Abstract—Toxicity reduction is a main criterion in prioritizing industrial wastewater treatment objectives. This paper utilized a comprehensive survey of 41 industrial facilities to characterize their wastewater quality parameters and to assess their wastewater toxicity. The 41 factories were grouped under eleven industrial categories. Microtox relative toxicity test results indicated that industrial wastewater in Kuwait are mostly very toxic to toxic with the exception of farms wastewater which was found to be slightly toxic. The highest ranking toxic wastewaters were found to be metal forming, printing, dairy, slaughterhouses, petrochemical, poultry, food, paper and packaging, beverage, and construction materials industries in order. Among the contributing factors to the toxicity of industrial wastewater are temperature, pH, metals, COD, TOC, NH₃, TPH, phenol, and BTEX.

Index Terms—Industrial wastewater, Microtox, pollution, toxicity.

I. INTRODUCTION

Fast paced industrialization and the complexity of the industrial supply chain increases the production of industrial wastewater which contains highly toxic components. Depending on the type of industry, the industrial wastewater may contain variable levels of toxic compounds [1]. Industrial wastewater is one of the major environmental pollution sources among all sources [2], it contains a mixture of chemical compounds, which are used during industrial processing which are not usually degradable using conventional treatment and have adverse impacts on the environmental health [3]-[12]. Moreover, industrial wastewater causes severe toxic effects in aquatic ecosystems [13].

Industrial wastewater is often depleted in dissolved oxygen due to its high organic content and, thus, encourages anaerobic/anoxic conditions, leading to odour problems [14]-[16]. Also, the elevated concentration of heavy metals may cause low quality water when discharged to water bodies and cause contamination of agricultural soils [17]. However, the heavy metal toxicity depends to a great extent on its chemical speciation and thus, the associated health effects are influenced by the chemical forms of exposure [18].

The presence of pathogens in Industrial wastewater has been documented and reviewed by many [12], [19]. Since industrial wastewater is rich in organic and inorganic constituents it may provide a chance to a variety of pathogenic bacteria to flourish as these constituents may act as a source of nutrients [16], [19].

Typically, wastewater analysis includes certain physico-chemical, biological, and organic analysis [1] based on legal obligations. Due to advances in analytical chemistry, increasingly more pollutants can be identified and quantified at very low concentrations [13]. This routine chemical analyses do not take into account the toxic effects of wastewater [1]. Recently, more attention is paid to the toxicity evaluation for industrial raw and treated effluents due to the imposition of stringent laws on discharge standards [20]-[22].

This paper investigates the common pollutants found in eleven industrial categories in Kuwait and their corresponding toxicity. This knowledge is important to further the abatement and management of the negative impacts of industrial wastewater [23].

II. METHODOLOGY

Agreement of the owners of 41 factories out of 75 contacted was obtained to participate in this study. The locations and coding of 14, 10, and 17 factories from three industrial areas (Fig. 1) are shown in Fig. 2–4. The 41 factories were grouped into 11 groups based on the type of industry as shown in Table I.

![Fig. 1. Location map of selected factories in three industrial areas of Kuwait.](image-url)
2019, resumed in June 2019, and was completed by the end of July 2019. Also, wastewater was not collected, especially when the wastewater collection points were dry during the visit of the field team to the factory.

The analysed parameters consisted of temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), and oxidation reduction potential (ORP), total suspended solids (TSS), total dissolved solids (TDS), total phosphate (T. PO$_4^{3-}$), ammonia (NH$_3$), total Kjeldahl nitrogen (TKN), total nitrogen (TN), sulphide (S$^2-$), free chlorine (F. Cl$_2$), floatables, fluoride (F), chemical oxygen demand (COD), biochemical oxygen demand (BOD), total organic carbon (TOC), oil and grease (O & G), total petroleum hydrocarbon (TPH), phenol, benzene, toluene, ethylbenzene, and xylene, Aluminium (Al), Arsenic (As), Barium (Ba), Boron (B), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Copper (Cu), Iron (Fe), Mercury (Hg), Manganese (Mn), Nickel (Ni), Lead (Pb), Antimony (Sb), and Zinc (Zn). Finally, total coliform (TC), faecal coliform (FC), *E. coli*, *enterococci*, Salmonella bacteria, fungi, coliphage virus, parasites, and relative toxicity. Surfactants were analysed only for two detergent factories in Sabhan Industrial area.

| Sl. No. | Category of Industry | Number of Factories | Codes |
|--------|----------------------|---------------------|-------|
| 1      | Food                 | 8                   | NP07-SB04, NP08-SB01, NP09-SB01, NP09-SB02, NP09-SB03, NP19-SB01, NP19-SB03, NP07KC04 |
| 2      | Beverage             | 3                   | NP11-SB01, NP11-SB02, NP11-SB03 |
| 3      | Printing             | 2                   | NP13KC01, NP13KC02 |
| 4      | Farms                | 2                   | NP17KC01, NP17KC02 |
| 5      | Dairy                | 1                   | NP08KC01 |
| 6      | Poultry              | 2                   | NP07KC06, NP07KC07 |
| 7      | Slaughterhouses      | 2                   | NP07KC05, NP07KC03 |
| 8      | Petrochemical        | 5                   | NP10-SH01, PT03-SH01, PT01-SH02, PT02-SH02, PT02-SH03 |
| 9      | Metal forming        | 2                   | NP05-SH03, NP15-SB01 |
| 10     | Paper and packaging  | 4                   | NP12-SH01, NP12-SH02, NP12-SB01, NP15-SH02 |
| 11     | construction materials | 10                | NP14-SB01, NP14-SB02, NP03-SH01, NP03-SH02, NP16-SH01, NP02-SH01, NP01-SH02, NP04-SH01, NP04-SH02, NP16-SB02 |

In general, with the exception of surfactants, the 45 wastewater parameters were analysed for 41 factories distributed in three industrial areas on a biweekly basis for seven months' period. The wastewater field measurements, sampling, and laboratory analysis activities were carried out according to the Standard Method for Water and Wastewater Examination, American Public Health Association [24].

Relative toxicity was measured using Microtox rapid toxicity test because of its sensitivity and high reproducibility [25]. The relative toxicity of the industrial wastewater
samples was assessed by employing Microtox Assay System (Model 5000) with Microtox data collection and reduction software (Microtox Omni™, Microbics Corporation, Carlsbad, CA, USA). No adjustments to sample pH or other constituents were made. The assay was carried out according to the instructions of the manufacturer. Microtox reagent (freeze dried bacteria Aliivibriofischeri) was reconstituted in 1 ml ultra-pure water reagent (Azur Environmental (SDI)). All aspects of testing were performed following the U.S. EPA guidelines [26]-[29].

Microtox analyzer. The lyophilized Aliivibriofischeri bacteria were obtained from Azur Environmental (AZF686018A). All aspects of testing were performed according to the instructions of the manufacturer. Microtox reagent (Microbics Corporation, Carlsbad, CA, USA). No adjustments to sample pH or other constituents were made. The assay was carried out according to the instructions of the manufacturer. Microtox reagent (freeze dried bacteria Aliivibriofischeri) was reconstituted in 1 ml ultra-pure water reagent (Azur Environmental (SDI)).

The industrial wastewater samples (2.5 ml) and 0.25 ml osmotic solutions were mixed separately. This mixture was diluted serially in 4 separate cuvettes. The temperature was allowed to equilibrate for 5 min and the reagent was added to each of the cuvette, mixed thoroughly and allowed to stabilize for 15 min. Each cuvette was then read on the Microtox analyzer. The lyophilized Aliivibriofischeri bacteria were obtained from Azur Environmental (AZF686018A). All aspects of testing were performed following the U.S. EPA guidelines [26]-[29].

### TABLE II: PHYSICOCHEMICAL PARAMETERS OF INDUSTRIAL WASTEWATER (mg/L)

| Industry type       | Temperature | pH   | DO   | EC   | TDS  | TSS  |
|---------------------|-------------|------|------|------|------|------|
| Beverage            | 29.4±0.9    | 5.7±0.1 | 0.0±0.0 | 0.4±0.0 | 158.6±23.1 | 48.2±3.2 |
| Construction materials | 30.2±0.9  | 8.6±0.1 | 3.8±0.2 | 3.7±0.5 | 905.8±74.3 | 312.2±68.3 |
| Dairy               | 25.1±1.0    | 6.6±0.1 | 4.8±0.2 | 0.8±0.2 | 48.4±2.6  | 53.1±2.7 |
| Farms               | 25.1±1.0    | 7.4±0.1 | 4.8±0.2 | 0.3±0.0 | 66.1±9.4  | 16.0±1.8 |
| Food                | 27.0±0.8    | 6.8±0.1 | 0.9±0.1 | 1.3±0.2 | 106.8±15.0 | 43.5±7.5 |
| Metal forming       | 37.7±2.5    | 7.9±0.3 | 2.3±0.4 | 2.3±0.4 | 921.1±139.3 | 15.6±2.1 |
| Paper and packaging | 32.8±1.2    | 7.0±0.1 | 0.8±0.1 | 6.2±0.7 | 3978.1±522.9 | 636.7±70.1 |
| Petrochemical       | 26.6±0.8    | 8.2±0.1 | 1.3±0.2 | 4.1±0.7 | 1844.3±233.2 | 337.4±46.5 |
| Poultry             | 25.4±0.9    | 6.5±0.1 | 0.0±0.0 | 2.2±0.2 | 890.9±51.5 | 367.6±37.5 |
| Printing            | 23.9±0.7    | 9.1±0.4 | 0.0±0.0 | 10.9±2.0 | 4987.6±917.7 | 165.8±27.5 |
| Slaughterhouses     | 25.0±0.9    | 6.7±0.1 | 0.0±0.0 | 1.7±0.1 | 728±50.1 | 385.9±38.4 |

### TABLE III: NUTRIENTS CONTENT OF INDUSTRIAL WASTEWATER (mg/L)

| Industry type       | NH3   | TKN  | TN   | TP   |
|---------------------|-------|------|------|------|
| Beverage            | 7.1±1.3 | 16.8±1.7 | 21.9±1.8 | 0.3±0.1 |
| Construction materials | 2.2±0.2 | 7.9±0.7 | 18.1±1.8 | 0.5±0.1 |
| Dairy               | 4.5±1.1 | 26.2±2.1 | 34.1±2.7 | 0.1±0.0 |
| Farms               | 6.3±1.0 | 9.7±1.4 | 15.8±1.4 | 0.1±0.0 |
| Food                | 20.9±1.8 | 9.6±1.3 | 18.7±2.6 | 22.3±1.7 |
| Metal forming       | 2.9±0.7 | 4.6±0.8 | 11.8±2.2 | 0.1±0.0 |
| Paper and packaging | 8.3±1.5 | 21.9±2.3 | 29.9±2.5 | 0.5±0.1 |
| Petrochemical       | 10.0±1.7 | 16.7±1.7 | 23.2±2.2 | 0.3±0.0 |
| Poultry             | 20.1±3.6 | 314.5±49.5 | 318.5±49.8 | 0.6±0.1 |
| Printing            | 10.3±1.6 | 28.9±5.7 | 27.3±2.5 | 0.5±0.2 |
| Slaughterhouses     | 15.1±1.8 | 56.2±24.3 | 96.4±22.3 | 0.7±0.1 |

### TABLE IV: ORGANICS CONTENT OF INDUSTRIAL WASTEWATER (mg/L)

| Industry type       | O&G   | BOD  | COD  | TOC  | TPH  | Phenol |
|---------------------|-------|------|------|------|------|--------|
| Beverage            | 6.3±0.8 | 870.7±42.3 | 1211.5±12.1 | 31.5±3.8 | 4.3±0.8 | 0.1±0.0 |
| construction materials | 8.6±0.7 | 146.8±4.6 | 238.8±23.3 | 72.7±7.7 | 8.8±0.7 | 0.1±0.0 |
| Dairy               | 18.0±1.8 | 58.0±2.5 | 85.3±2.5 | 26.1±2.1 | 5.5±1.3 | 0.1±0.0 |
| Farms               | 18.2±1.7 | 12.2±1.7 | 20.2±2.1 | 7.0±1.0 | 1.0±0.0 | 0.0±0.0 |
| Food                | 4359.7±16.3 | 374.7±24.3 | 494±7.16 | 14.7±1.3 | 5.8±1.5 | 3.5±0.5 |
| Metal forming       | 2.5±0.5 | 32.1±2.1 | 84.1±10.3 | 19.3±2.7 | 2.0±0.0 | 0.1±0.0 |
| Paper and packaging | 9.7±1.2 | 936.8±125.3 | 1505.1±184.4 | 118.6±14.3 | 3.2±0.7 | 0.3±0.0 |
| Petrochemical       | 19.7±1.7 | 1002.6±150.2 | 1975.1±312.7 | 81.1±10.2 | 12.8±1.2 | 0.1±0.0 |
| Poultry             | 25.8±2.1 | 1922.1±86.5 | 3388.1±173.8 | 31.3±2.1 | 3.6±0.5 | 0.1±0.0 |
| Printing            | 3.2±0.6 | 190.1±39.4 | 298±61.0 | 13.3±1.8 | 1.4±0.3 | 0.1±0.0 |
| Slaughterhouses     | 14.1±2.0 | 562.9±187.3 | 926.6±314.9 | 22.5±1.9 | 2.9±0.4 | 0.1±0.0 |

From Table IV, O&G is the highest in the food industry as expected while BOD and COD are highest in the poultry and petrochemical industry. The TOC was highest in the paper and packaging industry, TPH was highest in the petrochemical industry as expected and was present at elevated levels in the construction materials industry.

However, the highest level of phenol was recorded in the food industry probably due to decay of organic compounds in wastewater. Surfactants were only detected in the food industry with average concentrations of 0.35±0.1 mg/l which could be attributed to use of excessive cleaning chemicals.

It is worth noting that BTEXs have only been detected in the petrochemical wastewater. Surfactants were only detected in the food industry with average concentrations of 0.35±0.1 mg/l which could be attributed to use of excessive cleaning chemicals. It is worth noting that BTEXs have only been detected in the petrochemical wastewater. Surfactants were only detected in the food industry with average concentrations of 0.35±0.1 mg/l which could be attributed to use of excessive cleaning chemicals.
the petrochemical industry at average values of 0.04±0.01, 0.11±0.03, 0.03±0.01, 0.09±0.03 mg/l for benzene, toluene, ethylbenzene, and xylene, respectively.

Metal toxicity is of great environmental concern because of their bioaccumulation and nonbiodegradability in nature (Igiri et al., 2018). Several inorganic metals like magnesium (Mg), nickel (Ni), chromium (Cr³⁺), copper (Cu), calcium (Ca), manganese (Mn), and sodium (Na) as well as zinc (Zn) are vital elements needed in small quantity for metabolic and redox functions. Metal toxicity is of great environmental concern because of their bioaccumulation and nonbiodegradability in nature. Several inorganic metals like magnesium (Mg), nickel (Ni), chromium (Cr³⁺), copper (Cu), calcium (Ca), manganese (Mn), and sodium (Na) as well as zinc (Zn) are vital elements needed in small quantity for metabolic and redox functions. Heavy metals such as aluminium (Al), lead (Pb), cadmium (Cd), gold (Au), mercury (Hg), and silver (Ag) do not have any biological role and are toxic to living organisms [30]-[33]. Toxicity of heavy metals depends on the bioavailability of heavy metal and the absorbed dose [34].

Table V shows the trace elements concentrations by industry type. It should be noted that sulphide, chloride, and fluoride were detected in small quantities in all wastewaters. No major deviations were observed except the presence of chromium, copper, and zinc at significant levels in the beverage industry, the presence of mercury in the food industry only in addition to lead.

In terms of biological analysis (Table VI), TC, FC, E. coli, Salmonella, and fungi, were detected in most wastewaters while enterococci, coliphage viruses, and parasites were not detected in any wastewater.

| Industry            | Fe | Hg | Mg | Ni | Pb | Sb | Zn | Al |
|---------------------|----|----|----|----|----|----|----|----|
| Bebereage           | 0.1±0.0 | 0.0±0.0 | 7.9±1.6 | 5.4±1.2 | 0.6±0.3 | 0.0±0.0 | 7.8±1.7 | 8.2±1.4 |
| construction materials | 0.1±0.0 | 0.0±0.0 | 5.5±0.7 | 2.6±0.4 | 0.7±0.2 | 0.0±0.0 | 10.2±1.6 | 9.4±0.8 |
| Dairy               | 0.0±0.0 | 0.0±0.0 | 2.6±0.8 | 2.7±0.6 | 0.4±0.3 | 0.0±0.0 | 5.0±1.6 | 12.8±2.5 |
| Farms               | 0.0±0.0 | 0.0±0.0 | 7.4±1.4 | 3.7±0.7 | 0.0±0.0 | 0.0±0.0 | 13.3±1.9 | 5.9±1.3 |
| Metal forming       | 0.2±0.1 | 0.0±0.0 | 5.0±1.3 | 3.3±1.4 | 3.0±1.1 | 0.0±0.0 | 5.6±1.4 | 8.2±1.8 |
| Paper and packaging | 2.1±0.6 | 0.0±0.0 | 6.6±1.0 | 6.2±1.0 | 5.2±1.1 | 0.0±0.0 | 9.3±1.1 | 9.4±1.2 |
| Petrochemical       | 0.6±0.2 | 0.0±0.0 | 5.7±0.8 | 3.9±0.7 | 2.2±0.5 | 0.0±0.0 | 8.5±1.0 | 8.9±0.9 |
| Poultry             | 0.0±0.0 | 0.0±0.0 | 10.8±1.8 | 3.3±0.9 | 0.5±0.2 | 0.0±0.0 | 12.7±1.7 | 11.4±1.9 |
| Printing            | 0.4±0.2 | 0.0±0.0 | 4.9±1.0 | 5.5±1.3 | 3.9±1.1 | 0.0±0.0 | 10.3±2.1 | 10.8±1.5 |
| Slaughterhouses     | 0.1±0.0 | 0.0±0.0 | 12.6±1.8 | 7.0±1.6 | 2.6±0.1 | 0.0±0.0 | 14.4±1.9 | 12.2±1.8 |

B. Industrial Wastewater Toxicity

Bioassays that employ different test methods can be used to directly characterize the toxicity levels of various industrial chemicals and wastewaters [35]. Previous studies have demonstrated that the dehydrogenase activity (DHA) assay can be used to evaluate biological wastewater treatments and water toxicity as the DHA assay as a bioassay method has high sensitivity, is simple to perform, has a low cost, and allows quantification [36], [37]. The freshwater luminescent bacteria Vibrio qinghaiensis is one of the most widely used organisms in toxicity analyses, has been used to facilitate easy, rapid, and suitable freshwater bioassays, and provides reliable toxicity measurements of chemicals and wastewater [3], [38]. In this study, the toxicity of the industrial wastewater in Kuwait was assayed using Microtox toxicity assay system that has found wide acceptance over the last decade. The test organism (luminescent bacteria, Aliivibriofischeri) is highly sensitive to a broad range of toxicants. The suspension used in the test contains about one million microorganisms which gives high resolution response compared to other bioassays
because of such a large population.

Toxicity averages for different industrial categories are shown in Fig. 5. It appears that the toxicity of the industrial wastewater is similar with the exception of farm wastewater which has a relative toxicity score higher that other industries. This is attributed to less use of chemicals in farms and therefore their wastewater is mostly less harmful. The most toxic type of industry was found to be metal forming, printing, and dairy which have relative toxicity of < 25%. In the second place came slaughterhouses, petrochemical, poultry and food industries which have slightly higher relative toxicity score. This ranking is an average ranking and, in many cases, individual samples have shown a different ranking.

Toxicity was classified into five groups based on the effective concentration (EC) values of the toxic material in the sample (Mantis et al. 2005, Katsoyannis and Samara 2007). These five groups are Very Toxic (EC50 :< 25%), Moderately Toxic (EC50: 25–50%), Toxic (EC50:51–75%), Slightly Toxic (EC50:75–100%), and Not Toxic (EC50 :> 100%). The results are shown in Table VII which indicates that industrial wastewater in Kuwait is mostly very toxic to moderately toxic. Mostly there were minor differences in the toxicity classification between industries as observed in wastewater treatment plant effluents by Ra et al. [39]. Very few samples fell in the slightly toxic to nontoxic which could be contributed to cleaning periods.

### Table VII: Results of Toxicity Classification of Industrial Wastewater

| Industry          | Total number of samples | <25 | 25-50 | 51–75 | 75-100 | >100 |
|-------------------|-------------------------|-----|-------|-------|--------|------|
| Beverage          | 15                      | 12  | 1     | 1     | -      | 1    |
| construction materials | 55              | 43  | 5     | 1     | -      | 6    |
| Dairy             | 6                       | 6   | -     | -     | -      | -    |
| Farms             | 12                      | 9   | -     | -     | -      | 3    |
| Food              | 34                      | 31  | 1     | 1     | -      | 1    |
| Metal forming     | 11                      | 11  | -     | -     | -      | -    |
| Paper and packaging | 23              | 20  | 1     | 1     | -      | -    |
| Petrochemical     | 29                      | 26  | 2     | 1     | -      | -    |
| Poultry           | 12                      | 10  | 2     | -     | -      | -    |
| Printing          | 13                      | 13  | -     | -     | -      | -    |
| Slaughterhouses   | 12                      | 11  | 1     | -     | -      | -    |

Few studies attempted to established correlations to infer wastewater toxicity using conventional water quality parameters [40], [41]. Industrial wastewater generally has a broad mix of different components, which implies that the resulting toxic properties may vary depending on the interaction between each of them. This high variability may be responsible for the poor correlation of some parameters with toxicity values [42]. For example, Boluda et al. [40] noted that in complex samples such as in the case of wastewater, COD cannot provide a good correlation with toxicity.

The difference between BOD and COD may represent the non-biochemically oxidizable organics, total metal presence, PAHs, phenol, and BTEX may be indicative of the reasons behind the toxicity of the different types of wastewater. The difference between the overall industrial wastewater average and the values of the indicators for the corresponding industry type is used to examine this hypothesis (Table VIII).

Although the beverage and metal forming industries do not show up under any categories, it was observed that the beverage industry has the lowest average pH (5.7±0.1), while the metal forming industry has the highest temperature (37.7±2.5 °C). These facts point towards the effect of pH and temperature on toxicity. Although the source of TPH in the dairy industry is not clear, the dairy industry wastewater is very toxic due to presence of elevated levels of TPH. This is the same in the case of farms wastewater. Mostly, dairy and farms are combined industries in Kuwait.
By examining Table VIII, metals in the printing industry are probably the main cause of toxicity, while metals and ammonia are the main contributors to the toxicity in slaughterhouses. Also, poultry wastewater has elevated levels of COD, ammonia, and metals as the major sources of toxicity, the paper and packaging industry are high in COD, TOC, and metals, the food industry has elevated levels of ammonia and phenol, while the construction materials wastewater has elevated levels of TOC and TPH [43]. The petrochemical industry is the only industry at which all parameters are contributing to its toxicity.

### IV. Conclusions

The survey results indicated that industrial wastewater in Kuwait are highly toxic with the exception of farms wastewater. Among the contributing factors to the toxicity of industrial wastewater are temperature, pH, metals, COD, TOC, NH3, TPH, phenol, and BTEX. This conclusion is important in prioritizing industrial wastewater treatment objectives while targeting toxicity reduction.

### Conflict of Interest

The authors declare no conflict of interest.

### Author Contributions

Mohd Elmuntasas Ahmed is the main writer of the paper, A. Al-Haddad conducted the research sampling and analysis, and S. Al-Dufaljeel was responsible for toxicity testing and reporting; all authors had approved the final version.

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