity indicating untreated industrial discharge exists from the beam house operations of tannery industries. However, when the summary (Table 1) data for the monitoring station is examined, it can be concluded that the observed solids and conductivity values are quite high proving that there is a relatively high discharge. In the second component, BOD and COD are important, demonstrated by the positive relationship between them in this component. The third, fourth, fifth and sixth components were significant towards alkalinity, chloride, sulphide and temperature respectively.

Tannery Effluent and Standard Limit in Nigeria

The One-Sample t-Test was used to test whether the mean of a single variable differs from a specified constant, which in this case are the specified standard limit for effluents discharge into surface water for all categories of industries in Nigeria (Table 4) set by FEPA (1991). A low significance *p* value (typically below 0.05) indicates that there is a significant difference between the test value and the observed value. The results (Table 5) show

Table 4: Interim effluent limitation guidelines in Nigeria for all categories of industries

Parameters	*Limit for discharge into surface water*	*Limit for land application*
Temperature	Less than 40°C within 15 metre of outfall	Less than 40°C
Colour (Lovibound Units)	7	-
pH 6-9	-	
BOD_5 at 20°C	50	500
Total suspended solids	30	-
Total dissolved solids	2,000	2,000
Chloride (as Cl^-)	600	600
Sulphate (as SO_4^{2-})	500	1,000
Sulphide (as S^{-2})	0.2	-
Cyanide (as CN^-)	0.1	-
Oil and grease	10	30
Nitrate (as NO_3^-)	20	-
Phosphate (as PO_4^{3-})	5	10
Arsenic (as As)	0.1	-
Barium (as Ba)	5	5
Tin (as Sn)	10	10
Iron (as Fe)	20	-
Manganese (as Mn)	5	-
Phenolic compounds (as phenol)	0.2	-
Chlorine (free)	1.0	-
Cadmium, Cd	Less than 1	-
Chromlum (trivalent and hexavalent)	Less than 1	-
Copper	Less than 1	-
Lead Less than 1	-	
Mercury	0.05	-
Nickel	Less than .1	-
Selenium	Less than 1	-
Silver	0.1	-

Units in milligram per decimeter (mg/dm^3) Unless otherwise stated.
Source: FEPA, 1991

Table 5: t-Test analysis for Tannery Effluents verses Standard Limits for discharge into surface water in Nigeria

Parameter	*All sites*	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*
pH	-	0.00	-	0.001	-	-	-	0.000	-
T °C	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
*TS (mg/dm^3)									
TDS (mg/dm^3)	0.000	0.001	0.000	0.000	0.000	0.017	0.043	0.01	0.001
TSS (mg/dm^3)	-	0.01	0.000	0.001	0.000	0.008	0.000	0.004	0.000
*Conductivity (ìS/cm)									
Chloride (mg/dm^3)	0.000	0.012	-	0.002	0.003	-	-	-	0.003
Sulphide (mg/dm^3)	-	0.026	0.035	0.004	0.000	0.025	0.014	0.02	0.000
*TKN (mg/dm^3)									
*Alkalinity (mg/dm^3)									
BOD (mg/dm^3)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.008
COD (mg/dm^3)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

- no significant difference
* not compared
TS = Total Solids, TDS = Total Dissolved Solids, TSS = Total Suspended Solids, TKN = Total Kjedahl Nitrogen, BOD = Biochemical Oxygen Demand, COD = Chemical Oxygen Demand

consistency in respect of some parameters such as pH, temperature, total dissolved solids, total suspended solids, chloride, sulphide, biochemical oxygen demand and chemical oxygen demand to exceed apparent standard limit for industrial effluent discharge in Nigeria.

In general, the observed disparity in significant differences among some of the effluents characteristics may be due to differences in wastewater treatment, production processes, chemicals and auxiliaries used raw materials and storage/preservation methods.

Conclusion and Recommendation

The Principal Components Analysis used in this study successfully showed that tannery effluent quality data could be used to group effluent discharges from tanneries. These groupings also followed differences among the effluents characteristics. From the physical and chemical data, six factors were identified and interpreted in terms of their relevancy to effluent quality conditions. From an environmental pollution view, variable selection is useful for reducing the number of variables required for statistical analyses since it can improve the reliability and stability of final results. PCA can be used to identify those variables that contain the most information from large environmental datasets for use in subsequent statistical analyses.

The present investigation has also shown beyond doubt that most of the pollution impacts of effluents discharged by tannery industrial sources is significant but neglected. Even though Federal Ministry of Environment in Nigeria documents talk about toxic waste minimization and prevention, virtually very little has been done to prevent the loading from tannery industries. It is also clear that end-of-pipe effluent treatment plants do not yield any satisfactory result. It may be the volume of effluents discharged is above the capacity of these plants. Treatments of these effluents are therefore recommended before discharge. Unavoidable and potential wastes, which are generated, should be utilized in a profitable manner either by recycling or conversion or transformation to some added products.

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