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APPLICATION OF MULTIPLE LINEAR REGRESSION MODELS TO DETERMINE MICROBIAL WATER QUALITY CHANGES ACROSS HIGHLY DISTURBED LOWER HIMALAYAN STREAM AND THE GROUNDWATER SOURCES IN THE PROXIMITY, JAMMU (INDIA)

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ABSTRACT

The study investigated the microbial quality of Behlol stream- a Lower Himalayan stream and groundwater sources in its proximity areas in terms of MPN index/100 ml for total and faecal coliforms and application of statistical tools like correlation and linear regression to deduce beneficial parametric associations for easy interpretation of the data. MPN/100 ml index analysis revealed severe microbial contamination at the surface water sampling site S2 and the nearby groundwater sites G2 and G3 indicating the impact of surface water pollution on the groundwater sources. The authors observed that the rate of groundwater contamination decreased with the increase in distance from the surface water sites suggesting that the groundwater pollution is mainly contributed by the release of combined industrial and sewage wastes into the Behlol stream. The study also identified bacterial genera like *Escherichia, Enterobacter, Klebsiella, Citrobacter, Proteus, Salmonella,* and *Shigella*, belonging to the family Enterobacteriaceae via colony cultural characteristics and biochemical tests. A significant relationship obtained from an orderly linear correlation and regression in this study provides a better alternative for a systematic study over the conventional techniques; reducing the quantum of analysis and can therefore be treated as a rapid method for water quality monitoring.

KEY WORDS : Himalayan stream, Groundwater, Microbial quality, MPN/100ml, Correlation, Multiple regression.

INTRODUCTION

The ubiquitous nature and remarkable ability of microorganisms to thrive in every possible environment that is hospitable for life has ensured their presence in almost all ecosystems of the world. Aquatic environments serve as a natural habitat for a wide array of microorganisms, but the pathogenic forms among these are considered etiological agents of infectious diseases; particularly in humans (Baker-Austin *et al.*, 2006; Rodrigues and Cunha, 2017) and may be used as an indicator for determining the suitability of water for intended usage (Okpokwasili and Akujobi, 1996; Some *et al.*, 2021). The microbiological examination of water and bacteriological information has assumed substantial significance in the case of pollution studies as well as in limnological studies. Microorganisms are transported to water sources from the air, soil, sewage, and organic waste present in industrial effluents, dead plants, and animals in addition to indigenous microbiota, which resume growth and multiplication under favourable environmental conditions in the aquatic environment. Regardless of all the contamination sources, sewage/ wastewaters continue to be the leading source of microbial contamination, specifically faecal contamination. For estimating the health risks associated with faecal contamination in the aquatic environment, it is vital to determine its source and identify probable measures to remediate polluted waterways (Malakoff, 2002; Rodrigues and Cunha, 2017).

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Surface water bodies are presumed to be more vulnerable to faecal contamination compared to groundwater reservoirs probably due to a lack of natural protection or filtration unit made of the soil layer, and short distances between the source of contamination and water extraction. The microbiological quality of shallow groundwater sources found in urban areas often shows marked seasonal variations with significant deterioration during the onset of the wet season (Howard *et al.,* 2003; Adesaki *et al.*, 2020). Various literature studies from India and abroad reported microbial contamination of surface and groundwater resources, rendering its usage unfit for consumption and other allied uses (Kanyerere *et al.,* 2012; Fuhrimann *et al.,* 2016; Yousefi *et al.*, 2018; Osiemo *et al.*, 2019). Reports of Shafi *et al.* (2013) from Manasbal lake of Kashmir; Dutta (2014) from Devak stream, J&K, and Mahajan *et al.*(2018) from Jammu have confirmed faecal pollution of water sources of J&K.

Drinking water contaminated with pathogenic microbes can transmit diseases such as cholera, typhoid, diarrhoea, dysentery, and hepatitis, and improperly managed water can cause varied health risks in humans. According to WHO (2019),785 million people lack basic drinking-water facilities, including 144 million people are dependent on untreated surface water and at least 2 billion people use drinking water sources contaminated with faeces. Contaminated drinking water is estimated to cause 4.85 lakh diarrhoeal deaths each year. The lack of safe drinking water and adequate sanitation measures results in the proliferation of several pathogens in water sources leading to waterborne diseases such as cholera, dysentery, salmonellosis, and typhoid which claim millions of lives in developing countries annually (Zamxaka *et al.,* 2004). Diarrhoea is reported to be the single largest cause of ill health and death among children, resulting from inadequate water quality along with poor sanitation practices and hygiene (World Bank Group report, 2017). Health statistics of UT of J&K, India indicated 32,0401 acute diarrhoeal cases/ infections; 32,731 infections of Enteric fever/ Typhoid; and 3,165 cases of viral hepatitis from Jammu division alone during the assessment period January to December 2017 (National Health Profile, 2018).

Thus, from a health viewpoint, it becomes imperative to critically monitor the microbial quality of water in order to highlight the poor quality of water and associated health risks, and to provide the impetus for sustained government intervention for proper management of such water sources (Loucks and Beek, 2017). The present study was designed to evaluate the extent of microbial pollution in the Behlol stream and to evaluate its impact on groundwater resources in the immediate vicinity of the stream, by assessing their water quality in terms of microbial contamination. Since most of the study area falls close to the Kandi belt (arid zone) with the scanty provision of non-polluted surface water sources for various domestic and other purposes, inhabitants of the area mostly rely on groundwater resources for consumption purposes, which in turn necessitated the quality evaluation of such sources for ensuring the wellbeing of users.

MATERIALS AND METHODS

Study area and sampling locations

Behlol Stream is an important tributary of river Tawi in the lower Himalayan region, lying between $74^0 50'$ E and $32^0 40'$ N at an elevation of 304.8 meters amsl. Behlol stream originates through a natural spring near village Purmandal at the upstream site and after passing through several villages at the midstream site finally joins river Tawi near village Nandwal. The water quality of the stream is subjected to severe alterations in the middle and downstream course due to the influx of industrial effluents, domestic wastes especially sewage, dumping of organic waste, and human and animal excreta from the catchment areas as the stream progresses downwards. For the purpose of the present study, surface and groundwater sites were selected along the entire course of Behlol stream. The selection of sites was done on the basis of varied anthropogenic activities in the catchment (Figure 1).

Sampling and analysis of Physico-chemical parameters

Monthly water samples were collected from designated sites for a period of one year viz. August 2016 to July 2017 (Table 1). The surface and groundwater samples were collected in polypropylene plastic bottles and analyzed in the chemical laboratory within four hours of their collection. Physico-chemical analysis of water samples was done using standard techniques (APHA, 2005). pH was measured by Century water/ soil analyzer kit (CMK 731); free carbon dioxide (fCO_2), dissolved oxygen (DO), and

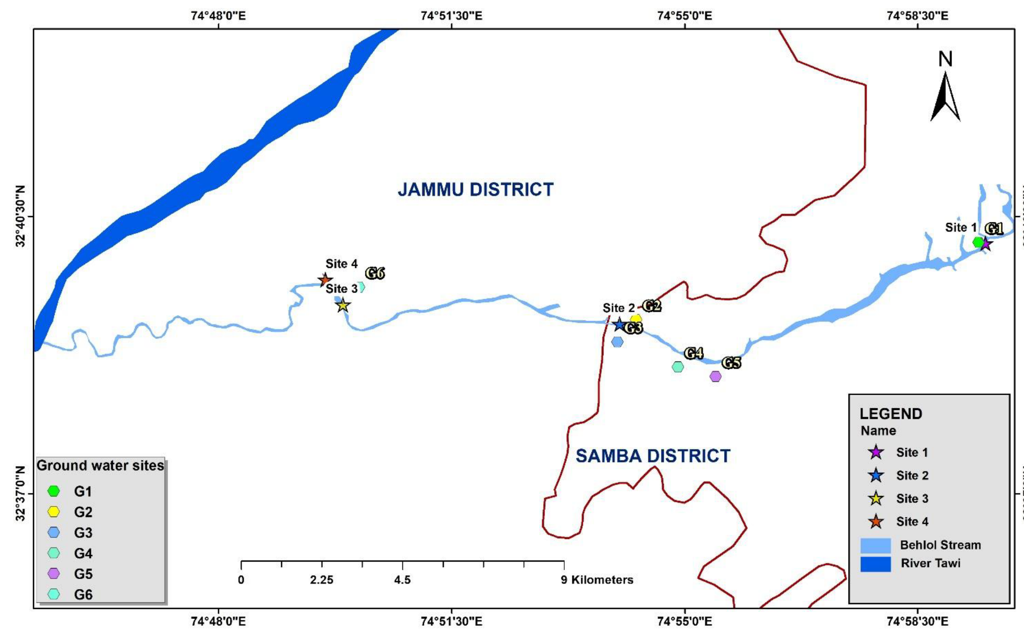


Fig. 1. Showing the surface and the ground water sites selected for the present study

biochemical oxygen demand (BOD), were analyzed by titration method. All these physico-chemical parameters *viz*. pH, fCO_2, DO and BOD were studied in relation to microbiological parameters to extract useful relationships influencing the water characteristics defining water quality.

Sampling and analysis of microbiological parameters

For microbiological studies, water samples were collected from the designated sites in sterilized BOD bottles and analyzed by standard methods (APHA, 2005). The quantitative assessment of the microbial load of selected water sources was done in terms of MPN index/100 ml. To estimate the MPN/100 ml for total coliform (TC) and faecal coliform (FC), a multiple-tube fermentation technique was employed, which is the basic test for MPN estimation (APHA, 2005).

Multiple-tube fermentation technique (MTF)

Presumptive Test

Fifteen fermentation tubes containing MacConkey lactose broth of variable strength (double strength

Table 1. Details of surface and groundwater sites selected for the present study

S. No.	Sampling Stations Surface water	Name	GPS coordinates Latitude	 Longitude	Location
1.	S1	Mandal	32.669326N	74.991937E	Upstream
2.	S2	Bari Brahmna	32.65237N	74.90032E	Midstream
3.	S3	Lower Gadigarh	32.656411N	74.831047E	Downstream
4.	S4	Lower Gadigarh, the confluence point of Behlol & Chatha nullah	32.661681N	74.826706E	Downstream
Groundwater					
1.	G1	Hand pump, Mandal	32.669514N	74.990195E	Upstream
2.	G2	Bore well, PHE pump, Jalluchak	32.65324N	74.90446E	Midstream
3.	G3	Hand pump, Bari Brahmna	32.64856N	74.89979E	Midstream
4.	G4	Hand pump, SIDCO complex	32.64327N	74.91492E	Midstream
5.	G5	Station Hand pump, SIDCO complex	32.64128N	74.92434E	Midstream
6.	G6	Hand pump, Lower Gadigarh	32.660096N	74.835077E	Downstream

for lower dilutions and single strength for higher dilution) with measured volumes of water samples for preparing 3 sets of 5 fermentation tubes of 0.1, 1 and 10 ml dilutions were used for MTF. Production of gas (a bubble filling the concavity of Durham's tube), acid formation, or abundant growth in the test tubes after 48 h of incubation at 35±0.5 °C constituted a positive presumptive reaction. All positive fermentation tubes were subsequently subjected to a confirmation test.

Confirmed Test

During the confirmed phase, brilliant green lactose bile broth was used as a culture medium for enumerating total coliforms and the fermentation tubes containing broth media were inoculated with positive presumptive cultures. The formation of gas in a brilliant green lactose bile broth fermentation tube at any time within 48 h of incubation at 35 ± 0.5 °C constituted a positive confirmation test. Simultaneous inoculation into brilliant green lactose bile broth for total coliforms and EC broth for faecal coliforms was carried out. The production of gas after 24 h of incubation at 44.5 °C in an EC broth medium was considered a positive result. The results of the MTF technique are expressed in terms of the most probable number (MPN) of micro-organisms present, i.e. MPN/100, which is a statistical estimate of the mean number/density of coliforms in the sample as computed from MPN index table (APHA, 2005).

Completed Test

To establish the presence of coliform bacteria and to provide quality control data, the completed test was performed on positive confirmed tubes. For confirmation and identification of pathogenic microbes, various biochemical tests like the indole test, lactose test, motility test, methyl red test, Simmons citrate test, and Voges Proskauer tests have been applied.

RESULTS AND DISCUSSION

Physico-chemical analysis

The physico-chemical variations for selected parameters among different surface and groundwater sampling sites are displayed in Table 2, in terms of mean, standard deviation, and range values. The parametric observations at surface sampling sites S2 (midstream site) and S4 (downstream site) followed a close trend of variability. pH remained mostly low (acidic) at Site 2 (6.91) and Site 4 (6.93) with high fCO_2 (38.82 mg/l; 37.16 mg/l) and BOD (219.04 mg/l; 216.98 mg/l) indicating excess pollution caused by the entry of combined sewage and industrial wastes at midstream site and entry of industrial waste, sewage and agricultural waste at the downstream site (Figure 1; Table 2). Among the groundwater sources, sites G2 and G3 both located very near to midstream site S2 have shown low pH (6.97; 6.93) and high fCO_2 (31.19 mg/l; 35.54 mg/l) and BOD (2.28mg/L; 2.48 mg/l) indicating impact of anthropogenic pressures in the vicinity on the groundwater sources.

Table 2. Descriptive statistics of physico-chemical parameters among surface and groundwater sampling stations.

Stations	St. code	pH		Free CO_2 (mg/l)		DO (mg/l)		BOD (mg/l)	
		Mean & SD	Annual Range	Mean & SD	Annual Range	Mean & SD	Annual Range	Mean & SD	Annual Range
Surface water	S1	7.36±0.5	6.90-8.4	20.77±9.1	12.04-38.35	6.58±1.24	5.42-8.7	2.58±1.25	1.06-5.5
	S2	6.91 ± 0.2	6.55-7.1	38.82±17.4	19.79-74.4	4.36±1.5	1.56-6.0	219.0±154.4	49.10-579.8
	S3	7.22 ± 0.5	6.80-8.3	29.99±11.2	19.79-51.5	5.78±1.4	3.77-8.6	3.93±2.87	1.12-10.0
	S4	6.93 ± 0.2	6.57-7.1	37.16 ±16.8	21.57-72.7	4.69 ±1.4	1.77-6.0	216.9 ±168.9	51.56-612
Ground water	G1	7.17 ± 0.1	6.96-7.4	16.71 ± 6.6	13.25-30.4	6.03 ± 0.6	5.26-7.5	0.93±0.33	0.63-1.9
	G2	6.97 ±0.2	6.62-7.2	31.19±14.5	18.68-61.6	5.34±1.1	3.16-6.3	2.28 ±0.54	1.76-3.6
	G3	6.93±0.2	6.59-7.1	35.54±15.8	21.35-69.5	5.01±1.1	2.94-6.1	2.48±0.54	1.83-3.7
	G4	7.08±0.1	6.92-7.2	22.97±7.1	17.19-36.7	5.95±0.6	4.76-6.6	1.55±0.72	0.87-2.9
	G5	7.14±0.1	6.97-7.2	19.51±6.3	12.46-30.3	6.20±0.5	5.19-6.8	0.90±0.13	0.71-1.1
	G6	7.05±0.1	6.86-7.2	26.24±9.4	15.13-48.23	5.68±0.8	3.94-6.7	2.12±0.37	1.63-2.8

*SD-Standard Deviation

Microbiological analysis

Seasonal variability of surface and groundwater sites for microbiological parameters in terms of MPN index/100 ml of total coliform (TC) and faecal coliform (FC) has been displayed in Table 3. A similar variability pattern was observed for surface water sites S2 and S4 as for microbial parameters with annual values ranging between 210 to >1600 for TC and 70-350 for FC(S2); 280 to >1600 for TC and 84-540 for FC (S4). Annual range values observed at site S3 were 46-350 for TC and 14 to 94 for FC. Site S1 located upstream recorded the lowest range values among all the sampled sites i.e., 24 to 220 for TC and 8.2 to 70 for FC. The groundwater variability trend for microbiological parameters was analogous to physico-chemical variability with sites G2 and G3 revealing close and higher annual range values whereas sites G1 and G5 followed close and lower range values among all groundwater sampled sites. An analysis of seasonal variations revealed pre-monsoon as the most microbiologically contaminated season with higher range values in the case of surface water sites, except for site S3 which was highly contaminated during monsoon season. Seasonal variability among groundwater sampling sites revealed both pre-monsoon and monsoon as highly contaminated seasons as compared to post-monsoon among all sampled sites. This may be explained by reduced water flow during pre-monsoon/ dry season leading to the concentration effect of faecal contamination, resulting in higher detection levels(Wright, 1986; Godfrey et al., 2005) and flushing of human and animal excreta into water sources during rains or monsoon season, thereby deteriorating microbial quality of such sources (Wright, 1986; Howard *et al.*, 2003).

Further, a comparative account of surface and ground water samples observations with national and international standards(WHO, 2008 & BIS, 1991) has been presented in Table 4.

These parametric observations clearly suggest that sites S2 and S4 are severely polluted sites as validated by a large influx of organic and industrial waste in the middle and downstream course of the stream; sites S3 was observed to be moderately polluted and site S1 was found to be least polluted among all surface water sampling sites via physico-chemical and microbiological analysis, which is clearly reflected through pollution sources contributing to the sites. Concerning groundwater quality of sources in the vicinity of the stream, groundwater sampling sites G2 and G3 were found to be highly impacted by the surface water pollution as these sites are in severely polluted middle course in close vicinity of the stream comparable to other groundwater sites in the same course located distantly from the stream source, thereby indicating

Table 3. Seasonal variation in MPN index/100 ml of TC and FC among the sampling stations

Sources	Parameters & sites	Seasons	Pre-monsoon	Monsoon	Post-monsoon	Annual Range
Surface water	S1	TC	40-220	33-140	24-32	24-220
		FC	14-70	17-39	8.2-17	8.2-70
	S2	TC	540->1600	430-920	210-540	210->1600
		FC	130-350	140-280	70-140	70-350
	S3	TC	70-280	46-350	49-170	46-350
		FC	24-79	17-94	14-33	14-94
	S4	TC	540->1600	350->1600	280-920	280->1600
		FC	140-280	170-540	84-170	84-540
Ground water	G1	TC	9.2-17	11-20	6.8-14	6.8-20
		FC	4.0-9.2	6.8-9.2	4.0-6.8	4.0-9.2
	G2	TC	14-20	14-26	4.5-12	4.5-26
		FC	7.8-12	4.5-14	2.0-6.8	2.0-14
	G3	TC	17-46	21-39	11-17	11- 46
		FC	6.8-14	9.2-24	4.0-7.8	4.0-24
	G4	TC	11-22	9.3-17	7.8-14	7.8-17
		FC	4.5-14	4.0-12	2.0-9.2	2.0-14
	G5	TC	6.8-14	8.2-14	6.8-12	6.8-14
		FC	2.0-6.8	4.0-9.3	4.0-6.8	2.0-9.3
	G6	TC	14-24	17-33	9.2-20	9.2-33
		FC	6.8-14	11-22	4.5-12	4.5-22

Table 4. Drinking water standards and comparison of sample parametric observations with standards

S. No.	Parameter	WHO standards 2008		BIS standards 1991		Comparison of observed parametric values with WHO and BIS standards.
		Desirable	Permissible	Desirable	Permissible	
1.	pH	6.5-8.5	No relaxation	6.5-8.5	6.5-8.5	All surface & ground water samples are within permissible range
2.	Free CO_2 (mg/l)	-	-	-	-	-
3.	DO (mg/l)	5	-	6	N.A.	Few Samples at surface water sites S2, S3 & S4 are below permissible range; few samples at ground water sites G2, G3 & G6 are below permissible range i.e. low DO range.
4.	BOD (mg/l)	2	-	3	6	Sites S2 & S4 observed high BOD values, well above permissible range while few samples at sites S1 & S3 are above permissible range; ground water sites samples are within permissible range ar per BIS standards.
5.	Total coliforms	Nil/100 ml	-	10/100ml	-	All surface water sites samples observed high total coliform content above permissible range; ground water sites G3 observed coliform content above permissible range, few samples at sites G1, G2, G4, G5, G6 exhibited high range values above permissible range as per BIS standards.
6.	Faecal coliforms	Nil/100 ml	-	Nil/100 ml	-	All surface and groundwater samples are beyond permissible range.

seepage of impurities into these groundwater sources from polluted surface waters. This deterioration of groundwater quality of vicinity sources coupled with pollution in surface waters is well reported by earlier researchers (Siddiqui and Sharma, 2009; Singh *et al.*, 2013).

Based on morphological characteristics of the microbial colonies on MacConkey Agar and biochemical tests performed in the study, the microbial diversity/pathogenic microbes were identified as *Escherichia coli*, *Enterobacter* spp., *Klebsiella* spp., *Citrobacter* spp., *Proteus* spp., *Salmonella* spp. and *Shigella* spp., belonging to family Enterobacteriaceae. *E.coli* and *Klebsiella* spp. were recorded from all the surface and the groundwater sites (Table 5). However, other species were only recorded in the surface water sites. Similar observations have been made by workers like Akani *et al.* (2018) who reported the presence of *E.coli*, *Klebsiella* spp., *Citrobacter spp.* and *Enterobacter* spp. from well water in the Rumuekini community in River State, Nigeria; Murray *et al.* (2018) recorded *E.coli* along with other coliforms from private drinking water wells in Maryland, USA, and Onyango *et al.* (2018) reported the presence of *E. coli* along with some other microbial genera from various surface and groundwater sources in Isiolo County in Kenya.

Statistical Analysis

A. Coefficient of Correlation (r) analysis

Surface water samples

Pearson correlation analysis was conducted among physico-chemical and microbiological parameters for surface water samples (Table 6). A strong positive correlation was observed between TC and FC; BOD and TC; free CO_2 and TC; DO and pH; free CO_2 and BOD with correlation coefficient (r) values ranging from 0.73-0.88($p < 0.01$). A strong negative correlation/ inverse relationship was observed between DO and TC; free CO_2 and pH; BOD and DO and free CO_2 and DO at significance $p<0.01$ with r values ranging from -0.72 to -0.97.

Groundwater samples

Pearson correlation analysis was conducted among physico-chemical and microbiological parameters for groundwater samples (Table 7). A strong positive correlation ($p < 0.01$) was observed between DO and pH; BOD and free CO_2; FC and TC; with correlation coefficient (r) values ranging from 0.8-0.99. A strong

Table 5. Colony morphology and biochemical characteristics of bacterial genera belonging to class Enterobacteriaceae

S. No.	Morphological characteristic	Bio-chemical tests						Bacteria identified
		Lactose test	Indole test	Methylred test	Voges-proskauer test	Simmon's-citrate test	Motility test	
1.	Appear as flat, pink, smooth, circular colony, moist with entire margins.	+	+	-	-	-	+	*Escherichia coli*
2.	Appears as light pink to red coloured, mucoid, small, circular, fluidy colonies.	+	-	-	+	+	+	*Enterobacter* spp.
3.	Appears as dark pink, circular, opaque, convex shaped, shiny or fluidy surface, mucoid colonies.	+	-	-	+	+	-	*Klebsiella* spp.
4.	Appear as pale turned pink coloured after 24 hrs incubation, small, circular, rough or mucoid forms, convex shaped colonies.	+	-	+	+	+	+	*Citrobacter* spp.
5.	Appear as colourless/ pale coloured, irregular, smooth, fluidy or shiny, translucent colonies.	-	-	+	-	+	+	*Proteus* spp.
6.	Appear as colourless/pale, smooth, transparent, circular, low convex shaped colonies.	-	-	+	-	+	+	*Salmonella* spp.
7.	Appear as colourless/pale colonies, circular, convex, transparent to moderately transparent, smooth with entire margins/edges colonies.	-	-	+	-	-	-	*Shigella* spp.

Table 6. Correlation matrix showing correlation coefficient (r) between paired parameters of surface water samples

Parameters	TC	FC	pH	DO	BOD	fCO_2
TC	1					
FC	0.877*	1				
pH	-0.499**	-0.388**	1			
DO	-0.716*	-0.498**	0.869*	1		
BOD	0.808*	0.551**	-0.520**	-0.776*	1	
fCO_2	0.731*	0.488**	-0.821*	-0.966*	0.787*	1

* Significant at $p<0.01$ i.e., 99% confidence level
** significant at $p<0.05$ i.e., 95% confidence level

Table 7. Correlation matrix showing correlation coefficient (r) between paired parameters of ground water samples

Parameters	pH	fCO_2	DO	BOD	TC	FC
pH	1					
fCO_2	-0.986*	1				
DO	0.985*	-0.990*	1			
BOD	-0.804*	0.800*	-0.814*	1		
TC	-0.544**	0.582**	-0.575**	0.667**	1	
FC	-0.319**	0.343**	-0.360**	0.506**	0.842*	1

* significant at $p<0.01$ i.e. 99% confidence level
** significant at $p<0.05$ i.e. 95% confidence level

negative correlation/ inverse relationship was observed between free CO2 & pH; BOD & pH; DO & free CO_2; BOD & DO at significance level p<0.01 with r values ranging from -0.8 to -0.99.

Regression analysis

Surface water samples

Regression analysis among a bivariate set of physico-chemical parameters of surface water samples revealed that free CO_2 and DO, pH and free CO_2, DO and pH, BOD and TC, and FC and TC are correlated, and the value of dependent variable (Y) may be predicted/ calculated using individual regression equations (Table 8).

Furthermore, R^2 values between free CO_2& DO, pH and free CO_2, DO and pH, BOD and TC and FC & TC were observed to be 0.93, 0.67, 0.65, 0.77 & 0.75 respectively, signifying 93%, 67%, 65%, 77% and 75% variability in dependent parameter relative to independent one (X variable). Linear plots of paired correlated parameters for surface samples have been represented in Figures. 2(a-e).

Furthermore, the study also applied a multiple linear regression approach with the objective of finding an equation that can predict the dependent variable as a function of several independent variables. For each sampled case as for surface water samples, a multiple linear regression (MLR) model was developed using systematic procedures to exclude insignificant response variables. The best MLR model was selected by analyzing the residuals and based on R^2 study with a ratio close to 1; the equation using this model wherein DO was selected as the dependent/ response variable and pH, fCO_2, BOD, TC and FC as independent variables along with other statistics is presented in Table 9.

Groundwater Samples

Regression analysis among bivariate set of physico-chemical parameters of groundwater samples revealed that free CO_2 and pH, DO and pH, BOD and pH, DO and free CO_2, BOD and fCO2, BOD and DO and FC and TC are correlated, and values of dependent variable (Y) may be predicted/ calculated using regression equations (Table 10).

Table 8. Regression equations between paired parameters of surface water samples using least square method.

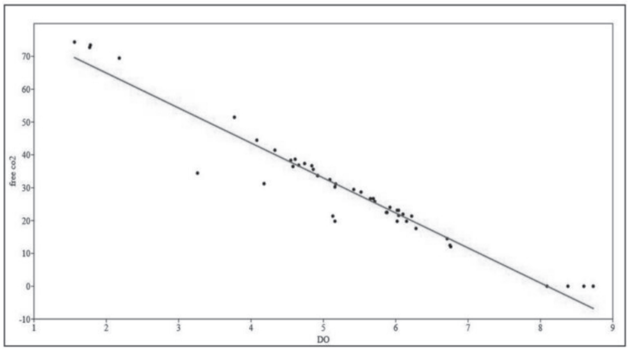
Variable Y	Variable X	R	Slope a	Intercept b	Regression Equation	R square
fCO2	DO	-0.97	-10.66	86.25	fCO2=-10.66(DO) + 86.25	0.93
fCO2	pH	-0.82	-35.93	284.59	fCO2= -35.93(pH) + 284.59	0.67
BOD	TC	0.81	0.25	-4.51	BOD= 0.25(TC) – 4.51	0.65
FC	TC	0.88	0.23	17.56	FC= 0.23(TC) + 17.56	0.77
DO	pH	0.87	3.45	-19.16	DO= 3.45(pH) – 19.16	0.75

Table 9. Multiple linear regression model for surface water sampled parameters

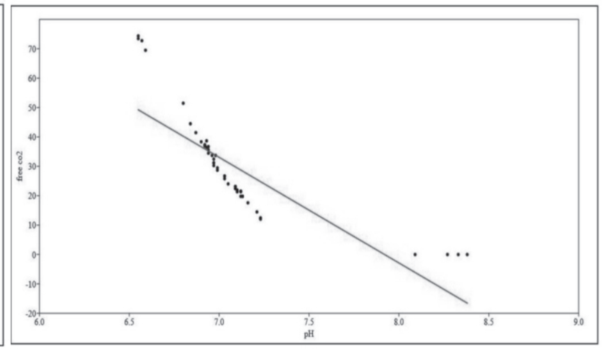
MLR model for DO	Beta coefficients	Multiple R	Multiple R^2	Multiple R^2 adjusted	df1, df2	F-value	p-value
Beta coefficient (constant)	-0.976	0.978	0.957	0.952	5,40	179.41	0.000
fCO_2	-0.056						
pH	1.144						
BOD	-0.001						
TC	-0.0001						
FC	0.0001						
Regression Equation	DO = -0.976 -0.056 fCO_2 +1.144 pH -0.001BOD -0.0001TC +0.0001FC						

Table 10. Regression equations between paired parameters of groundwater samples using the least square method.

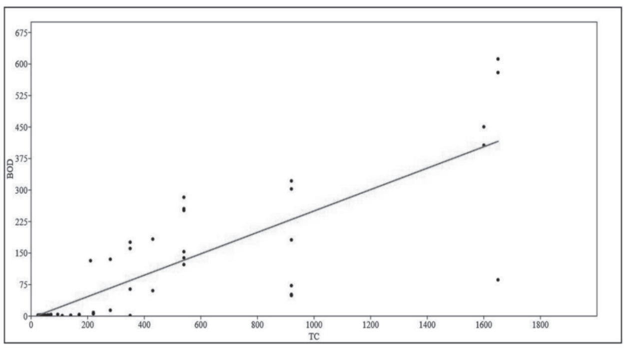
Variable Y	Variable X	R	Slope a	Intercept b	Regression Equation	R square
fCO_2	pH	-0.99	-80.38	592.66	fCO_2= -80.38 (pH) + 592.66	0.97
DO	pH	0.98	6.05	-36.91	DO= 6.05 (pH) – 36.91	0.97
BOD	pH	-0.80	-4.20	31.36	BOD= -4.20 (pH) + 31.36	0.65
DO	fCO_2	-0.99	-0.07	7.67	DO= -0.07(fCO_2) + 7.67	0.98
BOD	fCO_2	0.80	0.05	0.41	BOD= 0.05(fCO_2) + 0.41	0.64
BOD	DO	-0.81	-0.69	5.72	BOD= -0.69(DO) + 5.72	0.66
FC	TC	0.84	0.47	0.60	FC= 0.47(TC) + 0.60	0.71



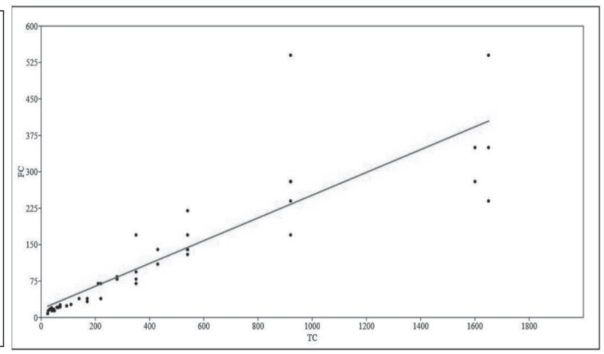
(2a). fCO_2 and DO.



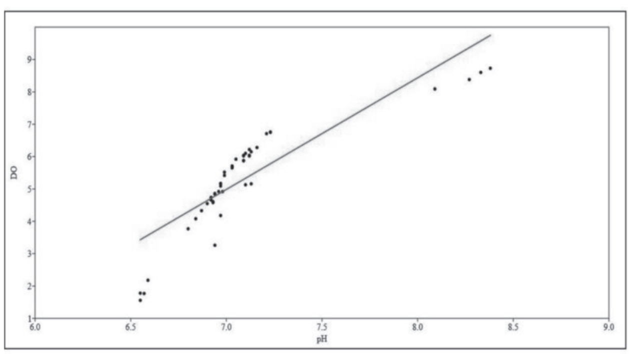
(2b). fCO_2 and pH.



(2c). BOD and TC.



(2d). FC and TC



(2e). DO and pH

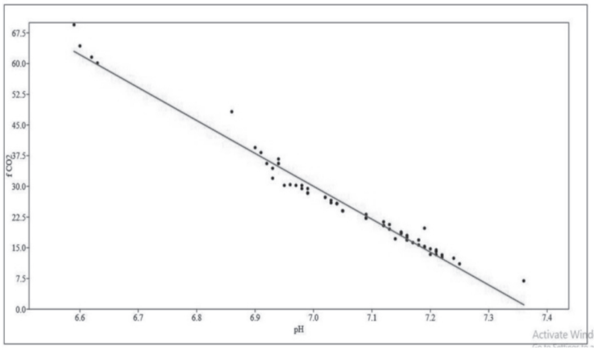
Fig. 2. Linear plots of correlated paired parameters in case of surface water samples. (a). fCO_2 and DO. (b). fCO_2 and pH. (c). BOD and TC. (d). FC and TC. (e). DO and pH.

Furthermore, R^2 values between fCO_2 and pH, DO and pH, BOD and pH, DO and fCO_2, BOD and fCO_2, BOD and DO and FC and TC were observed to be 0.97, 0.97, 0.65, 0.98, 0.64, 0.66 and 0.71 respectively; signifying 97%, 97%, 65%, 98%, 64%, 66% and 71% respective variability in dependent parameter is explained by independent one (X variable). Linear plots of paired correlated parameters for groundwater samples have been represented in Figures 3(a-g).

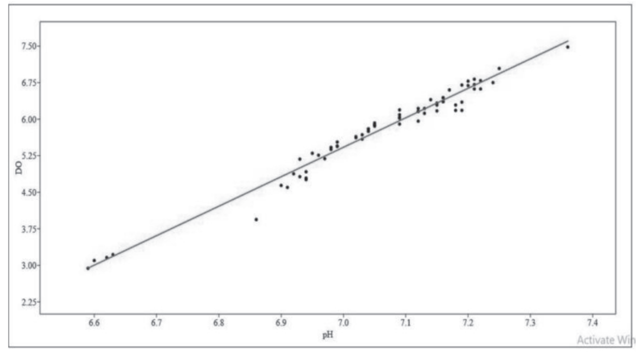
The best MLR model for groundwater sampled cases was selected by analyzing the residuals and based on R^2 study with ratio close to 1; the equation using this model where fCO_2 was selected as the dependent/ response variable and pH, DO, BOD, TC and FC as independent variables along with other statistics is presented in Table 11.

CONCLUSION

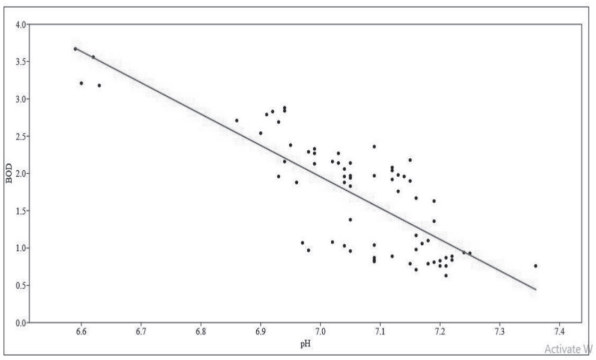
An attempt has been made to evaluate the water quality of Behlol stream and ground water sources



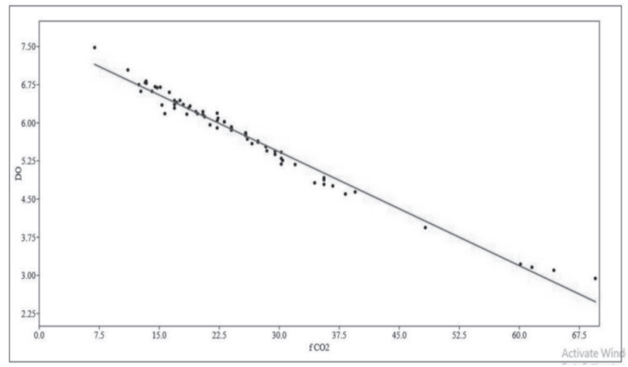
(3a). fCO_2 and pH



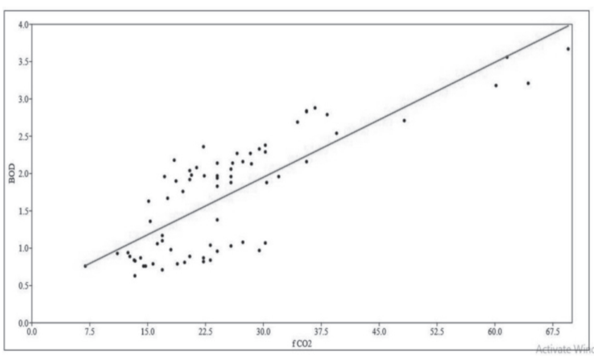
(3b). DO and pH



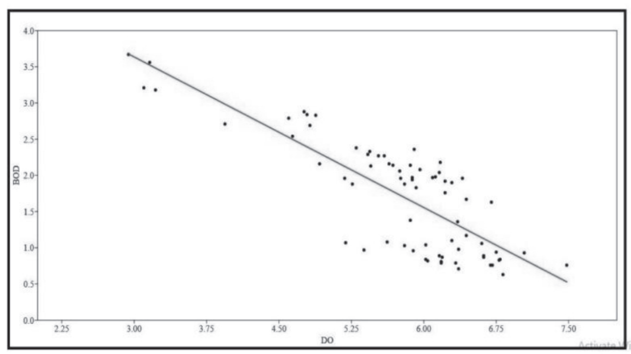
(3c). BOD and pH



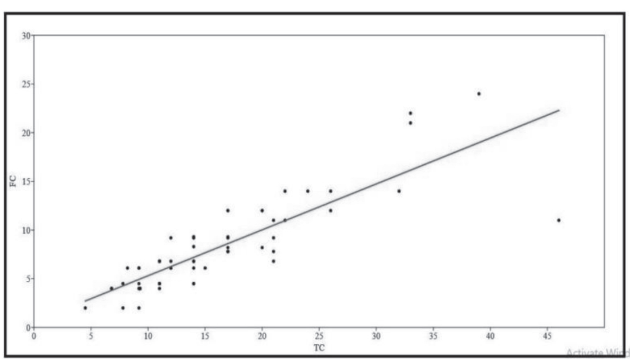
(3d). DO and fCO_2



(3e). BOD and fCO_2



(3f). BOD and DO



(3g). FC and TC.

Fig. 3. Linear plots of correlated paired parameters in the case of groundwater samples (a). fCO_2& pH (b). DO and pH (c). BOD and pH (d). DO and fCO_2 (e). BOD and fCO_2 (f). BOD & DO (g). FC & TC

Table 11. Multiple linear regression model for ground water sampled parameters

MLR model for fCO_2	Beta coefficients	Multiple R	Multiple R^2	Multiple R^2 adjusted	df1, df2	F-value	p-value
Beta coefficient (constant)	292.96	0.993	0.987	0.986	5,65	974.65	0.000
pH	-31.35						
DO	-8.03						
BOD	-0.62						
TC	0.17						
FC	-0.20						
Regression Equation	fCO_2 = 292.96 -31.35 pH -8.03 DO -0.62 BOD +0.17 TC -0.20FC						

of proximity areas by assessing the level of microbial contamination using statistical tools viz. correlation and regression analysis to deduce underlying associations between related parameters. The results revealed that:

i) The effect on ground water quality of vicinity sources due to pollution in Behlol stream was indicated by high pollution level at sites G2 and G3, signifying leaching of impurities into these ground water sources from polluted surface waters. Distance wise these two groundwater sources were located very near to the stream after site G1 which was located near Site S1 but showed less pollution due to low contamination at upstream area.
ii) MPN index/100 ml for total and faecal coliforms values at surface sites S2 and S4 were higher indicating the severe level of microbial contamination.
iii) Groundwater sampling sites G2 and G3 revealed higher range values in terms of MPN index/100 ml for total and faecal coliforms signifying a high level of contamination.
iv) Bacterial species like *Escherichia coli*, *Enterobacter* spp., *Klebsiella* spp., *Citrobacter* spp., *Proteus* spp., *Salmonella* spp., *Shigella* spp., belonging to the family Enterobacteriaceae were identified based on colony cultural characteristics on MacConkey agar and bio-chemical tests. Only, *E.coli* and *Klebsiella* species were recorded from ground water samples.
v) Correlation-regression study established significant relationship among different pairs of physico-chemical and microbiological parameters using bivariate linear plots, MLR model and regression equations.

The study concludes that an orderly linear correlation and regression study will greatly facilitate the task of rapid monitoring of the pollution status of water sources through indirect means and thus suggest some effective and economic way for water quality management.

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Conflict of Interest

The authors declare no conflict of interest.

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