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ORIGINAL ARTICLE

Physico-chemical and Bacteriological Quality Assessment of Groundwater Sources of Punjab, India

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ABSTRACT
The present study was undertaken to ascertain the quality of groundwater in Punjab, which has steadily declined in the recent years, due to overexploitation and heavy pollution. A total of 508 groundwater samples were collected from northern, central and southern regions of Punjab, and analyzed for various physico-chemical parameters and bacteriological contamination. Among the physico-chemical parameters, water samples were tested for pH, temperature, electrical conductivity (EC), total dissolved solids (TDS), turbidity, colour and dissolved oxygen (DO). Values for most of the investigated parameters exceeded the guideline values prescribed by WHO and BIS, and showed significant correlation with each other. The bacteriological quality of water was examined using Most Probable Number by enumerating total coliform and faecal coliforms. Out of the total samples analyzed, 179 (35.2%) samples proved to be fit for consumption, whereas 329 (64.7%) samples were found unfit. The data collected highlights the poor quality of ground water in Punjab, and the urgent need for implementing control measures to prevent its further deterioration.
Keywords: Groundwater, Punjab, Physico-chemical parameters, Coliform bacteria, Most Probable Number

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INTRODUCTION

Water quality is an index of health and plays a vital role in the sustenance of life and preservation of good health. Among various freshwater resources existing, groundwater offers a significant part of the total supply for domestic, industrial and agricultural sectors in numerous countries [16]. It is an essential resource for millions of people for both drinking and irrigation purposes [8]. Quality of water is chiefly influenced by pollutants generated from excessive application of fertilizers and pesticides; and, indiscriminate discharge of effluents from industries and sewage [11]. Human activities as well as geochemical reactions occurring in water cause significant changes in physico-chemical properties, such as pH, total dissolved solids, colour, turbidity, electrical conductivity, dissolved oxygen, etc. These parameters are regarded not only as criteria for water quality assurance, but their undesirable levels may produce adverse effects on environmental and human health. The study of bacteriological contamination of water is of immense significance in pollution studies, since it provides a direct measurement of the harmful effects of pollutants on human health [19]. Recurrent epidemics of gastroenteritis in India and other tropical countries have lead to substantial number of morbidity and mortality cases [13]. The indicator organisms currently used for the monitoring of drinking water in developed countries are total coliforms, faecal coliforms and/or E. coli [10].

Punjab, a north-western state in India, is predominantly dependant on its groundwater resources for irrigation and domestic activities. Protection of this valuable resource demands safeguarding groundwater quality against undesirable contamination due to disposal of municipal waste water and the increasing use of agrochemicals, fertilizers with their discharge in aquifers. There have been numerous research studies assessing physico-chemical and bacteriological quality of groundwater in Punjab [8, 16, 17]; however, these studies were limited to fewer districts. Considering the deteriorating quality of

groundwater in the state, this study was based on monitoring the physico-chemical and bacteriological parameters of groundwater from all the districts in Punjab, which may be valuable in implementing appropriate remedial measures for preventing drinking water contamination and for providing safe supply to the general public.

MATERIAL AND METHODS

Punjab, the land of five rivers, is located at the northwest end of India, between 29° 30'N to 32° 32'N latitude and 73° 55'E to 76° 50'E longitude. It marks a clear demarcation of India from the neighboring country of Pakistan. At present, there are 22 districts in the state of Punjab with a total area of 50,362 square kilometers divided into northern, central and southern regions (Agro-climatic Regional Planning, ACRP in India), contributing around 1.54% of the total geographical area of the country. In this study, a total of 508 groundwater samples were collected from northern, central and southern regions of Punjab. Samples were collected from all the districts in the state, and selection of tehsils and villages from each district was done randomly using Survey tool box. Water samples were collected in pre-cleaned polyethylene bottles and in sterilized glass bottles for physico-chemical and microbial analysis, respectively.

The pH, temperature, conductivity and DO were analyzed in-situ, while the remaining parameters were analyzed in the laboratory as per standard methods [4]. In order to ensure that the analysis was reliable and reproducible, blank, standard and pre-analyzed samples were analyzed after every 10 samples [9].

Bacteriological characteristics of the water samples were determined using multiple tube fermentation method (Most Probable Number) for enumeration of total coliforms and faecal coliforms based on U.S. Environmental Protection Agency (USEPA) method 8001. Suspected colonies of coliform groups were also identified based on morphological, cultural and biochemical characteristics.

All the statistical analysis was carried out using Microsoft Excel and SPSS (Special Package for Social Science) Microsoft version 21 for windows.

RESULTS AND DISCUSSION

Groundwater quality assessment for physico-chemical parameters was carried out to determine its suitability in terms of drinking purposes, and a correlation was determined among various parameters. Samples were examined for pH, temperature, electrical conductivity (EC), total dissolved solids (TDS), turbidity, colour and dissolved oxygen (DO) (Table. 1). In addition, bacteriological quality of water was also assessed for the presence of total coliforms (TC) and faecal coliforms (FC). All the parameters were compared with the guideline values prescribed by World Health Organization [20] and Bureau of Indian Standard [3].

Physico-chemical analysis

The mean values of pH in groundwater samples varied from 7.23 to 7.83, indicating a slightly alkaline nature. Lowest mean values were observed in samples from districts Amritsar and Gurdaspur, whereas highest mean value was observed in samples from Bathinda. Shah *et al.,* [15] also reported higher pH values in groundwater samples collected from Guru Nanak Dev Thermal Colony (7.85±0.37) and National Fertilizer Limited (7.73±0.12), Bathinda, Punjab. According to the WHO and BIS guidelines, pH values for drinking water range from 6.5 to 8.5, and pH outside this range may cause a nutritional imbalance or may contain toxic ions. The mean values for all the samples in this study were found within the prescribed range.

The temperature of water samples at the time of the analysis showed high variations, with samples from districts SAS Nagar and SBS Nagar reporting the lowest temperature of 15.83°C and samples from district Moga reporting the highest temperature of 38.17°C. The variation in water temperature may be due to different timing of collection and the influence of season [7].

The mean electrical conductivity values during the study ranged from 465.90 to 1097.88 µS/cm, from districts Kapurthala and Faridkot, respectively. High EC may be attributed to high salinity and mineral content in the sampling area. Similar values of EC were reported in Punjab by Singh *et al.,* [17]. Mukhopadhyay and Mukherjee [12] reported EC values ranging between 1230.70 to 1466.68 micromohs/cm in groundwater samples of Tamla Nala, Durgapur, West Bengal, suggesting the presence of high amount of dissolved inorganic substances in the area.

Total dissolved solids (TDS) are a measure of dissolved matter (salts, organic matter, minerals, etc.) in water. Inorganic constituents comprise most of the total concentration of TDS. In this study, water samples from district Kapurthala showed the lowest mean value of 233.15 mg/L and Faridkot reported the highest mean value of 548.81 mg/L. Groundwater from districts Bathinda and Faridkot, with mean

TDS values of 540.77 and 548.81mg/L, respectively, exceeded the acceptable limit of 500 mg/L prescribed by BIS. Total dissolved solids are considered a secondary drinking water standard, and do not have a significant impact on human health. However, water with higher TDS values reduces palatability, along with gastro-intestinal irritation and laxative effect [14].

In the present study, the turbidity of water samples were measured in Nephlometric turbidity unit (NTU) and mean values ranged between 0.32 to 7.05 NTU, from districts Pathankot and Rupnagar, respectively. The WHO and BIS recommended acceptable limit and maximum permissible limit for turbidity is 1 NTU and 5 NTU, respectively. Out of 22 districts investigated, mean values from most of the districts were within the acceptable limit, except samples from districts Amritsar, Bathinda, Faridkot, Fazilka, Ludhiana, Mansa and Tarn Taran. Moreover, samples from Rupnagar were comparatively more turbid with mean value exceeding the prescribed permissible limit of 5 NTU.

The study reported mean values for colour varying from 0.69 to 20.86 Hazen unit in samples from districts Pathankot and Rupnagar, respectively. Mean values from districts Bathinda, Faridkot, Hoshiarpur, SBS Nagar and Tarn Taran were found to exceed the acceptable limit of 5 Hazen unit, whereas, Rupnagar exceeded the permissible limit of 15 Hazen unit, prescribed by BIS. No health-based guideline value is proposed for colour in drinking water by WHO.

Dissolved oxygen in groundwater samples varied between 1.20 mg/L to 3.83 mg/L, from districts Bathinda and Muktsar, respectively. No health-based guideline value is recommended by WHO; however, Central Pollution Control Board [4] prescribes DO of 6 mg/L or more, in drinking water source without conventional treatment but with chlorination. Results revealed that that the groundwater quality with respect to DO was not suitable for drinking purpose since all samples reported very low DO. Heavy contamination by organic matter is chiefly associated with lower DO. Similar observations were reported by Das *et al.,* [5], in groundwater samples from Tripura. Findings of the present study were in agreement with Majagi *et al.,* [11], who revealed DO values ranging between 2.0 to 3.6 mg/L in Gulbarga district, Karnataka.

Statistical analysis

Correlation matrices among physico-chemical parameters of water were determined where in a statistically significant correlation was observed between various parameters indicating a close association with each other (Table 2). The pH showed negative but significant correlation with turbidity ($r = - 0.159$, $p < 0.01$), whereas, temperature had a non-significant effect on EC, TDS and DO but exhibited a significant negative effect on colour ($r = -0.172$, $p < 0.01$) and turbidity ($r = -0.134$, $p < 0.01$). EC showed a strong correlation with TDS ($r = 0.996$, $p < 0.01$), colour ($r = 0.293$, $p < 0.01$) and turbidity ($r = 0.166$, $p < 0.01$). Colour and turbidity also exhibited a strong correlation with each other ($r = 0.862$, $p < 0.01$). On the contrary, DO was negatively and significantly affected by EC ($r = - 0.309$, $p < 0.01$), TDS ($r = - 0.314$, $p < 0.01$), colour ($r = - 0.374$, $p < 0.01$) and turbidity ($r = - 0.262$, $p < 0.01$). In this study, a close association was found between EC and TDS. Similar results were reported by Ravindra and Garg [14], showing a strong correlation existing between the two parameters ($r = 0.93$, $p < 0.01$).

Bacteriological analysis

Bacteriological examination of groundwater samples revealed highest contamination in samples from central Punjab, followed by southern and northern Punjab with percent total coliform (TC) and percent faecal coliform (FC) as 67.7 and 61.1%; 60.6 and 50.3%; 64.6 and 55.7%, respectively. According to WHO and BIS, there should be no detectable TC or FC bacteria in 100 mL sample. Out of 508 samples examined, 179 (35.2%) samples proved to be fit for consumption, whereas 329 (64.7%) samples were found unfit. District Ludhiana reported the highest microbial pollution in groundwater with 88.4% and 83.7% samples containing TC and FC, respectively. High MPN values in the samples clearly indicate that the groundwater was heavily contaminated with coliform bacteria, indicative of sewage contamination, which may be a significant public health concern. These results corroborate with the findings of Barman *et al.,* [2] who reported occurrence of coliforms in groundwater samples from Guwahati city, Assam. Similarly, Abdul *et al.*, [1] evaluated the quality of municipal tap water in Bholakpur locality, Hyderabad, and reported presence of coliform bacteria in all water samples. Groundwater contamination is primarily caused by leaching of waste water from landfill areas into the aquifers [6].

Escherichia coli are a major constituent of the normal human intestinal flora and most varieties are regarded as harmless to human health. They are considerably shed in the environment and contaminate water bodies, due to poor sanitation and ignorance towards personal hygiene. In this study, 72 (14.17%) samples were identified as having *Escherichia coli,* based on the appearance of typical colonies with greenish metallic sheen on Eosin Methylene Blue (EMB) agar and biochemical characteristics based on IMViC test. Suthar *et al.,* [18] also observed occurrence of coliforms in drinking water from northern

Rajasthan, and reported *E. coli* prevalence rate of 20.43%, suggestive of the declining water quality of the region.

Since groundwater is a vital source of drinking water in Punjab, this study helps in highlighting its deteriorating quality, which may have a tremendous impact on the health of its population. The continuous consumption of such polluted water could pose serious health conditions, especially in infants that are extremely vulnerable to infections. Therefore, there is a need for effective regulation of water quality, along with regular monitoring of groundwater with special attention being given to municipal waste management and proper maintenance of bore wells, hand pumps and tube wells.

Table 1: The statistical analysis of physico-chemical parameters in groundwater samples of northern, central and southern regions of Punjab

	Districts	pH	Temp (°C)	EC (µS/cm)	TDS (mg/L)	Turbidity (NTU)	Colour (Hazen unit)	DO (mg/L)
Northern Punjab	Gurdaspur (N= 25)	[a] 6.84-7.78 [b]7.23±0.28	25.8-34.6 29.71±3.61	171-1323 612.80±277.26	86-662 300.72±136.86	0.21-1.52 0.48±0.29	0-8 1.68±1.84	2.18-3.54 2.67±0.36
	Hoshiarpur (N= 26)	6.09-8.17 7.30±0.44	15.6-32.5 24.52±7.19	175-1388 524.38±282.76	88-694 266.08±140.45	0.24-6.26 0.93±1.33	0-59 6.15±13.59	1.53-3.41 2.53±0.50
	Pathankot (N= 13)	6.81-7.92 7.29±0.31	18.4-34.2 29.76±6.51	219-1207 590.62±255.16	109-603 296.54±127.18	0.20-0.56 0.32±0.10	0-2 0.69±0.75	2.09-3.61 2.88±0.45
	Rupnagar (N= 21)	6.14-8.46 7.27±0.49	15.6-16.3 15.95±0.20	188-1225 565.62±352.81	94-612 282.81±176.30	0.35-42.00 7.05±12.90	1-94 20.86±34.18	1.59-3.26 2.47±0.41
	SAS Nagar (N= 22)	7.13-7.88 7.47±0.23	15.4-16.1 15.83±0.18	286-1054 609.91±218.40	143-527 297.86±106.83	0.21-1.48 0.42±0.26	0-10 2.77±2.52	2.10-3.29 2.58±0.38
	SBS Nagar (N= 22)	6.70-7.72 7.41±0.21	15.4-16.3 15.83±0.29	190-1225 661.95±250.29	95-614 330.91±125.26	0.21-1.94 0.64±0.46	0-32 7.91±8.22	2.04-3.42 2.54±0.42
Central Punjab	Amritsar (N= 23)	6.81-7.68 7.23±0.22	24.1-31.9 26.93±3.58	319-1586 691.87±357.30	159-793 344.30±179.13	0.20-9.56 1.30±2.32	0-9 2.39±2.48	2.06-3.69 2.80±0.49
	Tarn Taran (N= 22)	6.81-8.39 7.64±0.35	24.5-25.0 24.81±0.16	216-1792 737.32±390.59	108-896 368.68±195.38	0.21-20.90 2.19±4.54	0-43 11.95±12.94	1.95-3.52 2.59±0.37
	Jalandhar (N= 23)	7.20-8.14 7.66±0.25	24.0-34.2 25.41±3.03	281-947 550.04±185.35	141-473 275.13±92.69	0.28-4.17 0.75±0.89	0-12 2.43±2.90	2.19-3.62 2.69±0.35
	Districts	**pH**	**Temp (°C)**	**EC (µS/cm)**	**TDS (mg/L)**	**Turbidity (NTU)**	**Colour (Hazen unit)**	**DO (mg/L)**
Central Punjab	Kapurthala (N= 20)	7.55-8.40 7.77±0.20	24.2-24.5 24.35±0.10	352-623 465.90±84.99	176-311 233.15±42.25	0.33-4.98 0.73±1.01	0-28 3.00±6.10	2.03-3.52 2.68±0.41
	Ludhiana (N= 43)	6.85-8.01 7.34±0.23	19.7-34.2 26.77±5.28	392-1960 634.21±325.96	197-981 317.77±166.55	0.18-15.23 1.03±2.25	0-32 4.81±7.24	1.59-3.62 2.65±0.46
	Fatehgarh Sahib (N= 23)	6.98-8.42 7.52±0.33	23.8-25.8 25.09±0.49	312-1257 593.00±258.07	157-628 296.87±128.67	0.21-2.21 0.75±0.58	0-19 3.30±4.47	1.62-3.48 2.66±0.50
	Patiala (N= 23)	7.12-8.12 7.53±0.26	24.2-25.0 24.72±0.18	385-1573 617.52±259.26	192-787 309.17±129.71	0.24-2.53 0.66±0.51	0-22 3.57±4.84	1.99-3.42 2.53±0.38
S	Barnala (N= 29)	6.76-8.64 7.50±0.36	31.9-33.2 32.724±0.36	213-1494 743.14±342.22	106-752 371.90±171.02	0.13-2.23 0.61±0.57	0-28 3.97±6.48	1.39-3.31 2.37±0.4

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	Sangrur (N= 23)	7.07-7.80 7.39±0.20	24.3-34.1 31.55±2.28	412-1394 614.00±231.75	204-679 306.26±113.38	0.18-1.83 0.56±0.41	0-12 2.35±2.74	1.75-3.21 2.60±0.40
	Moga (N= 23)	7.25-7.83 7.51±0.16	37.9-38.4 38.17±0.16	298-1223 683.91±233.20	149-610 340.87±114.83	0.18-3.51 0.72±0.94	0-18 3.22±4.63	1.94-3.64 2.78±0.42
	Bathinda (N= 30)	7.18-8.68 7.83±0.43	17.2-33.1 19.02±4.75	192-3470 1082.91±862.83	96-1735 540.77±430.34	0.36-6.98 1.33±1.46	1-19 7.03±4.83	1.20-2.84 2.33±0.36
	Mansa (N= 23)	7.04-8.18 7.66±0.34	17.0-17.5 17.24±0.12	245-1656 885.52±382.09	122-831 442.65±191.76	0.29-4.89 1.68±1.62	1-9 4.84±2.88	1.25-3.51 2.59±0.46
	Faridkot (N= 16)	7.16-8.05 7.55±0.33	31.7-34.2 32.57±0.88	239-4863 1097.88±1258.37	120-2431 548.81±628.57	0.30-8.40 1.74±2.37	0-42 11.19±13.10	1.36-2.89 2.21±0.35
	Districts	**pH**	**Temp (°C)**	**EC (µS/cm)**	**TDS (mg/l)**	**Turbidity (NTU)**	**Colour (Hazen unit)**	**DO (mg/l)**
Southern Punjab	Ferozepur (N= 16)	6.69-7.81 7.36±0.33	28.7-34.3 32.88±1.77	239-3020 787.19±700.64	120-1050 365.44±260.07	0.23-3.33 0.89±0.97	0-15 3.19±4.84	2.23-3.54 2.91±0.42
	Muktsar (N=21)	7.24-8.22 7.56±0.27	33.2-33.7 33.43±0.14	130-1804 568.35±346.54	65-902 282.76±174.09	0.25-2.26 0.76±0.61	0-9 2.76±2.30	2.16-3.83 2.72±0.50
	Fazilka (N= 21)	7.38-8.29 7.69±0.23	33.2-33.6 33.39±0.12	339-1479 842.05±326.83	170-739 421.48±163.21	0.30-3.82 1.24±0.99	0-15 4.52±3.81	2.16-3.82 2.56±0.41

N=Number of sampling sites in each district; [a] Range; [b] mean ± std. deviation

NTU: Nephlometric turbidity unit

Table 2: Correlation matrix for physico-chemical parameters

	pH	Temp	EC	TDS	Colour	Turbidity	DO	Mean	Std Dev
pH	1.000	-0.079	-0.038	-0.035	-0.097*	-0.159**	-0.050	7.491	0.350
Temp		1.000	-0.038	-0.042	-0.172**	-0.134**	0.058	26.190	6.945
EC			1.000	0.996**	0.293**	0.166**	-0.309**	722.77	616.414
TDS				1.000	0.297**	0.167**	-0.314**	360.52	306.329
Colour					1.000	0.862**	-0.374**	5.22	10.318
Turbidity						1.000	-0.262**	1.201	3.247
DO							1.000	2.602	0.445

*.Correlation is significant at the 0.05 level (2-tailed)

**. Correlation is significant at the 0.01 level (2-tailed)

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