

## **Impact of pollution load on water quality of river Ravi in Pakistan**

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**Abstract:** Current study was carried out to evaluate the impact of untreated urban and industrial effluents on water quality of River Ravi. Water samples collected during low flow season from 10 polluted and relatively unpolluted sites at River Ravi were analyzed for heavy metals content and physico-chemical parameters. Dissolved oxygen was found to fall below the recommended limit for propagation of fish and aquatic life as the river flows through Lahore up to Balloki Headwork. Mn and Pb were detected in concentrations higher than recommended limits at several polluted sites of the river. Highest detected content of Ni, Zn, Mn, Cd and Pb in river water was 0.02 mg/L, 0.07 mg/L, 0.19 mg/L, 0.002 mg/L and 0.072 mg/L respectively. Findings revealed that river water has not been suitable to support fish and other aquatic life due to very low dissolved oxygen level at downstream sites of waste water carrying drains discharge points.

**Key words:** Aquatic biota, Heavy metals, Oxygen depletion, Urban and industrial effluents, Waste carrying drains

## **1. Introduction:**

Extensive provisioning services provided by rivers are accompanied by their water quality deterioration and loss of aquatic biodiversity (Vörösmarty *et al.*, 2010). Discharge of untreated waste water from industrial, urban and agricultural origin introduce more than a million types of toxic pollutants therein (Welch and Lindell, 2004; Forstner and Wittmann, 1981). The biological degradation of non-conservative pollutants takes place at the cost of dissolved oxygen in the receiving water bodies that can also lead to anoxic conditions (Miller and Spoolman, 2014; Jones *et al.*, 1972). Moreover, the hazardous nature of heavy metals, a form of conservative toxicants, have been well documented for aquatic organisms (Zeitoun and Mehana, 2014; Spicer and Weber, 1991; Peterson *et al.*, 1984). Humans have been exposed to their toxic effects (Waheed *et al.*, 2013; Tchounwou *et al.*, 2012) either through exposure to polluted water or consumption of fish contaminated by their bioamplification in the food webs.

Pakistan is expected to be a water scarce country in future (WWF, 2007) with an expected water deficiency of 151 MAF in 2025. One of the major obstacles faced by the conservation practices is the level of pollution in the country's water resources. At present, majority of industrial units have been established either within or near the urban areas. More than 99% of urban and industrial effluents eventually dispose of in the natural water reservoirs without any treatment (MOE-PAK, 2005). Absence of regular monitoring programmes and surface water quality standards in the country also aid in the continuous deterioration of aquatic ecosystems (WWF, 2007).

River Ravi, a transboundary river enters Pakistan at Shakkargarh (Sialkot) and empties in River Chenab near Shorkot. Extensive pollution load that it receives through its course of flow through Lahore has converted the river into a waste water drain especially during low flow season. In addition to five primary drains, the river receives huge load of industrial effluents through Hudiara Drain and Deg Drain. Former carries the polluted industrial water of

more than 100 industries of Pakistan and India each while latter is polluted with the toxic effluents of about 150 industries of Lahore and its surroundings (Saeed and Bahzad, 2006). Both drains contributes more than 500 cusec effluent to the river each (Ejaz *et al.*, 2011). The degree of pollution of the river is a serious threat for aquatic life and underground water reservoirs of the region. It is, therefore, necessary to monitor the river water quality on regular basis to investigate its pollution status so that the appropriate mitigation strategies might be adopted. A clearer picture of the fluvial environment can be achieved during the low flow season due to absence of dilution effects that can occur during high flow period. The current study was, therefore, based on analysis of various physico-chemical parameters and toxic heavy metals content in the river water during the low flow season.

## **2. Materials and methods**

A stretch of about 160 km of River Ravi starting from Shakkargarh, Sialkot upto Balloki Headworks was evaluated for water quality. Water samples were collected in triplicate from 11 sites. The site selection was based upon the discharge points of point pollution sources in the river. Sample collection was completed during the low flow season from January to February.

### ***2.1. Description of study area***

River Ravi receives its major share of pollution through six primary drains; Shahdara Drain, Shalimar Escape Channel Drain, Upper Chota Ravi Drain, Lower Chota Ravi Drain, Sattu Katla Drain and Cantt Drain. In addition, two tributaries viz. Hudiara Drain and Deg Drain dispose of huge amount of untreated effluents in the river. The detail of waste water carrying primary drains/ tributaries is presented in Table 1. Following is the brief description of the sampling sites. The sites codes that will be used throughout the article along with the sites coordinates are presented in Table 2.

### 2.1.1. *Kot Nainan, Kala Khtai and Village Khokhar (KNS, KKN, VK)*

Kot Nainan, Kala Khtai and Village Khokhar were the first three sampling sites in the current study. River Ravi enters in Pakistan at Kot Nainan, Shakkargarh (KNS) and keeps flowing on either side of Indo-Pak boundary until it permanently enters in Pakistan near Ravi Siphon. Kala Khtai (KKN) is located near Narang Mandi Town about 15 km upstream of Ravi Siphon. After its entrance in Pakistan at Ravi Siphon, the river flows along the Kala Khatai-Narang Mandi Road upto Village Khokhar (VK). There is no identifiable point source of pollution upto Village Khokhar. Therefore these three sample collection sites; KNS and KKN and VK are considered as relatively unpolluted.

### 2.1.2. *Old Ravi Bridge (ORB 1 and ORB 2)*

Shalimar Escape Channel Drain discharges its waste water in the river between Village Khokhar and Old Shahdara Ravi Bridge. Two sampling sites were selected at Old Ravi Bridge. ORB 1; where river water was not completely mixed with drain water and ORB 2; where river water was mainly carrying the drain's waste water.

### 2.1.3. *Village Gopi Rai and Shahpur Kanjra (VGR, SPK)*

While flowing through Lahore, the river receives the waste discharge of Shahdara Drain and Lower Chota Ravi Drain near New Shahdara Ravi Bridge and Sagian Bridge respectively. Village Gopi Roy is situated near Lahore-Islamabad Motorway. The river at this site serves as upstream site of discharge point of Cantt drain in the river. A portion of Cantt drain waste water joins an Escape Channel that emerges from Lahore Branch Canal near Thokar Niaz Beg and empties in River Ravi at Shahpur Kanjra (SPK). The river at Village Gopi Rai (VGR) and Shahpur Kanjra (SPK) serves as upstream and downstream of discharge point of Cantt drain effluents in the river.

#### 2.1.4. *Village Khudpur* (VKPU and VKPD)

Sattu Katla drain; another primary drain that originates from Fruit and Vegetable Market at Ferozpur Road joins the Hudiara Drain near Valencia Housing Society. Hudiara Drain carrying waste effluents of Sattu Katla Drain as well as the industrial effluents of India and Pakistan empties in River Ravi at Village Khudpur. Both upstream and downstream site (VKPU and VKPD) of discharge point of Hudiara Drain in Ravi are accessible at this site.

#### 2.1.5. *Village Nano Dogar* (VNDS)

Village Nano Dogar near Sunder Industrial Estate (VNDS) is situated at downstream of Village Khudpur. The site serves as the downstream site of discharge point of Hudiara Drain and Deg Drain. The latter is another waste water carrying tributary that empties in the river from the opposite side near the Shraqpur.

#### 2.1.6. *Balloki Headworks* (BHW)

Although there is no traceable point source of pollution, but the river looks like a sewage drain at this site especially during the low flow season due to the pollution load it has received through its course of flow through Lahore. The site served as the last sampling site of the current study.

### 2.2. *Sample collection and preservation*

Water samples at each sampling site were collected from three sublocations situated at symmetrical distance from each other. Water samples were collected almost 30 cm below the surface from each sampling sublocation and stored in two 500 ml acid rinsed polyethylene bottles. The samples in one bottle were acidified immediately after collection with concentrated nitric acid to pH<2 for heavy metals analysis. Water samples in the second bottle were used for the determination of Physico-Chemical parameters. The sample bottles were transported to laboratory in portable ice boxes and stored in the refrigerator at 4<sup>0</sup>C until processed for analysis.

### **2.3. *Water analysis for physico-chemical parameters***

Temperature and dissolved oxygen (DO) of water samples was determined on site. Temperature was measured by direct insertion of a laboratory thermometer in the river water at the sampling site. Water sample for dissolved oxygen determination was collected by filling the BOD bottle with river water at a depth of about 30 cm. Bottle was overflowed with water about three times of its volume and capped with stopper while within water to avoid entrapping of air. Dissolved oxygen was determined by Winkler Method with azide modification (APHA, 2012). Oxygen deficiency in the river water was calculated according to Boyd (2015). Conductivity, pH and turbidity of water samples was determined in the laboratory using electronic instruments following the standard methods (APHA, 2012).

### **2.4. *Water analysis for heavy metals***

All the glassware used for the preparation and storage of water samples for heavy metals analysis was rinsed with acid to prevent any contamination. The acid preserved water samples were digested for heavy metals using nitric acid-hydrochloric acid digestion according to the procedure described in APHA (2012). The digested samples were analyzed for Ni, Mn, Zn, Cd and Pb by ICP (Perkin Elmer; Optima 7000 DV) with optical emission detection. Calibration curves for ICP-OES analysis were prepared with working standard solutions of the metals of interest. Perkin-Elmer multi element mixed standard solutions were used for the preparation of working standard solution.

### **2.5. *Statistical analysis of data***

Data on water quality parameters at various sites was statistically analyzed through one way analysis of variance to compare the means for statistically significant differences. Post hoc analysis was performed through Fisher's Least Significant Difference (LSD) test to identify the difference between pair of means. All statistical analysis was carried out using Minitab-17 software.

### **3. Results and discussion**

Results of the current water quality survey of River Ravi has revealed that pollution load through untreated municipal and industrial discharge is deteriorating its aquatic environment through dissolved oxygen depletion and higher toxic metal content. Table 3 shows water quality guidelines for propagation of fish and aquatic life as well as drinking and irrigation water. Physico-Chemical parameters and the heavy metals content of the river water as investigated in the present study are presented in Table 4 and Table 5 respectively along with analysis of variance.

#### ***3.1. Physico-Chemical Analysis***

River water was analyzed for its physico-chemical characteristics viz. temperature, dissolved oxygen, pH, conductivity and turbidity. One way ANOVA indicated significant differences among the analyzed parameters at various sampling sites ( $P < 0.05$ ). Water temperature ranged from  $12.5\text{ }^{\circ}\text{C} \pm 0.06\text{ }^{\circ}\text{C}$  (at VK) to  $20.5\text{ }^{\circ}\text{C} \pm 0.10\text{ }^{\circ}\text{C}$  (at SPK) as measured during the sampling duration of two months. The proposed water temperature for aquatic organisms suggests a temperature change of less than  $3\text{ }^{\circ}\text{C}$  in either direction as compared to an upstream control point. The temperature of the upstream control point in the present study viz. KNS was found to be  $16.6\text{ }^{\circ}\text{C} \pm 0.10\text{ }^{\circ}\text{C}$ . The greater temperature variation, however, can be attributed to the different sampling times and days. Dissolved oxygen, one of the most critical water quality parameter for aquatic life, was found to be higher than the recommended limit of  $>5\text{ mg/L}$  for aquatic life and  $>4\text{ mg/L}$  for recreational purposes from KNS up to ORB1 and ORB2. However it was well below these proposed limits at all the other sites. DO exhibited a decrease of about 77% from ORB2 to VGR. Dissolved oxygen content of less than  $2.2\text{ mg/L}$  was found at all sites from VGR up BHW while it remained undetected at VNDS. Dissolved oxygen level in the river water reflects the pollution load it receives at these sites. Likewise the oxygen deficiency of the river water was found to be increased along the length of the river

with highest deficiency detected at VNDS (Figure 2). River water was found to be deficient in oxygen at all sampling sites with lowest oxygen deficiency (1.72 mg/L) detected at KKN and highest (9.6 mg/L) at VNDS.

pH of the river water ranged from  $7.41 \pm 0.02$  (VKPD) to  $8.61 \pm 0.02$  (KKN). Water quality guidelines for drinking water, for propagation of fish and aquatic life and recreational purposes (Table 4) suggest water pH of 6.5-8.5. Maximum pH of  $8.61 \pm 0.02$  detected at KKN was slightly higher than the recommended limits of 6.5-8.5. However, this increase cannot be attributed to pollution load as no point source of pollution can be identified at these sites. Moreover, suitable pH limit of 6.5-9 has been reported by Boyd (2015) for freshwater fish propagation. The pH at all the polluted sites was less than 8 and ranged from  $7.41 \pm 0.02$  at VKPD to  $7.91 \pm 0.04$  at ORB1. Conductivity of the river water ranged from  $329 \pm 3.09$   $\mu\text{S}/\text{cm}$  (at KNS) to  $1072 \pm 1.53$   $\mu\text{S}/\text{cm}$  (at VNDS) and was less than maximum recommended limits of  $<1500$   $\mu\text{S}/\text{cm}$  for fresh water aquatic life and recreational use at all sites. Moreover, water conductivity exhibited gradual increase along the length of the river from KNS up to BHW except at VNDS where it abruptly increased to  $1072 \pm 1.53$   $\mu\text{S}/\text{cm}$  from  $641 \pm 2.08$   $\mu\text{S}/\text{cm}$  detected at VKPD exhibiting 67% increase. Turbidity of the river water was found to vary from  $1.78 \pm 0.02$  NTU (at KNS) to  $41.0 \pm 0.25$  NTU (at ORB2). Water turbidity at all sites was higher than the maximum recommended limit of 5 NTU for drinking water except at KNS (Table 4). However, it was lower than 50 NTU that is suitable turbidity value suggested by Borok (2010) for warm water aquatic life.

### ***3.2. Heavy Metals Analysis***

Significant differences in content of heavy metals were found at various sampling sites ( $P < 0.05$ ). Mn was detected in the river water at all sites except KKN and VK. The maximum suitable limit for Mn suitable for propagation of aquatic life is proposed to be 0.1 mg/L (Table

3). Detected Mn content in river water ranged from  $0.02 \pm 0.00$  mg/L (at KNS) to  $0.19 \pm 0.02$  mg/L (at VNDS). Mn concentration slightly higher than the proposed limit ( $0.12 \pm 0.00$  mg/L) was found at VKPD that increased to  $0.19 \pm 0.02$  mg/L at VNDS exhibiting about 58% increase in its content. At VGR, SPK, VKPD, VNDS and BHW, Mn content exceeded the USEPA's maximum recommended limit of 0.05 mg/L for drinking water. Ni remained undetected at all sites except VNDS. Its detected content ( $0.02 \pm 0.00$  mg/L) at this site was below the maximum proposed limit of 0.05 mg/L for aquatic life, and equal to maximum allowable limit of 0.02 mg/L set for drinking water by WHO as well as Pakistan EPA. Cd was either not detected or remained below the proposed limit of 0.002 mg/L for propagation of aquatic life at all sampling sites except at VKPD where it just reached the maximum limit. Cd content exhibited an abrupt increase of about 233% from VKPU ( $0.0006 \pm 0.0002$  mg/L) to VKPD ( $0.002 \pm 0.00$  mg/L).

Zn was detected only at three sites (VGR, SPK and VKPU) where its concentration remained below the maximum proposed limit for aquatic life and for river water used for drinking or recreational purposes (Table 3). Pb was detected in river water at all sampling sites except at KNS. Its concentration varied from  $0.020 \pm 0.004$  mg/L (at VK) to  $0.072 \pm 0.001$  mg/L (at VNDS). Detected content of Pb at all sites was higher than the maximum recommended limit for fish and aquatic life, recreational use and drinking water as proposed by WHO and US EPA while at VKHP and VNDS, it exceeded the proposed limit for drinking water set by Pakistan EPA. Pb concentration of  $0.034 \pm 0.01$  mg/L in water at KKN showed 41% decrease at VK ( $0.020 \pm 0.004$  mg/L). A gradual increase in lead content was found from VK upto VNDS where river water showed 260% higher Pb content than VK. Following VNDS, a decrease of about 39% was observed in the river water Pb content at BHW.

### **3.3. Discussion**

Freshwater ecosystems that provide multifarious services to the mankind (Speed *et al.*, 2016) are subjected to substantial variation that cause manipulation of ecological structure and

processes (Carpenter *et al.*, 2011). Unique quality characteristics of each natural freshwater reservoir are regulated by multiple natural factors and anthropomorphic activities (Vigil, 2003). The topographical feature (Ye *et al.*, 2009) and climate of the area (Whitehead *et al.*, 2009), abundance and diversity of riparian and aquatic vegetation (Ghermandi *et al.*, 2009) and the morphometric features of the water body (Park *et al.*, 2014) are the major natural conditions affecting the surface water quality. Pollution load from the civilizations in the form of waste water is the most critical one among the anthropomorphic activities (Vigil, 2003).

Preceding research on the surface water quality in Pakistan has revealed a parallel rise in aquatic pollution with increase in industrialization and urbanization (Shakir *et al.*, 2013; Mirza *et al.*, 2012; Tariq *et al.*, 1994). Devastating variation in physico-chemical parameters or addition of poisonous substances cause acute or sublethal toxic effects in the aquatic organisms and lead to altered community balance (Hellowell, 1986). At present River Ravi receives about 1810 cusec polluted urban and industrial effluents through wastewater drains and a number of pumping stations in Lahore. More than 1300 tons of toxic and hazardous waste is being discharged in the river on daily basis (Yasar *et al.*, 2010).

Microbial heterotrophic utilization of non-conservative organic loads lead to dissolved oxygen depletion in the receiving water bodies. The acceleration of this utilization at higher temperature as well as lower dissolved oxygen saturation level of warm water make summer the critical period for the aquatic biota (Kneese, 2015). A minimum of 5 mg/L dissolved oxygen must be present in the water body to sustain healthy growth of fish and other aquatic organisms (Boyd, 2015; WWF, 2007). DO lower than 5 mg/L may lead to a course of physiological reactions in fish as it tries to compensate for low oxygen availability. These compensatory responses can help the healthy fish to survive for a certain period of time, after which, low oxygen concentrations lead to fish mortality (Boyd, 2015). Moreover, low dissolved oxygen stressor also lead to disease outbreak in fish population (Snieszko, 1974). According to the

present study, the pollution load received by River Ravi has lowered its dissolved oxygen to drastic levels at downstream sites of discharge points of waste water drains. The river water quality has been deteriorated to such an extent at Village Nano Dogar (situated at downstream vicinity of discharge points of Hudiarra Drain and Deg Drain) that dissolved oxygen remained undetected at this site. Dissolved oxygen of less than 2.2 mg/L from Village Gopi Roy upto Balloki Headworks has indicated that the river water is not suitable for survival of fish and sensitive aquatic populations at these sites. There is a negative correlation between water pH and heavy metals solubility in river water with the latter increasing with a decrease in pH (Javed and Hayat, 1999). Hydrogen ion concentration remained within the proposed limits in the current study, however, the decreasing pH observed along the river stretch may lead to higher metals solubility in the river water.

Among different groups of toxic chemicals, heavy metals are of special consideration in the fluvial environment due to several aspects. Their conservation in the aquatic medium (Reza and Singh, 2010), accumulation and resuspension from the bottom sediments (Förstner and Wittmann, 1981) and tendency to bioaccumulate and bioamplify through the aquatic food webs (Wei *et al.*, 2016) are the phenomena that put the aquatic and human life at great risk (Förstner and Wittmann, 1981). Their toxicity to aquatic organisms depend on a number of factors like concentration and nature of the metal, presence of other metals, type of organism and physico-chemical qualities of water (Mance, 1990). However the environmental hazard posed by these toxic metals to living forms can be greatly reduced by their adsorption on the river sediments or particulate matter that significantly affects the physical and chemical nature of the metals present in the riverine water thereby influencing their bioavailability (Saeedi *et al.*, 2004, Hart, 1982). According to present study, River Ravi is polluted with heavy metals especially Pb, Mn and Cd whose content higher than safe limits proposed for propagation of fish and aquatic life has been detected at a number of sites where river receives untreated urban

and industrial effluent discharge. In the current study, heavy metals concentration of river water decreased in the following order:  $Mn > Pb > Zn > Ni > Cd$ . A decreasing trend in metals concentration has been observed at Balloki Headworks that may be attributed to the dilution effect caused by relatively unpolluted water of Qadirabad-Balloki Link Canal that joins the river about 15 km ahead of Balloki Headworks. Similar results have been found by Rauf *et al.* (2015), Shakir *et al.* (2013) and Javed and Hayat (1999) who have also reported decreased metal concentration in river water at Balloki Headworks. Metal content in river water detected in the present study was lower than that determined by other investigators at different time periods (Javed and Hayat, 1999; Javed and Mahmood, 2001; Shakir *et al.*, 2013; Tabinda *et al.*, 2013) (Table 6). This variation can be attributed to the temporal variation in the metallic toxicants entering the riverine environment through untreated waste water and their possible adsorption at the river sediments.

#### **4. Conclusion**

Current study has revealed that addition of untreated effluents is alarmingly causing deterioration of aquatic ecosystem of River Ravi particularly at Village Khudpur, Village Nano Dogar and Balloki Headworks. On the basis of its turbidity and Pb content, its water is not suitable for drinking purposes. River water is not able to support fish and aquatic biota at the polluted sites due to its intimidating dissolved oxygen level. Moreover, content of certain heavy metals as detected in present study not only raises questions about healthy growth and physiological conditions of fish and other aquatic life in the river but also indicates an alarming situation for the human population. Aquatic organisms can bioconcentrate the heavy metals up to 1,000,000 times their content detected in water column (USEPA, 1992a, 1992b). The consumption of contaminated fish can expose the human beings to harmful effects of heavy

metals as they are at the top of the food chain and can be the victim of bioaccumulation and biomagnification of pollutants in in edible fish species.

On the basis of current pollution status of River Ravi, following recommendations has been proposed to restore the ecosystem and prevent its further degradation.

1. Establishment of waste water treatment plants to treat the municipal and industrial effluents has become inevitable in order to control further degradation of receiving water reservoirs. Treated water discharged in the inland water bodies must meet the National Environmental Quality Standards (NEQS).
2. To control the presence of toxic substances in industrial effluents, the stringent laws should be implemented. The industrial units that volunteer to install treatment plants at their facilities should be facilitated by the tax rebate or relevant financial privileges such as provision of required technology at low cost rates.
3. Chemical analysis of water in waste water carrying drains should be carried out as a regular activity to monitor the level of toxins and recommend mitigation measures. Formulation of a database based on type and concentration of identified pollutants as determined in periodic analysis will aid in design and operation of treatment plants.
4. Extensive water quality analysis of river water should be carried out at regular intervals along the entire length of the river to reveal the pollution status and health of the aquatic ecosystem so that the appropriate preventive measure may be adopted.
5. The seasonal variation in heavy metals content of River Ravi should be determined to gain further insight about the level of ecosystem deterioration.
6. Heavy metals contents in the body organs of edible fish fauna should be examined regularly as bioindicator of river pollution and to explore the possible threats posed to human health through contaminated fish consumption.

7. Consumer awareness programmes should be initiated to create awareness about the polluted state of the aquatic ecosystem to realize the public about the role it can play for aquatic pollution control.

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**Table 1: Primary drains/ tributaries discharging in river Ravi**

<b>Sr. No.</b>	<b>Primary drain/ Tributary</b>	<b>Length (KM)</b>	<b>Start</b>	<b>Receiving Water Body</b>	<b>Location of Discharge in Receiving Water Body</b>	<b>Daily Discharge (Cusec)</b>
1	Shahdra Drain	4.11	National Bank, Shahdara	River Ravi	Farukh Abad Chowk, Lahore	119.5
2	Shalimar Escape Channel Drain	10.00	Wapda Colony, GT Road, Lahore	River Ravi	Village Khokhar, District Lahore	86.0
3	Upper Chotta Ravi Drain	4.26	China Scheme, Lahore	River Ravi through Shad Bagh sludge carrier	Village Pamba Chugiyani, District Lahore	133.0
4	Lower Chotta Ravi Drain	4.26	Bagh Munshi Ladha, Lahore	River Ravi	Sagian Bridge, Lahore	63.0
5	Sattu Katla Drain	17.68	Fruit & Vegetable Market at Ferozpur Road, Lahore	Hudiara Drain	Valencia Housing Society, Lahore	248.0
6	Cantt Drain	15.39	Jorey Pull (Saddar), Lahore	River Ravi	Shahpur Kanjran, Lahore	208.9
7	Hudiara Drain	98.6	District Gurdaspur India, Enters in Pakistan at Village Lallo, District Lahore	River Ravi	Village Khudpur, District Lahore	>500
8	Deg Drain	256	Indian held Kashmir, Enters in Pakistan at Jangu Chak, District Narowal	River Ravi	Shraqpur, District Sheikhpura	>500

**Table 2: Description of sampling sites**

Sr. No.	Sampling Site	Site Code	Location		Site Description/ Point Pollution
			Longitude (E)	Latitude (N)	Source
1	Kot Nainan, Shakkargarh	KNS	32°08'11.6000	75°15'47.7000"	No traceable point source in immediate vicinity
2	Kala Khatai, Narang	KKN	31°50'38.1000"	74°33'11.5002"	Not traceable point source in immediate vicinity
3	Village Khokhar	VK	31°37'51.9600"	74°19'45.9000"	Upstream site of Shalimar Escape Channel Drain discharge point
4	Old Ravi Bridge	ORB1	31°36'28.3200"	74°17'35.4000"	Downstream site of Shalimar Escape Channel Drain discharge point
5	Old Ravi Bridge	ORB2	31°36'21.6600"	74°17'41.2200"	Downstream site of Shalimar Escape Channel Drain discharge point
6	Village Gopi Rai	VGR	31°29'13.6200"	74°11'06.3600"	Upstream Site of Cantt Drain discharge point
7	Shahpur Kanjra	SPK	31°28'05.5800"	74°10'35.4600"	Downstream site of Cantt Drain discharge point
8	Village Khudpur	VKPU	31°24'26.2000"	74°06'10.1000"	Upstream Site of Hudiara Drain discharge point
9	Village Khudpur	VKPD	31°24'26.2000"	74°05'58.5000"	Downstream site of Hudiara Drain discharge point
10	Village Nano Dogar, Sunder	VNDS	31°22'01.2000"	74°03'04.2000"	Downstream site of Hudiara Drain and Deg Drain discharge points
11	Balloki Headworks	BHW	31°13'09.9000"	73°51'29.7600"	No traceable point source in immediate vicinity

**Table 3: Guidelines for various water quality parameters**

<b>Water Quality Guidelines</b>	<b>Temperature (°C)</b>	<b>DO (mg/L)</b>	<b>pH</b>	<b>Conductivity (µS/cm)</b>	<b>Turbidity (NTU)</b>	<b>Mn (mg/L)</b>	<b>Ni (mg/L)</b>	<b>Zn (mg/L)</b>	<b>Cd (mg/L)</b>	<b>Pb (mg/L)</b>
For fish and aquatic life <sup>(a)</sup>	ΔT<3 than control	> 5	6.5-8.5	1500	-	0.1	0.05	0.086	<0.002	0.01
For recreational purposes <sup>(b)</sup>	ΔT<3 than control	4	6.5-8.5	1500	-	-	-	15	0.01	0.01
Drinking water (Pakistan) <sup>(c)</sup>	-	-	6.5-8.5	-	<5NTU	≤0.5	≤0.02	5	0.01	≤0.05
Drinking water (WHO) <sup>(d)</sup>	-	-	6.5-8.5	-	<5NTU	0.5	0.02	3	0.003	0.01
Drinking water (USEPA) <sup>(e)</sup>	-	-	6.5-8.5	-	-	0.05	-	5	0.005	0.01

a, b: (WWF, 2007), c:(NSDWQ, 2008), d: (WHO, 2004), e: (USEPA, 2009)

**Table 4: Physico-Chemical parameters of river water at various sites (mean (n=3) ± SD)**

Sr. No.	Site Code	Temperature (°C)	pH	DO (mg/L)	Conductivity (μS/cm)	Turbidity (NTU)
1	KNS	16.6 ± 0.10 <sup>d*</sup>	8.20 ± 0.05 <sup>b</sup>	7.30 ± 0.12 <sup>d</sup>	329 ± 3.06 <sup>h</sup>	1.78 ± 0.02 <sup>h</sup>
2	KKN	14.0 ± 0.06 <sup>i</sup>	8.67 ± 0.02 <sup>c</sup>	8.60 ± 0.12 <sup>a</sup>	367 ± 3.61 <sup>f</sup>	9.6 ± 4.96 <sup>f</sup>
3	VK	12.5 ± 0.06 <sup>j</sup>	8.55 ± 0.03 <sup>a</sup>	8.50 ± 0.06 <sup>b</sup>	340 ± 1.00 <sup>g</sup>	5.64 ± 0.02 <sup>g</sup>
4	ORB1	14.0 ± 0.00 <sup>i</sup>	7.93 ± 0.05 <sup>d</sup>	7.80 ± 0.06 <sup>c</sup>	385 ± 0.58 <sup>e</sup>	13.6 ± 0.35 <sup>d,e</sup>
5	ORB2	14.2 ± 0.06 <sup>h</sup>	7.72 ± 0.04 <sup>e</sup>	5.30 ± 0.06 <sup>e</sup>	533 ± 3.06 <sup>d</sup>	41.0 ± 0.25 <sup>a</sup>
6	VGR	18.2 ± 0.00 <sup>b</sup>	7.91 ± 0.04 <sup>d</sup>	1.20 ± 0.00 <sup>g</sup>	535 ± 2.31 <sup>d</sup>	25.5 ± 0.31 <sup>b</sup>
7	SPK	20.5 ± 0.10 <sup>a</sup>	7.77 ± 0.04 <sup>e</sup>	1.30 ± 0.12 <sup>g</sup>	534 ± 2.52 <sup>d</sup>	16.0 ± 0.20 <sup>d</sup>
8	VKPU	15.8 ± 0.00 <sup>g</sup>	7.42 ± 0.02 <sup>h</sup>	2.20 ± 0.06 <sup>f</sup>	639 ± 1.00 <sup>c</sup>	12.2 ± 0.20 <sup>e</sup>
9	VKPD	16.2 ± 0.06 <sup>e</sup>	7.41 ± 0.02 <sup>h</sup>	0.60 ± 0.06 <sup>h</sup>	641 ± 2.08 <sup>c</sup>	19.8 ± 0.40 <sup>c</sup>
10	VNDS	17.2 ± 0.01 <sup>c</sup>	7.52 ± 0.01 <sup>g</sup>	ND <sup>i</sup>	1072 ± 1.53 <sup>a</sup>	24.5 ± 0.36 <sup>b</sup>
11	BHW	16.0 ± 0.06 <sup>f</sup>	7.59 ± 0.01 <sup>f</sup>	2.10 ± 0.06 <sup>f</sup>	852 ± 2.52 <sup>b</sup>	16.3 ± 0.26 <sup>d</sup>

ND: Not Detected, Means with similar superscripts in one column are statistically similar at P > 0.05.

**Table 5: Heavy metals content of river water at various sites (Mean (n=3) ± SD)**

Sr. No.	Site Code	Mn (mg/L)	Zn (mg/L)	Cd (mg/L)	Ni (mg/L)	Pb (mg/L)
1	KNS	0.02 ± 0.00 <sup>e*</sup>	ND <sup>d</sup>	ND <sup>c</sup>	ND b	ND <sup>g</sup>
2	KKN	ND <sup>f</sup>	ND <sup>d</sup>	ND <sup>c</sup>	ND b	0.034 ± 0.01 <sup>d, e</sup>
3	VK	ND <sup>f</sup>	ND <sup>d</sup>	ND <sup>c</sup>	ND b	0.020 ± 0.004 <sup>f</sup>
4	ORB1	0.043 ± 0.01 <sup>d</sup>	ND <sup>d</sup>	ND <sup>c</sup>	ND b	0.031 ± 0.001 <sup>e, f</sup>
5	ORB2	0.020 ± 0.01 <sup>c</sup>	ND <sup>d</sup>	ND <sup>c</sup>	ND b	0.040 ± 0.001 <sup>c, d, e</sup>
6	VGR	0.070 ± 0.01 <sup>c</sup>	0.06 ± 0.03 <sup>d</sup>	ND <sup>a, b</sup>	ND b	0.043 ± 0.01 <sup>c, d, e</sup>
7	SPK	0.073 ± 0.01 <sup>c</sup>	0.04 ± 0.01 <sup>d</sup>	ND <sup>b</sup>	ND b	0.048 ± 0.005 <sup>b, c, d</sup>
8	VKPU	0.012 ± 0.01 <sup>b</sup>	0.07 ± 0.04 <sup>b</sup>	0.0006 ± 0.0002 <sup>a</sup>	ND b	0.050 ± 0.006 <sup>b, c</sup>
9	VKPD	0.12 ± 0.00 <sup>b</sup>	ND <sup>a</sup>	0.002 ± 0.00 <sup>c</sup>	0.02 ± 0.00 <sup>a</sup>	0.060 ± 0.02 <sup>a, b</sup>
10	VNDS	0.19 ± 0.02 <sup>a</sup>	ND <sup>b</sup>	0.0006 ± 0.0002 <sup>c</sup>	ND b	0.072 ± 0.001 <sup>a</sup>
11	BHW	0.12 ± 0.01 <sup>b</sup>	ND <sup>c</sup>	0.0004 ± 0.0003 <sup>c</sup>	ND b	0.044 ± 0.005 <sup>c, d, e</sup>

ND: Not Detected; Means with similar superscripts in one column are statistically similar at P > 0.05.

**Table 6: Comparison of heavy metal content (mg/L) in river Ravi water at Balloki Headworks**

<b>Metal</b>	<b>Present Study</b>	<b>Shakir <i>et al.</i> (2013)</b>	<b>Tabinda <i>et al.</i> (2013)</b>	<b>Javed and Mahmood (2001)</b>
Pb (mg/L)	0.044	1.34	-	0.37
Cd (mg/L)	0.0004	0.13	-	-
Ni (mg/L)	ND	1.54	0.04	0.56
Mn (mg/L)	0.12	6.43	-	0.94
Zn (mg/L)	ND	29.12	0.172	0.63

ND: Not detected

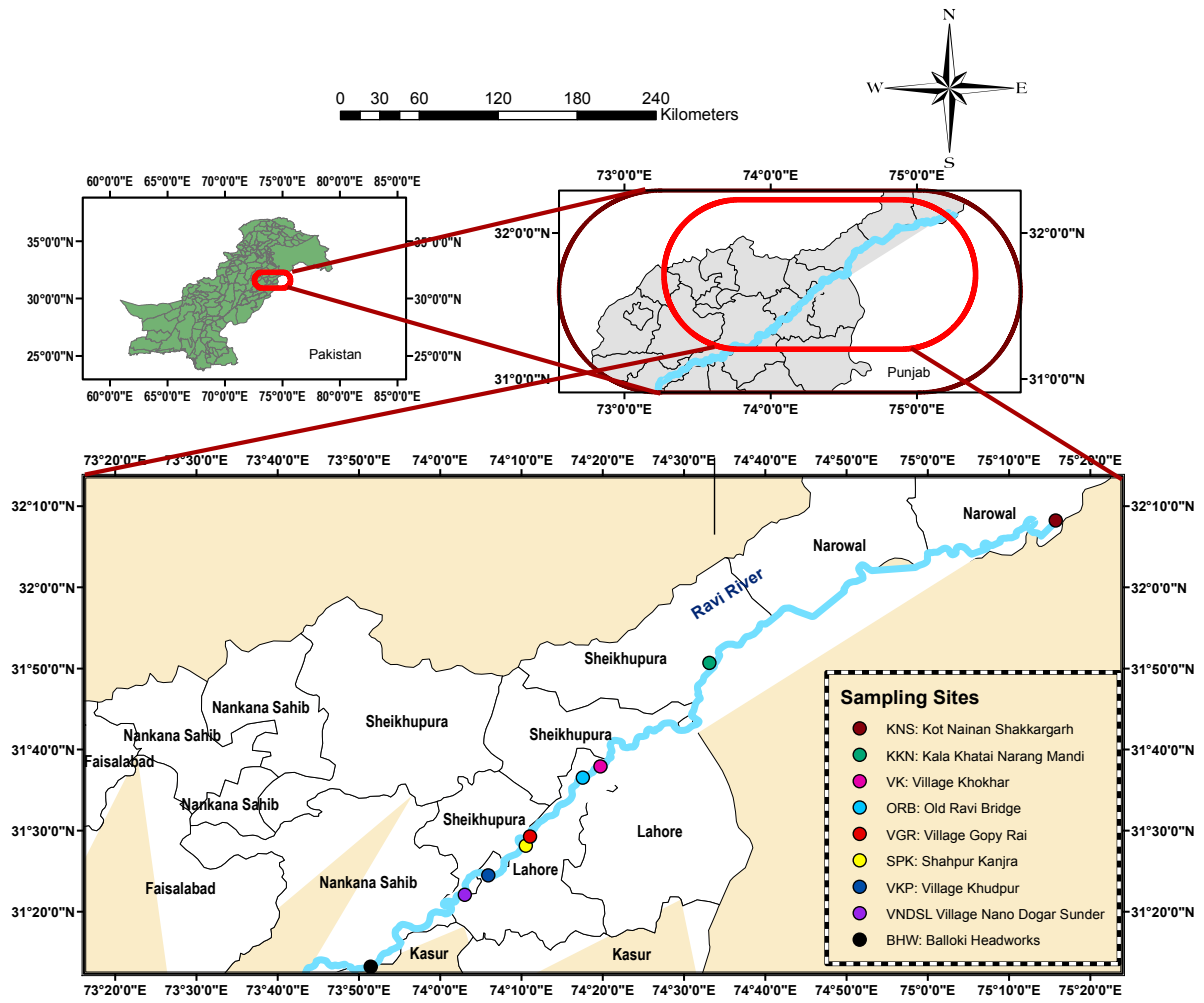


Figure 1: Map of sampling sites at river Ravi

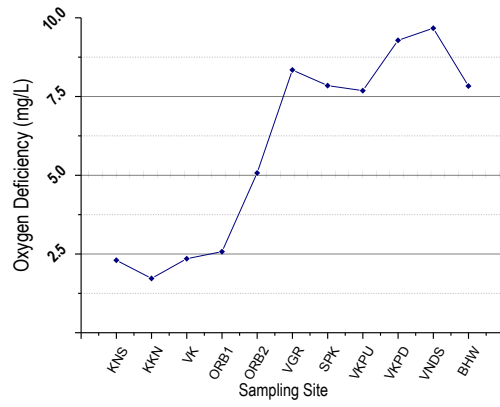


Figure 2: Oxygen deficiency in river Ravi at various sites