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MULTIVARIATE ANALYSIS OF WASTEWATER QUALITY OF DIFFERENT RURAL HUMAN SETTLEMENTS IN PUNJAB (INDIA)

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Abstract

An attempt has been made in the present study to investigate the wastewater characteristics from six different rural human settlements in the state of Punjab, India. The six selected rural catchments are located on a radius of about 5-50 kilometers from Phagwara town, Kapurthala district. The study area comprises the villages of the districts of Jalandhar, Kapurthala and Shaheed Bhagat Singh Nagar in Central Punjab. The wastewater samples were collected between January, 2012 and July, 2012 and analyzed for BOD_5, COD, TSS, TDS, Nitrates, pH, TKN, Alkalinity, Total P, Coliforms, heavy metals (Cd, Ni, Pb, Cr, Cu, Zn, Fe, Mn and As) and elements (B, Ca, Mg, S and K). The study revealed that the village ponds are the only disposal point where the major portion of the wastewater generated from rural micro watersheds is being disposed. TSS, COD, Nitrates and Coliforms were found to be major pollutants in the wastewaters of rural micro watersheds (all exceeded the surface water quality standards developed by Central Pollution Control Board, India). BOD_5 and Ammoniacal nitrogen (NH_3-N) were found to be exceeding these standards occasionally. Investigations also revealed a very low ratio of BOD_5 to COD for the rural wastewaters which indicated that the contribution of cattle wastewater is significant in the wastewater originating from rural catchments. Principal component analysis was applied to identify linkages between the individual pollutant parameters generated from the rural micro watersheds.

Key words: low cost wastewater treatment, micro watershed, principal component analysis, wastewater characterisation

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1. Introduction

The village ponds which once used to be the center of thriving rural activity are disappearing fast throughout the state of Punjab, India. Presently most of the village ponds in the state are silted, encroached upon and being used for disposing village wastewater. The wastewater dumped in the ponds is polluting the groundwater further, in their surrounding areas. Only 4.2 percent of rural households in Punjab have closed drainage connectivity whereas 73.8 percent continue to dispose of their wastewater in open drains (Census GOI, 2001). The wastewater thus generated from various household and other activities in rural areas are also being disposed of into village ponds thereby contaminating it. The highly polluted stinking stagnant water and growth of unwanted aquatic plants in these contaminated ponds contribute to growth of vector diseases, poses serious health hazard and poor living environment (Singh and Singh, 2007).

It has been observed by the researchers that variation of wastewater characteristics in rural areas considerably affects the performance of the low cost wastewater treatment plants. Alongwith wastewater pollutants, pond water in many micro-watersheds has also been found to contain micronutrients (Zn, Cu, Fe

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and Mn) in high amounts, which indicate its suitability for irrigation (Al-Zou'by et al., 2017; Chawla and Khepar, 2001; Toor et al., 2010). But, the high organic content, solids loading and coliform count are the main hindrance in its intended use in irrigation (Elmitwalli et al., 2003). Therefore, before planning and adopting any wastewater treatment option for village wastewater, it is first necessary to specify the characteristics of the wastewater originating from micro-watersheds.

Some state governments in India on their own or in collaboration with the stakeholders have initiated the process of restoration of the ponds and are providing economical and sustainable wastewater treatment solutions (AUD, 2004; Saxena, 2006). The studies have revealed that the renovation of village ponds have positive affect on the environment, rural economy and the groundwater regime in the vicinity of declining water table (Chawla and Khepar, 2001). But, due to the non-existence of the authentic and comprehensive characterisation data of village wastewaters, it has become extremely difficult for the agencies engaged in the water resources management to find out the area specific solutions for the deteriorating environmental health of these village ponds.

To target the specific polutants during treatment process, efforts have also been made by researchers to establish the relationships between specific water/wastewater pollutants by using statistical techniques. Nkansah et al. (2016) through multivariate analysis determined that the salon wastewater was primarily influenced by the physicochemical source of the variability, agriculture and other anthropogenic activities. In another study, multivariate statistical technique was used to optimize a water quality monitoring network in Klang River Basin in Malaysia (Mohamed et al., 2015). The objective of this study was to investigate the characteristics of wastewater originating from six different rural human settlements in Doaba region of Punjab, India. Results obtained from this study were used to identify specific pollutants that should be targeted for treatment and to make pond water usable for agriculture and other purposes. Inter-relationships among the pollution parameters were understood through Principal Component Analysis and Spearman correlation analysis of the wastewater characteristics and used in designing a scheme of wastewater treatment. As comprehensive characterisation of the wastewater, a major source of water for village ponds during non-rainfall period was carried out, the outcome of this work can be used by the agencies engaged in water resources management for selecting and designing an appropriate treatment technology for rural micro-watersheds.

2. Materials and methods

2.1. Description of the rural catchments

Six rural micro-watersheds were identified in Doaba region of Punjab state to serve as catchments for the present study. The six catchments represent a wide range of population sizes, cattle number, provision of piped water supply and catchment areas of the pond.

The catchments were chosen in the radius of around sixty kilometers so as to represent the three prominent districts of the region .i.e. Jalandhar, Kapurthala and Shaheed Bhagat Singh Nagar (Nawanshahar). Tayabpur (Kapurthala) is a small catchment village having only one pond serving as an outlet for whole of the catchment. Sodhian (Shaheed Bhagat Singh Nagar) is a mid sized village with only one pond for collection of almost whole of the wastewater generated in the catchment. Samrai (Jalandhar) is a large village having more than one outlet for village catchment area. Masitan (Kapurthala) is a mid sized catchment served by only one pond. Kultham (Shaheed Bhagat Singh Nagar) is a large village with three ponds existing in the catchment area. Pippa Rangi (Kapurthala) is a large village located at the outskirts of an urban centre and having multiple outlets for the catchment wastewater flow. Table 1 provides a summary of the relevant characteristics of each catchment.

Table 1. Characteristics of selected rural catchments

Rural Catchment	*Catchment Location*	*Catchment Area (m^2)*	*Catchment Population*	*Cattle number*	*Land Use (in percentage)*			
					impervious cover	*grass cover*	*crop cover*	*tree canopy*
Masitan	31°17’03.48” N 75°12’45.00”E	71974	1153	231	88	6	5	1
Sodhian	31°05’38.87” N 76°01’37.90” E	69287	1040	235	72	20	6	2
Tayabpur	31°23’48.29” N 75°18’50.34” E	34658	540	141	65	13	18	4
Pippa Rangi	31°12’22.60” N 75°47’19.01” E	40522	858	24	78	18	0	4
Kultham	31°11’33.07” N 75°51’01.76” E	33118	698	48	78	12	9	1
Samrai	31°10’43.30” N 75°37’57.26” E	98087	1879	144	87	11	0	2

The information on the village catchments has been formulated using the survey maps provided by the Department of Water Supply and Sanitation, Government of Punjab and physical survey visits. The data pertaining to rainfall and dry weather time was obtained from India Meteorological Department. The locations of the selected catchments are shown in Fig. 1 and Figs. 2 (a) and 2 (b), whereas Figs. 3 (a) to 3 (f) represent the areas of these rural catchments. The multiple outlets existing in the selected catchments are also depicted in Fig. 3.

2.2. Sampling and analysis

For each of the six catchments in Fig. 2, multiple grab samples of wastewater were collected from inlet point of the ponds at different time periods of the day as described in Table 2. A total of six samples were collected from each catchment between January 2012 and July 2012. Because individual water-using events occur intermittently and contribute varying quantities of pollutants, the strength of residential wastewater fluctuates throughout the day (University of Wisconsin-Madison, 1978).

Since, this research aims to design a micro-watershed level wastewater treatment and disposal system, involving the collection or storage of wastewater and then subsequently treating it. Hence, grab sampling was preferred over flow weighted measurements. Wastewater samples were analyzed for numerous water quality parameters, including: pH, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Bio-chemical Oxygen Demand (BOD_5) 5 days at 20º C, Chemical Oxygen Demand (COD), Total Kjeldhal Nitrogen (TKN), Total Phosphorous (TP), Nitrates, Alkalinity, Total Coliform count, Fecal Coliform count, heavy metals: Cd, Ni, Pb, Cr, Cu, Zn, Fe, Mn and As and elements: B, Ca, Mg, S and K.

Samples were collected in polyethylene bottles cleaned in advance by soaking overnight in 10% HNO_3, rinsing twice with tap water and then with double distilled water, drying to complete dryness in a clean oven at 60º C and capping in the laboratory. Glass containers were used to collect samples for the determination of heavy metals and wide mouthed sterilized bottles were used for microbial examination.

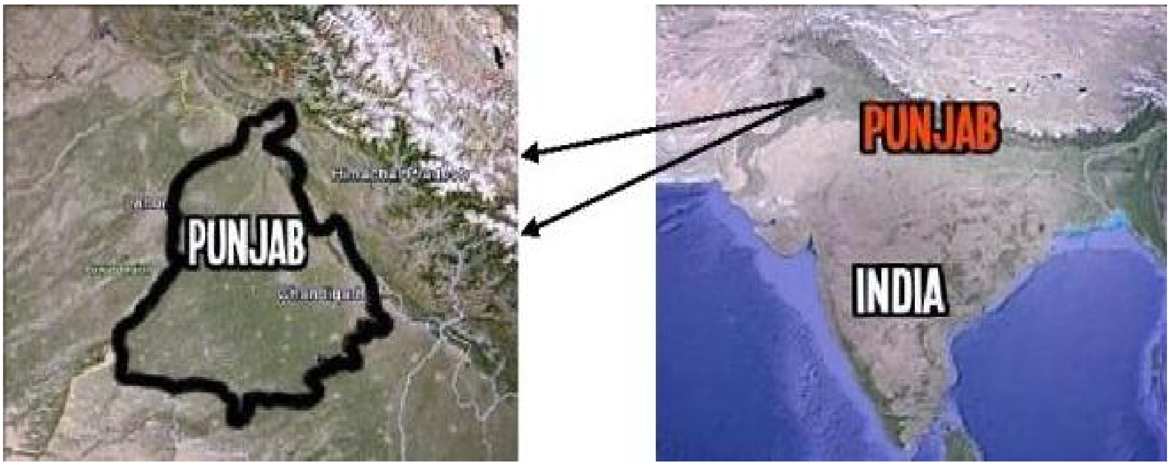
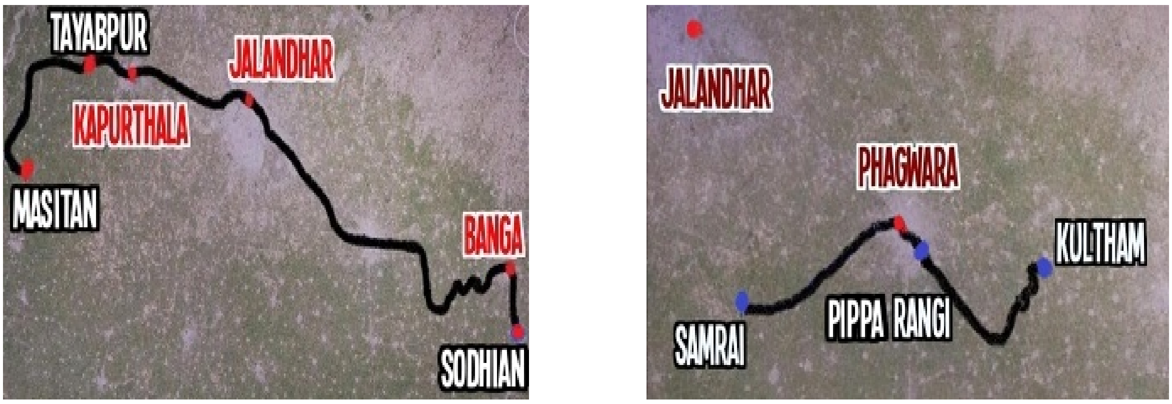
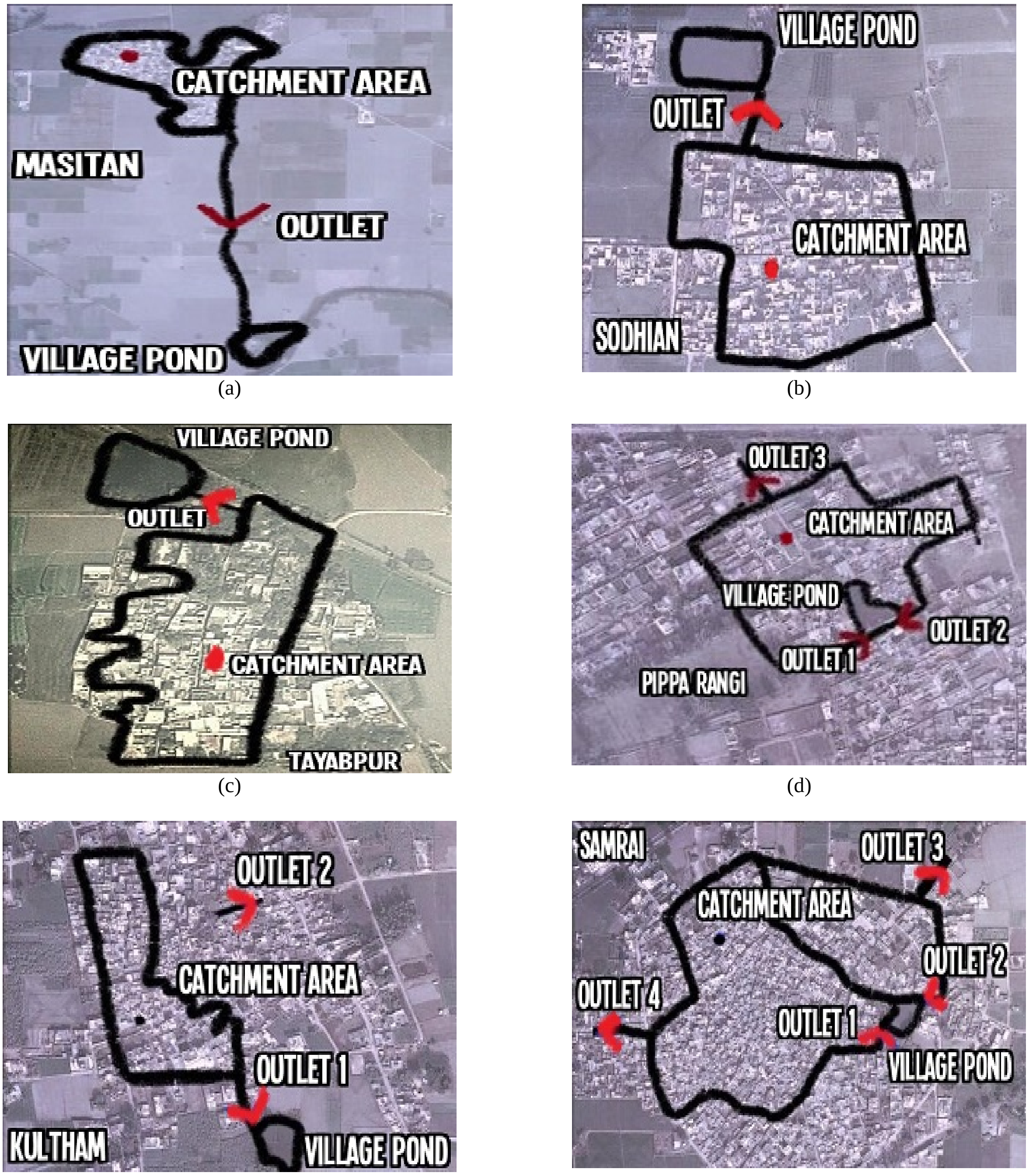


Fig.1. Location map of Punjab state



(a) (b)

Fig. 2. (a) Location of catchments of Masitan, Tayabpur and Sodhian; (b) Location of catchments of Kultham, Pippa Rangi and Samrai



(a) (b) (c) (d) (e) (f)

Fig. 3. Catchments of (a) Masitan; (b) Sodhian; (c) Tayabpur; (d) Pippa Rangi; (e) Kultham; (f) Samrai

Field and laboratory blanks (double distilled water) were also maintained throughout the sampling and analysis. The collected samples were stored in a deep freeze and analyzed according to APHA testing procedures for the examination of water and wastewater (APHA et al., 2005) in Environmental Laboratory of Guru Nanak Dev Engineering College.

2.3. Field and laboratory data quality assurance and quality control

Standard field and laboratory quality assurance/ quality control (QA/QC) procedures were followed, using the procedures specified in APHA testing procedures for the examination of water and wastewater (APHA et al., 2005). Principal QA/QC was performed on duplicate samples which include field (all constituents); lab (all constituents) and blank runs (all constituents).

2.4. Data processing and statistical methods

Correlations between wastewater quality parameters were performed using Spearman's non-parametric rank correlation procedure. This Spearman correlation analysis was principally used to identify chemical constituents that potentially serve as surrogates for other constituents.

Table 2. Sampling details in selected catchments

Rural Catchment	*Sample collection Date and Time*	*Rainfall*	*Dry Weather Time before sample collection*
Masitan	17 February – 03:00 pm	Nil	03 days
	11 March – 09:30 am	Nil	26 days
	02 April –12:30 pm	Nil	19 days
	28 May – 05:15 pm	Nil	27 days
	27 June – 02:00 pm	Nil	57 days
	29 July – 11:15 am	Nil	08 days
Sodhian	18 February – 01:00 pm	Nil	04 days
	12 March – 09:00 am	Nil	27 days
	02 April – 08:15 am	Nil	19 days
	28 May – 11:00 am	Nil	27 days
	29 June – 03:00 pm	Nil	01 day
	29 July – 05:00 pm	Nil	01 day
Tayabpur	17 February – 05:00 pm	Nil	03 days
	11 March – 11:00 am	Nil	26 days
	06 April – 09:00 am	Nil	23 days
	22 May – 12:00 pm	Nil	21 days
	27 June – 03:15 pm	Nil	57 days
	28 July – 10:00 am	Nil	07 days
Pippa Rangi	27 January – 12:00 pm	Nil	10 days
	29 February – 11:00 am	Nil	43 days
	25 March – 03:00 pm	Nil	11 days
	15 May – 05:30 pm	Nil	13 days
	28 June – 09:15 am	Nil	57 days
	29 July – 01:30 pm	Nil	07 days
Kultham	27 January – 10:30 am	Nil	10 days
	29 February – 12:00 pm	Nil	43 days
	25 March – 01:45 pm	Nil	11 days
	15 May – 03:45 pm	Nil	13 days
	28 June – 05:00 pm	Nil	57 days
	29 July – 09:00 am	Nil	07 days
Samrai	25 January – 02:00 pm	Nil	08 days
	24 February – 12:15 pm	Nil	38 days
	26 March – 08:30 am	Nil	12 days
	15 May – 05:30 pm	Nil	13 days
	27 June – 10:30 am	Nil	56 days
	28 July – 03:00 pm	Nil	06 days

However, for practical purposes and to identify potential monitoring surrogates, only correlations with a Spearman R value larger than 0.8 were considered.

Principal Component Analysis (PCA), a multivariate statistical data analysis technique which reduces a set of raw data into a number of principal components was used for pattern recognition. Principal components retain the most variance within the original dataset in order to identify possible patterns or clusters between objects and variables (Arora and Reddy, 2012)

3. Results and discussion

3.1. Wastewater characteristics of micro-watersheds

Wastewater quality parameters, whose arithmetic mean concentrations exceeded the Indian standards for discharge of environmental pollutants in surface water (EP Rules, 1986), were identified as the major pollutants and have been listed in Table 3. This Table also contains the other parameters for characterization of rural wastewater which were selected and analyzed based on the earlier studies. Comparing the results obtained for the mean pollutant concentrations, a large variation is observed among the different micro-watersheds.

These dissimilarities can be attributed to the appreciable differences observed in population characteristics, cattle number, size of catchment and provision of piped water supply and wastewater management in the six micro-watersheds.

- Sodhian, a mid sized catchment village in terms of population, exhibited highest concentration of BOD_5, TSS and TDS in the wastewater samples, with mean concentrations of 306 mg/L, 2616 mg/L and 1307 mg/L, respectively. These high concentrations may be attributed to the existence of highest number of cattle population among all the selected catchment areas in this study.
- Nutrients like TP and TKN were observed to be the highest for the catchment of village Masitan. This may be due to the mixing of runoff from agricultural fields in the wastewater drain passing along the edge of the fields.

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Table 3. Mean values of parameters analyzed along with their permissible limits as per Indian standards for discharge of environmental pollutants in surface water

Parameter	*Units*	*Kultham*	*Samrai*	*Pippa Rangi*	*Masitan*	*Tayabpur*	*Sodhian*	*Permissible limits*
TDS	mg/L	1193.67	1087.33	1236.83	839.33	669.67	1306.50	2100.0
TSS	mg/L	171.83	273.33	482.17	2185.67	1070.00	2615.83	100.0
BOD_5	mg/L	289.5	276.67	261.67	164.00	205.50	306.00	30.0
COD	mg/L	744.17	726.83	664.50	523.50	500.33	657.00	250.0
Nitrates	mg/L	59.98	61.53	49.80	36.80	35.32	39.20	10.0
TP	mg/L	47.08	23.92	39.40	42.43	35.73	30.72	5.0
TKN	mg/L	41.98	47.86	54.27	90.68	65.23	66.00	100.0
Total Coliform	MPN/100 mL	$5.20X10^6$	$2.78X10^6$	$4.23X10^6$	$3.18X10^6$	$5.04X10^6$	$5.89X10^6$	a
Fecal Coliform	MPN/100 mL	352667	280333	335500	312333	525667	584167	a
As	ppm	0.003	0.001	0.004	0.02	0.004	0.012	0.2
B	ppm	0.553	0.845	0.757	0.97	0.996	0.914	a
Ca	ppm	247.00	323.902	184.85	148.77	209.225	113.77	a
Cd	ppm	0.003	0.010	0.004	0.01	0.012	0.009	2.0
Cr	ppm	0.607	0.469	0.872	0.40	0.304	0.434	2.0
Cu	ppm	0.204	0.108	0.109	0.11	0.107	0.052	3.0
Fe	ppm	1.958	3.519	3.256	3.97	2.942	3.294	3.0
K	ppm	62.568	51.342	62.858	111.36	152.423	113.38	a
Mg	ppm	59.993	50.170	46.773	45.64	48.658	43.64	a
Mn	ppm	0.30	0.134	0.201	0.20	0.205	0.243	2.0
Ni	ppm	0.056	0.054	0.046	0.08	0.145	0.142	3.0
Pb	ppm	0.085	0.059	0.051	0.08	0.064	0.018	0.1
S	ppm	31.822	30.632	39.563	51.24	58.267	40.56	a
Zn	ppm	0.674	0.490	0.388	0.46	0.452	0.232	5.0

[a]*Standards are not available {Central Pollution Control Board (CPCB), India}*

- The mean concentration of nitrates was found to be exceeding the limits of general standards for discharge of environmental pollutants (EP Rules, 1986) in all the catchments. The highest mean value of 61.53 mg/l was observed in the wastewater of catchment of Samrai village. This poses a substantial danger to the groundwater of the area surrounding the micro-watersheds since during infiltration all the nitrogen and nitrates leaches to groundwater alongwith the wastewater (Brown et al., 1978; Walker et al., 1973a, 1973b).
- Masitan and Sodhian exhibited different wastewater characteristics, although, the two catchments had almost similar population characteristics, cattle number, size etc. This could be attributed to the condition of wastewater drains in the village. In Sodhian village, although the drains were brick laid but their condition was not as good as those existing in Masitan village which might have significantly contributed in the pollutant load.
- Organic pollution of the wastewater originating from the catchments of Kultham and Samrai was found to be among the highest as shown in Table 3. This observation may be due to the high affluence of these two rural human settlements in comparison to other villages.

Elemental analysis of the wastewater resulted in the detection of 14 major elements including the heavy metals like As, Cd, Cr, Pb, Ni and Cu.

Concentration of Iron (Fe) was marginally higher in the catchments of Pippa Rangi, Sodhian, Masitan and Samrai villages. Concentrations of other heavy metals were found to be within the limits of Indian standards for discharge of environmental pollutants in surface water (EP Rules, 1986). The results indicate that the important factors which influence the pollutant concentration are the cattle population and affluence of the human settlements. Concentrations for various parameters showed considerable variations among the sampling events and also varied with the micro-watershed.

3.2. Multivariate data analysis for correlating micro-watershed characteristics with wastewater quality

3.2.1. Micro-watershed 1: Kultham

- Total P and TKN are strongly correlated with each other and with TSS indicating that most of the nutrients are particle bound (Fig. 4).
- Most of the organic pollutants are in suspended form as TDS is not correlated to COD and BOD whereas TSS is weakly correlated to these parameters.
- Among the heavy metals Cd, Cu, Mn, Cr, Zn and Pb are strongly correlated with each other but are not correlated with TSS. Hence, these metals exist in dissolved form for this micro-watershed. Same is also true for As, Fe and Ni which shows strong correlation with each other and are unrelated to TSS.
- Strong correlation between total coliforms and fecal coliforms exists in this micro-watershed which shows that fecal matter is the main contributor of microbial contamination.
- Nitrates are found to be not correlated to TSS but very much correlated to TDS suggesting that inorganic pollution is present in dissolved form.

3.2.2. Micro-watershed 2: Tayabpur

- As Total P and TKN are strongly correlated with each other and with TSS, it indicates that major nutrients are particle bound in the wastewater of this micro-watershed (Fig. 5).
- Non-biodegradable organic pollutants show strong correlation with TDS and hence are present in dissolved form. Biodegradable organic pollutants also show significant correlation with TDS suggesting that most of the organic pollution is present in dissolved form.
- Heavy metals like Ni, Cu, Pb, Fe and Zn are strongly correlated with each other but not correlated with TSS. Cr and Mn have shown strong correlation with each other but again they are also not correlated with TSS, hence both these groups of heavy metals are present in dissolved form in this micro-watershed.
- Total coliforms and fecal coliforms show no correlation with each other for this micro-watershed, suggesting sources of microbial contamination other than fecal matter.

Nitrates are found to be weakly correlated to TSS suggesting that inorganic pollution is present as particle bound in this micro-watershed.

3.2.3. Micro-watershed 3: Samrai

- Total P and TKN exhibit some degree of correlation with each other but are not correlated to TDS. However, TKN is weakly correlated with TSS suggesting most of the nutrients are particle bound (Fig. 6).
- COD and BOD parameters are found to be correlated with each other and weakly correlated with TSS, suggesting that organic pollutants are particle bound in this micro-watershed.

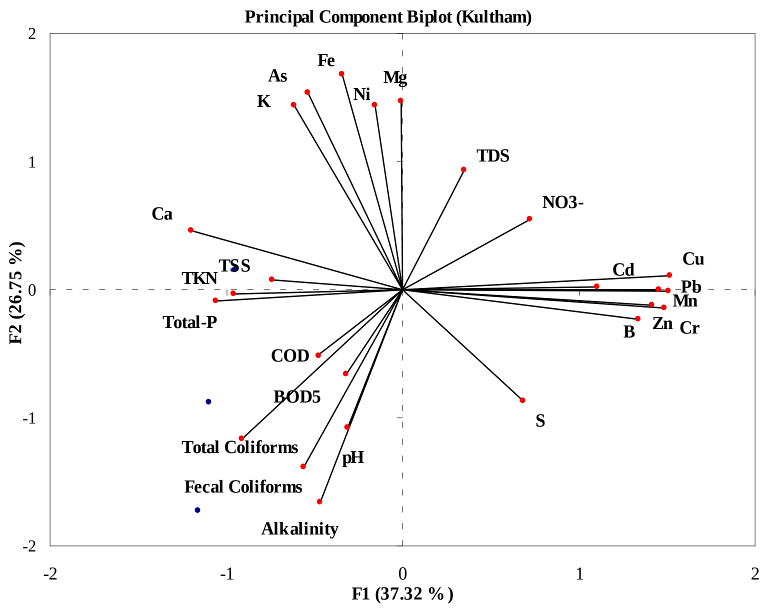

Fig. 4. Principal Component Biplot for Kultham

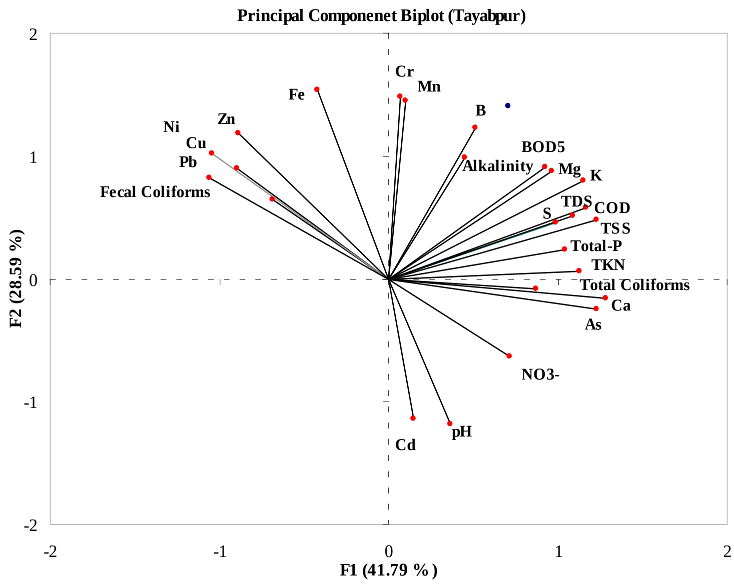

Fig. 5. Principal Component Biplot for Tayabpur

- Among the heavy metals Pb, Mn, Zn and Fe are strongly correlated with each other and with TDS. Ni is also strongly correlated with TDS indicating that all these metals are present in dissolved form.
- Total coliforms and fecal coliforms show strong correlation with each other for this micro-watershed suggesting fecal matter to be the source of microbial contamination. Also strong correlation with TSS signifies that coliforms are particle bound in this micro-watershed
- Inorganic pollution is in dissolved from in this micro-watershed as no correlation exists between nitrates and TSS.

3.2.4. Micro-watershed 4: Pippa Rangi

- In this micro-watershed, Total P and TKN are found to be strongly correlated with each other and with TSS. So, it can be summarised that nutrients are particle bound (Fig. 7).
- Organic pollutants are observed to be particle bound as strong correlation exists between COD, BOD and TSS in this micro-watershed.
- Among the heavy metals Mn, Fe, Pb, Cr, Cu and Zn are strongly correlated with each other and with TDS and hence are present in dissolved form. Ni on the other hand is not correlated with TDS whereas Cd weakly correlates with TSS pointing out that they are particle bound.
- Strong correlation among total and fecal coliforms for this micro-watershed, suggest fecal matter to be the source of microbial contamination. A weak correlation between fecal coliform and TSS suggests that coliforms are possibly particle bound.
- Nitrates are not correlated to TSS but weakly correlates with TDS suggesting that anions are in dissolved form.

3.2.5. Micro-watershed 5: Masitan

- Total P and TKN correlates with each other as well as strong correlation with TSS is also being established which suggests that nutrients are particle bound in this micro-watershed (Fig. 8).
- Most of the organic pollutants are in dissolved form as TSS is uncorrelated with COD and BOD, whereas a weak correlation of these organic pollutants exists with TDS.
- Cr and Cd show strong correlation with TDS and hence exist in dissolved form. Heavy metals like Pb, Ni, Cu, Zn, Mn and Fe are not correlated with TSS, it can be summarized that most of the heavy metals are in dissolved form.
- Total and fecal coliform are strongly correlated with each other and with TSS indicating that coliforms are particle bound in this micro-watershed.
- Nitrates exhibit strong correlation with TSS suggesting that anions are particle bound in this micro-watershed.

3.2.6. Micro-watershed 6: Sodhian, Fig. 9

- Nitrogen is present primarily in dissolved form as TKN strongly correlates with TDS whereas Total P correlated with TSS more prominently so it is particle bound in this micro-watershed.
- Biodegradable and non-biodegradable organic pollutants are particle bound as strong correlation exists between COD, BOD and TSS.
- Among heavy metals Cd, Fe, Cr, As, Ni and Mn does not correlate with TSS, so it can be summarized that these metals are present in dissolved form. Pb on the other hand correlated with TSS and hence is particle bound.
- Total and fecal coliform are strongly correlated with each other indicating that fecal matter is the main contributor of microbial contamination.
- Nitrates exhibit strong correlation with TDS suggesting that anions are in dissolved form in this micro-watershed.

Multivariate analysis gives an insight that the provision of sedimentation basins or constructed wetlands as the primary treatment option for the rural wastewaters.

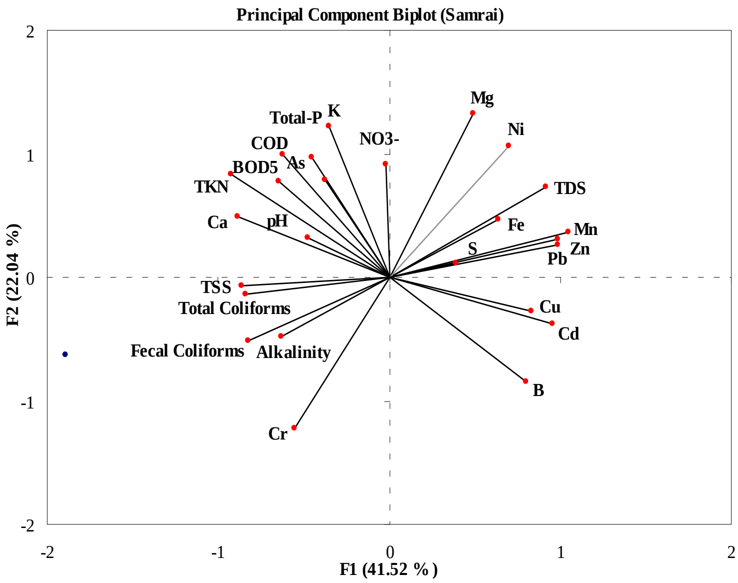

Fig. 6. Principal Component Biplot for Samrai

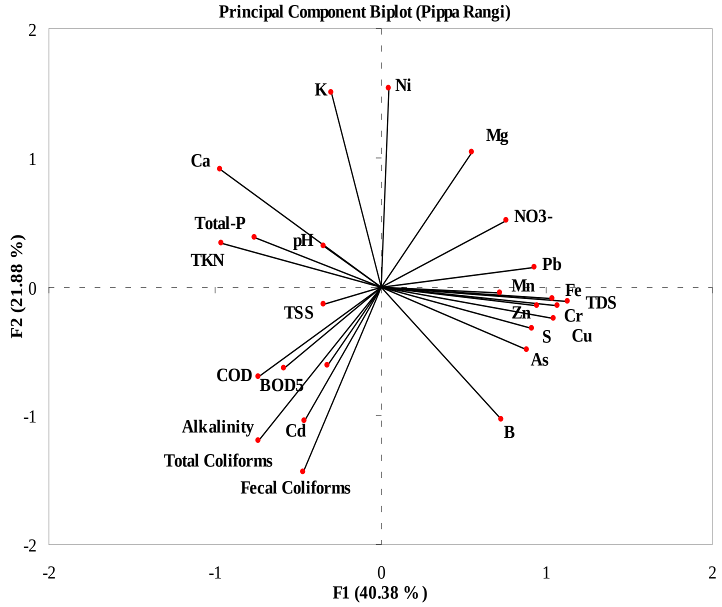

Fig. 7. Principal Component Biplot for Pippa Rangi

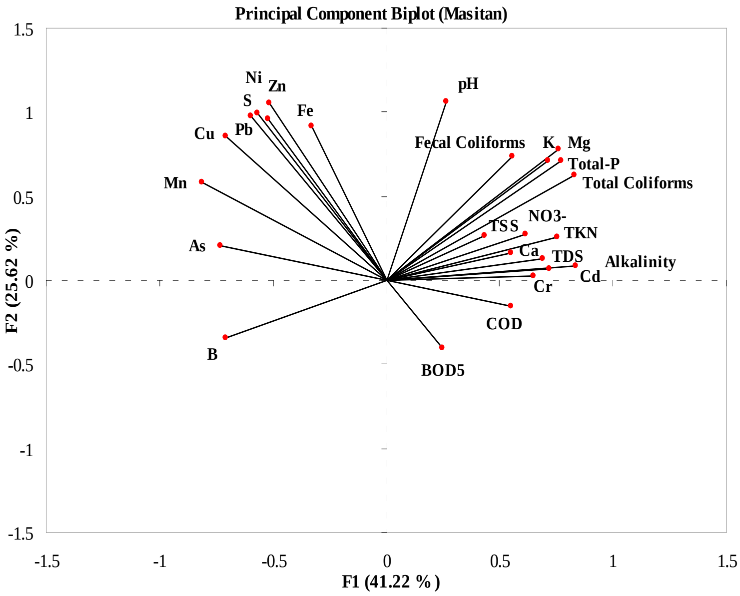

Fig. 8. Principal Component Biplot for Masitan

It will be quite effective in removing suspended solids, organic pollution, coliform bacteria and nutrients to certain extent, but not necessarily be effective in removing the pollutants such as nitrates and heavy metals. Any structural measures to be adopted should depend on targeted pollutants and management strategies adopted should take into consideration the demographic and physical characteristics of the area.

4. Conclusions

The comprehensive analysis of wastewater samples collected from six different rural catchments has resulted in the spatial as well as temporal variations in the water quality parameters. The variation is found to be the highest in TSS, TDS, BOD_5 and COD.

From the characterization of the village catchment wastewater, it has become evident that the wastewater quality of every catchment depends upon a host of factors. An attempt to generalize the characterisation exercise on the basis of any one aspect may result in erroneous outcomes of the analysis.

The high and varying values of different pollution parameters indicate that rural wastewaters need to have a fully developed wastewater management strategy involving a combination of low cost wastewater treatment techniques such as constructed wetlands, algal ponds, sand filters etc. Site specific analysis can more thoughtfully guide pollutant reduction efforts and in the end, achieve a higher level of success.

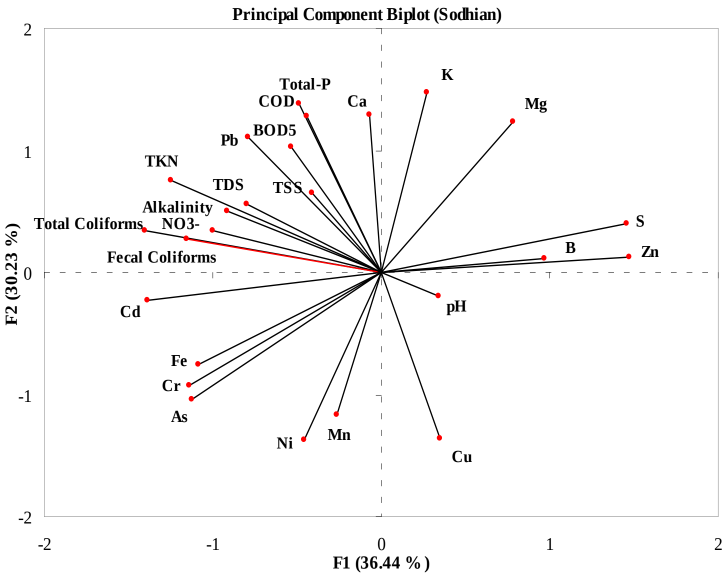

Fig. 9. Principal Component Biplot for Sodhian

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