GIS Based Seven Digit Coding System to Delineate Aquifer Contamination Zones in PCMC Area, India.

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ABSTRACT: A network of fifty sampling stations was established to monitor the groundwater quality and delineate the zones of contamination in the industrial township of Pimpri-Chinchwad Municipal Corporation (PCMC) in western India. The studies have brought out increase in concentrations of chemical parameters and presence of pathogenic bacteria as strong an evidence of sewage contamination of groundwater. Using GIS and remote sensing data a comprehensive seven-digit coding system was developed to classify and map the zones of contamination of groundwater in PCMC. The coding system indicated that the groundwater is divisible into three categories such as slightly polluted, polluted and highly polluted. Slightly polluted areas are found to be associated with the vegetated areas, irrespective of the relief category. The relative proportion of polluted to highly polluted wells is higher in the built-up area situated in the lower elevation zone Wells in the barren and open area also indicate some evidence of pollution of groundwater due to point sources. The major portion of PCMC has been classified as polluted to highly polluted. The measures have been suggested to control the groundwater pollution.

1. INTRODUCTION

Several workers have attempted application of GIS in hydrogeological studies (Ravishankar and Mohan 2005; Solomon and Quiel, 2006). However, use of GIS in groundwater pollution studies is sparse. Pollution of surface and groundwater resources poses a serious threat to human health and environment. In urban areas surface sources of water are largely influenced by anthropogenic activities (Aiuppa et al 2003). As most surface water sources are already polluted by rapid urbanisation and industrialisation, its adverse effects on shallow subsurface groundwater aquifers are a cause of concern as large amount of population is dependant on it. Several studies have reported groundwater pollution (Kayabali et al 1999, Karaguzel and Irlayici, 1998, Pawar et al 1998, Ali and Jain, 1998) by different anthropogenic sources.

In India rapid growth of industrialisation has forced the process of large-scale urbanisation. As a result, large number of new industrial townships has come up in the last three to four decades. The Pimpri Chinchwad MunicipalCorporation (PCMC) is one of such industrial cities in West central India. Unlike other townships pollution of surface and groundwater is a serious issue faced by PCMC. Although there is lot of information available on pollution of urban aquifers in many parts of the world (Kayabali et al 1998; Jarvie et al 2000; Oguchi et al 2000; Hiscock and Grischek, 2002, Lake et al 2003; Wycisk et al 2003; Aiuppa et al 2003 etc.) literature on contamination of PCMC aquifers is negligible. This has complicated the search for remediation strategy. In view of this the studies were initiated on delineating aquifer contamination zones of PCMC by adopting GIS technique. The work was aimed at adopting multiparametric approach to identify distribution and occurrence of pollution zones in the shallow aquifers. The results of these investigations are presented in this article.

2. THE STUDY AREA: PCMC

The PCMC is one of the most industrialized and urbanized mega city located 140 km south of Mumbai in western India (Fig.1). The city is spread over gently sloping and undulating

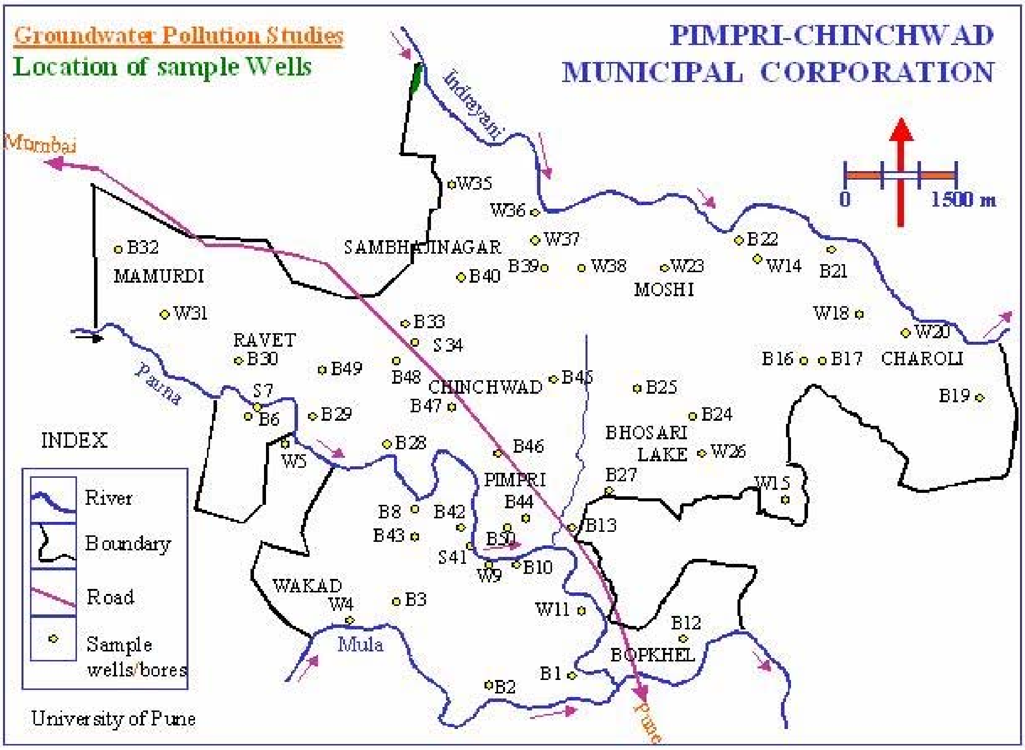

Figure.1 Location map of PCMC, India

urban development of PCMC area is localized on the Indrayani-Pauna interfluve. The divide between Pauna and Mula is almost feature-less and rocky with outcrops of porphyritic basaltic flows. The soil cover is generally thin over most of the interfluve areas. Only along the main rivers, thick alluvium is seen at places. The tributaries of Indrayani, Pauna, and Mula are short, lower order ephemeral streams with limited catchments. Most of the untreated urban effluents of PCMC are discharged in these streams, which ultimately join the main rivers. Amongst these rivers Pauna is severely polluted due to industrial and domestic effluents.

Phenomenal growth of population during the last three decades coeval with rapid industrialisation and urbanisation has increased the geographical area of PCMC from a mere 86 km^2 to about 206 km^2. The total population of PCMC rose from 0.1 million in 1971 to 0.65 million in 1991 and over one million as per 2001 census. This has substantially changed the land use and land cover characteristics that are primarily reflecting the combined effect of several factors on hydrochemical regime of groundwater.

From hydrogeological point of view basaltic flows from PCMC area possess very low primary porosity leading to lower permeability. The flows can be separated into two main units as lower massive and upper vesicular unit (Naik and Awasthi, 2003). The massive unit possesses negligible primary porosity or permeability and acts as an impermeable zone. However, at places on account of occurrence of joints, fractures and weathering, moderately permeable rock structure is developed which can be observed in open dug well sections. Vesicular unit on the other hand, reflects primary porosity and is also more susceptible to weathering (Naik and Awasthi 2003). As a result of this it is more permeable and forms good aquifers in the PCMC area. Groundwater is tapped by both open dug wells and bore wells.

3.METHODOLOGY

The methods of analyses included use of remote sensing and GIS techniques and hydrogeological, hydrogeochemical and microbial studies.

3.1. Remote sensing and GIS analyses

The modifications in land cover and the pattern of land use change were studied by using the Indian Remote Sensing Satellite (IRS) data by taking the images for December 1993 and 2000. To describe the relief, drainage and land use / cover characteristics of the PCMC area, Survey of India topographical maps, IRS remote sensing data, field observations and Government and PCMC records were used. Topographical maps of the area were used to prepare the base map and to understand broadly the nature of land use before the advent of remote sensing technique. Remotely sensed data was then used for identification, characterisation and classification of geomorphic, land cover and land use details. Various interpretation elements such as tone, colour, texture, pattern, association, site, etc were used for it through visual interpretation techniques. The images were visually interpreted and details were identified, demarcated and mapped. The interpreted land use/land cover categories were transferred onto the base map. To evaluate the changes in the land use between 1993 and 2000 as well as to understand the nature of relationship between the elevation above sea level, the drainage network and road network on one hand, and the land use / land cover types on the other, the Windows-based IDRISI geographic information software was used. The GIS analysis could not be carried out for the entire study area because the available satellite data does not cover the extreme western part of the study area. A 'scoring system' was adopted for each of the thematic map.

3.2. Hydrogeological, geochemical and microbial studies

Due to diversity of both geological, hydrogeological, land use and other environmental conditions in the PCMC area, fifty water-sampling locations were identified to represent as many factors as possible. The environmental determinants such as type of land use, aquifer type and slope, besides operating conditions of well were taken into account before sampling. The collection of groundwater and a few surface water samples were done to represent parts of the main town as well as fringe areas with newly incorporated villages. The sampling stations include dug wells, bore wells and river / streams etc. In all 30 bore wells, 17 dug wells and 3 surface water collection spots were identified for the periodic collection of water samples during the period 2000 – 2001. Using Dionex 600, High Performance Ion Chromatography System (HPIC) the analyses of major anionic constituents present in the groundwater was performed. Varian AA-220 AAS was used for the analyses of cationic constituents. The bacterial analysis included determinations of total coliforms, faecal coliforms, Salmonella, Shigella, Vibrio and Streptococcus species. Of all these parameters electrical conductivity (EC), total hardness, chloride (Cl), sodium (Na), microbial count, elevation and land use have been used to devise coding system to identify aquifer contamination zones.

4.RESULTS AND DISCUSSION

4.1. Changes in the urbanization

The remote sensing analysis shows that the built-up and urban area has registered a significant increase during the last seven years (Pawar et al 2001). In general, PCMC area is characterized by various types of land use and land cover like natural and stressed vegetation, cultivated area, barren and wasteland, and water bodies**.** The proportion of the area under vegetation cover and cultivation is significantly less for the year 1993. The area is mostly dominated by barren and wasteland, and followed by built-up and urban area. The GIS analysis shows that the urban and built-up area is confined to the interfluves and is mostly concentrated along the Mumbai-Pune National Highway and the railway line (Pawar et al 2001). The cultivated area is confined in the narrow valley-bottoms close to the Indrayani, Pauna and Mula Rivers and their tributaries. The barren area and the wasteland are observed along the divide line between Indrayani and Pauna Rivers. Field observations show that this area is rocky with thin soil cover and small ephemeral streams.

The analysis further revealed some degree of change in all the land use categories. However, there is no noteworthy change in the area under cultivation between December 1993 and

2000. On the other hand, the area under vegetation cover and barren land shows a significant decrease and a corresponding increase in the urban and built-up area. Numerous patches of vegetation cover within the PCMC area that were observed in 1993 have either become smaller or have been completely disappeared. The year 2000 was marked by poor monsoon rainfall, as compared to the 1993 monsoon. Therefore, the apparent shrinking of the area under vegetation cover can also be attributed to early reduction in moisture conditions in that year.

It is further observed from the remote sensing analysis that the built-up and urban areas have registered a significant increase during the last seven years. The recent growth has mostly been confined to barren and wasteland area between the Indrayani and Pauna Rivers forming the highest part of the terrain. Consequently, all the waste generated by urban and industrial areas will be transported to the low-lying parts and ultimately to the streams and rivers. As a result, not only the surface water but also the groundwater is likely to be severely affected by this situation over the entire area.

4.2. Geochemical changes in the water quality

4.2.1. Electrical Conductivity

Higher values of EC have been obtained for the wells tapping groundwater from alluvial aquifer reflecting geological control over ionic content (Table 1). Lower EC values from interfluve area between Indrayani and Pauna especially around isolated hills suggests control of slope conditions on groundwater flow. Absence of any source of pollution in the vicinity of these wells sets the background chemical composition of groundwater in the area. As against this, comparatively higher EC values obtained for samples of groundwater for areas close to Pauna are as a result of chemical pollution of groundwater. On the basis of EC, the groundwater from PCMC area predominantly represents fresh (EC = < 500 μS/cm) and medium conductive class - I (EC = 500 – 1000 μS/cm). However, a pocket of slightly brackish groundwater with medium conductive class II (EC = 1000 – 3000 μS/cm) has been observed from alluvial aquifer in the NW part of the area. It is interesting to note that salinity relatively decreased during summer 2001 possibly due to over-extraction of groundwater due to water scarcity, as 2000 monsoon was very poor. Medium conductive class – II groundwater is restricted to polluted river watercourses indicating mixing of polluted surface water with the groundwater.

4.2.2. Total Hardness

Total hardness of the groundwater from PCMC varies from 46 mg/l to 546 mg/l during rainy season 2000 (Table 1). On the contrary river water hardness ranges from 50 mg/l to 140 mg/l. In general, surface and groundwater samples belong to hard to very hard type except S-7 during June-July: 2000. The post monsoon samples (December, 2000) show variation from moderately hard to very hard. The hardness of water was found to be higher in December 2000 than June-July 2000. This is possibly due to insufficient recharge to the aquifers as the year witnessed less rainfall. Therefore, there was no dilution effect observed in the groundwater as reflected in the high hardness values.

4.2.3. Sodium and Chloride

A cursory look at the data (Table 1) indicates that Na values range from 8 mg/L to 135 mg/L in rainy season, which increased in winter by two fold. This suggests that there is high input of Na from recharge waters during the rainy season. However, in summer 2001 the concentration of Na again decreased due to cessation of recharge. The remaining cationic chemical constituents also depict similar trends. Higher concentration of Na in winter is possibly on account of mixing of polluted surface water recharge in the groundwater. This indicates that the groundwater quality is deteriorated. A few dug wells (W-19, W-20 and W-21) also show higher values of Na on account of natural salinity developed in the alluvial aquifers due to quasi-stagnant conditions. However, during summer-2001, the values have decreased, possibly due to flushing of salts from the aquifer due to excessive extraction of groundwater. Higher pumping rates could have possibly disturbed quasi-stagnant conditions, which helped in improving water quality by reducing the salinity. The wells from other parts do not show this pattern indicating active sources of input from pollution factors.

Cl can be considered as an indicator of pollution because of its conservative behavior. Under natural conditions Cl in the water is not expected to exceed more than 30–40 mg/L because of its origin from rainwater. However, the values of Cl in the groundwaters from PCMC area are very high reflecting additional sources of Cl. Since the host rock basalt does not represent Cl in its composition, the increase in its concentration is undoubtedly the result of input from human induced sources. It is observed that in the rainy season the groundwaters from fringe areas of PCMC depict <40-ppm Cl suggesting background concentration.However, the remaining areas display higher Cl values possibly indicating pollution of groundwater. In contrast, in the winter season the area covered by background values of Cl becomes less as most of it is converted into high Cl groundwater zone. This suggests that polluted groundwater zone relatively expanded during winter 2000 as compared to summer 2000. This is possibly due to polluted groundwater recharge, shallow water table conditions and innumerable point sources of pollution of groundwater.

4.2.4. Bacteria in the groundwater

Varied and active microorganisms have been observed in the PCMC groundwater. The most important pathogenic bacteria reported during present work are *Salmonella sp., Shigella sp., Vibrio cholerae, enterotoxin forming E.Coli and Pseudomonades*.The presence of these pathogenic bacteria is therefore indicative of sewage contamination of groundwater. This is because in municipal sewage, the concentration of E.Coli is of the order of 10^5 to 10^6 / ml (Lance 1984) and in surface waters about 10^2 to 10^3 / ml. The rivers draining PCMC are overloaded with these species due to release of sewage / domestic effluents (Pawar et al 2001). It is possible that these organisms occupy voids, interstices and pore spaces in soil and alluvium. Whereas in the basaltic aquifers of PCMC area, joints, cracks and fissures are expected to be serving as conduits for the movement of bacteria within the subsurface. Their transport in the subsurface could be in free-floating form or as an attachment to solid suspended particle besides their adsorption on to the solid surfaces (Britton and Berba, 1984). Outbreaks of diseases have occurred in PCMC on some occasions due to consumption of poor quality groundwater. Risk is higher where private wells are in proximity to poorly constructed septic tanks. Because of filtering capability of soil, most of the pathogenic organisms present in the sewage, including bacteria, viruses, protozoa and parasitic worms are effectively removed in alluvial aquifer. However, basalt being fractured media their removal from the water phase is dependent only on adsorption.In the present study it is seen that the bore wells located close to polluted watercourses and in densely urbanized areas (S. Nos. B2, B22, B24, B25, B28, B32 and B33) are characterized by high level of pathogenic bacteria. As against this some wells (B1, B3, B39, B40, B46 and B49) are free from pathogenic bacteria as they are relatively at safer distances from pollution sources. Most dug wells show presence of pathogenic bacteria indicating large-scale pollution of groundwater.

Table 1: Range of cationic constituents in the waters from PCMC area (50 samples/season).

Parameter	Rainy 2000	Winter 2000	Summer 2001
Na (mg/L)	8 – 135	4.5 –235	4 –125
Cl (mg/L)	12.8 – 245.4	4.29 – 574	21 – 178
EC µS/cm	160 -2000	150 -2420	160 -1818
Hardness (ppm)	46 -546	72 -789	62 -460

5. DELINEATION OF AQUIFER CONTAMINATION ZONES

In order to identify zones of groundwater pollution, the water quality data derived from 50 locations covering different seasons, the elevation data and the land use data were considered. Using these data a seven-digit coding system was developed. The first digit represents EC, the second hardness, the third is chloride, fourth is Na, fifth is total microbial count, sixth is elevation of the area, and seventh digit represents land use. The value of each digit varies from 1 to 6 as per Table 2.

The above seven-digit coding system was used to classify and map all the 50 sample wells into three categories:

Slightly polluted

Polluted and

Highly polluted

A map was prepared on the basis of the seven-digit code (Fig. 2). The map illustrates that slightly polluted areas are found between Pimpri and Kalewadi phata and and an isolated spot at Nigadi. The remaining locations locations include, Punawale, Sangvi, Wakad, Bopkhel, Dighi, Bhosari Lake, Indrayani Nagar, Sambhajinagar (Nigadi), Dadulgaon, Charoli, Borde vasti. The last three have been included in the highly polluted class due to development of natural salinity. Besides these locations, all the remaining locations all the remaining locations have been designated as polluted in terms of five parameters.

Table 2. Coding of the parameters for delineating aquifer contamination zones.

Digit	Parameter	Codes
First	EC	1 = low 2 = medium I 3 = medium II
Second	Hardness	1 = moderately high 2 = high 3 = very high
Third	Chloride	1 = unpolluted 2 = polluted 3 = highly polluted
Fourth	Na	1 = unpolluted 2 = polluted
Fifth	Microbial count	1 = low 2 = moderately high 3 = high 4 = very high
Sixth	Elevation	1 = 540 - 560 m ASL 2 = 560 - 600 m ASL 3 = 600 < m ASL
Seventh	Land use	1 = Barren/open land 2 = Vegetation 3 = cultivated land 4 = rivers 5 = lakes 6 = built-up/urban area

Further, classification of wells on the basis of relief and land use indicates that highly polluted wells are generally absent in the vegetated areas, irrespective of the relief category, and that the relative proportion of polluted to highly polluted wells is higher in the built-up area situated in the lower elevation zone. Wells in the barren and open area also indicate some evidence of pollution of groundwater due to point sources. River water sample No. S-7 collected at the entry point of Pauna River into the city and stream water No. S-34 indicates relatively less pollution. However, the lone sample S.No. S-41 from the stretch of the river in the city area shows high pollution level. This therefore indirectly suggests that the pollution hazards increase if the surface water is stagnant. This is also seen in some wells located close to river stretches with pounded river water. The wells with high salinity problem are associated with cultivated areas and are found in the lower and middle altitudinal class. The number of wells included in this study is higher in the cultivated area land use category. This is not unusual because the wells are primarily used for irrigation purposes and not just of domestic purposes.

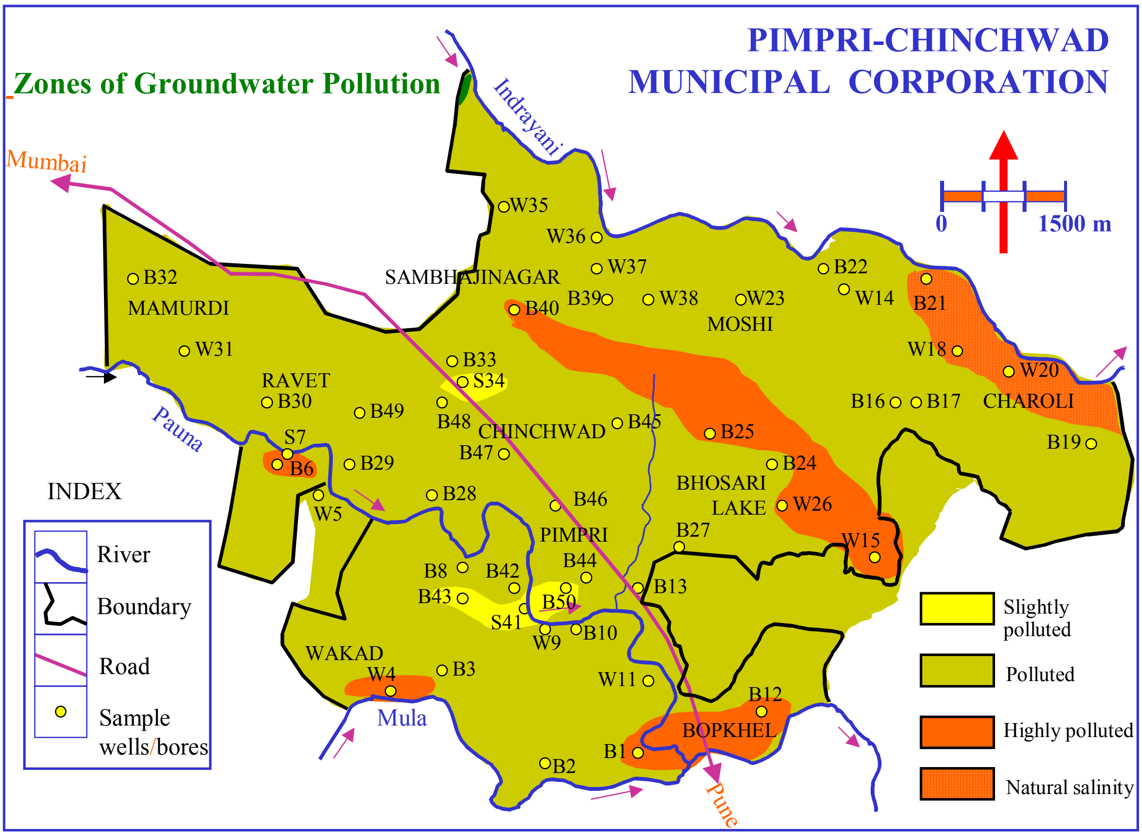

Figure.2 : Zones of groundwater pollution in PCMC area, India

6. SOURCES OF GROUNDWATER POLLUTION AND SUGGESTIONS FOR CONTROL

Until recently there was no scientific data available regarding the status of groundwater quality in the PCMC area. However, the present work has generated baseline data as well as identified the areas that are polluted. Therefore, such areas need an immediate attention of the concerned civic authorities to offer some pollution control program. The major sources of groundwater pollution in PCMC are domestic and industrial effluents discharged into the rivers and small streams, individual sewage disposal systems such as septic tanks, dumping of household wastes into the open dug wells, solid waste disposal sites (e.g. abandoned quarries / open dumps/ landfills) and application of sewage effluents and polluted stream / river waters to agricultural areas.

Large quantities of industrial and sewage wastes disposed off into the streams and rivers are not in proportion with the quantity of base flow. This is because the degree of dilution is governed by the base flow. Under natural conditions during the dry period, the base flow becomes minimal in the main river and it completely ceases to flow in the case of small streams. As a result of this, the stream becomes influent to the aquifer and the polluted water starts mixing with the groundwater. Under such conditions if some wells, which are located along the stream courses start abstracting groundwater, then induced infiltration occurs because of hydraulic continuity between the streambed and the aquifer. This leads to rapid mixing of polluted surface water with the groundwater causing pollution. This is evident from the occurrence of polluted zone mainly along the watercourses. Similar mechanism occurs in the case of leakage from septic tanks or even from the infiltration of sewage effluents applied to the agricultural areas.

Since, there are varied sources responsible for polluting the groundwater in the PCMC area, it is essential to design control program to take care of all the point sources. In view of this following recommendations are made.

1. Concrete lining of the effluent carrying streams channels and nalas.
2. To treat the effluents before discharging into watercourses.
3. Septic tanks installed by large housing colonies should be well maintained and periodic checks should be undertaken to detect leakages.
4. Water proofing at the base of existing solid waste disposal sites and locating suitable sites for solid waste disposal by studying the local hydro-geological characteristics. Waterproofing can be achieved simply by using a layer of clayey soil.
5. Stabilization of water table at greater depths to increase the vertical distance between pollution source and the water table. In this regard it is important to encourage the pumping of groundwater and its use for gardening purpose in municipal offices, schools, industries and hotels. This will on one hand save treated water provided by PCMC through taps, and also lower the groundwater table, which is essential in certain situations to the minimize the interaction between polluted surface water and groundwater.
6. Sewage treatment plants need to be installed at all the major point pollution sources.
7. Abandoned quarry sites need to be converted into gardens/parks to resist the local population from using these sites as a waste disposal grounds.
8. Stretches of rivers and streams with stagnant water pools should be periodically de-weeded and the stream flow should be maintained even during the dry season.
9. Local population should be discouraged from dumping solid waste into the dug wells, streams and rivers particularly during festival times and during the dry season.
10. The minimum distance between the source of pollution and location of well should be between 15 and 50 meters.

7.CONCLUSIONS AND RECOMMENDATIONS

The need for undertaking this work was mainly felt due to the extraordinary growth of population during the last two to three decades coeval with rapid industrialization and urbanization in the PCMC area. Available data indicate that between 1971 and 2001 the population increased by two orders of magnitude (by 1212%). The rapid population and industrial growth has resulted in the problem of water pollution, mainly due to release of industrial and domestic effluents into the adjoining watercourses. In addition to this landfill sites, abandoned quarries and dug wells used for the disposal of solid wastes have developed leachates of polluted water in the downstream areas. In fluent nature of small streams, leakages developed in the sewerage network and septic tanks have further deteriorated the groundwater. The present work has brought out increase in concentrations of chemical parameters and presence of pathogenic bacteria as strong evidences of sewage contamination of groundwater. A comprehensive seven-digit coding system used to classify and map the PCMC area has indicated that the groundwater is divisible into three categories such as slightly polluted, polluted and highly polluted. Slightly polluted areas are found between Pimpri and Kalewadi phata and an isolated spot at Nigadi. The remaining locations have been classified as polluted to highly polluted. The measures have been suggested to control the groundwater pollution.

Acknowledgements

The authors gratefully acknowledge the facilities provided by Department of Geology, University of Pune and financial support given by PCMC.

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