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EFFECT OF HUDIARA DRAIN ON THE QUALITY OF GROUNDWATER IN THE HOUSING SCHEMES OF LAHORE

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Abstract

A study was carried out to assess the effect of Hudiara Drain on groundwater quality in its vicinity, particularly some well planned residential neighborhoods such as Khayaban-e-Amin and Valencia in the city of Lahore. A total of eleven sampling points were selected. Three samples were collected from Hudiara Drain and eight samples were drawn from deep and shallow groundwater wells. Eight physical, chemical and biological parameters including pH, turbidity, total dissolved solids, total hardness, chloride, total iron, lead and total coliforms were examined and compared with the desired values mentioned in National Standards for Drinking Water Quality (NSDWQ) and World Health Organization (WHO) guidelines. The test results indicated that physical quality of all groundwater sources was satisfactory. Chemical quality of all groundwater sources was satisfactory for total dissolved solids (TDS), total hardness, and chlorides, however for total iron and lead the water quality was not meeting NSDWQ and WHO guidelines. Bacteriological contamination was also detected in almost all groundwater samples. The presence of higher concentrations of lead in groundwater certainly indicates that there is an external effect on groundwater. It is recommended that release of industrial wastewater in Hudiara Drain should be controlled and strictly monitored. In addition, proper disinfection should be practiced at the tube wells to ensure safe drinking water at the consumers end.

Keywords: Surface drains; Groundwater contamination; Bacteriological contamination; Groundwater quality; Lead; Wastewater.

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1. Introduction

Groundwater contamination may be defined as the artificially induced degradation of groundwater quality [1]. It may also be defined as groundwater affected by anthropogenic activities to the extent that it has higher concentration of suspended or dissolved constituents than maximum permissible limits established by national or international standards for drinking, agricultural or industrial purpose [2]. Movement of water with the hydrological cycle affects the quality of the water depending on the type of environment through which it is being transported. These changes may be natural or anthropogenic [3]. Sources of groundwater contamination problems may be developed on land surface and sub-surface above or below ground water table [4]. The major source of contamination is the dumping of waste materials either in deep excavations commonly mines or open pits. Moreover, infiltration of contaminated surface water has caused groundwater contamination in several cases around the globe [5].

Contamination of soils around industrial units or near mining activities is quite common. In contrast, air pollution does not respect boundaries and quite often toxics released in one area travel long distances and can sometimes even be detected in the neighboring countries. Like soil contamination, water contamination is mainly confined to individual countries. However, there are examples of trans-boundary water pollution issues as well; one such example is Hudiara Drain [6]. Hudiara Drain (formerly a natural storm water channel), originates from Batala City in District Gurdaspur, India, and then enters into Pakistan at village Laloo [7]. The total length of Hudiara Drain is 98.6 km; 44.2 km in Indian territory and rest in Pakistani territory. After flowing for almost 55 km inside Pakistan, it merges into the River Ravi. Hudiara Drain itself is in poor condition. All along its way in Pakistan and India domestic and industrial wastewaters are being discharged into the drain without proper treatment [8]. As a consequence, organic wastes and toxic chemicals have badly affected aquatic life in the drain as well as in the River Ravi [9]. Presently, the drain is almost completely devoid of oxygen and is adding a BOD load of about 230 ton/day into the River Ravi [10]. Above are the direct impacts of contaminated water of Hudiara drain on surface waters, on the other hand the groundwater has also been affected when chemicals from surface water seep into the soil and come in contact with the flowing groundwater. Wastewater contains pathogenic microorganisms and toxic elements having the potential risks to cause diseases. This can cause immense harm to public health. The impact of Hudiara drain on groundwater quality has not been investigated so far. This research work was undertaken to achieve two objectives. Firstly, evaluation of water quality as affected by Hudiara drain in the nearby developed and the semi developed housing societies (HS) such as Khayaban-e-Amin,Valencia Town and many others (Fig. 1) in Lahore. Secondly, suggest and recommend remedial measures in case of obtaining adverse effects on groundwater from the findings of the present study.

Study area

To determine the effect of Hudiara Drain on groundwater quality in these housing societies, the portion between Badian Road and Raiwand Road was selected as the study area and is shown in Figure 1. Hudiara Drain flows along the periphery of the city of Lahore. The area along the Hudiara Drain from Pakistan-India border to Badian Road is predominately agricultural. The land use between Badian Road to Lahore-Kasur Road is semi industrial and semi agricultural. During the field visits, it was observed that the wastewater from the Hudiara drain was being pumped for agricultural use at a number of locations [11]. Many industries (approximately 100) across the drain are discharging their effluent without any treatment into the Hudiara Drain [12]. The land use change has also been observed from agriculture to residential and industrial in the area between the Lahore-Kasur Road and the Raiwand Road (Figure 1). In the recent past, a number of housing societies including NESPAK, Khayaban-e-Amin and Valencia Town have developed rapidly.

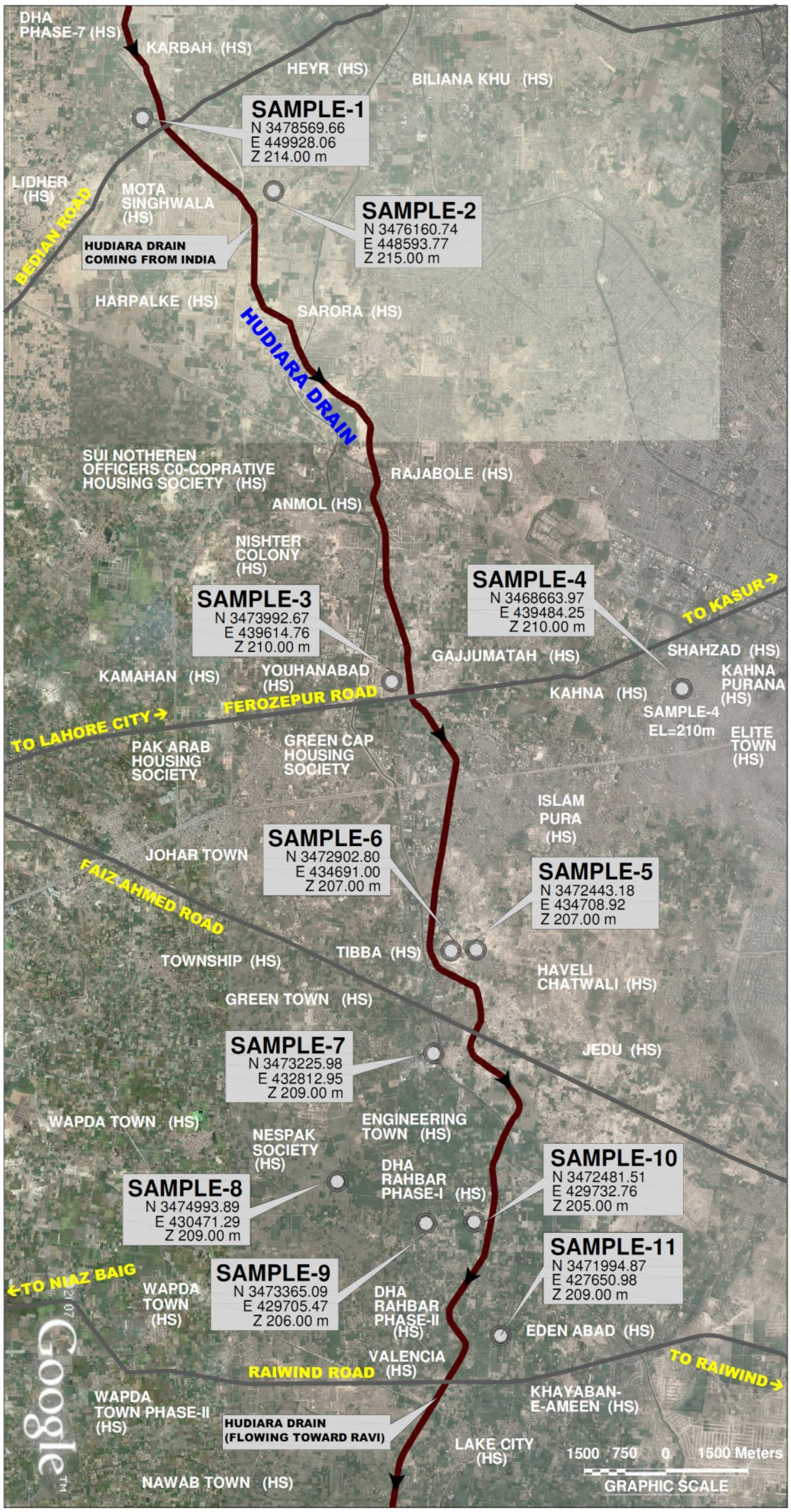

Figure 1: Location Plan of Study Area and Sampling Points

2 Materials and methods

2.1 Sampling

Three samples were collected from the Hudiara Drain for wastewater analysis; whereas, eight samples were collected from groundwater sources in the near proximity of the Hudiara Drain. The location of the sampling points is as shown in Figure 1. Exact location of all the sampling points along with the source of sample and the sampling depth are given in Table 1. It can be seen in Table 1 that sample No 1, 5 and 10 were the wastewater samples directly obtained from Hudiara Drain. The remaining groundwater samples were collected from shallow and deep groundwater sources. The water table in the study area varies from 40 to 50 ft.

Table 1: Sampling Location and Description

Sr. No	Location	Source	Depth of water source (ft)
Sample-1	Near Badian Road	Hudiara Drain	Not applicable
Sample-2	Along Hudiara Drain	Hand Pump	80
Sample-3	Near Lahore-Kasur Road	Donkey Pump	100
Sample-4	Near Purana Kana	Donkey Pump	100
Sample-5	Along Hudiara Drain (Near IEP Town)	Hudiara Drain	Not applicable Not applicable
Sample-6	Along Hudiara Drain (Near IEP Town)	Hand Pump	100
Sample-7	In NESPAK Housing Scheme	Tube well	600
Sample-8	In NFC Housing Scheme	Tube well	550
Sample-9	In Valencia Housing Scheme	Tube well	650
Sample-10	Khayaban-e-Amin	Hudiara Drain	Not applicable
Sample-11	Khayaban-e-Amin	Tube well	650

2.2 Tests conducted

The samples collected from the groundwater and the wastewater were analyzed for pH, turbidity, total dissolved solids (TDS), total hardness, chlorides, iron, lead and total coliforms. The testing procedures as prescribed in Standard Methods for the examination of water and wastewater (2012) were used and are listed in the Table 2.

Table 2: Test Conducted on the Wastewater and Groundwater Samples

Sr. No.	Test	Testing Method
1.	pH	pH Meter, 4500 H^+ [13]
2.	Turbidity	Turbidity Meter, 2123 B [14]
3.	Total Dissolved Solids	2540C [15]
4.	Total Hardness	EDTA Titration, 2340 C [16]
5.	Chloride	Mercuric Nitrate titration, 4500-Cl^- [17]
6.	Total Iron	Phenanthroline method 3500-Fe [18]
7.	Lead	3500-Pb B [19]
8.	Total Coliform	9221 C [20]

2.3 Geological data and conceptual hydrogeological model

The zones of groundwater generally consist of aquifers and aquitards. Aquitards are the geologic deposits of sufficiently low hydraulic conductivity (lower permeability) such as rock or clay. The aquifers underneath aquitards are considered as the confined aquifers, and can be considered more protected for municipal water supplies against contamination from surface water sources. In this regard, a layer of clay with 20ft to 30ft thickness can be considered as a safe thickness of the aquitard; furthermore, the integrity of an aquitard increases with increasing thickness of rock or clay [21]. The groundwater aquifer underneath the city of Lahore is spatially quite vast and covers the entire city. The soil characteristics are almost consistent with minor differences. In this connection, bore log of tube well installed at sampling point-11 was obtained and is produced in Figure 2 [22].

It can be seen in Figure 2 that there is a 90ft (30m) clay layer exists between 390 ft and 480 ft depth of bore log. Although, the groundwater below this layer can be assumed safe from the surface water contamination, a possibility of a gap (i.e., geological window) in the aquitard cannot be ignored completely [21]. Such gaps may increase the travel path or travel time of the contaminant but does not completely diminish the susceptibility of the well operating in confined aquifer.

A simplified hydrogeological conceptual model based on the information provided in Figure 2 is developed for estimation of the impact of Hudiara drain on groundwater quality. A schematic presentation of this conceptual hydrogeological conceptual model is shown in Figure 3. Gelhar and Wilson [23] assumed groundwater and the surrounding soil as a well-mixed linear reservoir to model groundwater quality. According to their conceptual model, the average concentration of the contaminant in the aquifer and the surface water body become equal after a certain time period (steady-state condition). This assumption can be adequately applied in case of Hudiara drain which continuously has been flowing for decades. Moreover, it is a continuously flowing drain all over the year due to domestic and industrial wastewater discharges from different catchments of Lahore city and India as well. The assumption is valid in case of both the conservative (TDS, total hardness, chlorides, total iron, and lead) and non-conservative (total coliforms) substances. The concentration of conservative substances remains same throughout the zone; whereas, non-conservative substances will die-off along the depth due to unfavorable conditions for their survival in soil environment.

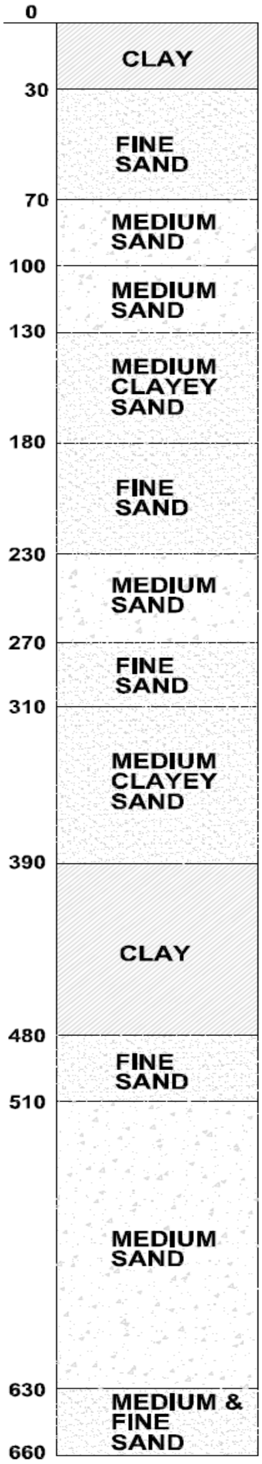

Figure 2: Geological information at sampling point-11(Source: WASA)

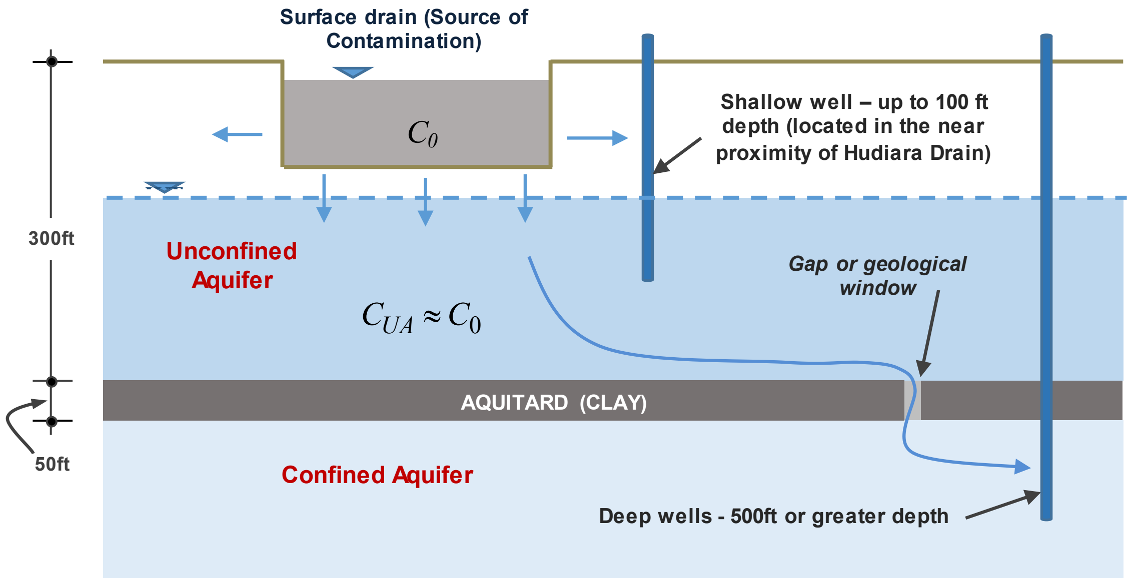

Figure 3: Conceptual hydrogeological model

According to Ahmad et al. [24], the aquifer less than 200 feet depth was considered as the shallow aquifer; whereas, from 300ft to 600ft depth, the aquifer can be considered as the deep aquifer for the city of Lahore. Based on this information and the bore log shown in Figure 2, the depth of unconfined aquifer shown in Figure 3 is assumed up to a depth of 300ft instead of 390ft to cover the average environmental conditions. The corresponding concentrations of the contaminants in this unconfined aquifer are assumed to be equal to the concentrations in Hudiara drain. Moreover, an average depth of aquitard is assumed to be 50 ft instead of 90ft (i.e., bore log information shown in Figure 2). As far as non-conservative contaminants like coliforms are concerned, as per USEPA [25] a reduction of 95% can occur within 7ft depth of soil. In this study, a constant reduction of 95% has been assumed for every 7ft depth up till 50ft. Consequently, it was estimated that at a depth of around 50 feet, a reduction of about 99.9999% can be achieved. This assumption also shows that very shallow hand pumps having suction lines installed at 80-100 feet in the near vicinity of such a polluted surface drain could be significantly contaminated with coliform microorganisms. These assumptions are evident from the study results in the following sections of this paper. Sampling points 3 and 6 (shown in Figure 1) are located in the close proximity of drain. The samples from these points were drawn from shallow (donkey and hand pump) wells operating at 100ft depth (Table 1). The laboratory results of the samples collected at sampling point 3 can be compared with the results of sampling point 1. The concentrations of conservative substances do not change along the length of the drain unless it receives discharge from a new tributary. For total coliforms, the decay along the length can be ignored due to favorable conditions of untreated domestic wastewater in the surface drain. However, the sampling location 6 is almost adjacent to the drain's sampling point 5; therefore, its results can be compared with the results obtained at sampling point 5 in order to validate the above stated assumptions of the conceptual hydrogeological model (Figure 3).

3 Results and discussion

The laboratory analyses of the collected groundwater and wastewater samples for both the conservative and non-conservative contaminants are discussed in the following sections.

3.1 pH

The observed pH values of all the wastewater and groundwater samples are shown in Figure 4. It can be observed from Figure 4 that mean values of pH varied from 7.25 to 7.92 for wastewater and 6.86 to 8.50 for groundwater, respectively. The test results of the Hudiara drain show that the pH value increases from 7.2 to around 8 while traveling through Pakistan region. Similar trend can also be observed for pH of the groundwater samples. The mean value of pH is within the range of NSDWQ (i.e. 6.5 – 8.5). [31]. However, no relationship for pH could be established from these results, with decrease or increase in depth, or location of groundwater samples with respect to the Hudiara drain. Many industries including textile mills are located along the reach of Hudiara Drain in Pakistani territory. Different studies have revealed that the effluent of these textile mills has high pH value [26], which is one of the reason for gradual increase of pH value along Hudiara Drain.

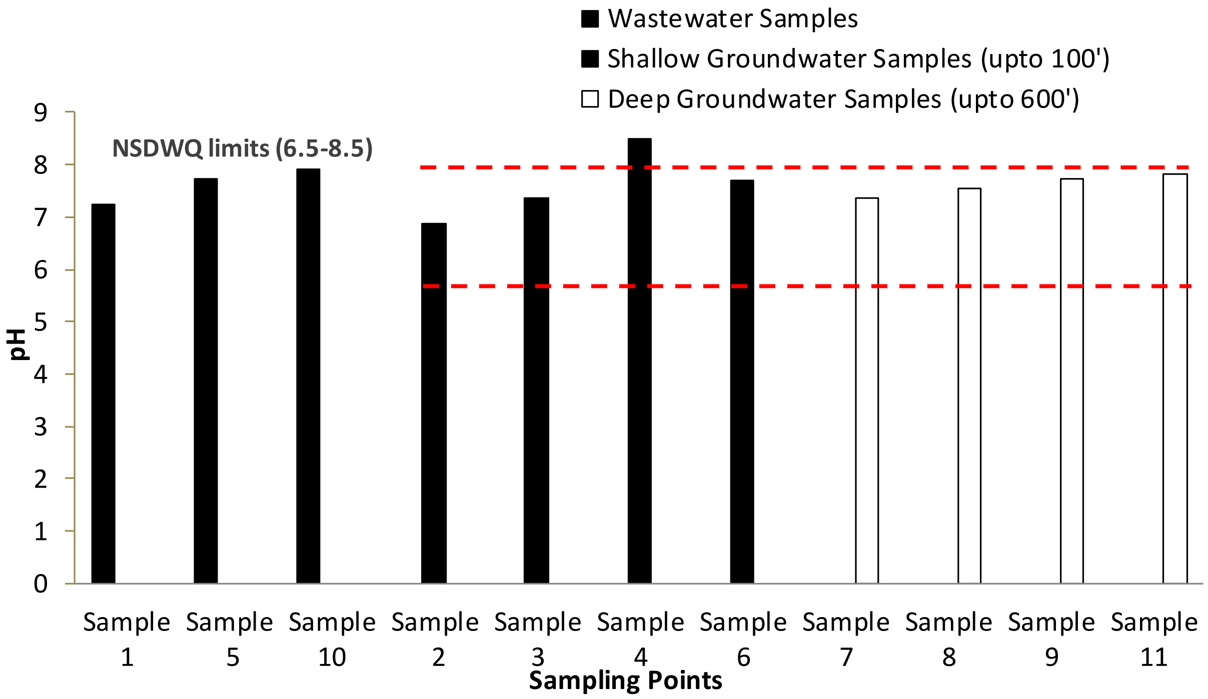

Figure 4: Value of pH at Different Sampling Points

3.2 Turbidity

The results of turbidity for all of the wastewater and groundwater samples are shown in Figure 5. It can be observed from the Figure that mean values of turbidity in Hudiara Drain ranges between 150 and 250 NTU, which is a typical nature of domestic and industrial wastewaters. Moreover, the drain also receives agricultural and urban runoffs consisting of high sediments load, which also adds up the turbidity in Hudiara Drain during monsoon period. However, the turbidity in the almost all of the groundwater samples was less than 5 NTU (NSDWQ), except sample No. 6 (i.e., shallow hand pump) was found to be 7.2. This could be either due to the low bore depth or the old and ruptured strainer or both.

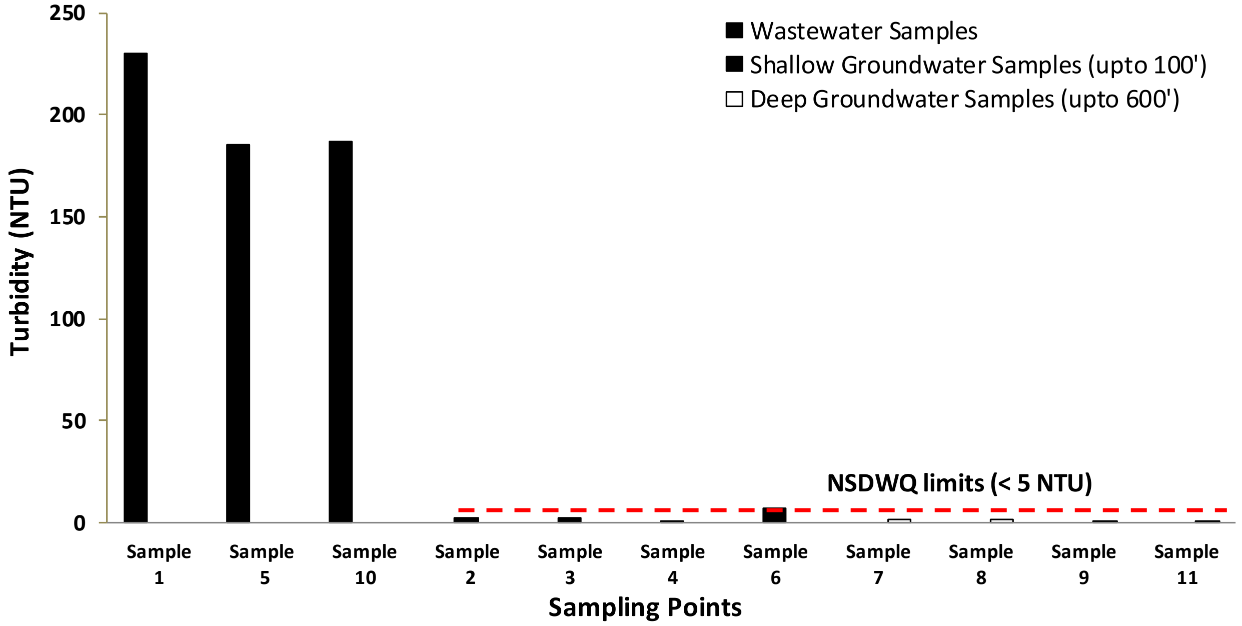

Figure 5: Mean Value of Turbidity at Different Sampling Points

3.3 *Total Dissolved Solids (TDS)*

The TDS results of both the wastewater and groundwater samples are presented in Figure 6. The mean values of TDS varied from 725 mg/L to 933 mg/L and 256 mg/L to 919 mg/L in the wastewater and groundwater samples, respectively. The TDS of wastewater increased after Hudiara drain enters Pakistan and then it remained stable for long distance. At sample No. 1 (Figure 1), the TDS value of wastewater samples was found to be 725 mg/L which then increased to 933 mg/L at sample No. 5. The increase in the TDS of wastewater might be due to the addition of domestic and industrial wastewaters of Lahore which contain high salt content.

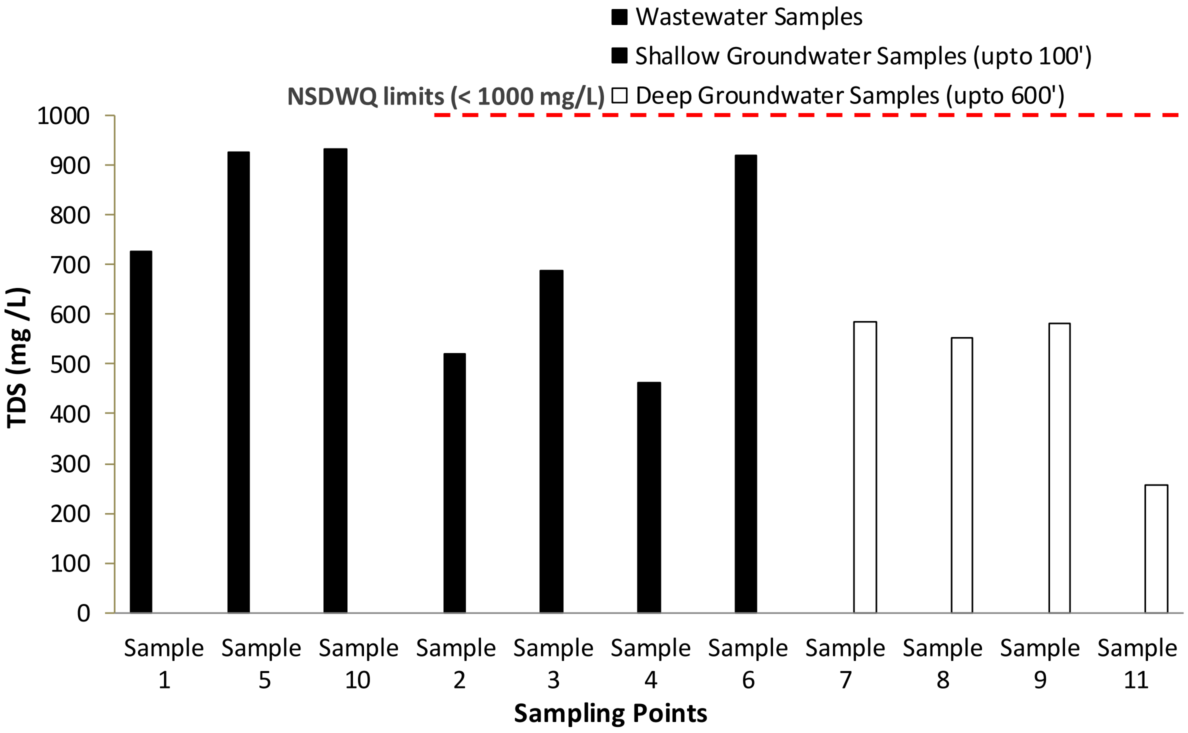

Figure 6: Mean Value of TDS at Different Sampling Points

The TDS concentration of the groundwater sample No. 6 (i.e., 100ft deep shallow well) is almost equal to the TDS concentration of sample No. 5 obtained from the contaminated drain; these results shown in Figure 6 validate the assumptions of the conceptual hydrogeological model described above in section 3. However, TDS levels in all the other groundwater sources were found to be satisfactory when compared with NSDWQ value of 1000mg/L for drinking water use.

3.4 Total Hardness

Figure 7 presents the analysis results for total Hardness of all the wastewater and groundwater samples. It can be observed that mean values of total hardness varied from 480 mg/L to 528 mg/L for wastewater and 184 mg/L to 508 mg/L for groundwater, respectively. The total hardness in Hudiara Drain remains almost stable for all of the wastewater samples (No. 1, 5 and 10). The results also show that groundwater sources which are near the Hudiara Drain except Sample No.11 have high value of total hardness. Again, the same values of hardness (i.e., 480mg/L) observed for the sample no. 5 & 6 (refer to Figure 7) support the conceptual hydrogeological model's assumptions. However, all the values were found within the limits of NSDWQ (500 mg/L) for drinking water.

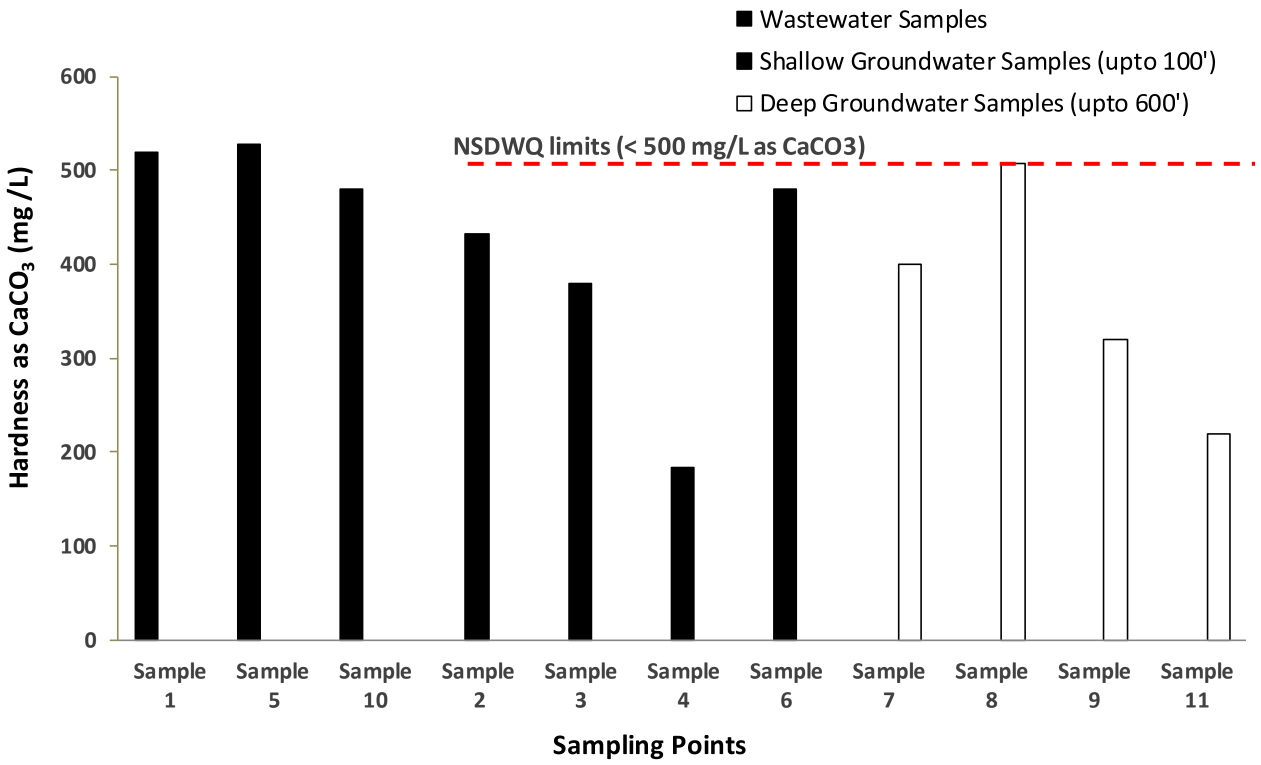

Figure 7: Mean Value of Total Hardness at Different Sampling Points

3.5 Chlorides

The mean values of chlorides varied from 190 mg/L to 250 mg/L for wastewater and 40 mg/L to 150 mg/L for groundwater samples respectively (Figure 8). The chloride concentration in wastewater is well below the National Environmental Quality Standards (NEQS) for effluents (i.e., 1000 mg/L) [33]. However, again the increase in the concentration of chlorides in wastewater from sample No.1 to sample No.10 can be observed, which may be due to discharge of industrial effluents into the Hudiara Drain.

The chloride concentrations in all the groundwater samples were found to be satisfactory as they meet the NSDWQ values (250 mg/L). The chloride concentrations in both the shallow and deep groundwater sources show almost the same behavior, except for Sample No.6 which shows slightly higher value than other samples being closest to the drain.

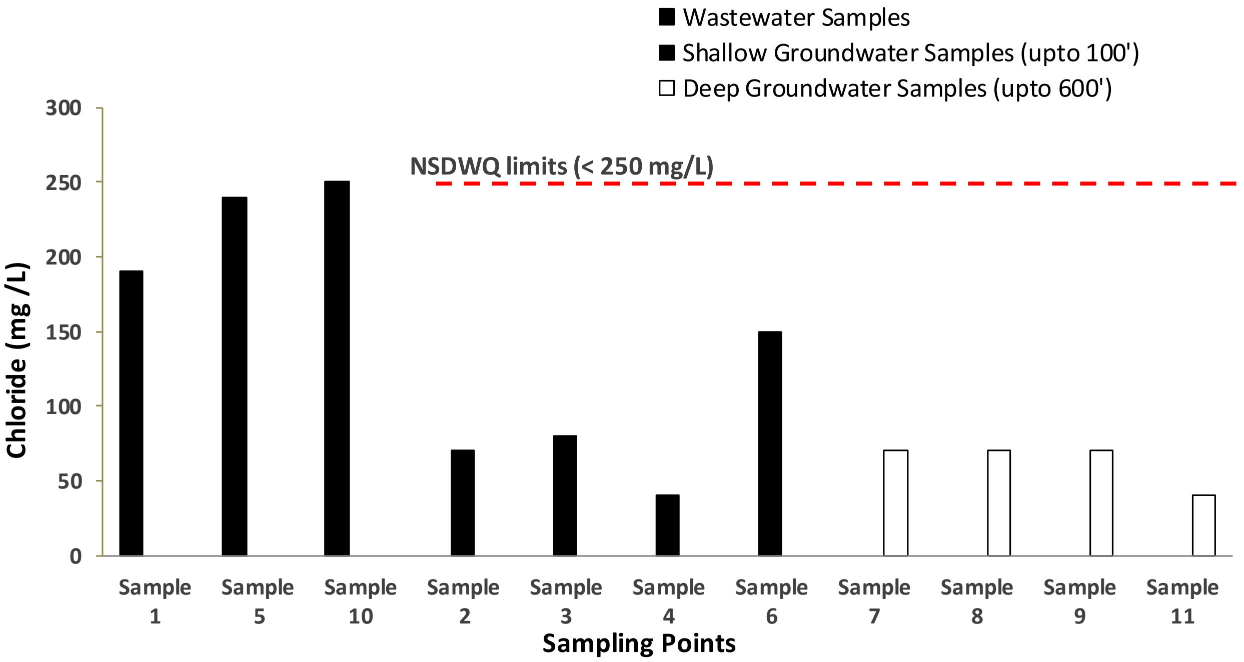

Figure 8: Mean Value of Chloride at Different Sampling Points

3.6 Total Iron

The results of total iron concentration in all the wastewater and groundwater samples are presented in Figure 9. It can be observed that mean values of total iron varied from 0.73 mg/L to 3.0 mg/L for the wastewater samples. The NEQS value for iron is 8.0 mg/L, therefore no violation of NEQS exists for wastewater in Hudiara drain [30]. Iron contents of wastewater sample (sample No. 10) are very high. This may be due to effluent discharge of an industry having high iron contents.

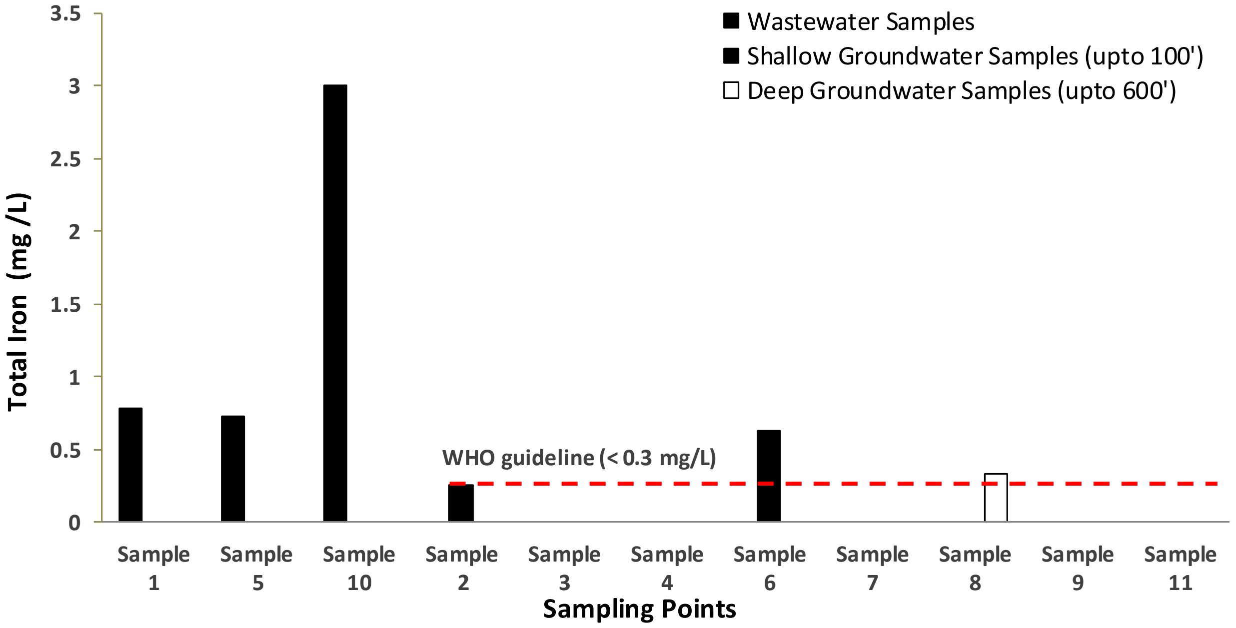

Figure 9: Mean Value of Total Iron at Different Sampling Points

Total iron value for groundwater varied from 0 mg/L to 0.63 mg/L. NSDWQ does not prescribe any limits for iron. However, WHO guidelines for drinking water give an upper limit of 0.3 mg/L for total iron [32]. It can be seen in Figure 9 that the groundwater sources which are near to Hudiara Drain and shallow in depth (i.e., Sample No. 2 and 6) have higher values of total iron. The results also show that the total iron in the Hudiara drain has no impact on deeper groundwater sources. Except sample no. 8 in which the iron concentration was found to be 0.33mg/L. The reason of such higher concentration could be a gap (geological window) in the aquitard. Furthermore, the comparable result of sampling points 5 and 6 are also verifying the conceptual hydrogeological model's assumptions. Once again, sample No. 6 contains much higher concentration of total iron than the acceptable prescribed limits of drinking WHO water quality guidelines.

3.7 Lead

The laboratory analyses results of lead for the groundwater and wastewater samples are shown in Figure 10. The results show typical behavior of wastewater in Hudiara Drain. Near Badian Road Hudiara Drain has a lead concentration of 0.31 mg/L. The NEQS prescribe a limit of 0.5 mg/L for waste effluents. After traveling some distance along the drain, the lead concentration increases and just approaching the residential neighborhoods its concentration increases to 0.41 mg/L which indicates the impact of industrial pollution load. After this point up to sample No. 10 its concentration decreases and fall up to 0.16 mg/L. The possible reason may be the precipitation and sedimentation of lead at the bottom of Hudiara drain with the flow. As the pH of wastewater increases along the route of Hudiara Drain the tendency of precipitation and settling of lead also increases [27].

The results also show that all groundwater sources which are near or far from Hudiara Drain and shallow or deeper in depth have high values of lead. The NSDWQ prescribe and upper limit of 0.05 mg/L of lead, which is not satisfied in any of the groundwater samples. These results show that contamination of lead in groundwater has occurred due to the intrusion of wastewater from Hudiara drain either directly to the unconfined aquifer or through geological window below the aquitard up to the confined aquifer.

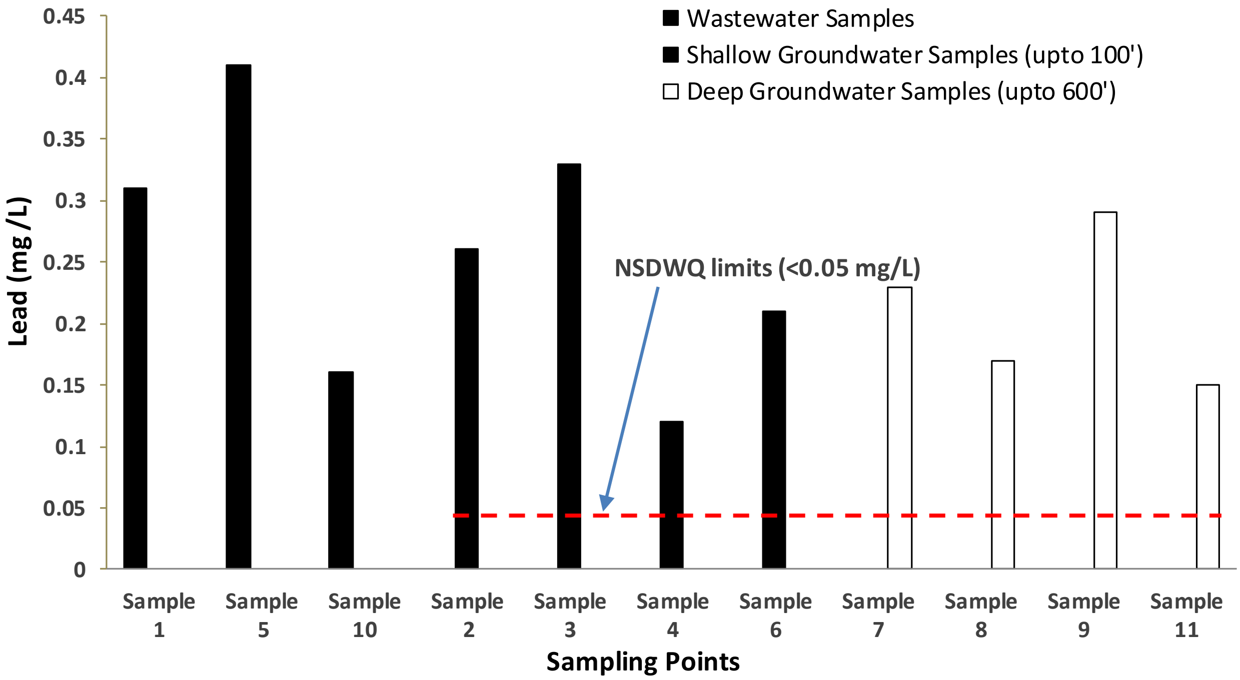

Figure 10: Mean Value of Lead at Different Sampling Points

3.8 Total Coliform

The total coliforms detected in the wastewater and groundwater samples are presented in Figure 11. It can be seen in the Fig that the mean values of total coliform varied from 9x10^7 MPN/100mL to 8x10^8 MPN/100mL for wastewater and 2 - 25 MPN/100mL for groundwater samples, respectively. In sample No.1, the total coliform value is less as compare to the Sample No.10. The gradual increase of Total Coliform is due to the addition of more domestic waste of Lahore into the Hudiara Drain. The reason of decrease due to either filtration or natural die-off in total coliforms has already been stated in conceptual hydrogeological model section. The results presented in Figure 11 support the assumptions of this model. The maximum concentration of total coliforms was found in sample no. 6 which depicts 99.999% reduction of the total coliforms found in sample no. 5. The WHO guidelines prescribe a value of zero/100 mL for drinking water.

The results of the groundwater samples shown in Figure 11 drawn either from tube wells or shallow groundwater sources were found to be contaminated with total coliforms. This may be due to leakages observed in the pumping assemblies of all the pumps. The results also show that shallow groundwater sources are more contaminated than deep sources due to the intrusion of wastewater into the shallow unconfined groundwater. Furthermore, poor well maintenance and construction (particularly shallow dug wells), and presence of total coliforms in soil can increase the risk of bacteria and other harmful organisms getting into a well water supply. According to USEPA [28] total coliform rule, monitoring of total coliform is required to decrease the risk of waterborne illness. Moreover, implementation of total coliform rule provides a multi-barrier approach in public health protection against endemic and epidemic disease. The results of the present study reveal that both the shallow and deep ground water wells could be contaminated with the coliforms and thus the ground water supplies should be treated with primary disinfection trough UV-radiations or chlorination.

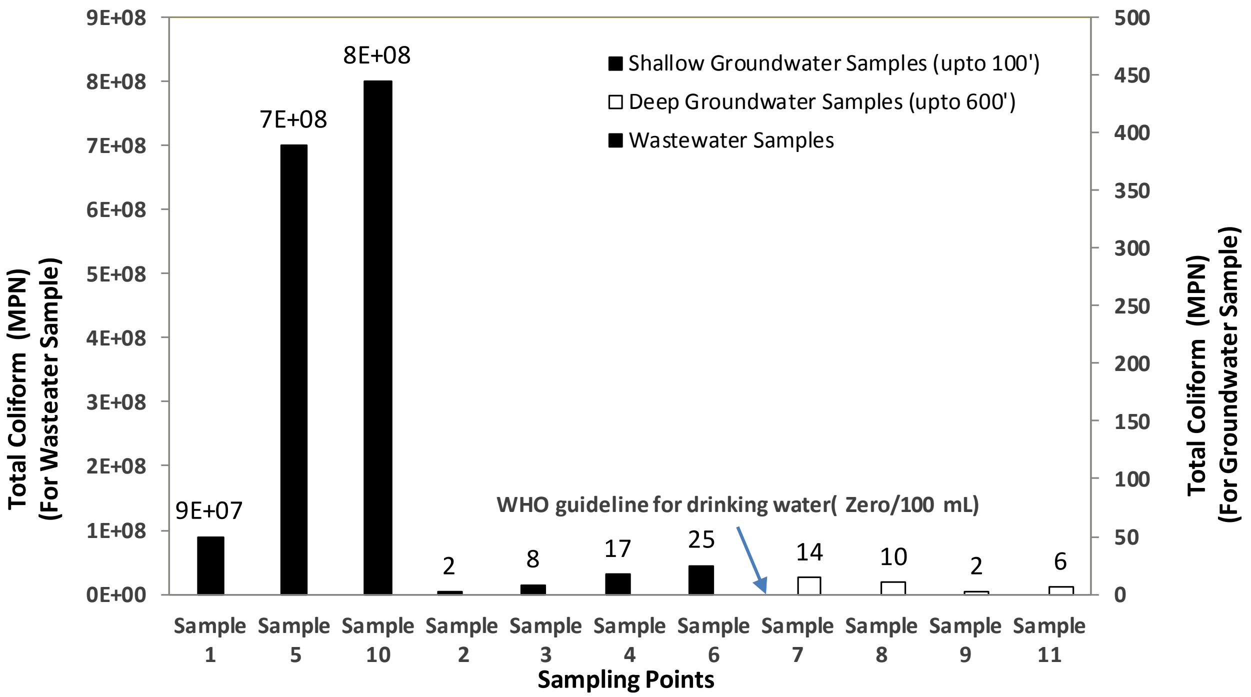

Figure 11: Mean Value of Total Coliform at Different Sampling Points

4 Conclusions and Recommendations

Following conclusions can be drawn from the present study.

1. The results indicate that Hudiara Drain wastewater has high turbidity and pH. The groundwater samples were found within the desirable limit of drinking water quality per WHO guidelines for these parameters. The test results showed that turbidity values for deeper groundwater sources were within limits but for shallow sources values were slightly higher.

2. The test results indicate that Hudiara Drain wastewater had low pH as it enters into the Pakistan region; then, after traveling some distance, pH value started increasing. This may be due to addition of textile industrial waste which usually have higher pH values. Similar trend can also be seen in groundwater behavior.

3. All the samples collected from Hudiara Drain as well as from different groundwater sources, tested for chemical parameters (TDS, hardness and chloride), were found within the desirable limit of NEQS and drinking water quality as mentioned in WHO guidelines.

4. The test results indicated that bacteriological contamination was also found in all of the groundwater sources. The reason may be old and rusted pumping assembly, inadequate maintenance of tube wells and leakages from discharge head of pumps. This was also observed in visits that no chlorination was in practice at all the groundwater sources.

5. The presence of lead in groundwater in higher concentration certainly indicates that there is external effect on groundwater. This effect is found not only in shallow groundwater sources but also in deeper groundwater sources and the most probable reason seems to be the seepage from Hudiara Drain.

Following recommendations are suggested based on the present study.

1. Groundwater contamination can only be avoided by controlling the surface pollution in Hudiara Drain. For this purpose, domestic and industrial waste treatment plants should be installed on priority basis as suggested in the Integrated Master Plan for Lahore - 2021 in order to promulgate NEQS for wastewater effluents [29].

2. Strict strategic monitoring plan should be developed in Indian Territory as well as in Pakistan. Mechanism should be developed for controlling the untreated industrial discharges into Hudiara Drain. Moreover, following the polluter pays principle, heavy fine should be imposed on the violators.

3. Extraction of water from shallow wells installed in individual houses (particularly in the near vicinity of Hudiara drain) should be strongly discouraged to avoid use of unsafe water which may be found at shallower depths.

4. The leakage problems in pumping assembly should be rectified by replacing old and rusted parts and using chemical sealants at the earliest.

5. At source disinfection of water is strongly recommended to stop bacteriological contamination in water supplies. Chlorination equipment must be installed at every tube well with the surety of effective operation and maintenance.

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