Water Quality Assessment of Effluent Receiving Streams in Pakistan: A Case Study of Ravi River

NAEEM EJAZ*, HASHIM NISAR HASHMI**, AND ABDUL RAZZAQ GHUMMAN**

RECEIVED ON 02.05.2009 ACCEPTED ON 10.03.2010

ABSTRACT

In this research various parameters for surface water quality degradation in Pakistan were investigated. Ravi River was selected as a case study to highlight the main issues, concerned with untreated wastewater. This paper represents that the mixing of effluent in huge quantity without any treatment in Ravi is a serious threat to the environment. Surface water quality parameters like, BOD_5 (Biochemical Oxygen Demand), DO (Dissolved Oxygen), COD (Chemical Oxygen Demand), suspended solids, phosphorus, chloride, sodium, total kjeldahls nitrogen, nitrate, nitrite, oil & grease and total coliforms were tested on fourteen selected sampling stations for a period of three years. During this assessment, the samples were collected from the field and tested in the laboratory using standard methods. The effluent characteristics of Lahore city were also analyzed from the main city outfall sewers and compared with NEQS (National Environmental Quality Standards of Pakistan). Unfortunately selected parameters are at least four times above the allowable standards. This investigation shows that the environmental condition of Ravi is becoming worse day by day and the river is acting almost a wastewater carrier. Increased rate of pollutants in the river may be more dangerous and may create serious threats to groundwater quality and local environment in near future. Water quality and other environmental conditions in this river can only be improved by proper wastewater treatment plant, environmental management and powerful environmental legislation.

Key Words: Effluent, Stream Water Quality, River Ravi.

1. INTRODUCTION

Developing countries like Pakistan are disposing great amount of domestic and industrial wastewater into streams and rivers without any treatment. Poor management and lack of implementation of environmental legislation is making the condition worse day by day [1]. Water quality of natural rivers and streams are becoming inferior due to mixing of large quantity of untreated wastewater. It is necessary to analyze and formulate such strategies for water quality management which would maintain acceptable water quality standards for irrigation and public use [2-4]. Considering these issues, it is required to manage all natural rivers and streams properly. In Pakistan, most of effluent receiving rivers like Ravi are being used for irrigation and livestock purposes [5- 6]. Due to heavy load of untreated effluent, River is acting as a wastewater carrier.

*Research Scholar, and ** Professor,
Department of Civil Engineering, University of Engineering and Technology, Taxila.

Different research work has been carried out previously on Ravi, to investigate the water quality issues. Some of the studies were carried out from 1977-1979 by the IPHER (Institute of Public Health Engineering & Research). The main objective was to maintain river water quality with the help of effluent treatment practice. Previous investigations showed that point and non-point sources of pollution are affecting the quality of water in Ravi [7]. From the literature it is clear that the low flow in the river, especially after "Indus Water Treaty" is creating serious negative impacts on quality of water in the river. In late nineties, some related research was made by the CEWR (Center of Excellence in Water Resources), Lahore on same river. Comparison of this research with the previous studies is clearly indicating that pollution level in the river has been increased from 4- 10 times. Due to lack of proper monitoring plan most of the streams in Pakistan are losing their environmental values so quickly. Unfortunately at present there is no monitoring for assessment of river water quality in Pakistan. Some of the rivers in India like "Kali River" are also presenting the same pictures due high pollution concentrations. According to the environmental standards, most of the steams in the world are classified on behalf of DO concentration. According to the standards the DO level must not be less than 5 mg/L for a good water quality, ecology and marine life. Most of the marine species cannot survive effectively when the DO concentration decreases less than 5 mg/L in a natural stream [1,6].

Heavy metals like Cd, Ni, Pb, and Cu present in the industrial effluents are seriously degrading the soil properties in the surrounding of Ravi [8]. These contaminations are also creating a serious threat to the local dwellers. High values of BOD, COD and other pollutants in different drains surrounding Lahore are mainly due to untreated industrial effluents [9]. Most of the drains in the vicinity of the Ravi are producing BOD, COD, TSS values more than the allowable effluent standards [10]. According to the latest report by 2009, the Main City outfall on the Ravi is highly polluted by the untreated communal wastewater [10]. According to Saeed and Bahzad, 2003, Ravi is just like a wastewater carrier with high discharge variation of 270 -81,000 ft^3/sec and approximately 750 ft^3/sec of untreated effluent is being added to the river. At present, approximately 2500 ft^3/sec fresh water from MR Link canal is required for the augmentation purposes and after ten year this demand will increase up to 4000 ft^3/sec [11]. The untreated industrial effluents are adding reasonable amount of toxic metal to Ravi [12]. Ammonia and fecal coliform concentrations are also found very high in the Ravi [13-14].

2. EFFLUENT CHARACTERIZATION AND MAGNITUDE

The results obtained during the study as shown in the Fig. 1 indicate that the domestic effluent of Lahore has high pollution load in terms of its BOD_5, COD, Suspended solids and total solids concentration. The limitations set by Pak-EPA (Pakistan Environmental Protection Agency), the NEQS does not permit the effluent discharge of any domestic and industrial effluent into any receiving bodies which has BOD_5, COD more than 80 and 150 mg/L, respectively. Similarly the NEQS does not permit the wastewater having TSS concentration more than 150 mg/L to be discharged in any receiving body without any treatment. The BOD_5 had been increased from 410-495 mg/L, COD from 815-870 mg/L, TS from 1280-1400 mg/L during the investigation period, this might be due to the fact that there is a rapid growth of urbanization in Lahore and the municipality conditions are becoming worse day by day. Field investigations and data collection from the concerned departments are exploring that maximum amount of effluent from the city is being disposed off into Ravi without any treatment.

Pumping stations at "Shadbagh", "Chota Ravi", "Mainoutfall" and "Multan Road" etc. are the main contributors to the river pollution. Table 1 represents estimated discharge of these pumping stations. According to WASA Lahore, the accumulative estimated discharge from these pumping stations is approximately 1650 cusecs.

On the other hand background flow in the river during the study period was approximately 1850 cusecs on the basis of minimum monthly average daily flow and 600 cusec on the basis of minimum daily discharge for seven consecutive days occurring once in ten years (MA7CD/10). Considering the minimum monthly average flow in river there is a ratio of approximately 1:1 for effluent and river flow but considering the other criteria of MA7CD/10, the quantity of effluent increases three times the river flow which is extremely dangerous for river ecology and environment.

3. ISSUES AND OBJECTIVES

The Environmental condition of the River is deteriorating day by day. Fishing, boating and tourism at Ravi are affected badly as highly polluted water is not suitable for aquatic life and tourism. The major sources of pollution to the Ravi are untreated municipal effluent and polluted storm water drains (especially Deg Nullah and Hudiara Nullah) carrying industrial effluents as well. Reasonable flow in a river supports healthy environmental condition while low flow causes many problems [15].

The main objective of this study was to assess the water quality of Ravi under the high concentration of untreated municipal and industrial effluents from Lahore city. The results of this case study can be implemented to the other effluent receiving streams as overall condition is almost same in other areas of Pakistan.

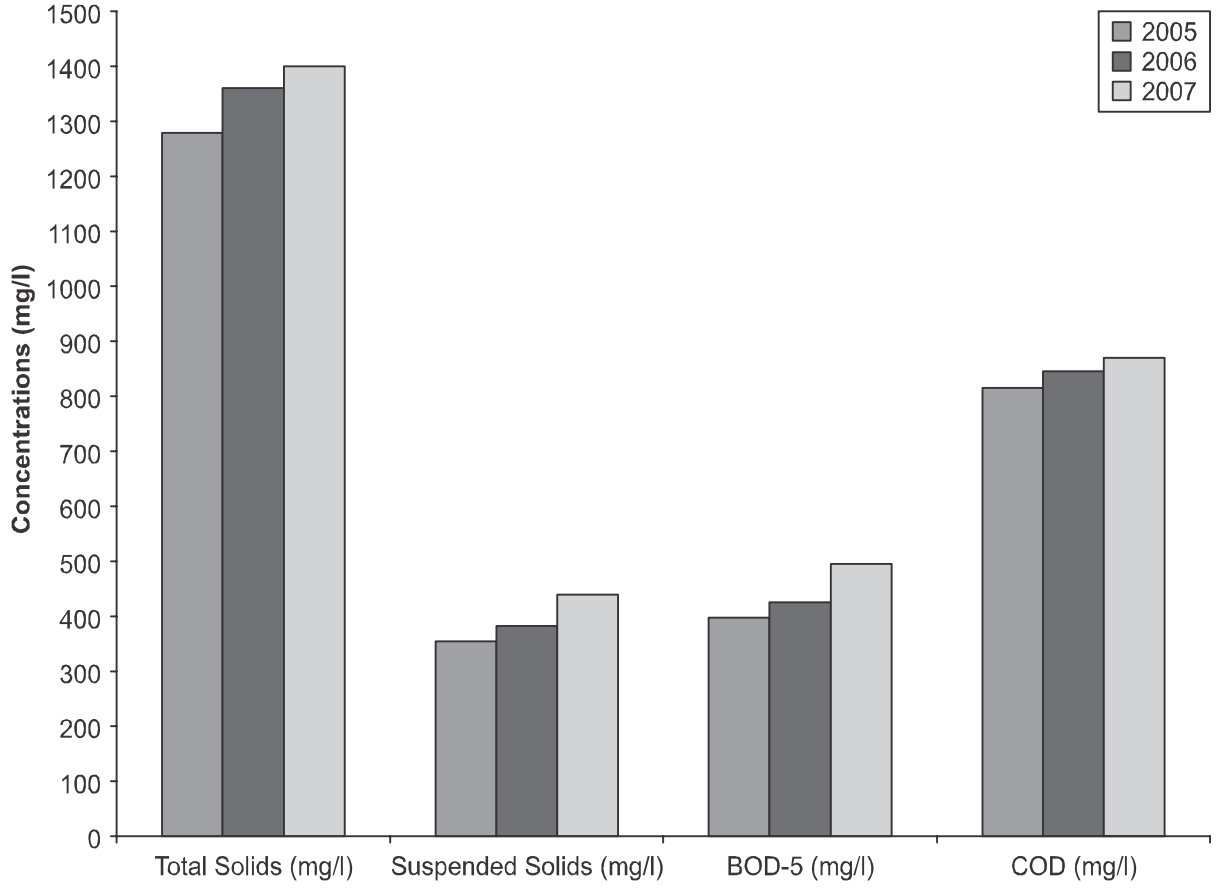

FIG. 1. AVERAGE CONCENTRATION OF TOTAL SOLIDS, SUSPENDED SOLIDS, BOD-5 AND COD OF LAHORE EFFLUENT FOR 2005-2007

4. DESCRIPTION OF STUDY AREA AND SAMPLING STATIONS

During the investigation a reach of Ravi from "Yarpur Village" to the "Balloki headworks" was selected. Municipal and industrial effluents of Lahore city and surrounding areas discharge into the river through different tributaries and outfalls. Major outfalls and tributaries joining Ravi in this reach are: "North East Lahore pumping station", "Shadbagh Pumping station", "Shahdara Pumping Station", "Main Outfall Pumping Station", "Gulshan-e-Ravi Pumping Station", "Multan Road Pumping Station", "Hudiara Drain" and "Deg Nullah". All of these pumping stations discharge effluent into Ravi without any treatment.

During this field investigation various effluent sources which contribute to the Ravi pollution were considered and their characteristics were studied. Sampling of the river water was performed in low flow season for a period of three consecutive years January 2005 to March 2007. Considering the critical conditions of low flow, the months of January, February and March were selected for the field sampling. Average values of all parameters for each year were presented and discussed. Approximately, 50 km length along the river was selected as shown in Fig. 2. Fourteen sampling stations were chosen in this reach based on their relative position with respect to wastewater outfalls as shown in Table 2. The estimated river distances between consecutive stations have also been noted.

5. INVESTIGATED PARAMETERS AND METHODS

The analysis was carried out using procedure described in Standard Method for the Examination of Water and Wastewater [16]. The OD of effluent and industrial wastewater indicates their potential for reducing the DO content of the river water. The BOD_5 and COD is a direct indication of the impact of a given wastewater on the receiving body [17-18]. The most important consideration in determining the self-purification capacity of a stream is its ability to maintain an adequate DO concentration which among other factors is controlled by atmospheric re-aeration, BOD, nitrification and temperature. In order to achieve and maintain a healthy aquatic environment DO content of the river water should be kept above 5 mg/L

Table 1. Discharge of pumping stations into Ravi

No.	Name of Disposal Station	Capacity (Cusecs)
1.	Farkha Abad (Shahdara side near Bara Dari)	111
2.	Saeed Pura (Shahdara side near old Ravi Bridge)	10
3.	Shahdara Town	24
4.	Forest Colony (Near Niazi Interchange)	28
5.	Main Outfall-I	175
6.	Main Outfall-II	102
7.	Main Outfall-III	87
8.	Walled City	100
9.	Gulshan-e-Ravi	320
10.	Multan Road	160
11.	Mehmood Booti	168
12.	Shadbagh	200
13.	Khokhar Road	168
14.	Alipura (Near Railway Bridge)	4
	Total (Approximately)	1650
	(WASA, Lahore)	

and at no time of the day it should drop below 4 mg/l [18]. Unfortunately the examined DO level was very low through the investigation period in study area. BOD_5 is tested with method described in part No. 5210 B 5 Days BOD_5 Test [16]. DO of the samples is measured as per Membrane Electrode Method described in Part No. 4500-O G, COD of the samples is measured as per Open Reflux Method described in Part No. 5220 B [16].

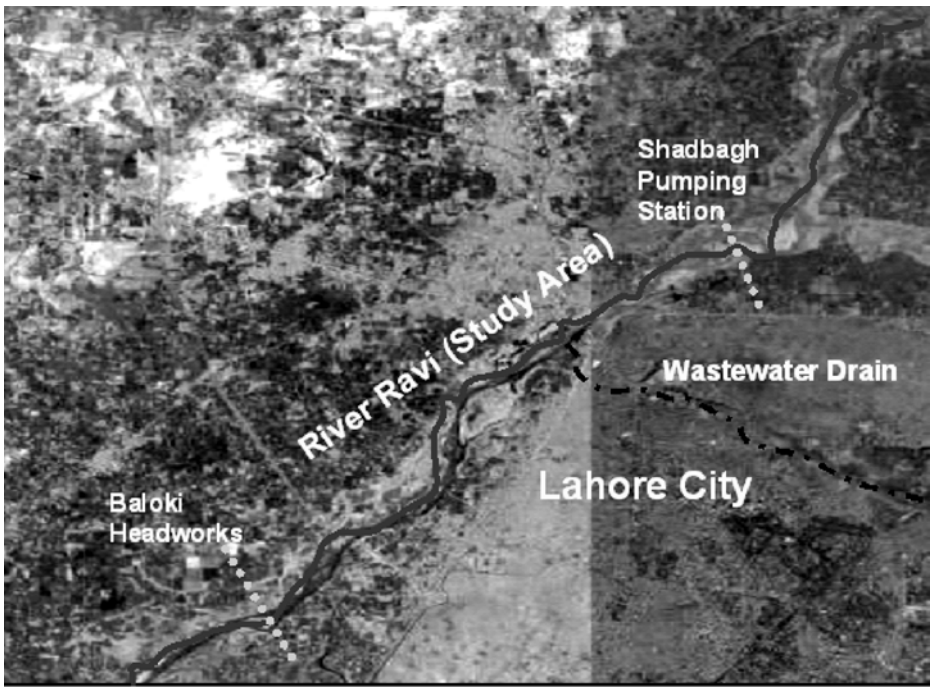

FIG. 2. LOCATION MAP OF STUDY AREA

TABLE 2. LOCATION, IDENTIFICATIONS OF SAMPLING STATIONS AND APPROXIMATED EFFLUENT DISCHARGE AT CRITICAL OUTFALL

Sampling Stations	Description of Sampling Station	Approximated Effluent Discharge to the Ravi River (Cusec)	Comments
SS-1	Yarpur Village	>200	Combined effluent from Shadbagh pumping station to the Ravi River
SS-2	Shadbagh Pumping Station		
SS-3	D/S of Shadbagh pumping station		
SS-4	Ravi Bridge Gauging Station	>375	Lahore city outfalls Combined effluent from babu Sabu pumping station to the Ravi River
SS-5	Main Outfall		
SS-6	D/S of Main Outfall		
SS-7	Babu Sabu Pumping station	>650	Babu sabu pumping station and adjoining areas
SS-8	D/S of Babu Sabu Pumping Station		
SS-9	U/S of Deg Nallah Outlet	>500	Point of intersection of Deg Nallah to the Ravi River
SS-10	Deg Nallah Outlet		
SS-11	D/S of Deg Nallah Outlet		
SS-12	Hudiara Nallah Outlet	>500	Point of intersection of Hudiara Nallah to the Ravi River
SS-13	D/S of Hudiara Nallah		
SS-14	Baloki Headworks		

Total suspended solids represent all organic and inorganic matter in water. In most cases the inorganic matter is present in greater quantity than the organic matter. Suspended Solids of the samples are measured as per method described in Part No. 2540-D [16]. Phosphates are present in land drainage and also in wastewater due to the use of phosphate fertilizers in agriculture [19]. Evidence indicates that high phosphate concentrations are associated with the eutrofication of waters. Phosphates in the samples are measured as per Vanadomoly phosphoric Acid Colorimeter Method described in Part No. 4500-P C [16]. Water quality parameters sodium and chloride were tested. Sodium and chloride contents of the samples are measured as per Atomic Absorption Spectrometric Method described in Part No. 3500-Na-B and Argentrometric Method described in Part No. 4500-Cl-B, respectively [16].

Nitrates are produced by the biological action on nitrogen present in sewage. They are also present in run-off from agricultural land where nitrogenous fertilizers are used. Nitrates act as a ready source of nutrients for plant growth and can give rise to aquatic plants in streams and algal blooms in reservoirs [20-21]. Greater attention to the design and operation of wastewater treatment plants for the oxidation of ammonia and organic nitrogen is needed to minimize the concentration of pollution in the stream [22]. Total Kjeldahl Nitrogen, Nitrite and Nitrate of the collected samples from the river were analyzed as per Macro Kjeldahl Method described in Part No. 4500-Norg-B, Colorimetric Method described in Part No. 4500-No2-B and Nitrate Electrode Method described in Part No. 4500-NO3-D, respectively [16].

Oil and Grease contents of the samples were measured as per Partition Gravimetric Method described in Part No. 5520 [16]. Oil and grease materials are assumed to have no sources or sinks other than local inflows or diversions. These materials are not significantly affected by change in temperature or any chemical, biological or other process [23-24].

Coliform organism standards are so important for design, operation, maintenance and regulation of sanitary systems [25-27]. Great numbers of coliform bacteria are contributed by domestic sewage, agricultural processing and disposed wastes. Coliform group of bacteria can be readily detected even at low density. Number of Total Coliform can be used as a tool in evaluating bacterial pollution of streams. Generally, coliform density rises shortly after each major community outfall. Their density gradually declines and then increases again by discharge from the downstream outfall. Total Coliform in the samples was measured as per Multiple Tube Fermentation Technique for Members of the coliform Group described in Part No. 9221 [16].

6. RESULTS AND DISCUSSION

Investigated parameters for the months of January, February and March for the years 2005-2007 are graphically presented to show the increasing trend of pollution in Ravi. Above mentioned months have been selected for field sampling to consider the low flow conditions in the Ravi. Low DO concentration and very high BOD_5 values are directly indicating the high pollution level. DO and BOD_5 values at Station-1, upstream to the Lahore city, indicate slightly better water quality as compared to downstream along the flow of river. The quality of river water at downstream deteriorates significantly due to disposal of untreated effluent from Lahore city and suburbs. Upper reaches of the Ravi within the selected stretch have BOD_5 in the range of 41.7-55 mg/L. At downstream, the average value of BOD_5 and DO at sampling Station-4 are respectively 132.3 and 3.3 mg/l (in 2007), indicating that 11 Km of the reach between sampling Stations-1 and 4 has relatively less organic pollution as compared to other reaches within the same study area. But unfortunately these values are still not fulfilling the NEQS requirements. DO values for sampling Stations-5-10 are considerably low. Low DO concentrations are responsible for the poor environmental conditions according to the river classification criteria. The sampling Stations 2, 5, 7, 10 and 12 are more critical. These mentioned

sampling stations are representing the effluent outfalls. The comparison of Figs. 3-6 is clearly indicating that DO concentrations at sampling Stations 2, 5, 7, 10 and 12 are relatively low as compared to the other sampling locations. At the same time BOD, COD and SS concentrations are high at these mentioned sampling locations. The remaining sampling locations 1, 3, 4, 6, 8, 9, 11, 13 and 14 are not representing any outfall or effluent carrier drain.

Untreated effluent from Lahore City through main sewer outfalls increases the average BOD_5 concentrations. The increasing trend of average BOD_5 concentration in 2007 was observed as 379, 223, 372.3 and 227.7 mg/L at sampling Stations-5-8 respectively. High concentration of organic matters is responsible for the low DO. The average DO level is dropped from 3.3 mg/L to less than 2 mg/L, from sampling Sation-4 to sampling station-9. According to the NEQS, this reach is not fulfilling the minimum criteria. It indicates that the DO level decreases at the downstream due to increase in organic load from the city outfalls. EPAs (Environment Protection Agencies) suggest that the minimum value of DO must be above 5 mg/L to keep the aquatic life and ecology of river in a proper way. During the investigation comparison of DO analysis with NEQS is not reflecting satisfactory results. Further, BOD_5 analyses show a sudden increasing trend down to main sewage outfall like at sampling Stations 2, 5, 7, 10 and 12. The annual comparison of BOD_5 and DO variation along Ravi is shown in Figs. 3-4, respectively. The yearly comparison reflects a clear picture that environmental quality of river is degrading rapidly.

Untreated effluent results high BOD_5 and COD concentrations in natural water bodies [28-29]. COD analyses show the same behavior like BOD_5 along the Ravi. Concentration of COD is very high at down to the main city outfalls. Fig. 5 represents the bad picture of COD pollution and shows that COD concentration is increasing on annual bases like other pollutants.

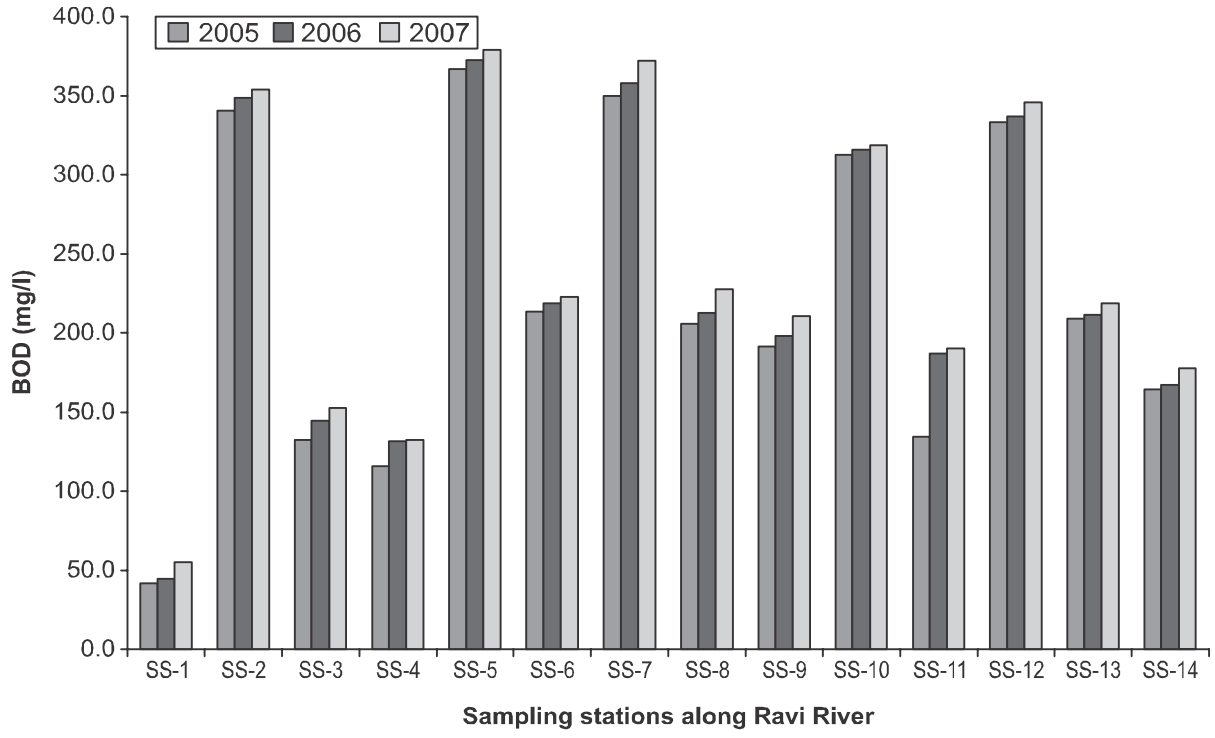

FIG. 3. BOD VARIATION ALONG RAVI BETWEEN SELECTED REACH FOR 2005-2007

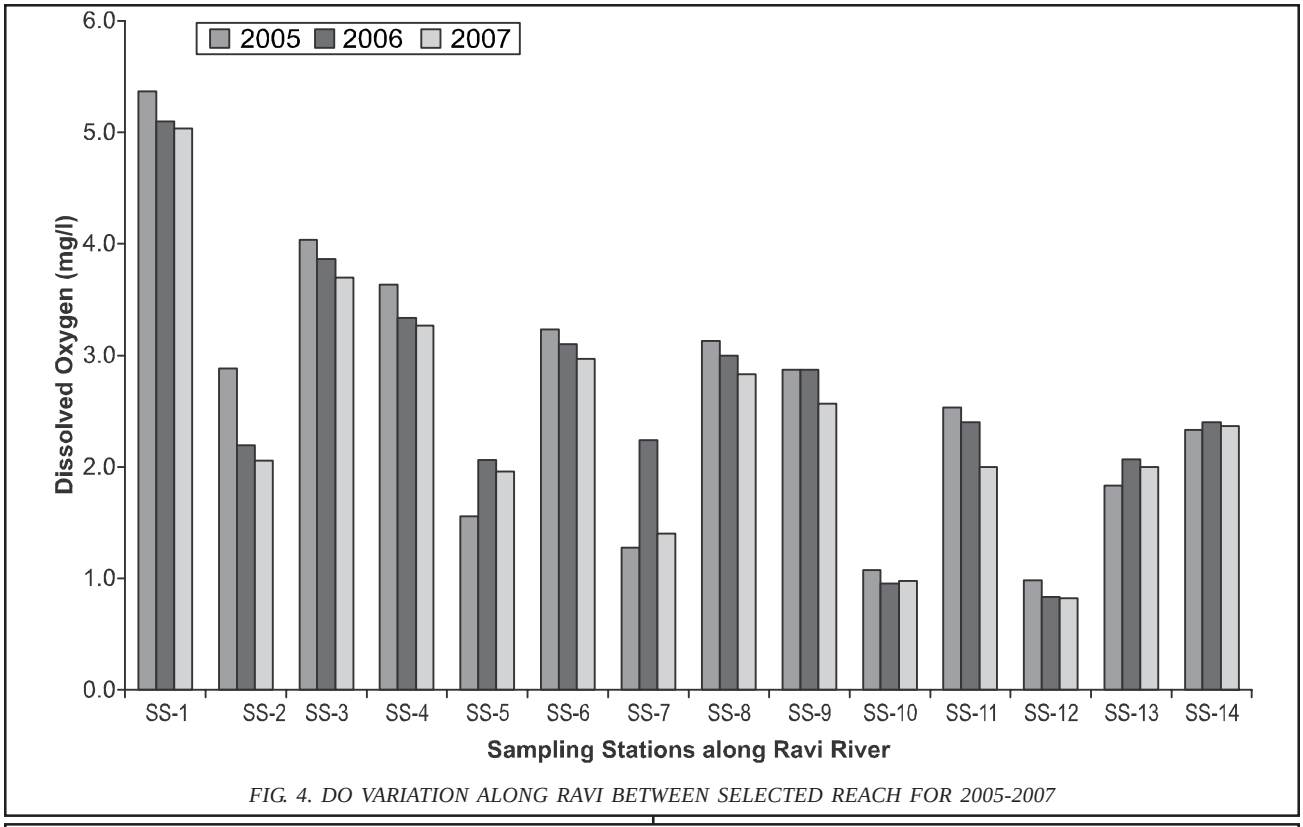

FIG. 4. DO VARIATION ALONG RAVI BETWEEN SELECTED REACH FOR 2005-2007

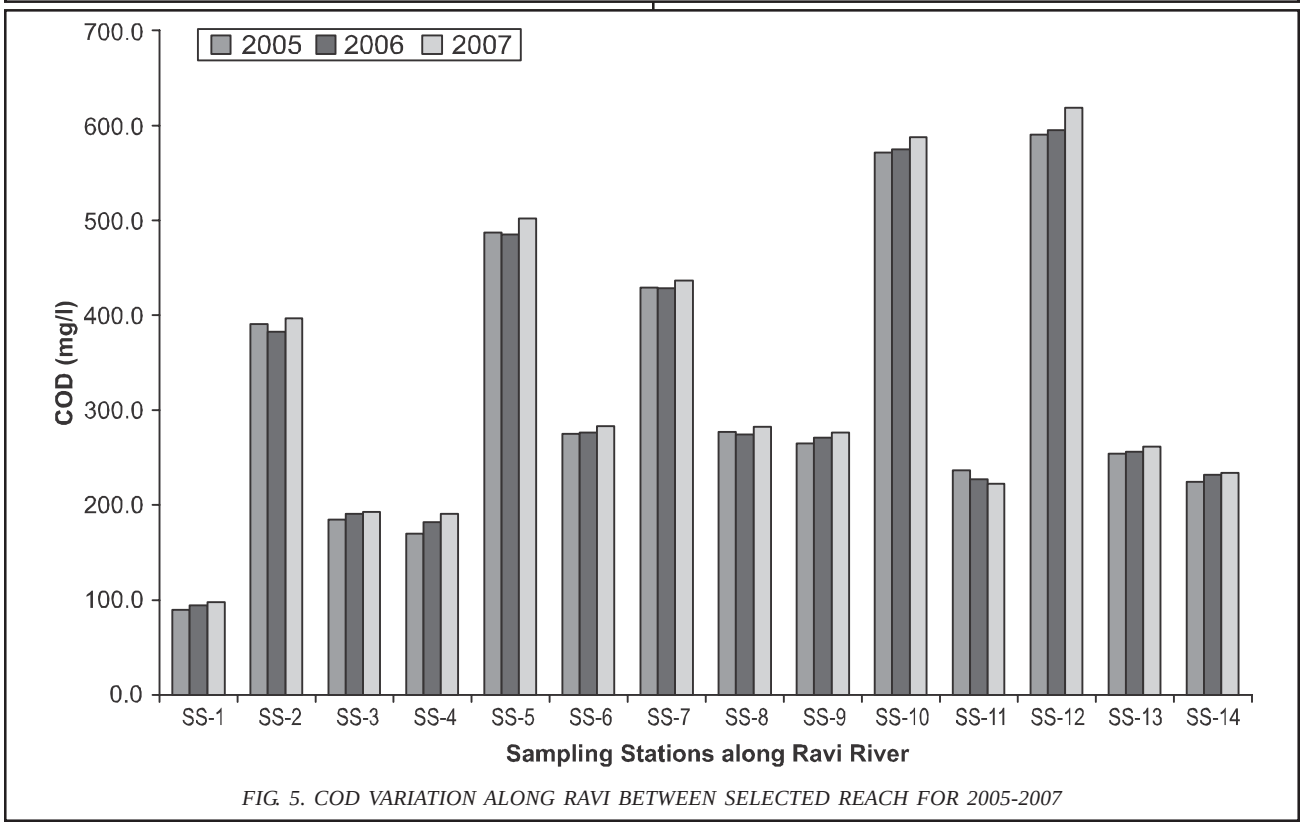

FIG. 5. COD VARIATION ALONG RAVI BETWEEN SELECTED REACH FOR 2005-2007

Untreated effluent from the Lahore city contains high concentration of suspended solids. At the point of mixing, very high concentration of suspended solids was observed. It was also noted during the investigation that suspended solids concentration drops along the flow of river in few segments due to settlement as shown in Fig. 6.

Phosphorus is required as an essential nutrient for the biological growth and can be derived from sewage effluents [30]. It is also present in land drainage due to the use of phosphate fertilizers in agriculture. From the analysis it is clear that the phosphorus concentration increases after mixing of untreated communal wastewater through city outfalls. Sampling stations close to the city are representing high concentration of PO_4^- up to 6.1 mg/L. It gives an indication that phosphorus concentration can be serious threat to the river ecology. Sodium and chloride contents were also found very high during the investigation as compared to the standards. The concentrations of these contents are increasing rapidly on annual basis due to increase of untreated municipal and industrial waste water quantity from Lahore City and suburbs.

The measurements of TKN (Total Kjedahls Nitrogen), Nitrites and Nitrates are necessary to assess the potential of eutrophication in the stream. A high content of inorganic nitrogen and phosphorus in stream may give rise to the production of algal blooms [30]. The results shown in Figs. 7-9 indicate that present concentration of nitrogen is more than adequate to promote biological purification. It can be seen that the amount of NO_2-N present in the river water is exceedingly higher than that usually required to stimulate algal growth in lakes and reservoirs i.e. 0.3 mg/L. The comparison of Figs. 7-9 is representing the same trend of pollution under the effluent outfalls. From these figures it is clear that TKN, NO_2-N and NO_3-N concentrations are high at sampling Stations 2, 5, 7, 10 and 12. As discussed above these locations are indicating the joining point of different effluent outlets to the river. After investigation it is concluded that proper effluent treatment practice may reduce the high peaks of these pollutants under the main sewer outlets.

Oil and grease concentrations can seriously affect the ecology of a water body [31]. These concentrations are increasing along the reach due to high concentration of

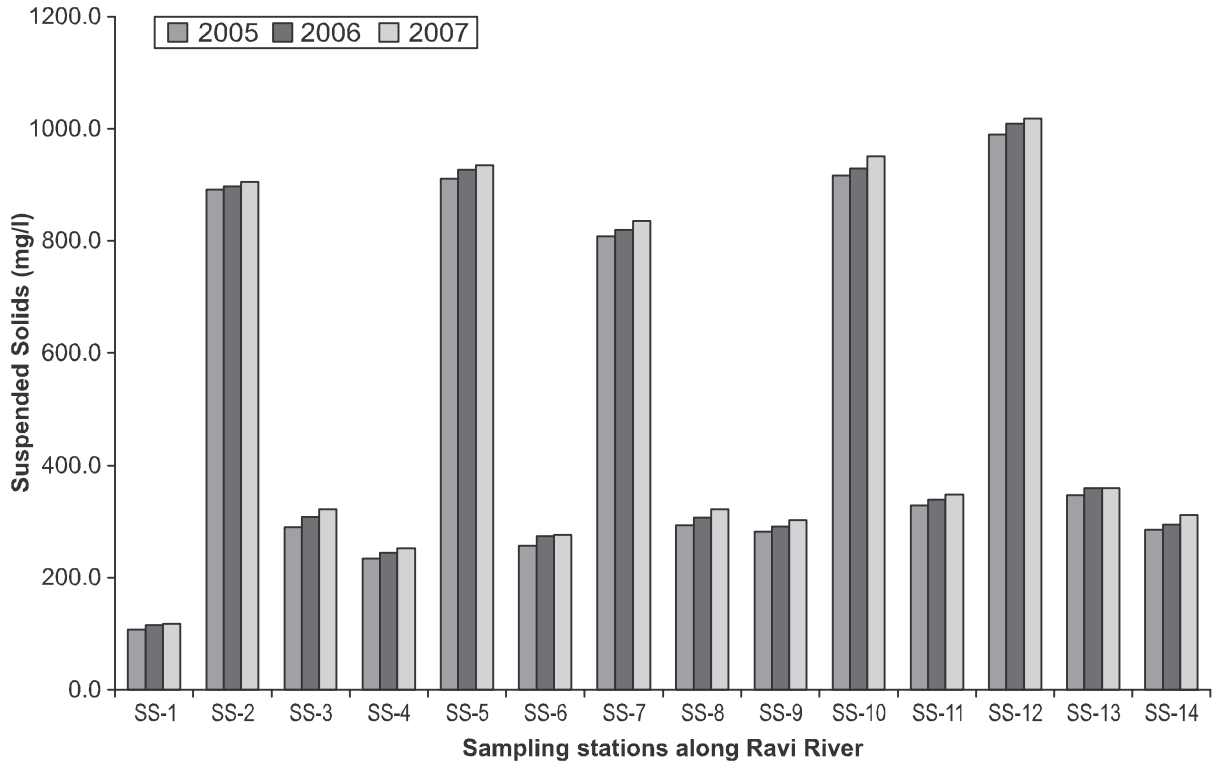

FIG. 6. SUSPENDED SOLIDS ALONG RAVI BETWEEN SELECTED REACH FOR 2005-2007

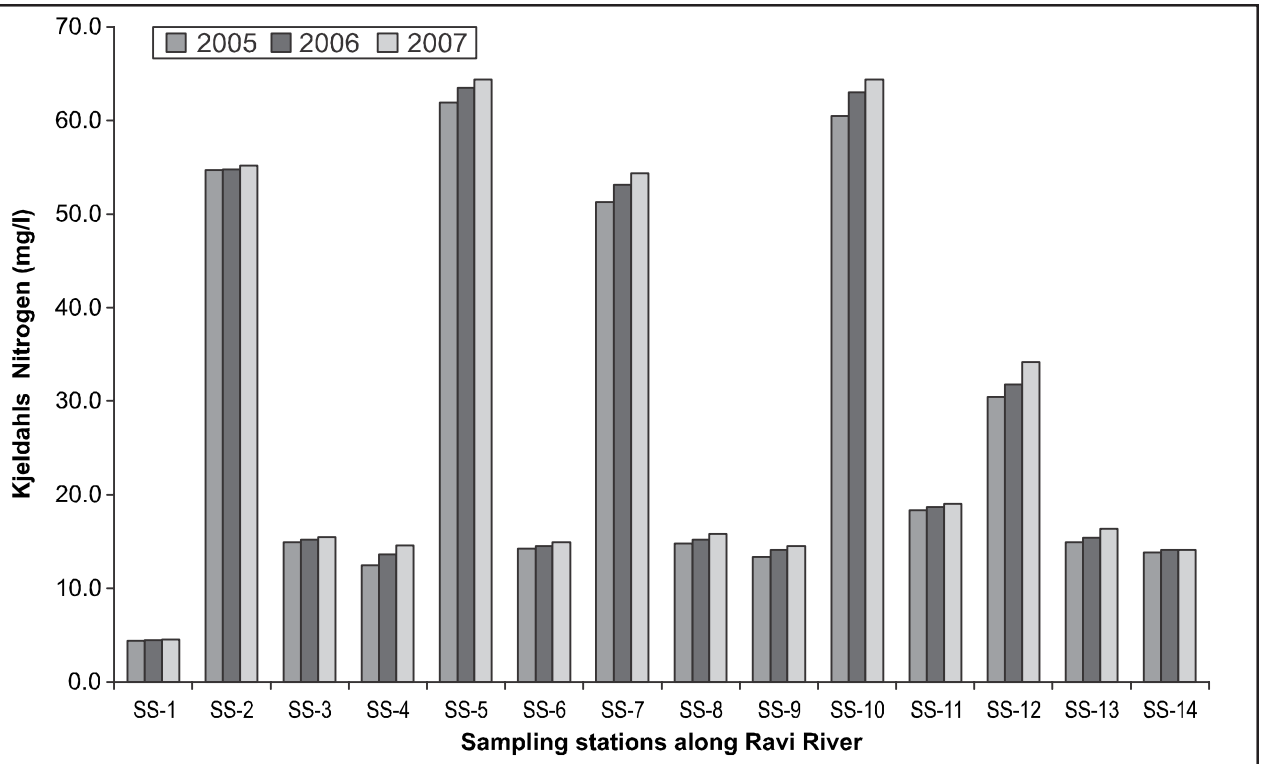

FIG. 7. TKN VARIATION ALONG RAVI BETWEEN SELECTED REACH FOR 2005-2007

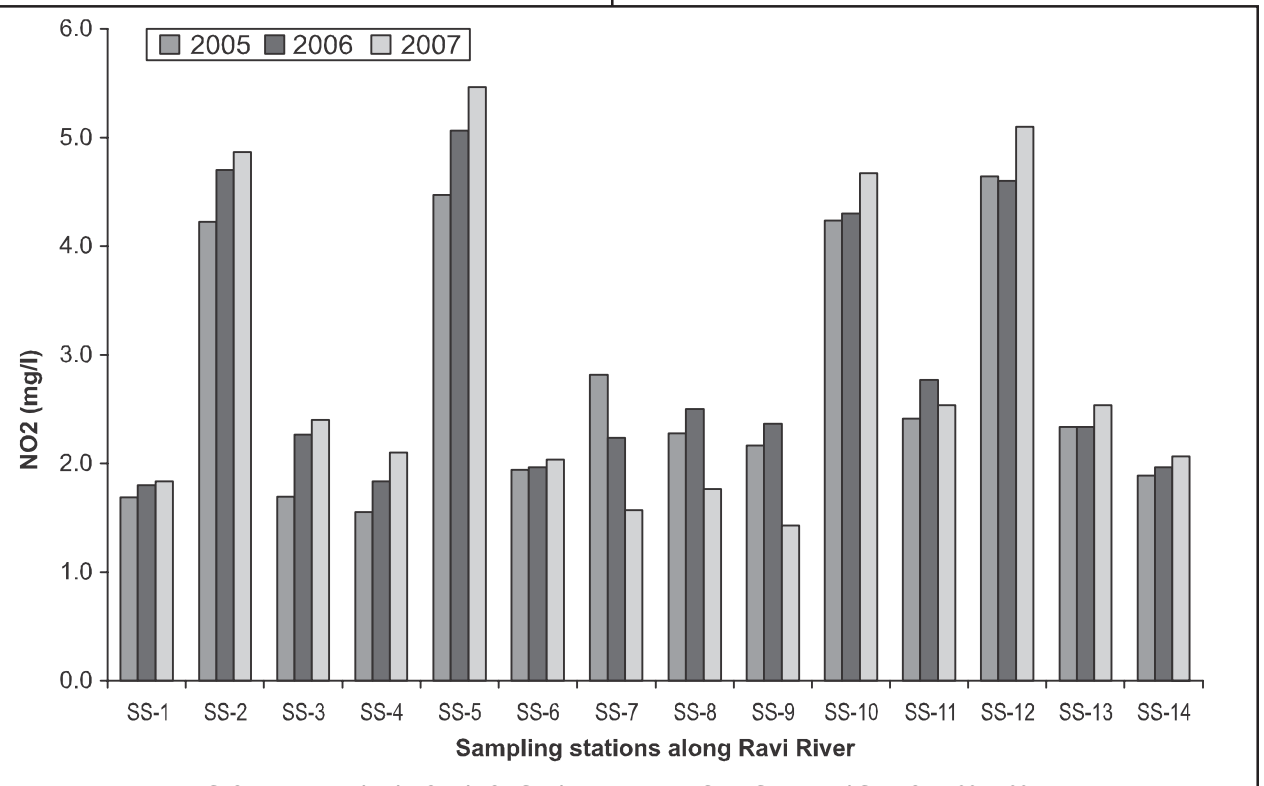

FIG. 8. NITRITE VARIATION ALONG RAVI BETWEEN SELECTED REACH FOR 2005-2007

untreated industrial wastewater from Lahore city and surrounding industrial estates. Fig. 10 represents the behavior of these contaminants along the Ravi at different sampling stations. These results show that concentration of oil and grease increases along the reach in the river. These concentrations are much higher as compared to NEQS.

Analyses of collected samples show that most of the sampling stations had high value of total coliform. Sampling Station-1-4, where the river is being used for recreational purposes, also representing high total coliform numbers. It indicates that there is inadequate dilution or self purification available in the stream to reduce the bacterial pollution. The river reach between "Main Outfall" and "Deg Nallah" is also indicating a bad picture. Fig. 11 is highlighting the total coliform concentration at selected sampling stations along the Ravi.

Comparison of all investigated parameters shows that concentration of pollutants in the river is very high. The NEQS for Pakistan are presented in Table 3 [32] for better comparison of investigated parameters. Concentration of BOD_5, COD, TS and SS are at least five times greater than the allowable standard according to NEQS.

7. CONCLUSION

It is concluded after field investigation that Ravi is highly polluted and unfit for recreational purposes. The concentration of investigated parameters like BOD_5, DO, COD, total suspended solids, phosphates, chlorides, sodium, TKN, nitrites, nitrates, oil and grease and total coliform were found very high when compared to the environmental standards. It was observed that the DO concentration decreases due to continuous mixing of wastewater along the length of the river. The effluent characteristics of Lahore city was also analyzed from the main city outfall sewers and compared with NEQS. Unfortunately selected parameters are at least four times above the allowable standards. The oil and grease content was found increasing continuously towards the downstream. The concentration of investigated parameters was found much higher. These concentrations increase simultaneously underneath the main city outfalls due to mixing of untreated effluent in huge quantity.

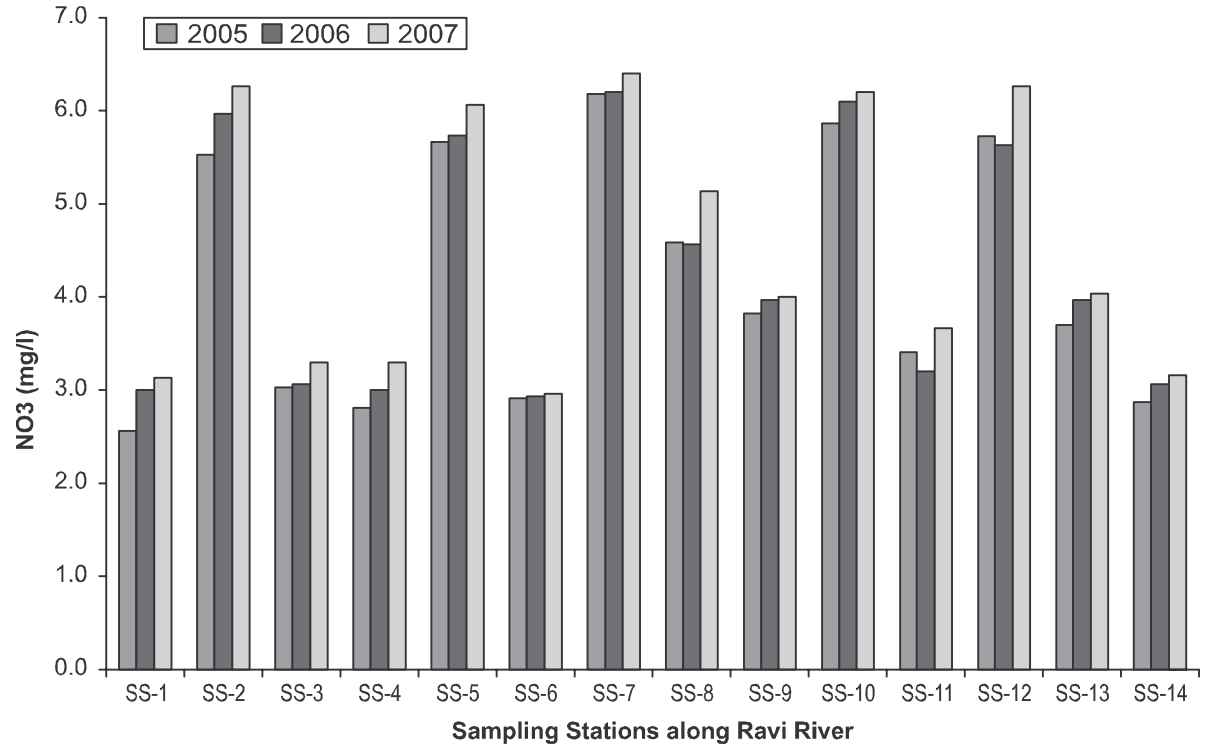

FIG. 9. NITRATE VARIATION ALONG RAVI BETWEEN SELECTED REACH FOR 2005-2007

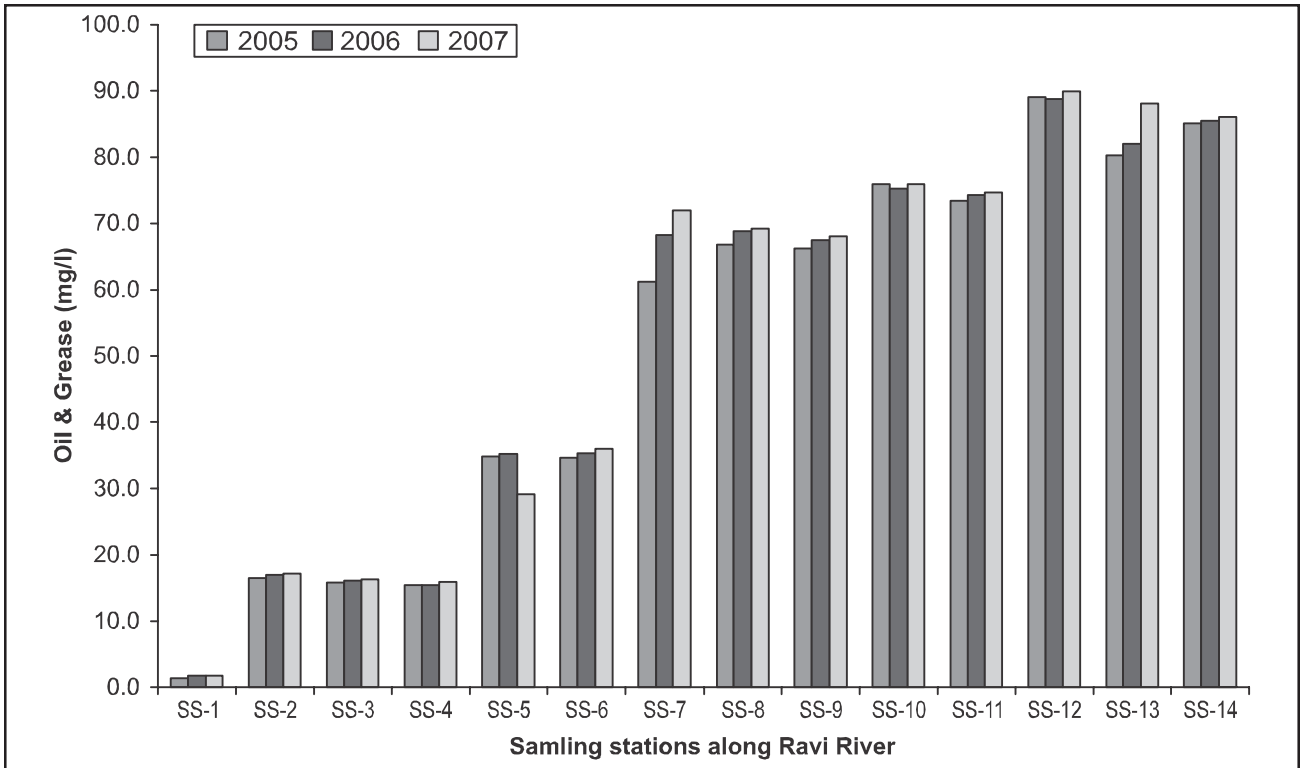

FIG. 10. OIL & GREASE VARIATION ALONG RAVI BETWEEN SELECTED REACH FOR 2005-2007

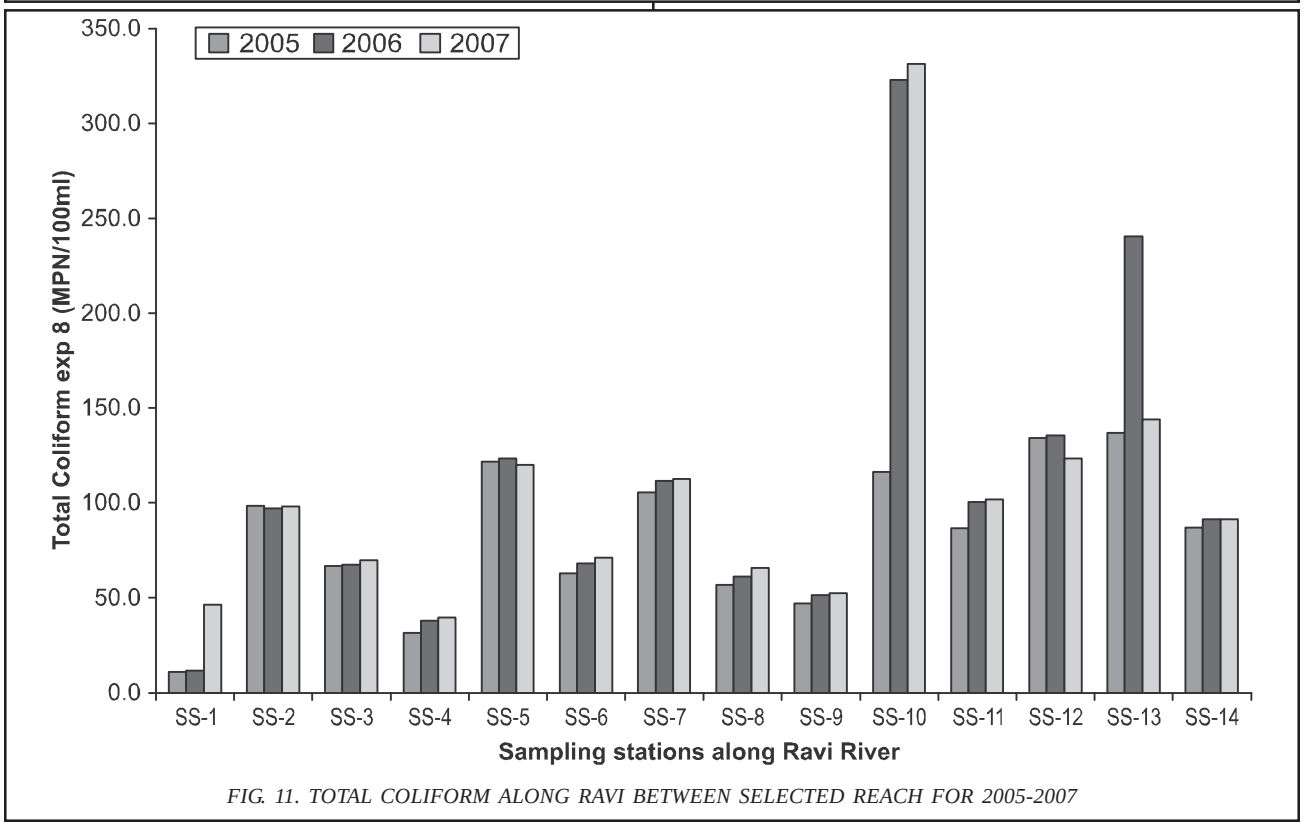

FIG. 11. TOTAL COLIFORM ALONG RAVI BETWEEN SELECTED REACH FOR 2005-2007

8. RECOMMENDATION

The domestic wastewater should be collected at prominent places where it should be treated before dispose of into the river. All industrial units are required to install specific treatment plant according to the requirements. To safe guard Ravi from environmental problems it is strongly recommended that small storage reservoir may be constructed upstream, to regulate and maintain minimum water level in low flow season. Environmental legislation, water quality monitoring program and enforcement of NEQS are most urgent to improve the stream water quality in Pakistan.

ACKNOWLEDGEMENTS

Authors are grateful to the Higher Education Commissions, Pakistan, for the partial funding during this research study. Authors are thankful to the University of Engineering & Technology, Taxila, Pakistan, for providing the resources and funding during the investigation. Related departments, WASA, WAPDA, PHE, EPD and EPA, Islamabad, are also seriously acknowledged for providing valuable data and information. Last but not least we are heartily obliged to the anonymous Referees/Experts, for their valuable comments.

REFERENCES

[1] Ziai, K.H., "Investigation of Rational Effluent and Stream Standards, Hudiara Nullah and River Ravi: A Case Study", National Workshop on Water Resources Achievements and Issues in 20th Century and Challenges to the Next Millennium, Islamabad, Pakistan, 1999.

[2] Balfours Report, "Feasibility of Treatment of Wastewater Discharges from City of Lahore", Punjab Province, Lahore, Pakistan, 1987.

[3] Khattak, F.M., "Revised Proposal for Chemical Analysis of Water to Certain the Effect of Industrial and Domestic Sewage on the Composition of Water", NWFP Government, Peshawar, Pakistan, 1991.

[4] Cheema, A.N., "Research Proposal for Design of Low Cost Treatment Methodology for Surface Water in Pakistan", 1991.

[5] WWF, "Pollution Monitoring of Hudiara Drain", A Two Year Project Funded by UNDP under GEF Small Grants Programme, Lahore, Pakistan, 2001.

TABLE 3. NEQS FOR MUNICIPAL AND LIQUID INDUSTRIAL EFFLUENTS IN PAKISTAN

Parameters	Proposed Standards
Ammonia (mg/L)	40
BOD_5 Days (mg/L)	80
COD (mg/L)	150
Chloride as Cl (mg/L)	1000
Cadmium (mg/L)	0.1
Chromium (Trivalent & Hexavalent) (mg/L)	1.0
Copper (mg/L)	1.0
Chlorine (mg/L)	1.0
Detergents (mg/L) (Modified Benzene Alkyl Sulphate MBAS)	10.0
Fluoride as F (mg/L)	10.0
Iron (mg/L)	2.0
Lead (mg/L)	0.5
Manganese (mg/L)	1.5
Mercury (mg/L)	0.01
Nickel (mg/L)	1.0
Oil and Grease (mg/L)	10
Phenolic Compounds as Phenol (mg/L)	0.1
pH value	6.0-10.0
Suspended Solids (mg/L)	150
Sulphates (mg/L)	600
Sulphide (mg/l)	1.0
Temperature ^oC	40
Total Dissolve Solids (mg/L)	3500
Zinc (mg/L)	5.0

[6] Qazi, S.A., "A Study of Municipal Wastes Pollutional Loads and Degree of Treatment for City of Lahore", M.Sc. Thesis, IEER, University of Engineering & Technology, Lahore, Pakistan, 1991.

[7] Lin, P.W., "Dissolved Oxygen in a River", Stream Pollution Survey Training Course, PHER, University of Engineering & Technology, Lahore, Pakistan, 1980.

[8] Younas, M., Afzal, F.S., Khan, M.I., and Ali, K., "Assessment of Cd, Ni, Cu, and Pb Pollution in Lahore, Pakistan", Environment International, Volume 24, No. 7, pp. 761-76, October, 1998.

[9] Afzal, S., Ahmed, I., Younas, M., Din, M., Zahid, M.H., Khan, A., Ijaz, A., and Ali, K., "Study of Water Quality of Hudiara Drain, India-Pakistan", Environment International, Volume 26, Nos. 1-2, pp. 87-96, August, 2000.

[10] Reza, A., "Ravi Threatens Aquatic Life, Groundwater", The News International, 11th August, 2009.

[11] Saeed. M.M., and Bahzad, A., "Simulation of Contaminant Transport to Mitigate Environmental Effects of Wastewater in River Ravi", Pakistan Journal of Water Resources, Volume 10, No. 2, July-December, 2006.

[12] Rauf, A., Javed, M., Ubaidullah, M., and Abdullah, S., "Assessment of Heavy Metals in Sediments of the River Ravi, Pakistan", International Journal of Agriculture & Biology, Volume 11, No. 2, 2009.

[13] Naseer, N., "Analyzing the Effect Industrial Waste on River Ravi", Pakistan Journal of Applied Sciences, Volume 3, pp. 587-603, 2003.

[14] Ahmad., K., and Ali., W., "Evaluation of Time Variation in the Water Quality of Deg Nallah", Institute of Public Health Engineering & Research, University of Engineering and Technology, Lahore, Pakistan, April, 1996.

[15] Shuval, I.H., "Water Quality Management under Conditions of Scarcity", Academic Press, 1980

[16] Andrew, D.E., Lenore, S.C., and Arnold, E.G., "Standard Methods for the Examination of Water and Wastewater", 19th Edition, American Public Health Association, American Water Works Association and Water Environment Federation USA, 1995.

[17] Okada, T., and Nakayama, K., "Density Intrusion and Variation in Dissolved Oxygen Concentrations in a Bay with a Sill at Its Mouth", Journal of Environmental Engineering ASCE, Volume 133, pp. 447-453, USA, April, 2007.

[18] Ramakar, J., Ojha, C.S.P., and Bhatia, K.K.S., "Development of Refined BOD and DO Models for Highly Polluted Kali River in India", Journal of Environmental Engineering ASCE, Volume 133, pp. 839-852, USA, August, 2007.

[19] Zou, R., Carter, S., Shoemaker, L., Parker, A., and Henry, T., "Integrated Hydrodynamic and Water Quality Modeling System to Support Nutrient Total Maximum Daily Load Development for Wissahickon Creek, Pennsylvania", Journal of Environmental Engineering ASCE, Volume 132, pp. 555-566, USA, April, 2006.

[20] Chung, J., Nerenberg, R., and Rittmann, B.E., "Evaluation for Biological Reduction of Nitrate and Perchlorate in Brine Water Using the Hydrogen-Based Membrane Biofilm Reactor", Journal of Environmental Engineering ASCE, Volume 133, pp. 157-164, USA, February, 2007.

[21] Sumer, D., Gonzalez, J., and Lansey, K., "Real-Time Detection of Sanitary Sewer Overflows Using Neural Networks and Time Series Analysis", Journal of Environmental Engineering ASCE, Volume 133, pp. 353-363, USA, April, 2007.

[22] Enrique, J., Motta, L., Silva, E., Bustillos, A., Pachon, H., and Luque, J., "Combined Anaerobic/Aerobic Secondary Municipal Wastewater Treatment: Pilot-Plant Demonstration of UASB/Aerobic Solids Contact System", Journal of Environmental Engineering ASCE, Volume 133, pp. 397-403, USA, April, 2007.

[23] Metcalf, and Eddy, "Wastewater Engineering Treatment, Disposal and Reuse", McGraw-Hill Edition, New York, USA, 1979.

[24] Saleemi, "Environmental Pollutants", Journal of Rural Environmental Engineering, USA, 1997.

[25] Song, I., Stine, S.W., Choi, C.Y., and Gerba, C.P., "Comparison of Crop Contamination by Microorganisms During Subsurface Drip and Furrow Irrigation", Journal of Environmental Engineering ASCE, Volume 132, pp. 1243-1248, USA, October, 2006.

[26] Fries, J.S., Characklis, G.W., and Nobel, R.T., "Attachment of Fecal Indicator Bacteria to Particles in the Neuse River Estuary, NC", Journal of Environmental Engineering ASCE, Volume 132, pp. 1338-1345, USA, October, 2006.

[27] Ahn, C.H., Park, J.K., and Kim, K.S., "Microbial Adaptability to Organic Loading Changes in an Enhanced Biological Phosphorus Removal Process", Journal of Environmental Engineering ASCE, Volume 132, pp. 909-917, USA, August, 2006.

[28] Prashanth, S., Kumar, P., and Mehrotra, I., "Anaerobic Degradability: Effect of Particulate COD", Journal of Environmental Engineering ASCE, Volume 132, pp. 488-496, USA, April, 2006.

[29] Iran, E. Neto, L., Zhu, D.Z., Rajaratnam, N., Yu, T., Spafford, M., and McEachern, P., "Dissolved Oxygen Downstream of an Effluent Outfall in an Ice-Covered River: Natural and Artificial Aeration", Journal of Environmental Engineering ASCE, Volume 133, pp. 1051-1060, USA, November, 2007.

[30] Ahn, C.H., Park, H.D., and Park, J.K., "Enhanced Biological Phosphorus Removal Performance and Microbial Population Changes at High Organic Loading Rates", Journal of Environmental Engineering ASCE, Volume 133, pp. 962-969, USA, October, 2007.

[31] Khan, S., Lau, S.L., Kayhanian, M., and Stinstrom, M.K., "Oil and Grease Measurement in Highway Runoff-Sampling Time and Event Mean Concentrations", Journal of Environmental Engineering ASCE, Volume 132, pp. 415-422, USA, March, 2006.

[32] Ahmed, K, "Environmental Engineering Laboratories", A-One Publishers, Appnedix-VII, pp. 213, Lahore, Pakistan, 1998.