Proceedings of the Pakistan Academy of Sciences:
B. Life and Environmental Sciences 53 (2): 93–102 (2016)

ISSN: 0377 - 2969 (print), 2306 - 1448 (online)

Pakistan Academy of Sciences

Research Article

Wastewater Characterization of Selected Industries in Quaid-e-Azam Industrial Estate: Treatment Options and Impact on Groundwater Quality

Sajjad Haydar[1], Ghulam Hussain[1*], Husnain Haider[2], and Attiq-ur-Rehman[1]

[1]Institute of Environmental Engineering & Research,
University of Engineering & Technology, Lahore, Pakistan
[2]University of British Columbia, Vancouver, Canada

Abstract: This research was carried out to characterize the wastewater of major industries of Quaid-e-Azam Industrial Estate (QIE), to analyze effect of wastewater drain on groundwater quality in the area, and to suggest appropriate wastewater treatment option(s) for QIE. Composite wastewater samples were collected and analyzed for pH, temperature, biochemical oxygen demand (BOD), filtered BOD (F-BOD), chemical oxygen demand (COD), filtered COD (F-COD), total Kjeldahl nitrogen (N), total suspended solids (TSS), total dissolved solids (TDS), sulphates, chromium (Cr), lead (Pb), cadmium (Cd) and copper (Cu). Results showed that BOD, COD, TSS, TKN, Pb and Cd exceeded the limits of National Environmental Quality Standards Furthermore, groundwater samples were collected from selected tube wells in near vicinity of QIE and analyzed for pH, nitrates, total hardness, TDS, turbidity, sulphates, Pb, Cd, Cr and Cu. The results showed that groundwater contamination with Pb, Cd, and Cr due to unlined industrial drain.

Keywords: Industrial effluent, Quaid-e-Azam Industrial Estate, groundwater, BOD, COD, heavy metals, CETP, pollution load, pollution surcharge

1. INTRODUCTION

Industrialization leads to socio-economic uplift, especially in developing countries [1]. However, industrialization also leads to environment deterioration [2-3]. One of its productions is the industrial wastewater, inadequate and unscientific management of which has become the most critical problem in developing countries, resulting in the pollution of receiving water bodies [4-5]. It not only affects aquatic life but also has adverse impacts on public health [6].

In Pakistan, most of the industrial effluents are discharged into unlined surface drains without any treatment. Poor management, lack of planning and implementation of environment legislation worsened the situation than it was in past [7-9]. The wastewater generated by various industries has different characteristics depending upon type of raw material used and the processes involved [10]. The wastewater usually contains suspended solids, heavy metals, organic matter, bases, acids and colouring compounds those could affect the quality of surface waters [11] and groundwater [12-14]. It can cause serious problems to aquatic flora and fauna and downstream water users. Presently, almost 3.4 million people die every year worldwide due to water borne diseases [15]. Cancer, diarrhea, hepatitis and different skin problems are the major illnesses that are evident as a result of groundwater contamination due to industrial effluent. Considering the gravity of the problem, there is an urgent need to treat industrial wastewater before discharging into receiving water bodies to ensure environmental protection [16].

The Quaid-e-Azam Industrial Estate (QIE) is one of the major planned Industrial Estates in Punjab. It spreads over an area of 565 acres (229 ha). It is located in the Southern part of Lahore on PECO

Received, April 2016; Accepted, June 2016
*Corresponding Author: Ghulam Hussain; Email: ghussain@uet.edu.pk

Road. The QIE is comprised of ≈ 475 industries of various types such as food, pulp & paper, pharmaceutical, textile dyeing, plastic and others. Industries daily discharge 134,541 m^3 of wastewater into main industrial drain which ultimately falls into River Ravi through the Sattukatla and Hudiara drains, the natural tributaries (Fig. 1). At present, no wastewater treatment facilities are available in the QIE. It may be the major reason of pollution of ground as well as surface waters.

This study was undertaken to: (i) find out the characteristics of untreated effluents from major industries at QIE, Lahore; (ii) asses the impacts of untreated effluents on the groundwater quality in proximity of estate and (iii) propose an appropriate treatment option for combined effluent of QIE.

2. EXPERIMENTAL

2.1 Selection of Industries for Sampling

The QIE is an industry-mix. , few industries of each type have been established and others still need some years to be developed. Five industries were selected from different sectors (Food, Pharmaceutical, Dying, Plastic and Paper) to characterize the effluent for each category. One composite sample was also collected to show the characteristic of effluent-mix of the QIE. The characteristic of this effluent-mix will help to select the appropriate CETP option.

2.2 Sampling

2.2.1 Wastewater Sampling

For characterization of industrial effluent, composite samples were collected from outlet of major industries. These include: Umer tissue (UT), ASMY dyeing (AD), Scherlin Pharmaceutical (SP), Chawla Plastic (CP) and Gourmet Food (GF). Furthermore, samples were also collected from the unlined industrial drain (ID) receiving combined discharge of all industries in QIE. For each industry and ID, three composite samples at different days were collected at different times to take into account the variations in wastewater characteristics. Mean values of these three samples are reported.

Composite samples were collected manually from the outlet of industries. A plastic bottle, rinsed with distilled water with reasonable weight and wide mouth tide to a rope was used for sampling. At each site, samples were collected at different times of a day and collected samples were mixed to make the composite sample. In the same way, three composite samples were collected from each site on different days.

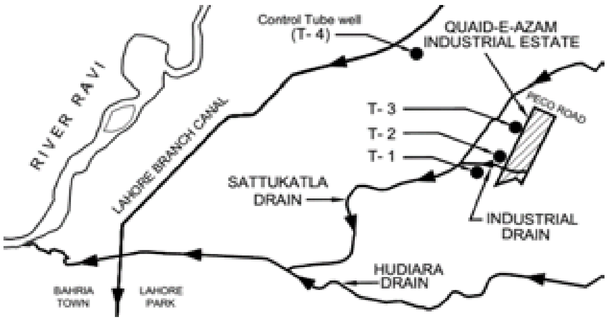

Fig. 1. Location map of Quaid-e-Azam Industrial Estate (not to scale).

2.2.2 Groundwater Sampling

To check the impact of untreated effluent on groundwater, various samples were collected from tubewells (T-1, T-2 and T-3) located at different locations; near to industrial drain(Fig. 1).The distances of T-1, T-2 and T-3 are 45, 65 and 980 m, respectively from ID. To verify the effect of industrial drain on the quality of groundwater in adjoining areas, one control tube well (T-4) was also selected, which is7 km away from the industrial main drain (Fig. 1).

Groundwater sample were collected from tap fixed on the delivery pipe of tube wells without splashing Standard transfer procedures were adopted for collection of sample. Moreover, proper identification number representing sample origin with date, time was attached on sampling bottles. Details of tube wells (location, depth etc.) are presented in Table 1.

2.3 Physical and Chemical Analysis

The wastewater samples were tested for temperature, pH, total suspended solids (TSS), total dissolved solids (TDS), sulphate, five-day biochemical oxygen demand (BOD), filtered BOD (F-BOD), chemical oxygen demand (COD), filtered COD (F-COD), total Kjeldahl nitrogen (TKN), chromium (Cr), cadmium (Cd), lead (Pb) and copper (Cu).

Table 1. Description of tube wells.

Sr. No.	Tube well Location	Designated	Capacity (cusec)	Bore depth
1	6A2 Township near Nursery Stop	T-1	4.0	Deep (> 400 ft)
2	5D1 Township near Industrial Drain	T-2	4.0	Deep (> 400 ft)
3	5D2 Township near Industrial Drain	T-3	4.0	Deep (> 400 ft)
4	Faisal Town (Control Tube well)	T-4	3.0	Deep (> 400 ft)

Table 2. Methods and instruments used for analysis of water and wastewater samples.

Sr. No.	Parameters	Test Method (Reference No.)/Instrument Used
1	Temperature (T)	2550 B*, pH Meter Make: HACH, *Model 51935-00 SensION*
2	pH	4500 H, pH Meter Make: HACH, *Model 51935-00 SensION*
3	Total Suspended Solids (TSS)	2540 C*
4	Total Dissolved Solids (TDS)	2540 C*
5	Biochemical oxygen demand (BOD)	5210 B*
7	Chemical Oxygen Demand (COD)	2520 C*
9	Sulfate	4500 E*
10	Total Kjeldahl Nitrogen	4500 N_{org}*
11	Nitrate	HI 3874*, Nitrate Test Kit, Colorimetric method
12	Hardness	2340C*
13	Turbidity	2130B*, Turbidity Meter, Make: HACH, *Model: 2100N*
14	Heavy Metals (Lead, Chromium, Cadmium and Copper)	3500*, Atomic Absorption Spectrophotometer Make: Perkin Elmer; *Model*: *AAnalyst 800*

* All the reference methods are based on "Standard Methods for Examination of Water and Wastewater" [17]

The COD and BOD tests were conducted on both raw and filtered samples to evaluate the proportion of total and soluble organic matters in wastewater.

Groundwater samples were tested for pH, TDS, total hardness, turbidity, SO_4, Pb, Cr, Cu and Cd. All these parameters were tested following the "Standard Methods for Examination of Water and Wastewater" [17]. Details of reference methods and instruments used for analysis of water and wastewater samples are provided in Table 2.

3 RESULTS AND DISCUSSION

The results for characterization of industrial effluent and groundwater are presented below.

3.1 Wastewater Characteristics

3.1.1 Temperature, pH, TDS, Sulphate

The mean value of temperature varied from 29 to 38 °C. These values are within the allowable limit (40 °C) prescribed by NEQS [18]. The mean value of pH in the industrial effluents varied from 5.6 to 7.3. These values are within the allowable limit (range 6-10) prescribed in NEQS (18) except for the Gourmet Food (GF) Industry which was 5.6.However, pH value of combined effluent (ID) was 7.2, which lies within the NEQS limits[18].

The TDS in water samples from various industries varied from 1,167 to 5,800 mg L^{-1} and values are within the permissible limit of 3,500 mg L^{-1} [18] except that for the GF Industry (5,800 mg L^{-1}). The TDS for the combined effluent (ID) was also within NEQS limits [18]. The results of sulphate for wastewater samples are plotted in Fig. 10. The mean value of sulphate varied from 27 to 542 mg L^{-1}. These values are less than the permissible limit (600 mg L^{-1}) prescribed by NEQS [18]. The concentration was quite less for the main industrial drain (40 mg L^{-1}) carrying combined effluent**.**

Results of those parameters which exceed permissible limits of NEQS are described in following sections.

3.1.2 *Total Suspended Solids*

The mean values of total suspended solids (TSS) varied from 300 to 1,800 mg L^{-1} (Fig. 2). The effluent of all industries contained TSS is more than the allowable limits (150 mg L^{-1}) of the NEQS. The lowest TSS was recorded for Chawla Plastic (CP) Industry (300 mgL^{-1}), while was the highest TSS for Umer Tissue (UT) Industry (1,800 mg L^{-1}).

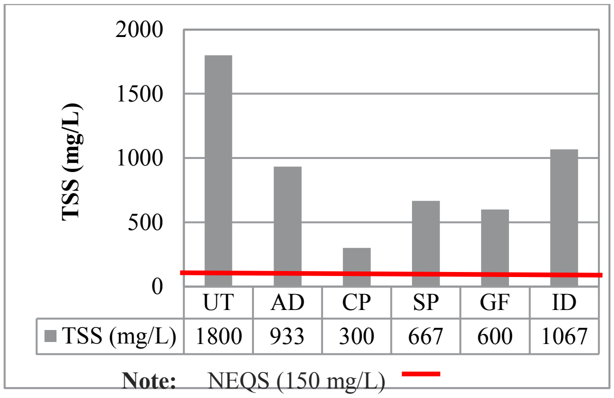

Fig. 2. TSS for the industrial wastewater samples.

In the UT Industry, water used in pulping operation carries tiny paper pieces which ultimately become a part of wastewater and increases the TSS value. In CP Industry, TSS value was the lowest. In CP, water continually remains circulating in pipe networks for cooling to decrease the temperature of machinery. Therefore, there is no direct source which contributes TSS value in wastewater. Apart from that, water used in washing floors and machinery may carries oil, dust and chemical reagents particles which finally become a part of wastewater to increase the TSS. Nevertheless, it is higher than the NEQS limits but lower compared to other industries investigated [18].

3.1.3 *Five Day Biochemical Oxygen Demand*

Total and filtered biological oxygen demand (BOD) for water samples from various industries is plotted in Fig. 3. The mean values of BOD varied from 118 to 2,337 mg L^{-1}. The mean BOD of filtered wastewater samples (F-BOD) ranged from 38 to 1,934 mg L^{-1}. All industries had BOD and F-BOD more than the permissible limits (80 mg L^{-1}) of NEQS except F-BOD value of ASMY Dyeing (AD) Industry.

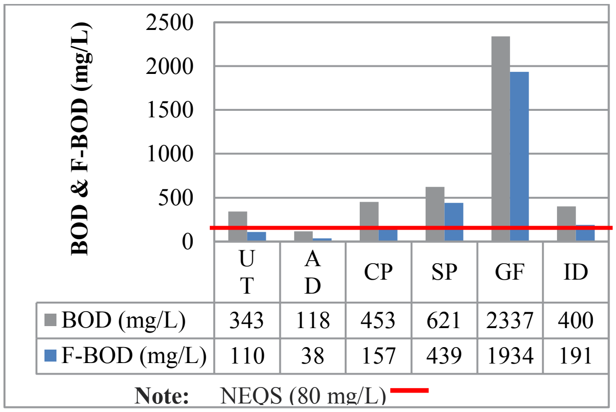

Fig. 3. BOD and F-BOD for the industrial wastewater samples.

The highest BOD for the GF Industry (2,337 mg L^{-1}) may be due to presence of a large quantity of biodegradable organic matter like fresh, fish remains, milk production waste, food and/or fruit processing waste in effluent The lowest BOD for the AD Industry (118 mg L^{-1}) may be due to the presence of large amount of chemicals or dyes discharged from different processing units containing low quantity of biodegradable organic matter.

The percentage reduction in BOD after filtering the samples (Fig. 4) ranged from 17 to 68%. Maximum BOD reduction was noted for the UT, AD and CP Industries. This shows that large proportion of organic matter was present in

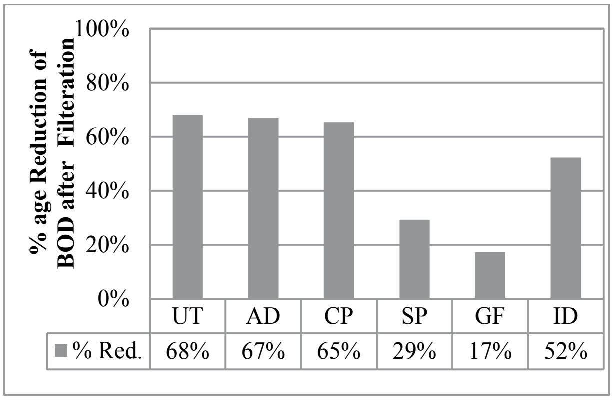

Fig. 4. Percentage reduction of BOD after filtration.

particulate form that could be removed in primary sedimentation step of treatment. However, for the GF Industry, the reduction was only 17% indicating that most of the organic matter is in dissolved form and an extensive biological treatment is required.

3.1.4 Chemical Oxygen Demand

Total and filtered chemical oxygen demand (COD) for all the samples are plotted in Fig. 5. The mean COD varied from 323 to 4,867 mg L^{-1}. Furthermore, mean COD for the filtered wastewater samples (F-COD) ranged from 120 to 3,600 mgL^{-1}. All the industries had COD and F-COD more than the permissible limits (150mg L^{-1}) of the NEQS except F-COD value of ASMY Dyeing Industry.

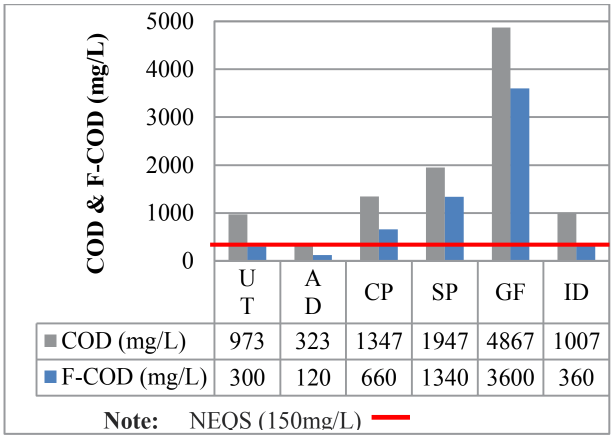

Fig. 5. COD and F-COD for the industrial wastewater samples.

The highest COD for the GF Industry (4,867 mgL^{-1}) could be due to presence of a large quantity of high organic load that requires more dissolved oxygen to oxidize it. The lowest COD was for the AD Industry (323 mg L^{-1}). The decrease in COD after filtering varied from 26 to 69%. After filtration, of the decrease in COD is plotted against each industry in Fig. 6. The maximum removal of COD was for the UT wastewater (69%) while the GF Industry experienced minimum removal (26%). The reasons appear the same as stated above for BOD.

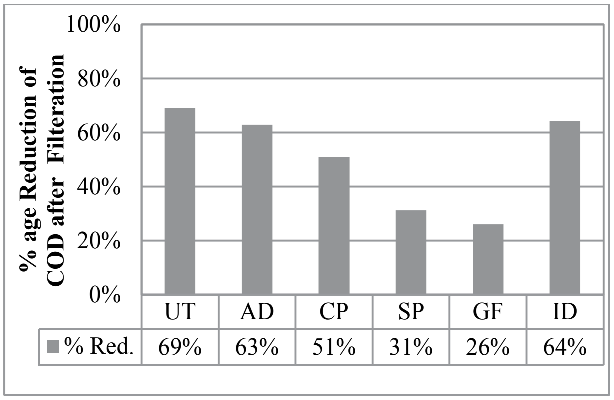

Fig. 6. Percentage reduction of COD after filtration.

3.1.5 Total Kjeldahl Nitrogen (TKN)

The mean values of total Kjeldahl nitrogen (TKN) varied from 1 to 25 mg L^{-1} for effluent samples (Fig. 7). These values are more than the permissible limit (10mg/$^{-1}$) provided by the IFC Guideline [19] except for the GF, AD industry and the ID. The high values of TKN at GF and AD Industry seem due to high usage of nitrogenous compounds as raw materials. These nitrogenous compounds are present in food preservatives [20] which come out as organic nitrogen pollutants in industrial effluent.

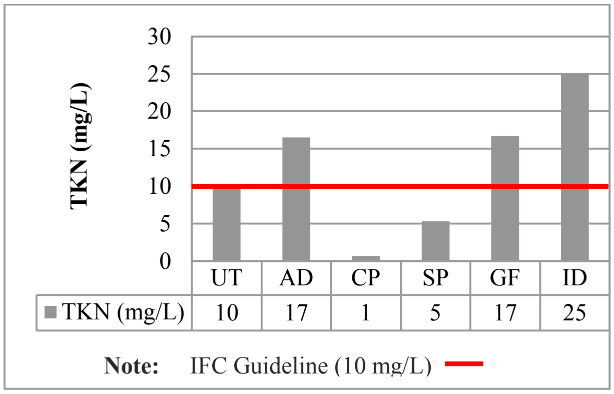

Fig. 7. TKN for the industrial wastewater samples.

The TKN for the ID had the highest value showing that significant quantity of Kjeldahl Nitrogen is perhaps added by other industries, e.g., textile dyeing, beverage and pharmaceutical [19].

3.1.6 Heavy Metal Concentrations

3.1.6.1 Lead

The mean value of lead (Pb) varied from 0.04 to 2.38 mg^{-1} for effluent samples (Fig. 8). These values are higher than the allowable limit (0.5 mg L^{-1}) given in the NEQS [18] except for the GF Industry.

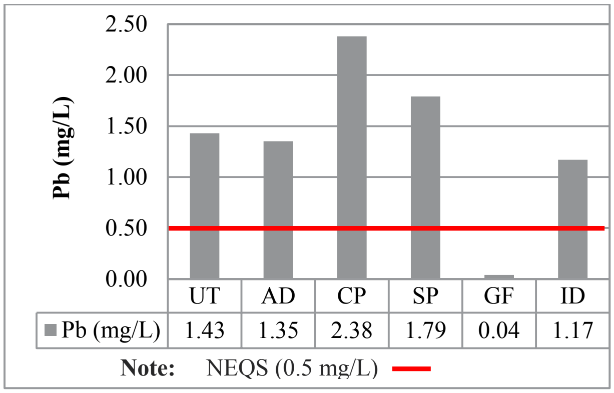

Fig. 8. Lead in the industrial wastewater samples.

The highest value of Pb for the CP Industry may be due to the use of lead oxide as vulcanizing agent to make plastic and/or rubber products more durable mechanically. The SP Industry contributed the second highest Pb pollution due to the presence of lead-organo compounds in manufacturing of drugs [21]. For the UT and AD Industries, Pb values might be due to the presence of lead chromate used in dyeing purposes. Effluent from other industries (like textile dyeing and rubber, etc.) is also discharged into industrial drain that would have increased the Pb content in the end [19].

3. 1.6.2 Chromium

The mean values of chromium (Cr) varied from 0.02 to 0.96 mg L^{-1} for samples (Fig. 9). These values are within the allowable limits (1 mg L^{-1}) given in NEQS [18]. The highest mean value of Cr was for the Industrial drain (combined effluent) Indicating that some industries (like textile dyeing and leather), not sampled, were also discharging high Cr effluent. The highest value of Cr is noted for the UT Industry (0.88 mg L^{-1}) as Cr is generally used in pigments in paper/tissue industries [22]. The Cr usually accumulate in aquatic or marine life and increase the risk to consumer taking it as food [23].

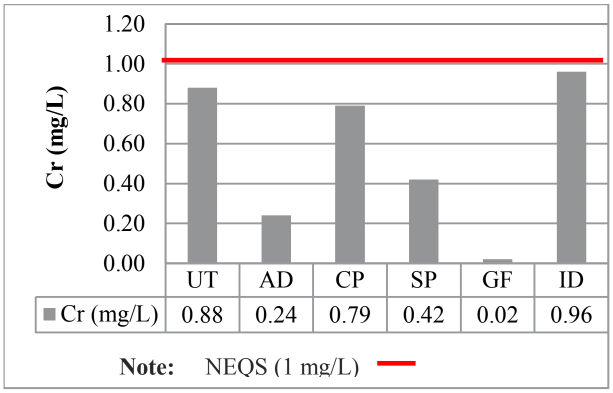

Fig. 9. Chromium in the industrial wastewater samples.

3. 1.6.3 Cadmium

Cadmium (Cd) concentration for samples is plotted in Fig. 10. The mean value of Cd varied from 0.03 to 0.38 mg L^{-1} which is higher than the maximum limits (0.1 mg L^{-1}) given in NEQS [18] except that for the GF Industry.

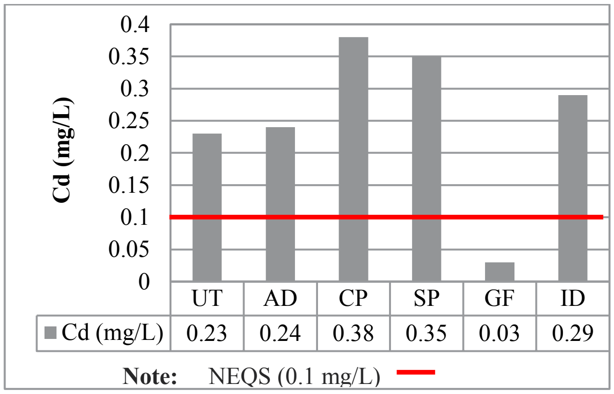

Fig. 10. Cadmium in the industrial wastewater samples.

The highest Cd was recorded for the CP Industry (0.38 mg L^{-1}). At CP Industry, the rejected plastic or rubber items like tires, shoe soles etc. are processed for making pellets which are used as raw material for making rubber and plastic mats. In this process, Cd is used as curing agent that could be the source of high Cd in wastewater. The Cd usually accumulates in different cells of plants that could result in high toxic effects on zooplankton and trout. The Cd can preferably accumulate in kidneys of cattle when they eat affected plants as their food [24].

3. 1.6.4 Copper

The mean value of copper (Cu) varied from 0.01 to 0.06 mg L^{-1} for samples (Fig. 11) and are within the allowable limits (1 mgL^{-1}) given in NEQS [18]. The highest value was recorded the CP (0.06 mgL^{-1}), UT (0.06 mg L^{-1}) and GF (0.06 mg L$^{-1)}$ Industries. The Cu is generally discharge from those industries where it is used in electrical gears, roofing, plumbing and heat exchangers. This element is essential nutrient and is component for the growth of animals and plants. Copper is an essential substance to human life, but in high doses, it can cause anemia, liver and kidney damage, and stomach and intestinal irritation [23].

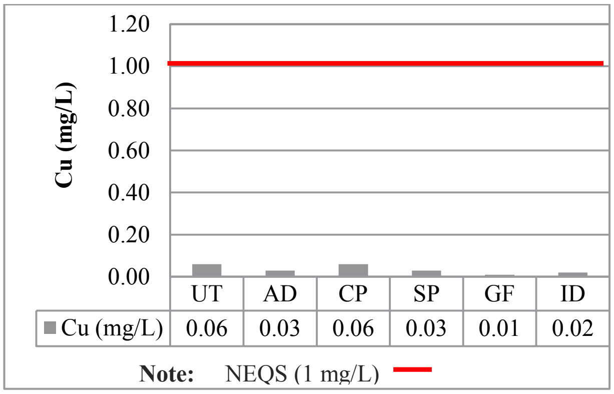

Fig. 11. Copper in the industrial wastewater samples.

3.2 Effect of Untreated Wastewater Unlined Drain on Groundwater Quality

3.2.1 pH, Total Hardness, TDS, Sulphate, Turbidity, Nitrates

The mean pH value for groundwater samples varied from 7.2 to 7.5 and are within allowable limit (6.5–8.5) for drinking water given in NDWQS[25]**.**The mean values of total hardness varied from 45 to 63 mg L^{-1} as $CaCO_3$ and are within the permissible limit (500 mg L^{-1} as $CaCO_3$) prescribed by NDWQS [25].The mean TDS varied from 550 to 567 mg L^{-1} for groundwater samples which are within allowable limit (1,000 mg L^{-1}) ofNDWQS[25]. The mean sulphates varied from 48 to 49 mg/L^{-1} for groundwater samples. These values are within allowable limit (500 mg L^{-1}) provided by WHO guidelines [26]. The turbidity varied from 0.6 to 1.2 NTU for groundwater. These values were within the allowable limits (5 NTU) prescribed in NDWQS (2010).The mean values of nitrates for all the collected samples was less than the detection limit (10 mgL^{-1}). The allowable limit for nitrates is 50 mg L^{-1} in NDWQS [25].

Results of heavy metals in ground water samples are discussed in details in following sections.

3.2.2 Heavy metals concentration

3.2.2.1. Lead

The mean concentration of Pb varied from1.17 to 1.56 mg L^{-1} for groundwater (Fig. 12). These values are more than the allowable limit (0.05 mg L^{-1}) provided by NDWQS (2010). The higher Pb values in groundwater might be due to the nearby flowing industrial drain having wastewater with high lead concentrations. The lead concentration for T-4 (0.008 mgL^{-1}) is within the permissible limits of NDWQS (2010). This shows the adverse effect of unlined industrial drain on the groundwater quality of nearby tube wells. Similar results were reported for contamination of lead in groundwater due to the intrusion of wastewater from Hudiara drain [27]. Leaching of Pb into groundwater is possible, under favorable conditions [28].

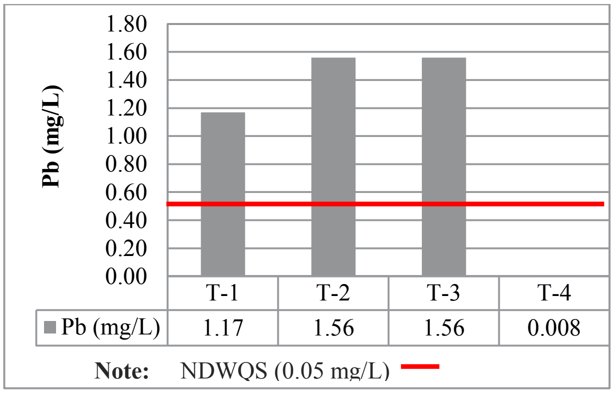

Fig. 12. Lead in groundwater samples.

The high concentration of Pb in groundwater creates numerous problems for children and adults like decrease in IQ level, increase in risk of hypertension during pregnancy, arterial disease, delay puberty in males or females and affect the central nervous system [24]**.**

3.2.2.2. Chromium

The Cr varied from 0.27 to 0.39 mg L^{-1} for groundwater (Fig. 13). These values are higher than the allowable limit (0.05 mg L^{-1}) provided by NDWQS [25]. These high values can be correlated with presence of nearby industrial drain with wastewater having high Cr concentrations. It can be seen that the Cr concentration (0.006 mg L^{-1}) for T-4 is within the permissible limits of NDWQS [25]. This shows the leaching effect from unlined industrial drain on the groundwater quality of nearby tube wells. Leaching of Cr into groundwater can occur, under favorable conditions [28].

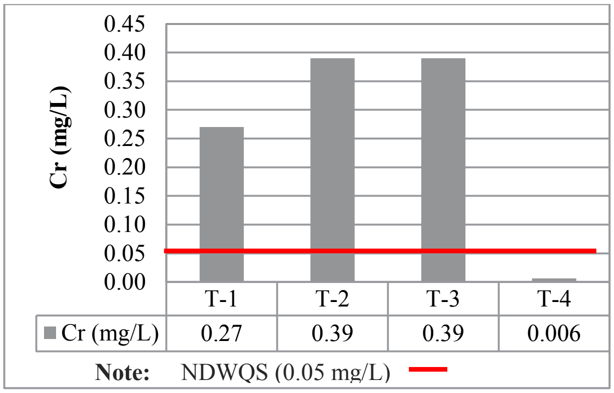

Fig. 13. Chromium in groundwater samples.

3.2.2.3. Cadmium

The Cd varied from 0.16 to 0.19 mg L^{-1} for groundwater (Fig. 14). These values are more than the allowable limit (0.01 mg L^{-1}) provided by NDWQS [25]. High values of Cd in groundwater seems due to recharge from the nearby unlined industrial drain carrying wastewater with high Cd concentration as the Cd concentration for T-4 (0.001 mgL^{-1}) is within the permissible limits of NDWQS. Cd can also leach into groundwater, under favorable conditions [28].

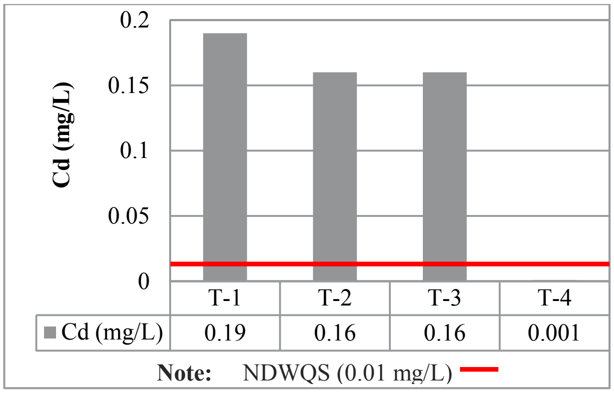

Fig. 14. Cadmium in groundwater samples.

The Cd in drinking water first enter into liver through the blood, then it makes complex bond with proteins and transport to the lower parts of body like kidneys. Here Cd accumulates and affects their normal functioning. This metal also causes different health issues like severe vomiting, diarrhea, affects central nervous and immune system [24].

3.2.2.4. Copper

The mean Cu concentrations varied from 0.03 to 0.04 mg L^{-1} for groundwater samples (Fig. 15). These values are less than the allowable limit (2mg L^{-1}) provided by NDWQS [25]. The concentration of Cu in industrial drain was also below NEQS value. This clearly shows a correlation of heavy metal concentration in groundwater with the nearby flowing industrial drain. The Cu value for groundwater at control tube well was below the detection limit.

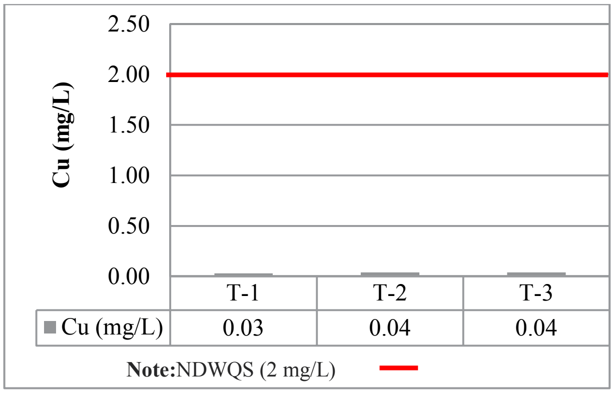

Fig. 15. Copper in groundwater samples.

4. CONCLUSIONS

Composite samples from major industries were tested for different physic-chemical parameters.

1. Concentrations of most of the studied parameters (i.e., BOD, COD, TSS, TKN, Pb and Cd) were above the allowable limit of NEQS.
2. The total and filtered BOD showed that Umer Tissue had most of the organic matter in particulate form (68%) while that for Gourmet food the organic matter (17%) was in the dissolved form.
3. The groundwater samples showed high values

of Pb, Cr and Cd that can be attributed to contamination by leaching from unlined industrial drain carrying effluent having high concentration of these metals.

5. ACKNOWLEDGEMNETS

This research publication is based on a post-graduate research study conducted at the IEER, UET, Lahore. The authors acknowledge the assistance provided by the laboratory staff of IEER.

6. REFERENCES

1. Pimple, D.S., R.S. Lokhande, & P.U. Singare. Study on physico-chemical parameters of waste water effluents from Taloja Industrial area of Mumbai. *International Journal of Ecosystem* 1(1): 1-9 (2011).
2. Qiao, Y., Y. Yang, J. Zhao, T. Ran, & R. Xu. Influence of urbanization and industrialization on metal enrichment of sediment cores from Shantou bay, South China. *Environmental Pollution* 182(1): 28-36 (2013).
3. Azizullah, A., M.N.K. Khattak, P. Ritcher, & D.P. Haider. Water pollution in Pakistan and its impact on public health: a review. *Environment International* 37(2): 479-497 (2011).
4. Haro, M., I. Guiguemde, F. Diendere, I. Bani, M. Kone, M. Soubeiga, J. Diarra, & A. Bary. Effect of the Kossodo Industrial wastewater discharges on the physico chemical quality of Massili River in Burkina Faso. *Research Journal of Chemical Sciences* 3(2): 85-91 (2013).
5. Fan, X., B. Cui, Z. Zhang, & H. Zhang. Research for wetland network used to improve river water quality, procedia. *Environmental Sciences* 13(1): 2353- 2361 (2012).
6. Hina, S., M. Zahid, I.H. Baloch, & T.S. Pasha. Environmental impacts of Quaid-e-Azam industrial estate on neighboring residential area in Lahore, Pakistan. *Journal of Water Resource and Protection* 3(1): 182-185 (2011).
7. Saif, M., N. Rashid, M. Ashfaq, A. Saif, N. Ahmad, & J.I. Han. Global risk of pharmaceutical contamination from highly populated developing countries. *Journal of Chemosphere* 1(1): 305-701 (2013).
8. Hanjra, M.A., J. Blackwell, G. Carr, F. Zhang, & T.M. Jackson. Wastewater irrigation and environmental health: implications for water governance and public policy. *Environmental Health* 215(3): 255-269 (2012).
9. Ejaz, N., A.R. Ghuman, & H.N. Hashmi. Water quality assessment of effluent receiving streams in Pakistan: a case study of Ravi river. *Mehran University Research Journal of Engineering & Technology* 30(3): 383-396 (2010).
10. Kesalkar, V.P., I.P. Khedikar, & A.M. Sudame. Physico-chemical characteristics of wastewater from paper industry. *International Journal of Engineering Research and Applications* 2(4): 137-143 (2012).
11. Shakir, H.A. & J.I. Qazi. Impact of industrial and municipal discharges on growth coefficient and condition factor of major carps from Lahore stretch of river Ravi. *The Journal of Animal & Plant Sciences* 23(1): 167-173 (2013).
12. Habib, A., R. Nadia, I. Ahmed, & T. Shafiq. Groundwater contamination by effluent from tanneries in Kasur, Pakistan. *Journal of Chemical Society of Pakistan* 30(3): 348-351 (2012).
13. Ullah, R, R.N. Malik, & A. Qadir A. Assessment of groundwater contamination in an industrial city-Sialkot. *African Journal of Environmental Science and Technology* 3(12): 429-446 (2009).
14. Tariq, M., M. Ali, & Z. Shah. Characteristics of industrial effluents and their possible impacts on quality of underground water. *Soil Science Society of Pakistan* 25(1): 64-69 (2006).
15. Anonymous. *World Health Statistics*. World Health Organization (2010).
16. Ashraf, M.A., M.J. Maah, I. Yusoff, & K. Mehmood. Effects of polluted water irrigation on environment and health of people in Jamber, Kasur-Pakistan. *International Journal of Basic & Applied Sciences* 10(3): 31-48 (2010).
17. Anonymous. *Standard Methods for the Examination of Water and Wastewater.* American Public Health Association (APHA), Washington, DC, USA (2005).
18. Anonymous. *National Environmental Quality Standards*. Environmental Protection Agency, Pakistan (2000).
19. Anonymous. *Wastewater and Ambient Water Quality, Environmental, Health and Safety Guidelines.* International Finance Corporation (2007).
20. Anonymous. *Manual of Methods of Analysis of Food*. Food Safety and Standards Authority of India (2012).
21. Paul, W. *Impact of Industrial Effluents on Water Quality of Receiving Streams in Nakawa-Ntinda, Uganda*. MS Thesis, Makerere University, Kampala, Uganda (2011).
22. Sarkar, B. Heavy metals in the environment. CRC Press, USA (2002).
23. Anonymous. *Heavy Metals*. Lenntech BV, Rotterdamseweg, Delft, Netherlands (2016).
24. Anonymous. *Final Human Health State of the*

Science Report on Heavy Metals. Ministry of Health-Canada 2(1): 55-68 (2013).

25. Anonymous. *National Standards for Drinking Water Quality*. Environmental Protection Agency, Pakistan (2010).
26. Anonymous. *Guidelines for Drinking-Water Quality: Recommendations*. World Health Organization (2004).
27. Haydar, S., H. Haider, O. Nadeem, G. Hussain, I. Jalees, & A. Qadeer. Effect of Hudiara drain on the quality of groundwater in the housing schemes of Lahore. *Journal of Faculty of Engineering & Technology*. *21*(2): 119-134 (2014).
28. McLean, J.E., & B.E. Bledsoe. Ground water issue: behavior of metals in soil. *EPA Environmental Assessment Source Book* No. EPA/540/S92/018) (1996).