Original article

A study on the groundwater of Peenya industrial area and its related elements in Bengaluru region of Karnataka State, India

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ABSTRACT

Groundwater samples were collected from the Peenya Industrial area of Bengaluru, India to test its quality, elemental composition and inherent bacterial population. Further analysis was done using GIS Based Geostatistical techniques to study the level of groundwater and to generate various maps of lineament, digital elevation, geomorphology, soil erosion, salt affected areas and water logging in this region. Physical and chemical parameters such as Total Dissolved Solids, pH, temperature, BOD, COD, metal ions present in the water samples were studied along with predominant microbial constituents. The Total Dissolved Solids and Total Hardness were far beyond the maximum concentration levels. Further analysis of the isolated bacteria was done using staining methods and biochemical tests. The results obtained showed that the area under study had wells ranging from shallow to deep heights of 30 to 80 meters, with a wide variety of 10-400 LPM; whereas the lineament map suggested that the area was bound with parallel ridges and joints. The geographical data represented pediplain complexes, anthropogenic terrains and water bodies. The area was found to go through a seasonal water logging and the soil loss was due to sheet erosion and rill erosion. It was also observed that the groundwater was contaminated with heavy metals such as lead, chromium etc. along with a diversified bacterial population.

KEY WORDS: industrial area groundwater; GIS; heavy metals; groundwater contaminants

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1. Introduction

Groundwater contributes to about eighty percent of the drinking water requirements in rural areas, fifty percent of urban water requirements and more than fifty percent of the irrigation requirements of the nation, but due to rapid industrialization and population explosion the groundwater quality and quantity have been significantly affected and overexploited (JAISHANKAR ET AL., 2014; MATHEW ET AL., 2016). 90% of the rural and 30% of the urban population depends upon groundwater for their domestic requirements (SHAH ET AL., 2003). This has led to an overwhelming rise in the research related to groundwater statistics, composition, quality aspects, recharge-discharge relationship and its resource potential.

This study is from III and IV phase of Peenya industrial area from the state of Karnataka that is

situated between 13.0308 and 13.0151 latitude besides 77.5060 and 77.5225 longitude with a total geographical area of 191791 km². Physiographically the state is divided into four regions having northern and southern plains, a western coastline and hilly areas. The elevation varies from 200 to 1900 meters above sea level and each region has a distinct climate that receives more than 250 cm of rainfall annually, but the rate of drawing water is more than that recharged each year. The groundwater condition in all four taluks of Bengaluru Urban district is deteriorating. Karnataka stands to have over-utilized 70% of its groundwater, out of which only less than 1% is fit for drinking according to the latest reports by the ministry of water resources (SHANKAR ET AL., 2008; JEROME & PIUS, 2010). The defilement of groundwater has occurred over the years and the contaminants are mainly heavy metals, microbes most commonly

being viruses and bacteria which are largely accountable for water-borne diseases. Environmental factors such as temperature, pH, soil moisture, rainfall etc. also affect the endurance and relocation of these microbes in groundwater. In particular, bacteria can function as a resourceful pollutant carrier due to its coagulating property and complimentary surface area (RAVIKUMAR ET AL., 2013; PRAKASH & SOMASHEKAR, 2006). This transfer of contaminants by bacteria enhances when it is in movement and when it is intermingled with soil particles, it exists in three different phases that constitute an aqueous phase, a transporter phase and a medium phase.

Within Bengaluru itself, several organizations such as the Central Ground Water Board, and Bangalore Water Supply and Sewerage Board; renowned Institutes like Indian Institute of Science, Jawaharlal Nehru Centre for Advanced Scientific Research, National Institute of Advanced Studies, Analytical Research Center Private Limited, Indian Institute of Soil and Water Conservation etc. along with individual scholars are carrying out various research activities using different techniques on groundwater to develop an assessment of its current condition and status (RAJU ET AL., 2012; VENKATESHARAJU ET AL., 2010; SINGH ET AL., 2010). Groundwater also has a quality index which depends upon the concentration of constituents of heavy metals and trace elements that it consists of. After a certain limit of safety, these metals can lead to several health issues and disorders causing threats to human life. Some of these toxic metals are arsenic, lead, cadmium, mercury etc. (JAISHANKAR ET AL., 2014; MATHEW ET AL., 2017). Metal distribution depends upon the environmental factors and property of metals. The composition of metal decides the spatial distinction of neighboring concentrations. When these metals are in low concentrations they help in the regular biochemical and physiological functions and can escape control mechanisms such as transportation and homeostasis, but as their concentration increases, these metals become deleterious as they start to get bound to protein sites, thereby resulting in cytotoxicity, followed by cellular breakdown (JAISHANKAR ET AL., 2014; MATHEW ET AL., 2017). Several researchers have proven through their work that the biological molecules go through hypoxia, due to the metal binding to nucleic acids and proteins (FLORA ET AL., 2008).

The quality of water present in any water body not only depends upon the rainfall, erosion, surface run-off, crusting and precipitation but also depends on the ecological factors such as evapotranspiration, population growth and related agricultural and

industrial activities (PAPATHEODOROU ET AL., 2006). Aquifers that are intermittent in nature are due to the craggy, hard and dense rock formations. When rigid rock territories undergo weathering, it results in basin fills, canals, and uninhibited rivers acting as storehouses of groundwater (CHANKAO ET AL., 1987). In this particular study, the groundwater of Peenya industrial area was considered extensively to know more about its physical, chemical and biological parameters. Efforts were made to analyze the geomorphology, lineament, terrain structures, soil erosion and water logging statistics of this area to understand the after effects of industrialization, over-population and waste disposal on the land. The probable source of groundwater pollution in this area is the high content of nitrates due to leaky septic tanks and open disposal of garbage. The hardness in the groundwater is due to untreated sewage. Iron manufacturing industries contribute to the rusting of pipe casings and improper disposal of iron scraps (SHIVASHANKAR & BHASKAR, 1995). The inappropriate treatment of industrial effluents and the surplus usage of insecticides for agricultural activities have also contributed towards the increase in concentration of fluoride and chlorides. There are electroplating, textile, pharmaceutical, turbine and chemical industries in this area which have also contributed to exceeding the limits of suspended particulate matter in air samples beyond the permissible standards of NAAQS (NAGARAJAPPA ET AL., 2012). In 2008, almost 51% of water samples were found to be non-potable (SHANKAR ET AL., 2008), whereas by 2017 more than 80% of water samples is considered as non-potable.

2. Materials and methodology

2.1. Study area and its location

The study area was the III and IV phase of the Peenya industrial area in the Bengaluru Urban District that is located in the southeastern part of Karnataka, as shown in Fig. 1. Peenya is known for its collection of metal, textile, leather and pharmaceutical industries. Peenya III Phase has an elevation of 911.8 meters, whereas Peenya IV Phase has an elevation of 906.7 meters. The area has a tropical climate with mean annual temperature from 23.6 to 32.7°C. The major rivers flowing around this region are the Vrishabhavathi and Arkavathi. Bengaluru receives about 97 cm of rain annually and is land-locked with Kolar and Chikkabalapur in the northeast region, Tumkur in the northwest, Mandya and Ramanagaram in the southeast and Mysore and Tamil Nadu in the south.

Fig. 1. Area under study

2.2. Geological data

Various topographic maps of the study area were prepared by employing ISRO's Bhuvan and digitized using ArcGIS v10.0 and ERDAS v9.1 software (NEAMATOLLAHI ET AL., 2012). Geological Survey of India (GSI) in the scale of 1:432,562 and 1:50,000 were used to generate the thematic maps of landforms, lithology, terrain structures, soil erosion and water logging statistics.

Groundwater prospects (depth of wells). There is an uneven dispersal of groundwater in various regions of the city due to diverse characteristics of terrain and spatio-temporal dissimilarities in precipitation (RAVINDRAN & JEYARAM, 1997). The factors that govern this parameter are climatic conditions such as rainfall, heat etc.; topography that consist of land elevation and slope, geological structures that can explain the weathering, usage of land and hydrological parameters (KRISHNAMURTHY & SRINIVAS, 1995). These are some important information that can be generated by using Geographical Information Systems (BAHAIRE & WHITE, 1999). The demarcation of groundwater prospects is much simpler to achieve now due to the National Drinking Water Mission that makes use of visual interpretation of satellite data in the scale of 1:250000 to 1:50000.

Geological parameters. Karnataka has mainly three principal zones called the coastal strip, the Western Ghats and the Deccan Plateau. These three zones consist of four geological formations that have granites, charnockite rocks, sandstone, limestone, basaltic lava and deposits after the cessation of volcanic action (INDIAN SPACE RESEARCH ORGANIZATION, 1988; RADHAKRISHNA & VAIDYANADHAN, 1994; RAMACHANDRA & KAMAKSHI, 2005; BHUIYAN ET AL., 2009). The hills are formed because of the constant erosion, circum denudation, weathering and mass wasting, whereas the residual hills are a result of pediplanation that happens over time reducing the real heavy masses into scattered

pediplains. These residual hills have the weakest potential for groundwater as it is considered to be a run-off zone (WIRTHMANN, 2000; PAZZAGLIA, 2003). Standard visual interpretation methods have been used to classify this. A lineament map depicts the fracture, joints and faults of a certain region that decide the movement and location of groundwater to trace out the potential zones in a diverse geological set-up (SHAHID ET AL., 2000). Geomorphological and lineament maps were generated using Resourcesat-1 LISS III (KRISHNAMURTHY ET AL., 2000).

Soil erosion map. Soil erosion cannot be measured only by movement of sediments, status of nutrients and seepage on the surface, but also depends upon the rate of degradation of soil, water erosion and soil contamination. It results in salinity, acidity, loss of soil structure and excessive flooding leading to decline in the soil quality and fertility (O'RIORDAN, 2014; BALLAYAN, 2000). The soil types in Karnataka are divided into red, lateritic, black, alluvio-colluvial, forest and coastal soils. The annual rainfall ranges from 50 to 350 cm (VELAYUTHAM ET AL., 2000; RAKESH ET AL., 2015). The soil erosion also depends upon the slope percentage of the area that ranges from 0-3% to more than 35% (BASAVARAJAPPA ET AL., 2015; SAMEENA ET AL., 2009).

Salt affected and water logged areas. An upward flux of water when continuous can carry salts from the substratum onto the surface. The salt content affects the plant growth, nutrient uptake and quality of crops (BERNSTEIN, 1975). LISS III image spectrum was used to determine the status of green and dry areas.

2.3. Sampling and analysis

High-density polyethylene sample bottles were cleaned using nitric acid, before being used for sample collection. Water samples from a depth of 250-500 m were collected from boreholes located at various sites of stage III and IV of Peenya Industrial area of Bengaluru using techniques to ensure a minimum of surface contamination. Samples were collected in a criss-cross pattern within an area of 3 km during pre-monsoon and post-monsoon seasons during May 2015 and November 2015. A total of 28 samples were collected from both dug wells and bore wells, which are predominantly available in the area. Some of the physical characteristics such as pH and temperature were measured in the sampling location itself by using calibrated digital equipment and pH strips, after which the samples were transported to the lab immediately to measure the electrical

conductivity (S/m), total dissolved solids (ppm) and temperature (°C).

2.4. Physical investigation of water samples

pH. The acidity or alkalinity of water is determined by the hydrogen ion concentration which is generally termed pH (MCLEAN, 1982). In the area under study, the distribution of pH varied from 6.5 to 8.3. Out of all the samples that were collected, 60% were found to be well within the permissible limit for drinking water standards according to Bureau of Indian Standards (BIS, 1991), whereas the other 40% of the samples had a pH above 8.2 rendering them unsuitable for drinking purposes.

Electrical conductivity (EC). The higher the level of dissolved ions in the sample, the greater is its conductivity (REGHUNATH ET AL., 2002). The distribution of electrical conductivity in the Peenya region showed wide variations (72-4260 $\mu\text{S}/\text{cm}$ at 25°C), indicating that several water samples were not suitable for drinking purposes. The BIS has recommended a drinking water standard limit for total dissolved solids of 300 mg/l (corresponding to an EC of about 750 $\mu\text{S}/\text{cm}$ at 25°C).

Turbidity. For drinking water, the recommended turbidity value is less than five nephelometric turbidity units (NTU) (LECHEVALLIER ET AL., 1981). In the collected groundwater samples, the turbidity values ranged from 2.12 - 4.87 NTU.

Total Dissolved Solids. This refers to any minerals, salts, metals, cations or anions present in dissolved form (HOUNSLOW, 1995). The TDS values for the groundwater samples ranged from 2000±500 which is very high and unacceptable. Table 1 shows the physical analysis of the water samples.

Total Hardness. Calcium and magnesium ions are the major contributors of temporary hardness in groundwater (BRUGGEN ET AL., 2001), whereas sulphates and chlorides cause permanent hardness. The obtained values for hardness in the groundwater samples were in the range of 204 - 210 mg/l.

Temperature. The increase in temperature of water results in higher mobility of ions. Thus as the temperature increases, the resistivity decreases. As we go deeper, the temperature tends to rise due to the geothermal gradient. Even in the present study, the temperature of the groundwater samples was in the range of 27-38°C, which was almost 14°C higher than the average value of about 17°C (TODD, 1959).

2.5. Chemical investigation of water samples

The collection, preservation and chemical analysis for major ions of water samples were made by standard methods given by the BIS and American Public Health Association (APHA, 1998; PULS & BARCELONA, 1996). Ionic constituents like Ca^{2+} , Mg^{2+} , Na^+ , K^+ , Cl^- , CO_3^{2-} , HCO_3^- , and SO_4^{2-} were determined for the collected samples of groundwater. The heavy metals were quantified using inductively coupled plasma atomic emission spectroscopy (ICPOES) technique (SERESHTI ET AL., 2012). The sample collecting spots were flushed by pumping until at least three well volumes of water had been evacuated and the pH and conductivity were stable. Table 2 shows the chemical analysis of the water samples.

2.6. Bacteriological investigation of water samples

Isolates from the groundwater samples of Peenya industrial area phases III and IV were evaluated to study its biological entity. Sterile, one-litre bottles were filled with water for bacteria counts and all samples were placed on ice and transported to the laboratory for analysis within 1-2 hours. Viable counts were determined by filtering 1, 10, and 100 ml of water through 0.45 μm pore size using 47 mm diameter- HA type, membrane filters. Filters were then placed on 1% peptone-tryptone-yeast extract-glucose (PTYG) medium (HAZEN ET AL., 1991; STEEN ET AL., 2004) and incubated at 23°C for 2 weeks. The media, temperature and time of incubation were kept optimum for subsurface enumeration of bacteria. Bacterial colonies were counted with the aid of a stereomicroscope and the total cell count was determined by direct count (AODC) methods. Bacterial densities were found to be greater in groundwater samples by direct count when compared to the viable count. Bacterial concentration in groundwater was found to be 1.14×10^1 - 5.21×10^1 bacteria/ml for direct count and 6.12 - 3.24×10^6 CFU/ ml for viable count.

Bacterial isolation and identification. Subsurface and deeper bacterial isolates were collected from the groundwater samples and cultured in the lab using the techniques specified in Bergey's manual (KRIEG & HOLT, 1984; WILSON ET AL., 1983). Water isolates were obtained by random colony selections from 1% PTYG medium and were analyzed for physiological capabilities using several tests (WILSON ET AL., 1983).

Fig. 2. Nutrient Agar (NA), Tryptic Soy Agar (TSA), Mannitol salt agar (MSA), Simmons' citrate agar (SCA) and Salmonella Shigella Agar (SSA) plates

After collection, the bacteria in the water samples were cultured separately on to the Nutrient agar (NA), Mannitol salt agar (MSA), Simmons' citrate agar (SCA) and Salmonella Shigella (SS) Agar plates by the pour plate method, as shown in Fig. 2. For the growth of bacteria, the plates were incubated at 37°C for 24 h aerobically in a bacteriological incubator, after which the different colonies on the plate were marked on the basis of its shape, elevation and boundary or margin. Later a loopful of bacterial colonies from these incubated plates, which were marked to be different and unique, were streaked separately on fresh Nutrient agar (NA) plates and incubated at 37°C for 24 h in a bacteriological incubator. At a later stage, these cultures were monitored to check for any traces of contamination and were sub-cultured further using tryptic soya agar media to obtain pure culture sets, after which Gram staining and biochemical tests (KRIEG & HOLT, 1984; DUNPHY & WEBSTER, 1989) were performed to identify the bacteria, as shown in Table 3.

Gram staining. Morphological characterization of the isolated bacterial colonies was done by the Gram staining method. The bacterial smears were prepared from each of the pure cultural plates, fixed and stained using the Gram stains and examined under a microscope at various magnifications of 10X, 40X and 100x (MERCHANT & PACKER, 1967; MONTGOMERY ET AL., 1988), as shown in Fig. 9.

Biochemical tests. The bacterial isolates were also treated by the standard methods of biochemical, enzymatic, sugar utilization and antibiogram profile as prescribed by Bergey's manual of determinative bacteriology (HOLT ET AL., 1994), for their identification as shown in Table 3.

3. Results and discussion

3.1. Geological data

Groundwater prospects (depth of wells). Data obtained from satellite through remote sensing techniques provided a much better understanding of groundwater movement and localization by

the concept of digital elevation models, which represent the elevation at three different levels of 546, 1008 and 1469 meters, as shown in Fig. 3a. The random distributed water body in the area of study is represented by Fig. 3b.

Fig. 3. Digital elevation model (A) and water bodies present in the study area (B)

There was found to be a varied range of wells when studied in terms of yield denoted as litres per minute (LPM). In the present study area there were found to be five different types of wells, ranging from 10-20 LPM, 30-50 LPM, 50-100 LPM, 100-200 LPM and 200-400 LPM. The depth of wells was below 30 meters, between 30 to 80 meters and above 80 meters, as shown in the Fig. 4.

Geological parameters. Geomorphologically, the various hydrogeomorphic units are classified as Linear Ridge (LR), Residual Hills (RH), Inselberg (I), Pediments (P), Shallow weathered pediplains (PPS) and Valley Pills (VP). But the study area was divided based on its origin into moderately dissected hills and valleys, low dissected hills and

valleys and highly dissected hills and valleys. The data also represented pediplain complexes, anthropogenic terrains and water bodies, as shown in Fig. 5.

A lineament map consists of fold-aligned hills and valleys and also expresses the displacement in the structures and flaws in the zones of the earth's crust (HOBBS, 1904). It can be linear and continuous or aligned depressions like valleys, having justified end points and adjacent boundaries (PARSONS, 2002). The obtained data from the Geoplatform of ISRO, for the study area was divided into geomorphic and structural lineaments such as parallel ridges, joints, fractures and dykes, as shown in Fig. 6.

Fig. 4. Groundwater depth

Fig. 5. Geomorphological map of the study area

Fig. 6. Lineament map of the study area

Soil erosion map. The map, (Fig. 7A) shows that the soil erosion is mainly due to sheet erosion, loss of soil dunes and rill erosion that happens mainly due to water running through little streams. Fig. 7B represents the terrain structure. The terrain structures can be understood by studying the faults, folds, synclines and anticlines present in the region. This also provides information related to the subsurface geometry of rocks, stress at a specific

place, crust deformations, probable hazards such as landslides and earthquakes along with possible reserves of oil and gas.

Salt affected and water logged areas. The water-logged areas, shown in blue in Fig. 8, were found to accumulate more irrigation and seepage water. Red areas represent a shallow water table whereas regions under irrigation are shown in grey.

Fig. 7. Soil erosion map (A) and terrain structures (B)

Fig. 8. Salt affected and water logged areas

3.2. Physical analysis of water samples

Table 1 represents the physical analysis of water samples that form the characteristics of the geomorphological, climatic and geochemical conditions of the basin. The color of the water sample is mainly due to fulvic and humic acids, plankton and metals. In the current study the samples were found to be colorless, except a few samples that were light brown or amber in colour (LAANEN, 2007). Temperature is another factor that is responsible for the spatial changes occurring due to excessive heat or radiation. It affects the alkalinity, salinity and conductivity of the water. Turbidity is due to colloidal and suspended matter such as clay and silt present in the water samples and affects the scattering of light and absorption properties in a water body (OMAR & MATJAFRI, 2009). The collected samples were within the acceptable limits for turbidity. According to the general guidelines of water hardness 0 to 60 mg/L (milligrams per liter) of calcium carbonate is categorized as soft; 61 to 120 mg/L as moderately hard; 121 to 180 mg/L and above as hard and very hard respectively (THULIN & BRUMM, 1991).

Table 1. Physical analysis of groundwater samples

Parameter	Obtained values	Safe level/ MCL
Total Hardness	104 - 210 mg/l	17-120 mg/l
Total Dissolved solids	2000±500 mg/l	500 mg/l
Turbidity	2.12 - 4.87 NTU	< 5 NTU
Color	Dull coloration to colorless	Colorless
Odor	Odorless	Odorless
Transparency	Slightly transparent	Fully Transparent
Temperature	27 - 38 °C	10-24 °C
pH	6.5 - 8.3	6.5-8.5
Conductivity	72 - 4260 µS/cm	300

3.3. Chemical analysis of water samples

Table 2 shows the chemical analysis of water samples and here MCL represents the Maximum Contaminant Level according to the Bureau of

Indian Standards (BIS-10500-1991). This data helps us to study the long-term effects of the contaminated water body on the ecosystem and the possible threat of toxicity to aquatic life. A 5-day Biological Oxygen Demand (BOD) test showed the levels of oxygen used up by bacteria to degrade the organic matter in an aerobic setting, whereas the Chemical Oxygen Demand (COD) test showed the level of oxygen comparable to the organic matter in the sample that is susceptible to oxidation by a chemical oxidant.

Table 2. Chemical analysis of groundwater samples

Contaminant	Obtained Values	Safe level/ MCL
NO ₃ ⁻	7.45 mg/l	10 mg/l
SiO ₂	8.15 mg/l	20 mg/l
SO ₄ ²⁻	286 mg/l	250 mg/l
HCO ₃	210 mg/l	200 mg/l
Mn ²⁺	0.75 mg/l	0.05 mg/l
Fe ²⁺	3.68 mg/l	0.3 mg/l
F ⁻	0.04 mg/l	2 mg/l
Cl ⁻	741 mg/l	250 mg/l
K ⁺	9 mg/l	-
Ca ²⁺	105 mg/l	80
Na ⁺	408 mg/l	<135mg/l
Mg ²⁺	43 mg/l	6.4
Ni	0.4 mg/l	< 0.1 mg/l
Zn	6.5 mg/l	5 mg/l
Cu	0.7 mg/l	0.036 - 1 mg/l
Ba	2 mg/l	2 mg/l
Be	0.07 mg/l	0.004 mg/l
BOD	> 5 mg O/L oxygen consumed per liter	1 and 2 mg O/l
COD	0.08 mg/l	0.05 mg/l
Pb	0.02 – 0.5mg/l	0 mg/L
Cd	0 mg/l	0.1 mg/L
As	0 mg/l	0 mg/L
Cr	0.0 – 0.2 mg/l	0.1 mg/L
Hg	0.0 – 0.001 mg/l	0.002 mg/L

3.4. Bacteriological investigation of water samples

The biota in the collected water samples was found to be governed by various environmental conditions that were formed due to primary production of organic matter.

Gram staining. Fig. 9 shows the various bacterial cell cultures after Gram staining. Cultures 1, 4 and 7 were found to be Gram negative as they readily took up the safranin stain and appeared to be pink in colour, whereas cultures 2, 3, 5 and 6 were found to be Gram positive as they did not take up safranin after the crystal violet stain and appeared to be violet in colour. All the isolated cells appeared to be rod shaped. This staining procedure distinguishes the bacterial cells by the physio-chemical possessions of their cell walls by sensing the peptidoglycan layer which is thick and dense in Gram positive bacteria; when

compared to the peptidoglycan layer in Gram negative bacteria.

Biochemical tests. Studies on the biochemical, antigenic and other characters of bacteria can be done only if the organism is available in pure form. Thus the isolated colonies were sub cultured in a clean environment to obtain pure cultures free from any type of contamination. Further tests were carried out to determine the motility, fermentation and alkaline characteristics of the isolates. Table 3 shows the biochemical tests and colony characteristics of isolated bacteria.

Seven different bacterial cultures were found through the study and these were identified as *Escherichia coli* (culture 1), *Bacillus toyonensis* (culture 2), *Bacillus anthracis* (culture 3), *Acinetobacter baumannii* (culture 4), *Bacillus cereus* (5 and 6) and *Pseudomonas aeruginosa* (culture 7) species.

Fig. 9. Bacterial cultures under microscope after Gram staining

Table 3. Biochemical tests and colony characteristics of various bacterial isolates

Sl. No.	Name of the test	Culture 1	Culture 2	Culture 3	Culture 4	Culture 5	Culture 6	Culture 7
1	Gram's Staining	-ve, rods, non sporing	+ve, chain of bacillus, spore former	+ve, chain of bacillus, spore former	-ve, short rods	+ve, chain of bacillus, rods	+ve, chain of bacillus, spore former	-ve rods, non sporing
2	Motility Test (37°C@4 days)	Motile	Motile	Motile	Non motile	Motile	Motile	Motile (single flagella)
3	Catalase Test	+ve	+ve	+ve	+ve	+ve	+ve	+ve
4	Oxidase Test	-ve	-ve	-ve	-ve	variable	-ve	+ve
5	Hugh-Leifson's (37°C@4 days)		Fermentative	-ve	Fermentative		Fermentative	Fermentative
6	TSI-H ₂ S (37°C@7 days)	H ₂ S -ve Gas+ve	Alkaline-Slant Acid-Butt, H ₂ S Gas-ve	Alkaline-Slant Alcaline-Butt, H ₂ S Gas-ve	Alkaline-Slant Alcaline-Butt, H ₂ S Gas-ve	H ₂ S-ve Gas-ve	Alkaline-Slant Acid-Butt, H ₂ S Gas-ve	H ₂ S -ve Gas+ve
7	Urease Test (37°C@4 days)	-ve	-ve	-ve	+ve	-ve	-ve	-ve
8	Citrate Test (37°C@4 days)	-ve	-ve	-ve	+ve	+ve	-ve	+ve
9	Indole Test (37°C@48 hrs)	+ve	-ve	-ve	-ve	-ve	-ve	-ve
10	Glucose Fermentation (37°C@48 hrs)	+ve	+ve with gas production	+ve with gas production	+ve with gas production	+ve	+ve with gas production	-ve
11	Lactose Fermentation (37°C@48 hrs)	+ve	-ve	-ve	-ve	variable	-ve	-ve
12	Sucrose Fermentation (37°C@48 hrs)	variable	+ve with gas production	-ve	-ve	+ve	+ve with gas production	-ve
13	Salicin Fermentation (37°C@48 hrs)		-ve	+ve with gas production	-ve	+ve	-ve	
14	Dulcitol Fermentation (37°C@48 hrs)	+ve	-ve	-ve	-ve	-ve	-ve	
15	D-Mannitol Fermentation (37°C@48 hrs)	+ve	-ve	-ve	-ve	+ve	-ve	+ve
16	Inositol Fermentation (37°C@48 hrs)	-ve	-ve	-ve	+ve	+ve	-ve	
17	Lysine decarboxylase (37°C@4 days)	+ve	-ve	-ve	+ve	-ve	-ve	-ve
18	Arginine dihydrolase (37°C@4 days)	variable	+ve	+ve	+ve	-ve	+ve	+ve
19	Ornithine decarboxylase (37°C@4 days)	variable	-ve	-ve	+ve	-ve	-ve	-ve
20	Molonate Test (37°C@24 hrs)		-ve	-ve	+ve		-ve	
21	Gelatin liquefaction (37°C@4 days)	-ve	+ve	+ve	-ve	+ve	+ve	+ve
22	MR Test	+ve	+ve	-ve	+ve	-ve	+ve	-ve
23	VP Test	-ve	-ve	+ve	-ve	+ve	-ve	-ve

4. Conclusion

The study of the groundwater of Peenya Industrial area showed the impact of rapid urbanization and industrialization on the environment and the groundwater table. There was a clear degradation in the water quality and the expected standard of the groundwater is not being well maintained. Due to excessive contamination of the soil as a result of effluent release and industrial wastes, the groundwater is also affected in terms of quantity and quality. The declination of good areas in terms of groundwater resource is

due to the rainwaters which are recharged to the ground during the monsoons that react with the minerals present in the soils and rocks. The study suggests that GIS is one of the best techniques to analyze groundwater quality and the tools that are used in this study can be adopted for any other location to study groundwater quality. The chemical and biological characterization of the groundwater samples also suggested that the water was contaminated with heavy metals such as lead, chromium and mercury along with a diverse bacterial population that varied from time to time during collection of the samples. These sorts of

studies can help planners and managers to optimize their utilization of water resources and limit their free resources to help sustain the environment. Immediate measures must be taken to do everything to help replenish the groundwater.

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