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Evaluating the effect of landfill leachate on groundwater quality in relation to physicochemical and bacteriological characteristics

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ABSTRACT

Physico-chemical and microbiological parameters were analyzed in leachate affected groundwater samples obtained at different locations viz. Bhanpor District, Union Carbide Area, Shivnagar, Mohali village, Peoples Group Colony and Nishatpora. during December, 2008 to May 2009 in order to assess the impact of leachate percolation on groundwater quality in District, Bhopal (M.P). Different physico-chemical parameters (pH, Total Dissolved Solids, Electrical Conductivity, Dissolved Oxygen, Free Carbon dioxide, Alkalinity, Chloride, Total Hardness and Biological Oxygen Demand) and bacteriological parameters (Total Coli form, Fecal Coli forms and Fecal Streptococci) were analyzed using standard methodology in each of the collected samples. Total dissolved solids (TDS), electrical conductivity (EC), and Na^+ exceeded the World Health Organization (WHO) tolerance levels for drinking water in 62.5%, 100%, and 37.5% of the groundwater samples respectively with pH and Fe exceeding WHO limits in 75% of the samples. Our results suggest the altered Physico-chemical and bacteriological parameters compared to the drinking water standards laid by Indian Council of Medical Research (ICMR) and World Health Organization (WHO). For example the electrical conductance was in the range of 980 – 1490 simens. A good number of samples are also showing significant amount of organic matter that provides nutrition for the growth and multiplication of microorganisms, thus not fit for drinking purpose. Thus it was concluded that most of the water samples were non-portable for human beings due to high concentration of one or the other parameter and some remedial measures are suggested to reduce further groundwater contamination via Leachate percolation, hence the present study demands for proper management of wastes in Bhopal.

Key Words: Landfill site, Leachate, Ground water Quality, Physiochemical characteristics, Bacteriological parameters, Health risk.

INTRODUCTION

Municipal solid waste (MSW) disposal is a global concern, most especially in developing countries across the world, as poverty, population growth and high urbanization rates combine with ineffectual and underfunded governments to prevent efficient management of wastes [1,2]. Landfilling is the simplest, cheapest and most cost effective method of disposing of waste in both developed and developing nations of the world. However, in most developed nations there has been a reduction in the number of landfills as well as the amount of MSW landfilled over the years. There is a common misconception that since the materials placed in MSW landfills are basically household wastes, they are relatively "safe" and would not likely adversely affect public health and groundwater quality. One need only consider the proposition of drinking the ooze that develops at the bottom of a garbage can or the water used to clean a garbage can to understand that it is not desirable to have municipal solid waste leachate in one's drinking water. Even adding a drop of such garbage-can-derived liquid to a glass of drinking water, i.e., highly diluted leachate, would not be considered desirable. Yet this is what happens when municipal solid waste landfill leachate is allowed to contaminate water that is or could be used for domestic supply. A similar comparison can be made with regard to construction and demolition debris and rubble (sometimes classified as inert wastes) that some try to advocate as "safe" for land burial with minimal restriction. Wastes placed in landfills are subject to either groundwater underflow or infiltration from precipitation and as water percolates through the waste, it picks up a variety of inorganic and organic compounds, flowing out of the wastes to accumulate at the bottom of the landfill. The resulting contaminated water is termed 'leachate' and can percolate through the soil [3]. Municipal landfill leachate are highly concentrated complex effluents which contain dissolved organic matters; inorganic compounds such as ammonium, calcium, magnesium, sodium, potassium, iron, sulphates, chlorides and heavy metals such as cadmium, chromium, copper, lead, zinc, nickel; and xenobiotic organic substances [4, 5].

Leachate varies widely in composition depending on many interacting factors such as the composition and depth of waste, availability of moisture and oxygen, landfill design, operation and age [6]. Leachate composition is primarily a function of the age of the landfill and the degree of waste stabilization. The stabilization of waste is suggested to proceed in five sequential or distinct phases [7] and the rate of progress through these stages is dependent on the physical (availability of free oxygen), chemical and microbiological conditions developing within the landfill with the passage of time [8]. Historically, water bodies have been the main center for the development of human settlement indicating that water is an essential commodity for life. In the beginning water from these resources was clean and too portable. But in due course of time, due to population explosion, heavy industrialization and excessive use of fertilizers and pesticides water gets drastically polluted especially ground water [9,10]. As per the future prediction, the amount of waste generated around the world which stands at 12.7 billion tones in 2000 will be increase to approximately 19 billion tonnes in 2025 and to approximately 27 billion tones in 2050 (Report of Ministry of Environment, Japan, 2006). Asia, in particular, will see especially dramatic increases in the amount of waste generated. Furthermore, the municipal solid waste(MSW) generation amount in India, which was 0.46 kg per person per day in 1995 expected to grow to 0.7 kg per person per day by 2025 (Source: Secretariat of the Basal Convention). The amount of MSW generation rate both in terms of per day and per capita basis for the seven most important metros are shown in Fig. 1 [11-13]. Moreover, the collection, transportation and disposal of MSW are unscientific and chaotic in India [14]. Nearly all the Indian cities dispose off their waste simply by dumping and the environment friendly way of disposal like composting, incineration constitutes only about 9% [15,16]. If this big amount of MSW will not be managed properly, it will have a severe impact on environment. The waste management policies and strategies are still struggling with the conflicts arising between developmental and environmental goals. The draft National Environmental Policy of 2005, which incorporates the concept of the 3Rs, is currently under consideration (MoEF, India). The ever increasing demand for larger space for the disposal of domestic and industrial wastes generated from urban areas makes landfill site a necessary component of the urban life cycle. These low-lying disposal sites, being devoid of a Leachate collection system, landfill gas monitoring and collection equipment, can hardly be called sanitary landfills and are the potential threat for water resources, especially groundwater. The pollution threat becomes more important in regions where fractures or weak zones are present either just beneath the landfill or in its surrounding area.The impact of landfill sites on groundwater has been attempted by different workers in different perspectives [17-25]. Most of the works cited above are focused on assessing the pollution risk to groundwater due to landfill by using invasive as well as non-invasive methods. In view of lack of proper documentation on the characteristics of the waste, investigations on landfill become a very difficult task. In their study landfill sites have proved as a potential probable cause for the nitrate contamination in the groundwater environment of National Capital Territory (NCT) – Delhi [26]. Dissolution of solid waste combined with rainfall produces a large quantity of polluted water in the form of leachate [27]. In Athena region the groundwater quality has been greatly affected by the leachates, since most of the parameters examined were found high in their concentrations [28]. Consequently number of cases of water born diseases has been seen which poses a serious threat to human health [29]. So, it becomes necessary to observe the demand and pollution level of ground water [30]. Several experimental studies on ground water quality analysis are regularly performed by different researchers and scientists across the world [31-33]

In connection to this, the present experimental work is an attempt to examine the effect of landfill on groundwater quality with respect to physico chemical and bacteriological parameters, with special reference to Bhopal (M.P).

EXPERIMENTAL SECTION

Sample Collection:
A random sampling method was employed to collect the ground water samples during December, 2008-May 2009 with due consideration to represent land use pattern, topography and areas close to dumping site. The locations selected for sampling are; Bhanpor District, Union Carbide Area, Shivnagar, Mohali village, Peoples Group Colony and Nishatpora. The samples for physicochemical analysis were collected in sterilized plastic canes while as samples for bacteriological analysis were collected in sterilized microbiological glass bottles.

Physicochemical analysis:
In order to observe the variation in quality of water due to landfill leachate, the samples collected from hand pumps in air tight sterilized plastic canes were subjected to analysis of major physicochemical water quality parameters like temperature, Electrical conductivity (EC), pH, Total dissolved solids (TDS), Dissolved Oxygen (DO), Free Carbon dioxide, Alkalinity, Chloride, Total hardness, Calcium Hardness, Magnesium Content and Biological Oxygen Demand (BOD) as per the methods of assessment of ground water quality described in "Standard Methods for the examination of Water and Waste water, American Public Health Association [34]. The pH, EC, TDS and Temperature were recorded on site with digital pH meter, digital EC meter, digital TDS meter and digital thermometer respectively. For the analysis of biological oxygen demand (BOD), 250 ml capacity BOD bottles were used for the collection of samples and dissolved oxygen was fixed on site. The dissolved oxygen and BOD was estimated by Azide modification of Wrinkler method [34]. The free CO_2, Alkalinity, Chloride, Total hardness, Calcium hardness and Magnesium content were analyzed by titrimetric method [34].

Bacteriological Parameters:
For the analysis of bacteriological examination, the water samples were collected in air tight sterilized glass bottles and were immediately brought to the laboratory. These samples were then kept in refrigerator at temperature below 4^0C until analyzed [34]. For bacteriological examination Total coliform, Fecal coliform and Fecal streptococci organisms were studied by using the standard multiple tube dilution tests for the estimation of number of coliform groups and Streptococcus groups [34, 35].

RESULTS AND DISCUSSION

A total of 36 ground water samples from different hand pumps and tube wells, used by the people residing in close vicinity of landfill site of Bhanpur, Bhopal city (M.P) were collected in clean plastic canes and sterilized bacteriological bottles and were brought to laboratory for analysis [36, 34, 35]. The data revealed that there were considerable variations in the examined samples from different sources with respect to their physicochemical and bacteriological characteristics and indicated that quality of ground water considerably varies from location to location. The under ground water of the selected areas is characterized by a constant temperature range of about 18^0 C to 24^0 C and the highest temperature was recorded in People's Group Colony of the range of about 25^0C (Fig.-1).

The electrical conductance was highest in water samples of Union Carbide Area, Shivpora, Mohali Village Bhanpur District, Bhopal (M.P) of the range of about 980 – 1490 simens (Fig.-2). It is well known that electrical conductance of water increases with salts. Total dissolved solids and conductivity can be used to delineate each other and conductivity is proportional to the dissolved solids.

In the present study, pH variation is brought about by the organic matters that find assess to aquifers when it moves along with interior water land surface. The pH was found between the range of 6.0 – 8.0 and the desirable limit for drinking water is 6.5 –8.5 (Fig.-3). Beyond this limit water can affect the mucous membrane in human body [30]. Therefore the results indicate that most of the water samples showed the pH within the desirable range of portable water.

The water samples from Union Carbide area were found to possess TDS value in the range of 650-1180 ppm, whereas the TDS value was found to be low for the water samples collected from the Peoples Group Colony and Nishatpora which indicate that the recharging of underground water through either rain water or by the water from nearby canals. The Shivnagar, Mohali village and Bhanpur area were found to contain TDS value of the range of about 650-1180 ppm (Fig.-4). These TDS values thus indicate the percolation of some solid wastes from the landfill site into the ground water.

Dissolved oxygen present in drinking water adds taste and it is highly fluctuating factor in water. It is of great importance to all living organisms and is considered to be the lone factor which to a greater extent reveals the nature of aquatic system even when information on other physical, chemical and biological parameter is not available [36]. In the present investigation, dissolved oxygen content varied in the range of 1.0 – 5.4 mg/l and the highest value was found at Bhanpur district (Fig.-5).

The free CO_2 dissolved in water is essentially the only source of carbon that can be assimilated and incorporated into the skeleton of the living matter of all the aquatic autotrophs and once fixed it can further be utilized by the organisms of other categories. In the present study free CO_2 at the Union Carbide Area, Bhanpur area, Mohali village and Shivpura was found between the range of 20-38 mg/l, while at Peoples Group Colony and Nishatpora the value was found between the range of 9-24mg/l (Fig.-6). These values also indicated the pollution of ground water.

In the present investigation pH value did not exceed 8.2 and therefore carbonate ions were absent. When either of the two ions (CO_3 or HCO_3) $_0$is absent the value of the remainder is equal to the total alkalinity. The alkalinity was found between the range of about 25 mg/l to 78 mg/l at Union Carbide area, Peoples Group Colony and Nishatpura, while at Bhanpur village, Mohali village and Shivpura, alkalinity lies between the ranges of 42-104 mg/l (Fig.-7). Therefore these values signify that there is percolation of industrial wastes which showed pollution of ground water. A significant presence of anions like chloride is also observed in the water samples under investigation. It has been observed that greater amount of anions in drinking water causes diarrhea. The chloride amounts in the samples range from 22 – 83.99 mg/l at Union Carbide Area. At Shivpora and Mohali Village the chloride value ranges from 85.99 – 174.99 mg/l. In the area of Bhanpur the chloride ranges from 94 – 195 mg/l. The maximum chloride value was found at the Peoples Group Colony and Nishat Pora, with the range of about 166 – 337.29 mg/l (Fig.-8). Here it is observed that the chloride content is much higher than permitted values of WHO and ISI which indicates the pollution of ground water of these selected sites.

The summation of calcium hardness and magnesium hardness is regarded as the total hardness of water. In the present investigation it has been observed that the magnesium concentration is two fold higher than that of calcium concentration at Union Carbide Area, Peoples Group Colony and Nishatpura. At theses sites, the Water samples has registered higher value of magnesium of the range of about 55.96-104.96 mg/l, 89.58-107.97 mg/l and 21.00-99.23 mg/l respectively and the lower values of calcium concentration of the range of about 21.20-41.21 mg/l, 15.97-20.18 mg/l and 15.91-20.15 mg/l respectively, while as at Shivpura, Mohali village and Bhanpur village, the values of calcium was too higher than that of magnesium content and the value of calcium at these sites was recorded between the range of about 23.54-70.64 mg/l, 23.54-70.64 mg/l and 23.44-71.16 mg/l respectively, while the magnesium content was recorded at the range of about 0.38-23.86 mg/l and 8.39-21.11 mg/l respectively (Fig.-9-11). The limiting values prescribed by ISI and WHO are much less than reported values which indicated much more pollution of heavy metals.

BOD approximates the amount of oxidized matter present in the solution and this parameter can be used to access the degree of pollution due to organic matter of human and animal origin. In the present investigation it has been found that higher BOD value was recorded in the water samples collected from Bhanpur and Mohali village with the range of about 0 mg/l- 1.1 mg/l which revealed that the water samples are polluted to some extent (Fig.-12).

Most of the water samples contain significant amount of organic matter that provides nutrition for the growth and multiplication of microorganisms. The present investigation has shown the values of the range of about 23-2400 of MPN coliforms per 100ml of water sample, while as the feacal coliform and feacal streptococci exhibit values below hundred per 100ml (Table 1), which indicates that most of the water samples contain microorganisms that indicates the contamination of ground water [34].

While there are some who attempted to minimize the contamination of groundwater by MSW landfill leachate of the type generated today, as large amounts of highly hazardous industrial chemicals are prohibited from being disposed off in municipal landfills, which is not based upon technical facts. Most monitoring programs measure only about 200 of the more than 60,000 chemicals in commerce today, many of which could be present in municipal solid waste. the chlorinate 2-phenoxypropionic herbicides are ubiquitous in MSW landfill leachates in the US[37]. There are likely to be many other potentially hazardous or other deleterious chemicals and are yet to be identified in MSW landfill leachate. It is therefore clear that today's society had not found all of the highly hazardous chemicals that can cause cancer (carcinogens), birth defects (teratogens), and mutations (mutagens) till date and these highly hazardous chemicals or hazardous transformational products that are now part of the non-conventional contaminants in MSW landfill leachate will be still found in the future.

Drinking water quality standards as recommended by BIS and WHO

	BIS standards		
Parameter*	Desirable	Max. permissible	WHO standards
Color	5	25	—
Odor	Unobjectionable	Unobjectionable	-
Taste	Agreeable	Agreeable	-
pH	6.5-8.5	6.5-8.5	6.5-9.2
TH	300	600	300
TA	200	600	500
TDS	300	1500	250
Cl^-	250	1000	200
SO_4^{2-}	250	400	50
NO_3^-	45	45	0.5
F^-	1.0	1.5	100
Ca^{2+}	75	200	150
Mg^{2+}	30	100	200
K^+	-	-	200
Na^+	-	-	1.5
nh_4^+	-		0.0
Phenol	-		0.3
B	-		0.3
Fe	-		

"Except pH and color (hazen unit) all unit are in mg L^{-1}

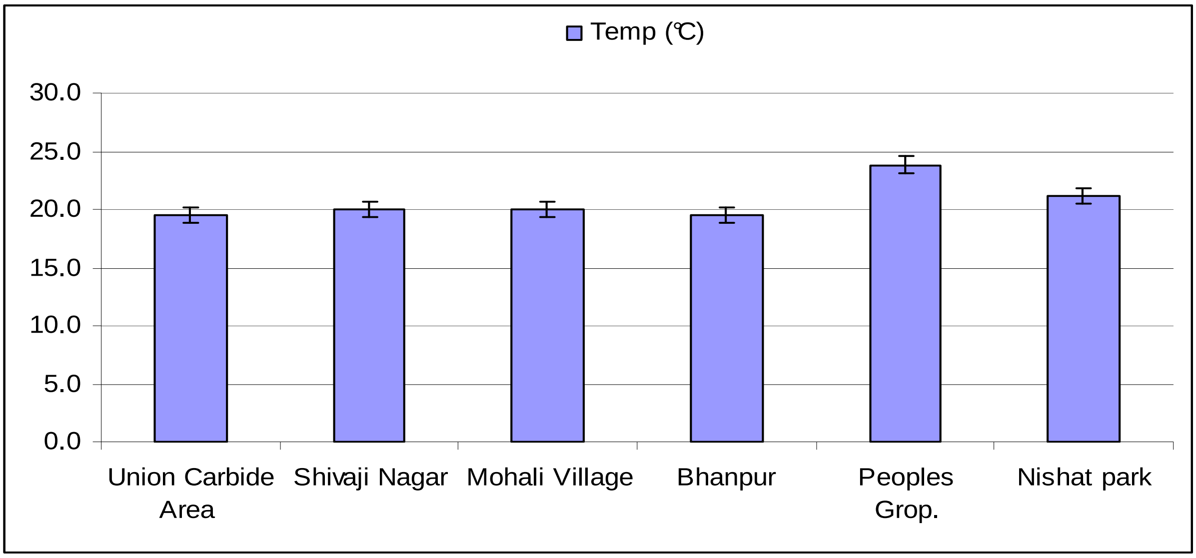

Fig 1: Samples from Different water bodies showing Temperature

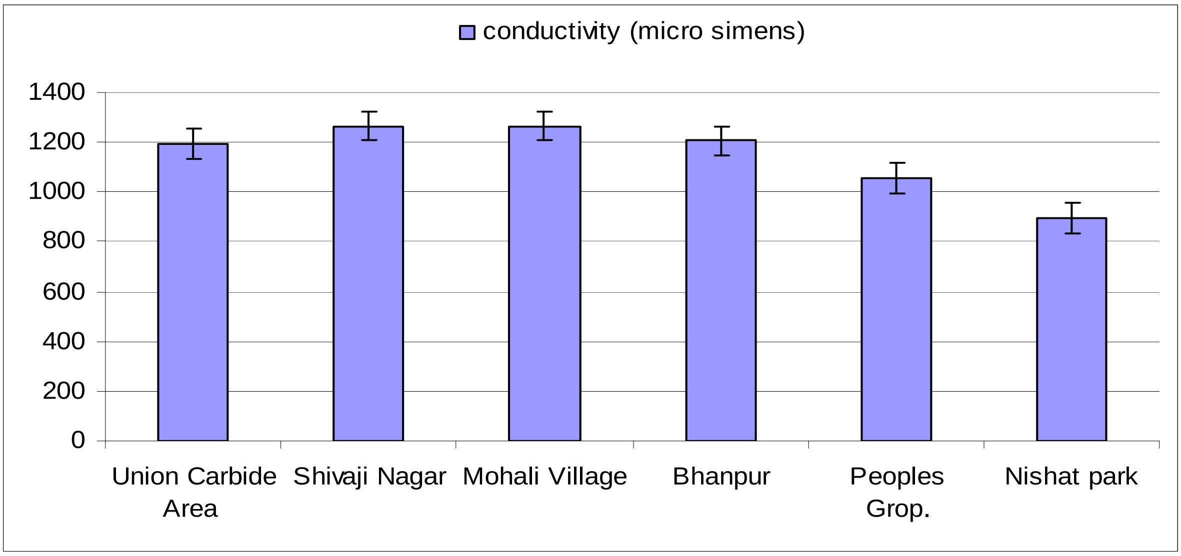

Fig 2: Samples from Different water bodies showing conductivity

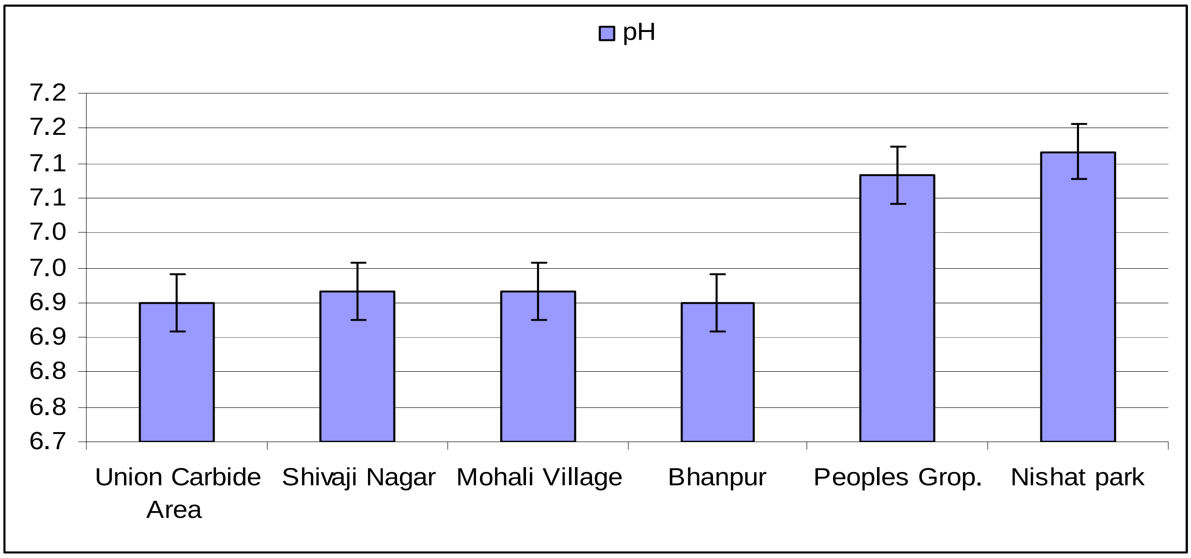

Fig 3: Samples from Different water bodies showing pH

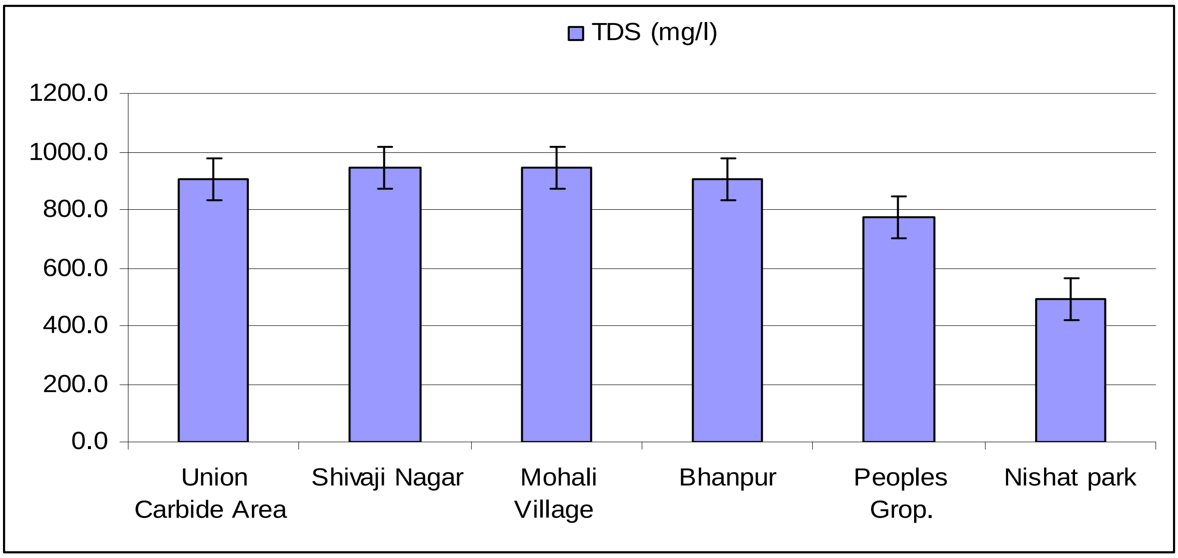

Fig 4: Samples from Different water bodies showing TDS

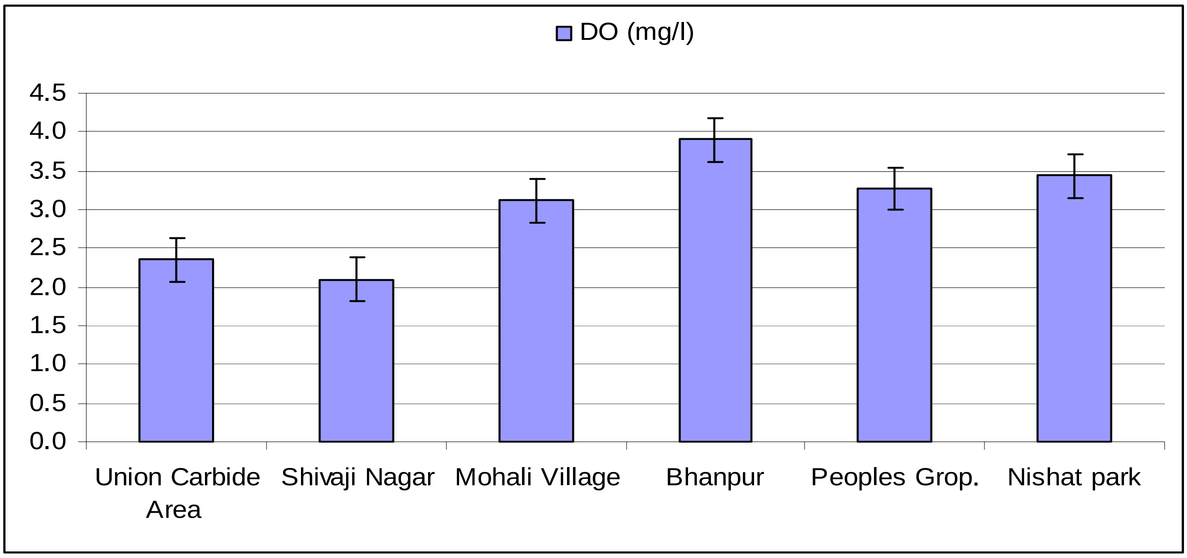

Fig 5: Samples from Different water bodies showing Dissolved oxygen

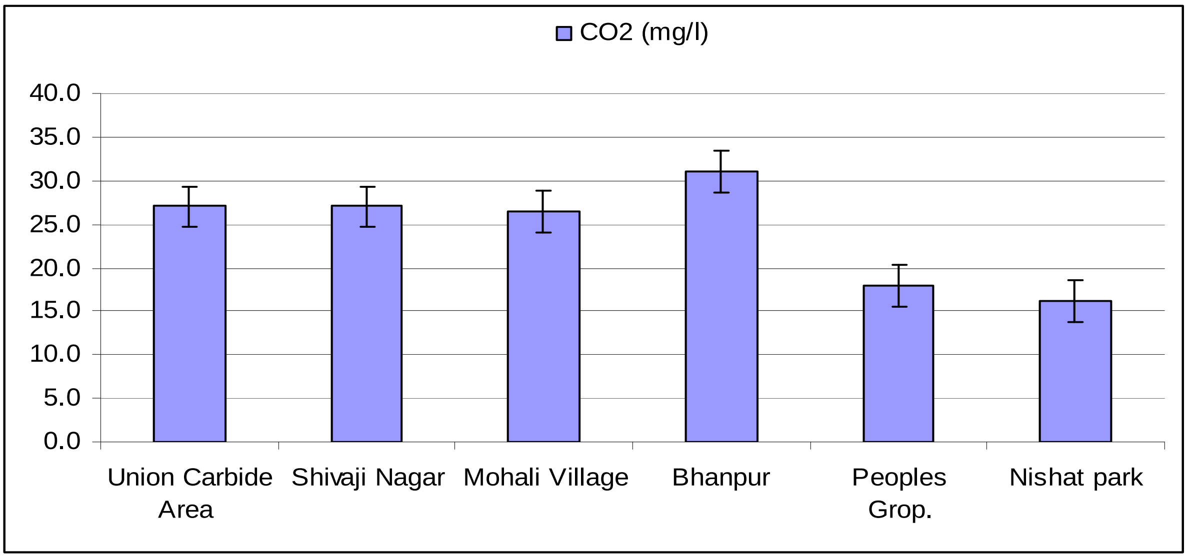

Fig 6: Samples from Different water bodies showing dissolved CO_2

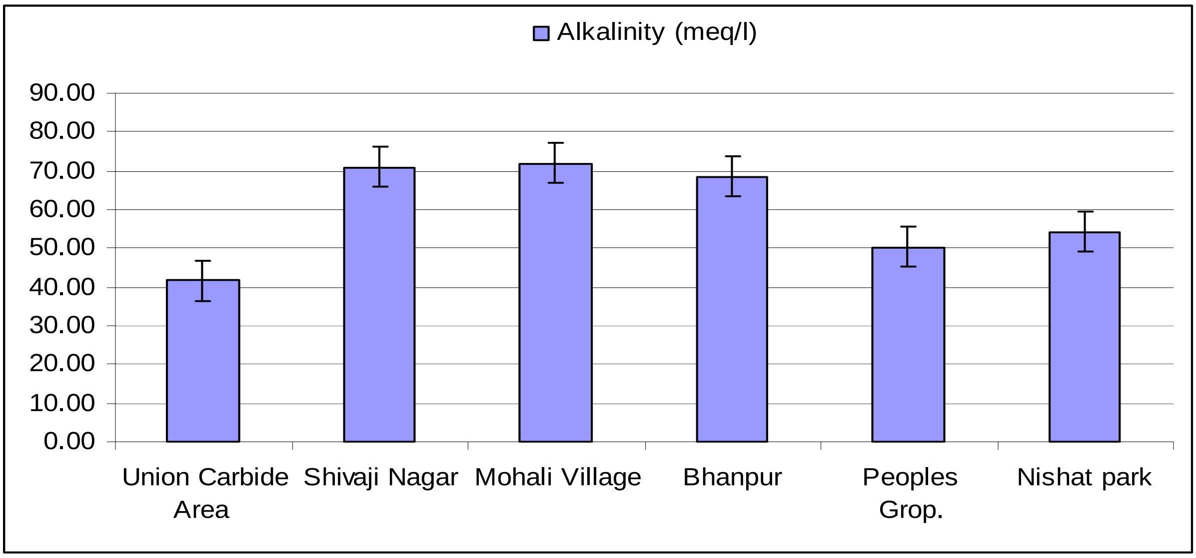

Fig 7: Samples from Different water bodies showing Alkalinity

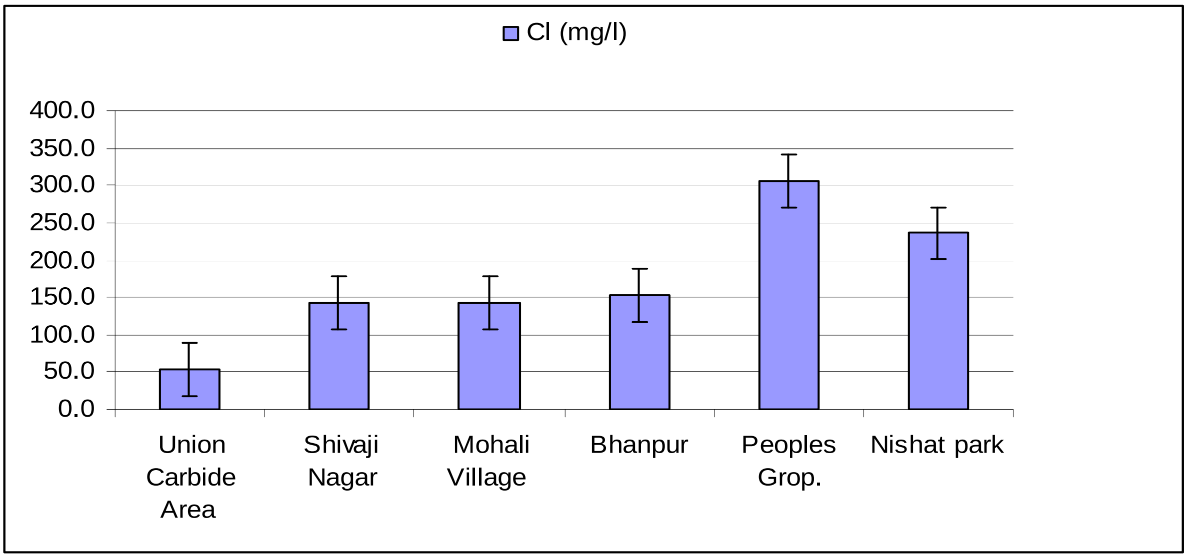

Fig 8: Samples from Different water bodies showing Chloride concentration

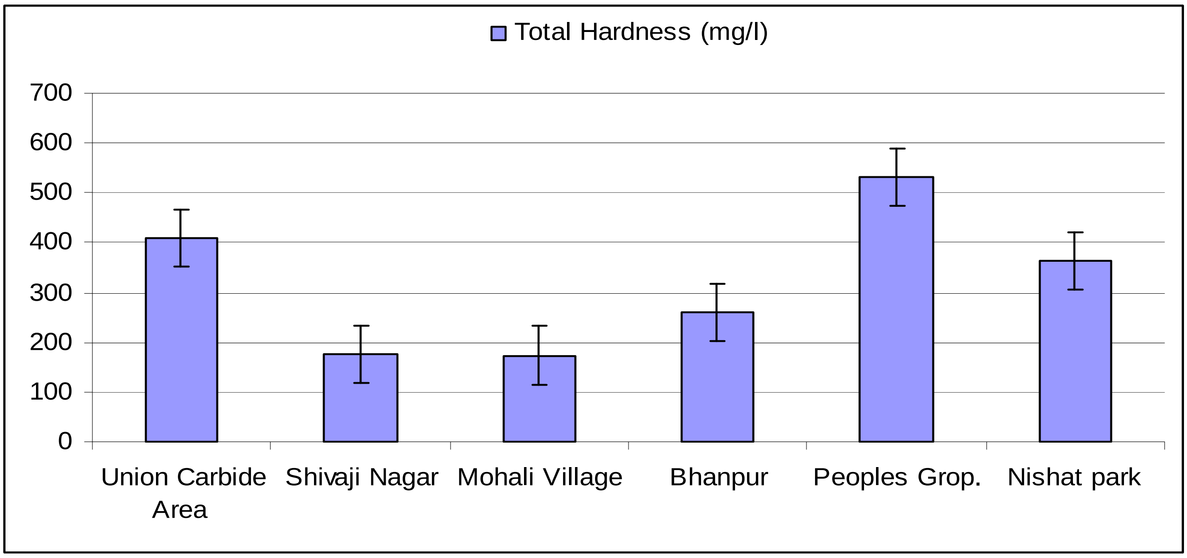

Fig 9: Samples from Different water bodies showing Total hardness in the form of Calcium content.

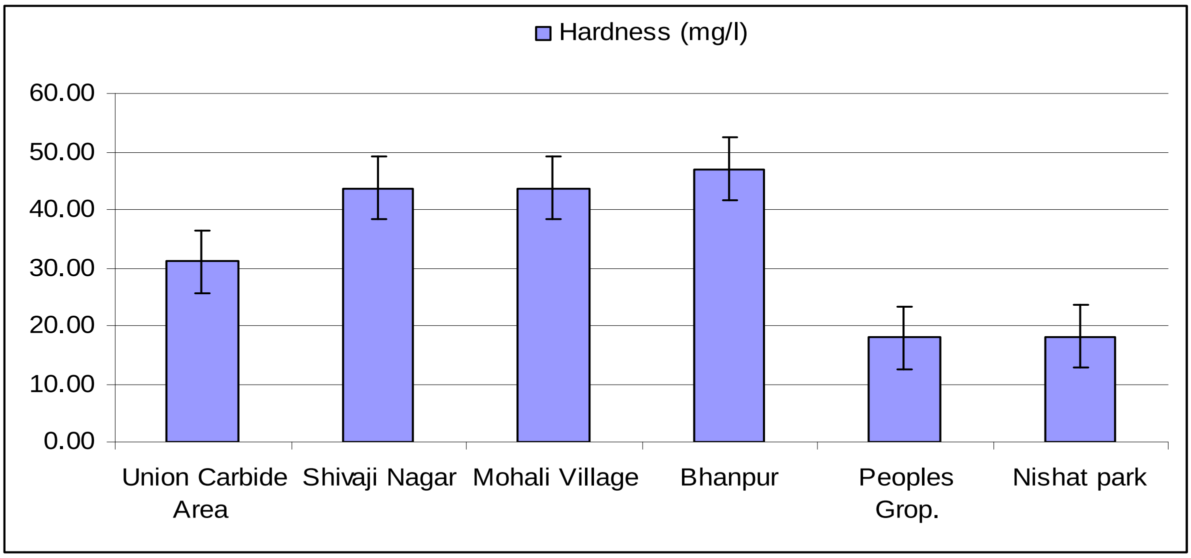

Fig 10: Samples from Different water bodies showing Hardness

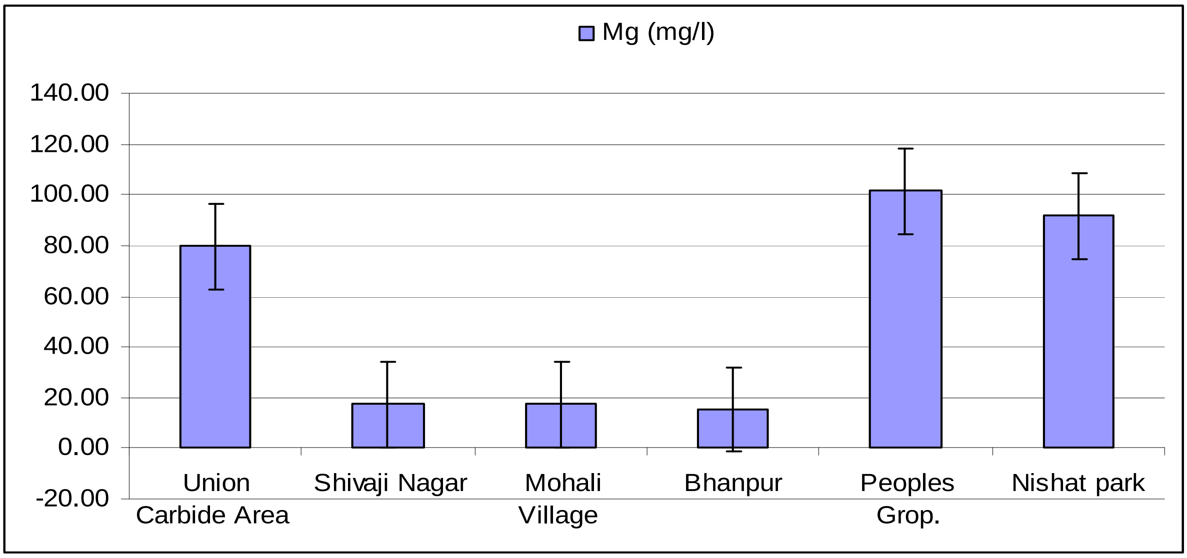

Fig 11: Samples from Different water bodies showing Magnesium content

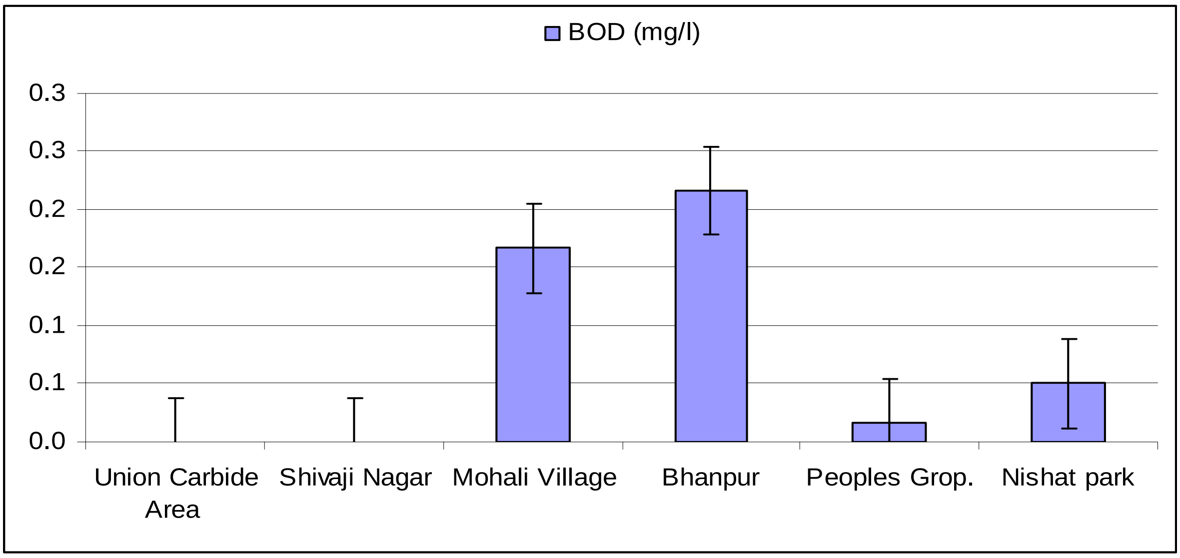

Fig 12: Samples from Different water bodies showing Biological oxygen demand

TABLE : (1) Bacteriological Characteristics of Ground Water

Area/Sites	Total Coliform	Faecal Coliform	Faecal Streptococci
1) Union Carbide			
1	75	< 3	9
2	93	< 3	9
3	210	< 3	20
4	23	< 3	< 3
5	3	< 3	< 3
6	3	< 3	< 3
2) Shivnagar			
1	15	< 3	4
2	15	< 3	15
3	4	< 3	43
4	150	< 3	7
5	23	< 3	4
6	43	< 3	< 3
3) Mohali Village			
1	9	< 3	< 3
2	39	< 3	< 3
3	> 2400	< 3	39
4	> 2400	< 3	93
5	28	< 3	21
6	> 2400	< 3	9
4) Bhanpur Village			
1	29	< 3	< 3
2	24	< 3	< 3
3	< 3	< 3	< 3
4	< 3	< 3	< 3
5	6	< 3	< 3
6	9	< 3	< 3
5) Peoples Group			
1	9	< 3	< 3
2	39	< 3	< 3
3	23	< 3	21
4	43	< 3	< 3
5	28	< 3	< 3
6	< 3	< 3	< 3

6) Nishatpora			
1	75	< 3	< 3
2	93	< 3	< 3
3	210	< 3	39
4	23	< 3	93
5	< 3	< 3	< 3
6	< 3	< 3	< 3

CONCLUSION

The present experimental work revealed that most of the physico-chemical parameters of ground water in most of the sites nearby landfill area of Bhopal district are not in accordance with the normal standards of portable ground water. Bacteriological parameters analyzed in the landfill area also lead us to conclude that the ground water is non-portable for human consumption and emphasized regular and effective monitoring of such hazardous sites. A particular attention should be paid to the tube wells situated near to the landfill area and the ground water nearby landfill area should be properly treated for making it safe for human health as municipal solid waste landfill leachate contains a wide variety of hazardous chemicals, conventional contaminants, and non-conventional contaminants. Contamination of groundwater by such leachate renders it and the associated aquifer unreliable for domestic water supply and other uses; "remediation" treatment does not restore their quality. Focus must be placed on prevention of pollution of groundwater by MSW landfill leachate. Commonly used indicator parameters (e.g., pH, TOC, TOX, TDS) do not provide adequate sensitivity to detect incipient landfill leakage. Typically, but not always, the VOC's, such as TCE and its transformation product vinyl chloride, are better indicators of leakage than the indicator parameters that are often used. A monitoring program must include routine measurement of a wide variety of chemicals that are known or suspected to be present in the landfill that can be measured at very low concentrations.

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