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Quantification and Seasonal Variation of Transboundary Pollution and Water Flow in the Streams of Central Punjab, Pakistan

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Abstract

Transboundary pollution and water harvesting from the upstream countries is a burning issue of today. In context of India-Pakistan situation there is a dire need to evaluate the temporal changes in quantity and quality of water. This study was aimed to determine temporal variation in flow rate and pollution level of the four trans boundary streams (Hudiara, Deg, Aik and Basanta). Water samples were collected at the entry points and were analyzed for different parameters. Hudiara showed BOD_5 (150 mg/L), high fecal contamination level (> 1600 MPN/100 ml) and total suspended solids (400 mg/L) whereas cooper contamination was also high (0.1238mg/l). These high pollution levels can directly affect aquatic and human life by entering into the food chain through agriculture as well as livestock. There was a significant temporal variation in the flows of the streams as flow rate of Hudiara was maximum in spring season whereas for Aik, it was highest (582 cusecs) in summer. Basanta showed highest flow rate (1286 cusecs) in winter season and minimum in spring (<200 cusecs) while complete unavailability of water in Deg during spring and summers showed water harvesting of these streams on the upstream side.

Key Words: Transboundary pollution; flow rate; organic load; fecal contamination; heavy metals.

1. Introduction

Around the globe, there are 263 international rivers which constitute 60% of the global fresh water [1]. Almost 40% of the river basins around the world are trans boundary water ways shared by two or more countries worldwide [2]. Most of these rivers have many trans boundary issues that may result in international disputes. The rivers that may cause disputes spread over five continents of the world and most of them are in Asia and Africa where developing countries are located and these countries have very few international treaties on the development and utilization of trans boundary water signed between the states.

Many problems are associated with trans boundary water. Instability in availability of water is a major problem. The availability of water is greatly affected by the conditions of the surrounding water resources. Most of the international rivers were formed by melting glaciers, which were affected by global climate change. Mostly the East Asian region is subject to the monsoon climate, the warm and wet winds in spring and summer times bring most of the annual precipitation [3]. Instability of water is also brought forth from the social aspect, including population growth, immigration and trans-boundary management of water resources [1]. Demand for water is increasing day by day due to growing population, increased economic activity and industrialization. Quality of rivers is seriously affected due to the discharge of untreated industrial and domestic waste water through number of wastewater pumping stations [4]. Aquatic species are also very much affected by the quality of water and it is a serious threat to the aquatic ecosystem [5]. This also effect other activities as thick mats of the plant reduce oxygen content, degrading water quality for aquatic species and curtail recreational activity such as boating, fishing and water intakes for irrigation. Livestock may be affected by poor quality of water causing death, sickness or impaired growth. This is commonly prevailing in most of the developing countries of South Asia like India, Nepal, Bangladesh and Pakistan [6]. The countries like Afghanistan, India, Korea, Iran and Pakistan are all downstream countries and are listed as highly water stressed countries in the future years. [7]

Pakistan also experiences water pollution problems as it receives wastewater from its neighboring country India. It also shares most of its water resources with India. Major River, river Indus enters into Pakistan from India. In various watersheds in Pakistan, the past trends of river flows are quite different from each other due to specific climate changes occurred in the past [8]. Transboundary water pollution is the serious problem of Pakistan. Many streams are entering into Pakistan from the boundary lines. The streams entering in central Punjab are Hudiara, Deg, Aik and Basanta. The objectives of the study were to determine the seasonal variation in water flow for four trans-boundary streams named Hudiara, Deg, Aik and Basanta, to check the extent of pollution and temporal variation in these streams and to quantify the inorganic and organic loading coming from India to Pakistan.

2. Materials and Methods

2.1 Description of study area

Hudiara enters into Pakistan from Atari Border near village Lallo. It is a natural storm water drain which carries sewage and untreated industrial waste from India. After travelling through 63 kilometers in Lahore, it joins river Ravi. Deg enters into Pakistan near Zafarwal. It travels through different areas of Sialkot and Sheikhupura and joins River Ravi near Sharqpur. Aik enters into Pakistan near Sialkot. It travels through different areas of Sialkot and Gujranwala and joins River Chenab near Wazirabad. Basanta enters into Pakistan near Shakargarh (Fig-1).

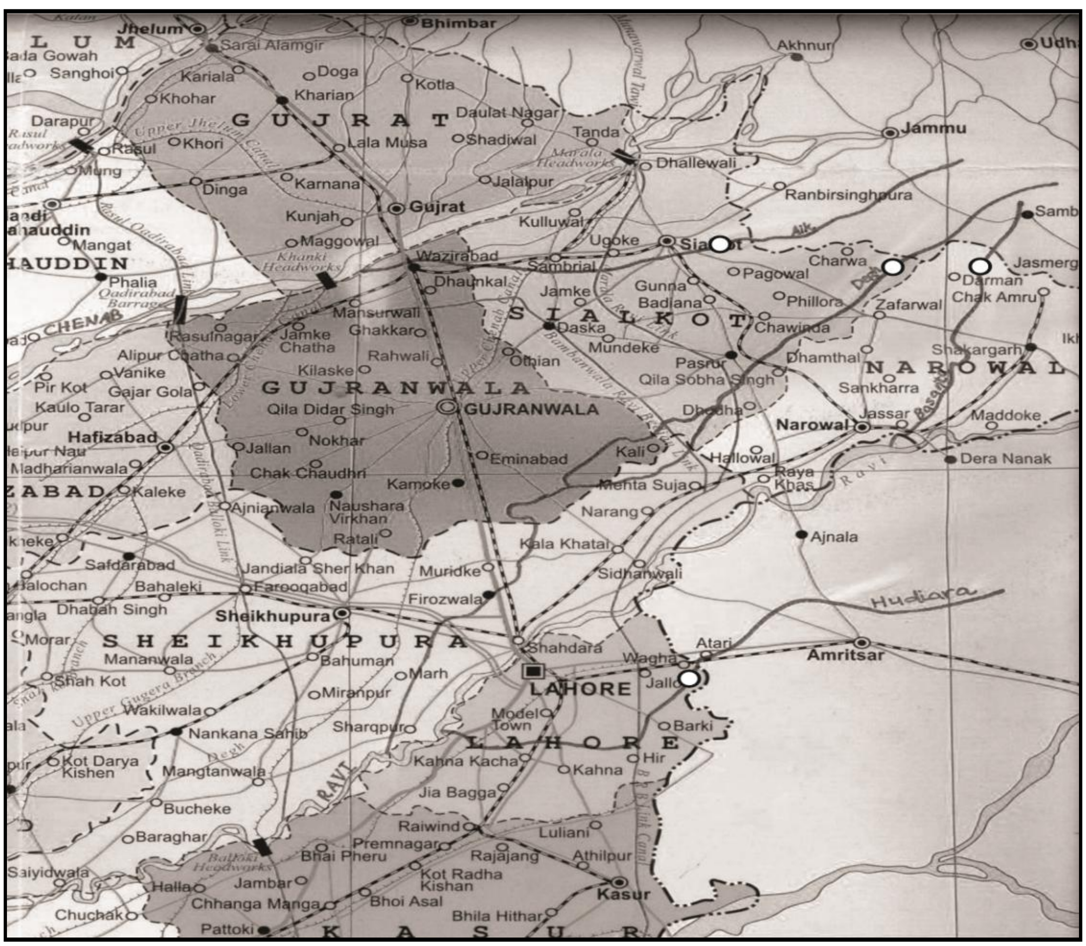

Fig. 1 Map showing the transboundary streams of Central Punjab, Pakistan

2.2 Water Sampling

Water samples were collected from the above four streams entering in Central Punjab. Samples were collected from the border side, at their entering point to Pakistan.

2.3 Sampling Frequency

Three samplings were done from December 2010 to June 2011. Water samples were collected during winter, spring and summer. Five samples were collected from five different points of each stream i.e. grab sampling was done. Statistical analysis was also performed, Average and Range was calculated.

2.4 Flow Rate and Organic Load Calculation

Flow of the stream was calculated by Bernoulli's Equation:

$$Q = A.v \tag{1}$$

Here,

Q = Water Discharge (m^3/s)
A = Area of cross section (m^2)
V = Velocity of water (m/s)

For calculating area, width and depth of the stream was measured with the help of measuring tape from the bridge. Velocity of flow was measured by taking a known distance and calculating the time for a floating thermopol sheet. Organic Load (kg/y) of the stream was calculated by taking the product of Volume of water (m^3) and Concentration of pollutant (kg/m^3). Organic load was calculated in (kg/y).

2.5 Analytical tests

Parameters like temperature, pH, electrical conductivity (EC), turbidity and dissolved oxygen (DO) were determined by digital meters (metric methods), as described by APHA (1998). 5-days biochemical oxygen demand (BOD_5) was determined according to APHA (1998) standard method (5210b-5 day BOD test). Chemical Oxygen Demand (COD) was determined by the standard method of APHA (1998) (5220C Closed Reflux Titrimetric Method). Sulphate, orthophosphate and nitrate were estimated by using Spectrophotometer (VIS 721) in accordance with APHA (1998) standard methods. Turbidimetric method, ascorbic acid method and colorimetric method were used for the estimation of sulphate, orthophosphate and nitrate respectively. Chlorides were determined by the titration method as described by APHA (1998). Heavy metals; chromium (Cr), copper (Cu) and lead (Pb) were detected by using Atomic Absorption Spectroscopy (FAAS, Shimadzu AA-7000F) and for the estimation of microbial contamination in the samples, fecal coliforms were determined by following APHA (1998) standard method (9221 C). MPN (Most Probable Number) Method includes the repetition of five samples for each dilution of 0.1,1 and 10ml and it calculated the probable number of fecal coliforms at confidence limit of 95%.

3. Results and Discussion

3.1 Physico-chemical analysis

The results for different physico-chemical parameters are shown in Table 1. Temperature of all the streams varied with the season. From winter to summer season the temperature varied from 18 to 33^{o}C. Temperature affects the metabolic rate and the reproductive activities of the aquatic life. By the rise in temperature, the metabolic activity increases and the demand of oxygen for fish's life also increase. Water temperature rises with respect to the season or when the streamside vegetation is removed. The solubility of many toxic and nutritive chemicals changes with the change in temperature and this effect the availability of substances to the aquatic organisms.

The pH of all the streams in all seasons was neutral and was within the standards except the sample of Hudiara in winter season which was slightly acidic, pH range of 7-8.56 in the stream indicate that this limit is in compliance with WHO Standards. Hudiara Drain carries industrial effluents along with sewage and rain water due to low flows in winter pH is in acidic range which gets neutralized due to high flows in summer and rainy season.

Electrical conductivity of water represents the concentration of total dissolved ions. According to Ntengwe (2005) conductivity 500 µS/cm is an indicator of pollution. The increase in the conductivity value of stream water showed that there was a source of dissolved ions in the vicinity. This also showed that the water is polluted or of low quality. The EC of Hudiara was in the range of 800-900 µS/cm higher than the EC for Deg, Aik and Basanta it was less than 500 µS/cm. The EC of Aik

Table 1: Seasonal variation of physio-chemical parameters in the streams

Parameters	HUDIARA			DEG			AIK			BASANTA		
	Winter	Spring	Summer	Winter	Spring	Summer	Winter	Spring	Summer	Winter	Spring	Summer
Temperature (°C)	17.0-19.3* (18.0)**	25.0-25.7 (25.4)	29.5-31.1 (30.32)	8.9-9.5 (9.08)			9.9-11.1 (10.6)	29.9-30.4 (30.3)	32.9-33.5 (33.22)	9.5-10.1 (9.6)	27.2-27.8 (27.6)	32.5-33.7 (33.20)
pH	6.5-6.7 (6.6)	7.2-7.3 (7.2)	7.2-7.3 (7.3)	7.6-7.3 (7.6)			7.3-7.5 (7.4)	8.0-8.3 (8.2)	7.6-7.6 (7.6)	7.1-7.7 (7.6)	8.3-8.7 (8.5)	7.8-7.9 (7.8)
EC (µS/cm)	815-820 (817)	847-869 (854)	865-1081 (985)	298-304 (301.2)			426-430 (428.2)	545-561 (552.4)	143-147 (145.78)	379-395 (385.8)	400-429 (412.4)	194-197 (195.68)
Turbidity (NTU)	232-258 (250)	115-142 (112)	110-136 (117)	10-12 (11)			10-12 (11)	13-15 (14)	97-107 (102)	7-17 (10)	6-10 (8.)	17-34 (27.31)
DO (mg/L)	0.37-1.98 (1.10)	0.48-0.91 (0.73)	0.26-0.41 (0.39)	10.6-10.6 (10.64)			10.59-10.72 (10.64)	8.10-8.46 (8.31)	6.72-7.23 (7.03)	10.63-10.67 (10.65)	8.49-8.57 (8.52)	6.51-6.94 (6.73)
BOD_5 (mg/L)	140-160 (150)	140-180 (160)	80-120 (98.00)	N.D.			N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
COD (mg/L)	170-196 (180)	211-320 (277)	274-292 (286.00)	N.D.			N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
TDS (mg/L)	489-492 (490.20)	508-521 (512.46)	519-648 (591.23)	178-182 (180.72)	Water Not available		255-258 (256.92)	327-336 (331.44)	85-88 (87.47)	227-237 (231.48)	240-257 (247.44)	116-118 (117.41)
TSS (mg/L)	234-510 (403)	128-189 (156)	311-624 (431.00)	20-71 (52.60)			153-273 (214.20)	109-219 (178)	289-485 (355.00)	90-260 (113.87)	87-184 (138)	283-334 (309.00)
VSS (mg/L)	2.87-5.91 (3.53)	2.46-2.52 (2.50)	4.54-8.93 (6.90)	10.1-10.2 (10.15)			10.2-10.5 (10.36)	11.9-12.3 (12.21)	9.4-13.6 (11.12)	9.9-10.5 (10.22)	11.8-13.3 (12.86)	9.4-12.2 (10.91)
Sulphate (mg/L)	52.7-72.5 (62.11)	75.1-82.4 (77.28)	35.6-58.3 (43.94)	1.81-2.57 (2.52)			3.7-5.2 (4.35)	38.6-45.4 (41.80)	1.6-1.9 (1.82)	3.9-4.6 (4.25)	44.6-47.9 (46.11)	1.5-2.1 (1.50)
Orthophosphate (mg/L)	13.2-13.7 (13.5)	9.5-12.6 (10.1)	13.2-14.3 (13.6)	0.4-1.0 (0.6)			0.6-0.9 (0.7)	1.9-2.4 (2.1)	1.0-1.1 (1.06)	0.9-1.0 (0.9)	1.4-3.0 (2.3)	2.1-2.7 (2.4)
Nitrate-N (mg/L)	0.2-1.8 (1.5)	11.0-21.9 (15.4)	2.3-3.0 (2.6)	3.5-10.9 (16.5)			2.7-15.8 (5.8)	4.0-20.2 (9.1)	16.3-22.0 (16.7)	3.2-4.2 (3.7)	15.5-17.1 (14.4)	4.2-16.7 (8.7)
Chloride (mg/L)	129.9-164.7 (140.1)	119.2-156. (136.4)	108-146 (123.3)	29.1-33.3 (31.9)			40.4-44.7 (42.3)	48.2-55.3 (52.8)	38.3-51.1 (41.7)	39.7-51.1 (45.5)	50.4-61.0 (56.0)	51.1-78.1 (64.7)

*Range, **Average

and Basanta in summer season dropped to 145.78 and 195.68 µS/cm respectively, which is due to the rainwater dilution. Turbidity in the samples indicates that suspended matter, such as silt, clay, organic particles and other microscopic organisms are present in the sample. High turbidity shows the bad water quality while low turbidity shows good water quality. The acceptable level of turbidity is 15 NTU [10]. The turbidity of Hudiara Drain in all the three season was very high within the range of 112 to 250 NTU as compared to Aik and Basanta. According to standards for streams [11], the DO of water should not be less than 5 mg/L. In the streams, rise in temperature causes decrease in DO. As the DO level decreases, the whole aquatic life gets disturbed. According to standards for stream water [11] the BOD_5 and COD of water should not be greater than 10 mg/L and 30 mg/L respectively. In Hudiara, the BOD_5 was within the range of 98 to 160 mg/L and COD ranged between 180 to 286 mg/L which showed that the water was highly polluted as it is very harmful to the aquatic life. BOD_5 and COD of the remaining three streams were not obtained which shows less pollution in the streams. According to (Iqbal *et al.*, 2011) [12], the BOD and COD values of Hudiara were 120-140 mg/l and 336 mg/l respectively. Total dissolved solids originate from the natural sources, industrial waste discharge and urban run-off. High levels of TDS represents that the water is of poor quality [10]. High values of TSS in water is harmful to humans and is also destroys the aquatic life [13]. The contributors to elevated levels of orthophosphates in surface waters is domestic wastewater which mainly contains detergents, fertilizer run off and industrial effluents and the high levels of orthophosphates indicates that pollution is present[13]. The standard of Orthophosphate for stream water is less than 0.1 mg/L but in all streams and in all seasons, it is higher than the standard value.

3.2 Cations and heavy metal analysis

The seasonal variation of cations and heavy metals in the streams is shown in Table 2. According to the Standards for stream water [11] copper must be 0.05 mg/L,for chromium, it is 0.07 mg/L and for lead it is 0.1mg/L. The concentration of copper (0.05-0.1mg/L) in all three streams in all seasons was above the defined standard limit as the highest level of copper showed by Hudiara drain during winter season was 0.123 mg/L, whereas the concentration of chromium was within the acceptable range. The highest level of lead showed by Hudiara drain during winter season was 0.154 mg/L and Basanta during summer season was 0.114mg/L. Cr and Cd content can be attributed to the effluents of tanneries, textile dying and other industrial units of variegated nature. The main sources of lead include paint and coating industries and lead batteries manufacturing units nearby industrial areas [14]. In another study [15] of Hudiara drain metal contamination in Hudiara drain was observed on three sample points in 12 months. The values for Cd were 0.037, 0.037 and 0.042mg/l respectively on 3 sites. The values of Cr was <0.1mg/l on all sites. The values of Cu were 0.270, 0.19 and 0.180mg/l. The values were below the limits of NEQS. But The Cd and Cu values were above the limits of irrigation water. The values of Cu of [15] were in line with the present study as in both studies values were above the standard limit.

3.3 Fecal contamination of different streams in different seasons

Fecal contamination in the streams was high in all the seasons. In Hudiara fecal contamination in all the three seasons was high and it was more than 1600 per 100 ml. (Fig-2a) Hudiara is polluted as it carries domestic waste with it [16]. Fecal contamination at Deg in winter season was less as the water source was glacier and snow melting. In Aik, fecal contamination was less in winter season and was nearly 500 per 100 ml whereas in spring and summer season its value was high as more than 1600 per 100 ml. (Fig-2b). The fecal contamination in Basanta was 50 per 100 ml in winter season and the contamination in spring and summer season was 150 per 100 ml and 1600 per 100 ml (Fig-2c). The variation in the fecal count during spring and summer season may be owed to the favorable temperature for re-growth and reproduction of pathogens. While in case of Hudiara this pathogen count remains constant for all the seasons because of the sewage flows in the Hudiara drain which maintained the similar and favorable conditions for the growth of pathogens [17].

Table 2: Seasonal variation of cations and heavy metals in the streams

Parameters	HUDIARA			DEG			AIK			BASANTA		
	Winter	Spring	Summer	Winter	Spring	Summer	Winter	Spring	Summer	Winter	Spring	Summer
Na^+ (mg/L)	164-191* (178.2)**	81-166 (120.16)	88.5-105.4 (96.9)	33-66 (40.2)	Water not available	Water not available	49-62 (53)	38.6-40.4 (39.18)	9.05-10.76 (9.73)	43-63 (52.0)	29.5-33.0 (31.32)	29.5-34.5 (31.5)
K^+ (mg/L)	31-36 (33.60)	10-21 (15.7)	13.9-17.7 (14.81)	3.0-3.2 (3.12)			6.0-7.0 (6.32)	11.4-12.1 (11.84)	3.6-4.4 (4.16)	3.1-3.8 (3.51)	4.9-5.4 (5.08)	3.2-5.7 (4.84)
Chromium (mg/L)	0.047-0.048 (0.047)	0.043-0.044 (0.043)	0.039-0.039 (0.039)	0.019-0.019 (0.019)			0.031-0.031 (0.031)	0.031-0.031 (0.031)	0.023-0.023 (0.023)	0.023-0.024 (0.023)	0.035-0.035 (0.035)	0.042-0.043 (0.043)
Copper (mg/L)	0.123-0.124 (0.123)	0.067-0.068 (0.067)	0.060-0.061 (0.060)	0.060-0.061 (0.060)			0.050-0.051 (0.050)	0.056-0.057 (0.056)	0.061-0.062 (0.061)	0.051-0.052 (0.051)	0.059-0.060 (0.059)	0.066-0.068 (0.067)
Lead (mg/L)	BDL	0.153-0.155 (0.154)	0.090-0.091 (0.091)	BDL			BDL	0.058-0.059 (0.059)	0.058-0.060 (0.059)	0.042-0.044 (0.043)	0.090-0.091 (0.090)	0.113-0.114 (0.114)

*Range, **Average, BDL (Below Detection Limit)

Fecal Streptococci and Escherichia coli, present in intestinal tract of humans, are excreted in large numbers in faeces of humans and other warm blooded animals. The fecal matter is potentially dangerous as it causes diseases like diarrhea, cholera, dysentery and skin, eye, ear, nose and throat infections.

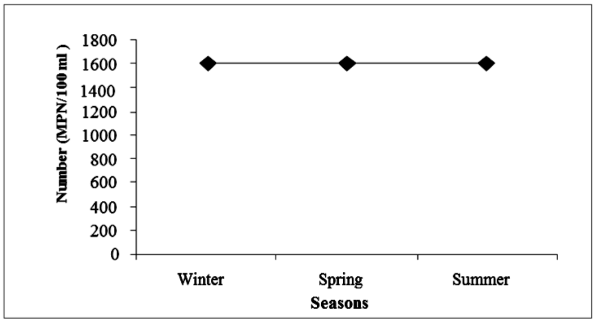

Fig 2a Seasonal variation of Fecal Contamination at Hudiara

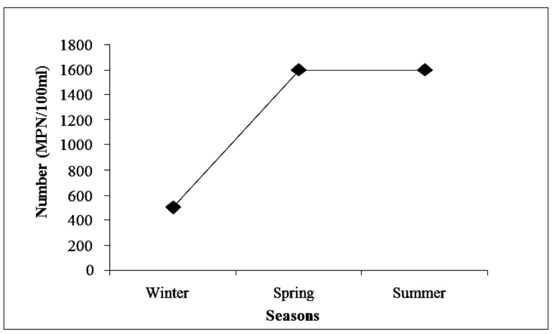

Fig 2b Seasonal variation of Fecal Contamination at Aik

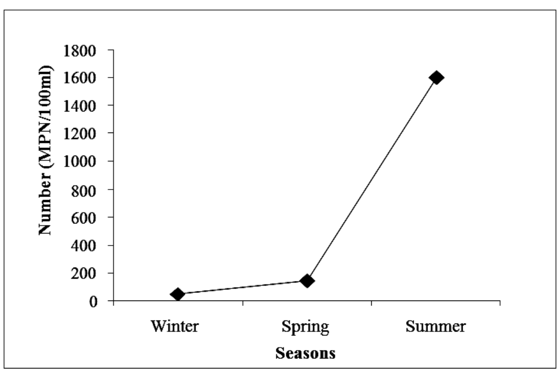

Fig 2c Seasonal variation of Fecal Contamination at Basanta

3.4 Flow rate of streams in different seasons

There was significant temporal variation in flows of the streams. In Hudiara, the flow rate increased in spring season as 443 cusecs whereas in winter and summer season, its values were 343cusecs and 306 cusecs (Fig-3a) and the average flow rate was 3.25x $10^8 m^3/y$. In winter season, flow rate of Deg was 7.80x $10^8 m^3/y$. In spring and summer season water was not available in the stream. It was due to the reason that India either has stopped the water flow towards Pakistan or using it in excess quantity for irrigation purposes or conserving it for dams and reservoirs. Flow rate of Aik was highest in summer season and it has the value of 582 cusecs whereas the flow rate in winter and spring season was 460 cusecs and 151 cusecs respectively (Fig-3b) and the average flow rate was $3.55x10^8 m^3/y$. The highest flow rate in all four streams was of Basanta having the flow rate of 1287 cusecs in winter season whereas in spring and summer season its flow rate was 172 cusecs and 242 cusecs respectively (Fig-3c) and the average flow rate was $5.06x10^8$. Hudiara is a natural water stream where as for Deg, Aik and Basanta the source of water is glaciers and snow melting. The decrease in flow rate of Aik and Basanta in spring and summer season is due to the reason that India stops the supply of water towards Pakistan.

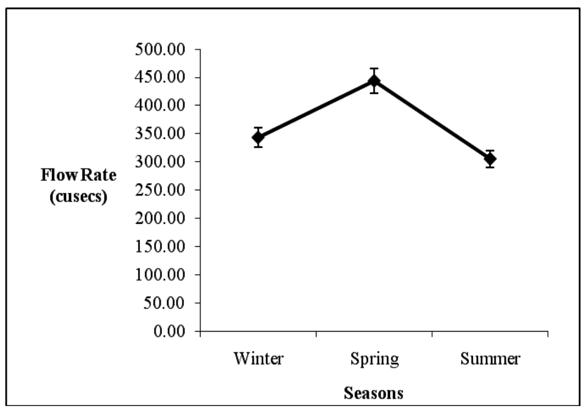

Fig 3a Seasonal variation of flow rate at Hudiara

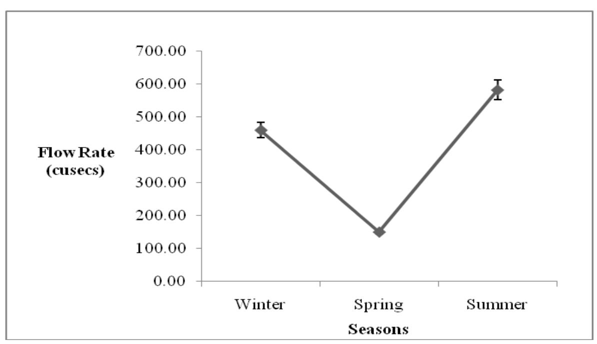

Fig 3b Seasonal variation of flow rate at Aik

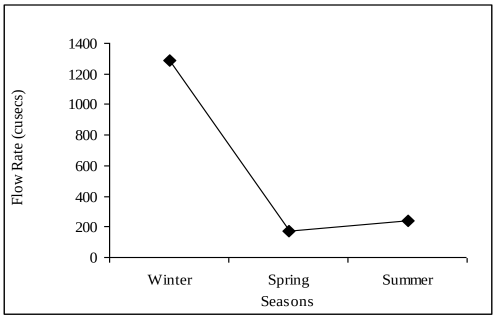

Fig 3c Seasonal variation of flow rate at Basanta

3.5 Seasonal variation in organic load of Hudiara Drain

BOD load of Hudiara was highest in spring season and its value was 63293 tons/yr whereas in winter and summer season, BOD load of Hudiara was 45727 tons/yr and 21760 tons/yr respectively (Fig-4a). COD load of Hudiara was also highest in spring season and its value was 109587.60 tons/yr whereas in winter and summer season, COD load of Hudiara was 55188 tons/yr and 77989 tons/yr respectively (Fig-4b). BOD and COD load in Hudiara showed that there were organic pollutants in the stream. Organic load of Deg, Aik and Basanta was not calculated as BOD and COD was zero in these streams which shows that there is very less organic pollutants present in these streams. The contribution of pollution load of Hudiara to the River Ravi is very harmful to the soil and for the irrigation purposes [15]

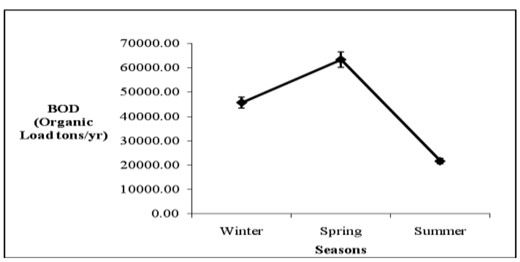

Fig 4a Seasonal variation of BOD load at Hudiara

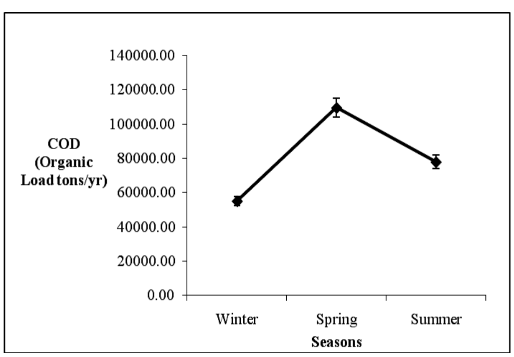

Fig 4b Seasonal variation of COD load at Hudiara

4. Cost Effective Restoration of Stream

Transboundary stream restoration is responsibility of both the countries India and Pakistan. The Indian government may be required to honour the bilateral Indus water treaty signed between India and Pakistan in 1960. According to its article 4, section 10, each party declares its intention to prevent, as far as possible, undue pollution of the waters of the Rivers. Wetlands, constructed wetlands and settling ponds could be the cost effective solution for the treatment of polluted stream water.

Wetland treatment requires large area, however to reduce the footprint and enhance the treatability [18]. The subsurface flow constructed wetland could be a better option for higher rates of pollutant removal per unit of land than the surface flow constructed wetland [19]. However SFCW, have advantage of both aerobic and anaerobic treatment zones and also of filtration and adsorption through the porous media of soil, sand, rocks, and gravel .Co-existence of aerobic and anaerobic zones are necessary for nitrification and denitrification [20] while sorption and precipitation through porous media removes the particulate and dissolved phosphorus [21]. Many multi-stage wetland systems combining SFCW and SSFCW in series are now being used to remove highly contaminated nitrogen in streams and rivers [22]. In northeastern Illinois Chicago, Polluted agriculture runoff was treated through the four constructed wetlands on the Des laines River [23]. In the central western Korea polluted water of Kyungan Stream was treated through the system of two wetlands, upper layer under aerobic condition in the first wetland and lower layer under anoxic condition in the second wetland by circulating the water flows .Upper layer treats the COD and produces oxidized nitrogen via nitrification which eliminates in the lower layer of the second wetland by denitrification. The SS reduction occurs in the lower layers, in the front of each wetland, by filtration and sedimentation while removal of the particulate and soluble phosphorus in this system relates to the adsorption and/or the precipitation.

Although the constructed wetland (CW) system could be the single most appropriate and cost-effective treatment choice [24], However For the acceptable results of the most polluted urbanized streams like Don River in Toronto, Ontario, Upstream controls, including source reduction of contaminant inputs, are necessary as essential component of such constructed wetland projects [25]. It is recommended that after restoration of the Hudiara drain stream, strict enforcements of NEQS will be required to stop industrial units discharging untreated effluent into the drain.

5. Conclusion

All the four trans-boundary streams, Hudiara, Deg, Aik and Basanta, are flowing from India to Pakistan, Hudiara is the most polluted one as it carries industrial and sewage waste across the border whereas Deg, Aik and Basanta are less polluted as their water source is rain and snow melting. The average BOD_5 of Hudiara (98 -160 mg/L) was higher than standards whereas TDS of Hudiara were also very high (450 – 650 mg/L) as compared to other. Flow rate of Hudiara was highest (443 cusecs) in spring season while for Aik, it was high (582 cusecs) in summer season. On contrary, Basanta had the highest flow rate (1287 cusecs) in winter season. Unavailability of water in Deg showed that water harvesting of the streams varied in different seasons on the upstream side. Organic load of BOD and COD in Hudiara Drain was very high which showed high pollution level; maximum BOD load was 63293 tons/yr whereas the maximum COD load was 109587 tons/yr.

6. Recommendations

Constructed wetlands preferably in stream wetlands could be the cost effective solution for the treatment of polluted stream waters. Construction points of these wetland systems could be at the entry point of the streams in Pakistan, in the mid way of the streams as per availability of the land and at the confluence points of the rivers

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