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Research paper

Pollution of Coastal Aquifers: A Human Induced Environmental Hazards, Visakhapatnam Area, Andhra Pradesh, India - A Remote sensing and G.I.S. approach

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Abstract

Groundwater forms very little quantity when compared to the total water available on the earth. Therefore it is very vital for all living beings especially for human consumption. Visakhapatnam is one of the fastest growing Coastal cities in India with rapid development of industrial and urban activity. The present study has been carried out to evaluate the Coastal aquifer Pollution and City area Ground water pollution using GIS. Thematic layers have been generated from Ground water quality data and available ancillary data, i.e. for index overlay operations for identification of groundwater pollution zones in the study area using statistical method of point data interpolation and GIS.

Keywords: Aquifers; groundwater; groundwater pollution; G.I.S.; Index overlay model.

1. Introduction

The problem of industrialization, urbanization and resulted reconstruction of Indian metropolitan cities like Mumbai, Delhi, and Calcutta have become chronic and it is almost difficult to get back the situation on to right track. A number of other cities which are growing with industrial activity and urbanization, especially in the light of economic liberalization also emerging as potential threats to the ecosystem. Unless it is not realized at this stage, it will be too late to clean up the environment. In addition, seawater intrusion is also a major problem in the coastal area due to the decrease in fresh water recharge and or excessive inland Groundwater pumping. As the seawater moves towards inland, aquifers become contaminated with salt water intrusion, which can cause permanent damage. The city Visakhapatnam that forms the study area for this investigation is belonging to this category.

Since Groundwater is a gargle and important resource, it must be carefully managed to maintain its purity. Rapid urbanization, industrialization and increasing use of agro chemicals on one hand and lacking or in adequate pollution control on the other is leading to contamination of groundwater and depressing levels of its quality

In view of the above facts, studies have been carry out using the GIS technology.

The concept of groundwater vulnerability is based on the assumption that the physical environment causes contain degree of protection to groundwater against natural impacts, especially with regard to contaminants entering the subsurface environment. As a result some land areas are more vulnerable to groundwater contamination than others. The ultimate goal of the study being the preparation of vulnerability maps for different sub-areas in the study region through acquiring the required primary and secondary data. In the present study the aquifer pollution vulnerability is obtained using two approaches, both being dependent on the GIS concept.

1.1. Objectives of the Study

1. Recognition of groundwater polluted zones with help of Index overlay model of different chemical
   parameters thematic layers in GIS.
2. To identify the sources of pollution of groundwater in the study area.
3. Identification of potential zones of Pollution

1.2. Data Used

1. Survey of India toposheet 1:50000 scale
2. Hydrogeological data from secondary sources (Groundwater Department of Andhra Pradesh and Andhra University)
3. Groundwater chemical data from A.U Chemistry department and Geology department.
4. Primary data regarding geology, geomorphological and land use / land cover, hydrogeological condition
   of Visakhapatnam.
5. Software used EARDAS and ILWIS.

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1.3. Location

The area under investigation lies in between the long E83^0 11'30" and E83^0 22'16" and lat. N17^0 39' 16" and N17^0 45' 58" as shown in Fig. 1, Panoramic view of Visakhapatnam from Dholphin nose and Kailasa hill view of satellite image is shown in 3-D.

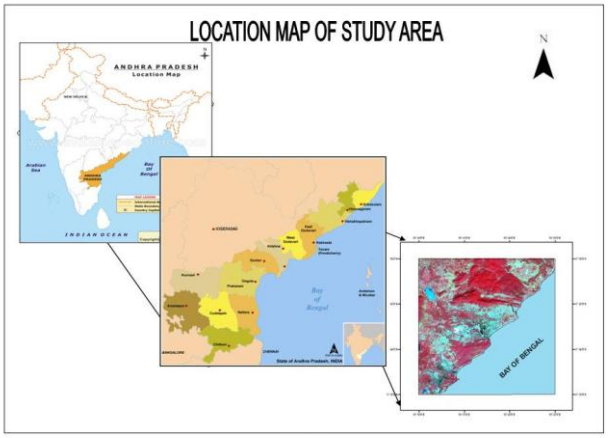

Fig. 1

2. Geology

The study area geologically belongs to Precambrian age. It is characterised by occurrence of meta-sediments and intrusive meta igneous bodies. The high hill ranges namely Kailasa, Yarada and Duvvada surround the study area in three directions and other side the Bay of Bengal makes the boundary. In this way the region is endowed with different physiographic features and resulting pictures sequence. Besides meta sediments this area is also distinguished by the occurrence of recent sediments like red sediments with calcium carbonate calcretes, dune sands, beach sands with economically important black sand concretions. All these rocks and sediments exhibit characteristically a variety of geomorphic features distributed from deepest hinterland to mere coastal plains

The chief rock types like garnet sillimanite gneiss (Khondalite), hypersthene granite (Charnockites) garnetiferous granites (leptynites) Quartzite, pegmatites occur as bedded and banded as well as massive formations in the study area. Khondalite group of rocks covering hill ranges of Northern part and hillocks in the Central part garnet-biotite sillimanite gneiss as well as garnet sillimanite occupy about 90% of the area as shown in Fig. 2.

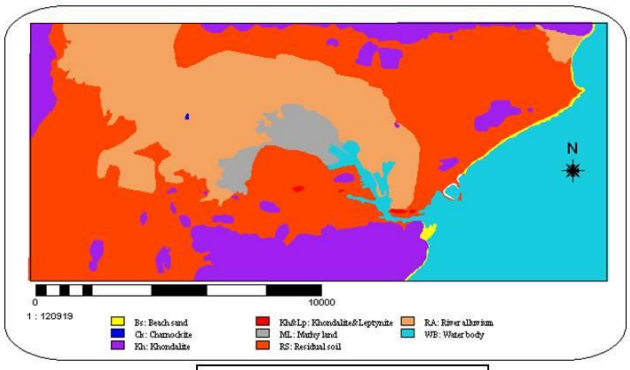

Fig. 2: Geology Map of the study area

Gneisses are present in the Yarada hill, hillocks of Waltair and at northern hill ranges to a minor extent. Occurrences of white and gray coloured quartzite's with thickness of few centimeters to thousand meters are also common. Charnockites can be called as hypersthene bearing granitic and mainly occur as two types. They are hypersthene bearing granitic rocks and porphyritic ferro hypersthene granodiorites. In the study area, these rocks occur at airport hill, Maddilapalm, Mudasarlova and pendurthi. At airport hill they are very prominent and other places they occur as small and irregular patches, layers, lenses and bands. They are blue, bluish black and greenish black in colour hard and compact medium to coarse grained with specific gravity varying from 2.7 to 3.3. Mineralogically they are composed of quartz, feldspar, hypersthene, biotite and garnet. The accessory minerals include, apatite, monazite, zircon, and iron ores. Depending up on variation in felesic minerals the overall composition will vary from acidic to basic.

According to [1] the Charnockites mostly confined to the axis of over turned folds exhibited by Khondalite hill ranges and occasionally shows a stock like intrusive relationship with garnet-biotite, granite (leptynites). Leptinites occur in association with khondalites and Charnockites having variable thickness of few meters to 1500 meters, which are mostly confined, to Waltair area. The geology of the area is shown in Fig. 2.

Remote sensing data is an important and effective tool to evaluate the hydromorphological and hydrogeological zones, which will be highly depending up on the physical, geological, hydrogeological and geomorphological characteristics. Therefore, studies have been carried out using remote sensing & GIS technique for hydromorphogeological investigation.

Besides these, many other studies in India and abroad have been carried out for the hydromorphogeological evaluations using remote sensing data. Hence, the through survey of literature proved that, the remote sensing is a quick and efficient method for demarcating and evaluating the zones of ground water pollution.
In the study area, the remote sensing has been effectively used as an important tool to delineate hydrogeomorphological features using GIS techniques.

3. Hydro-Chemistry Thematic Maps

Water samples have been collected from different locations of the study area are tested for the values of pH, TDS, TH and other major elements, using standard techniques. These values are used to extract the chemical quality maps through GIS analysis. The chemical values are plotted as point data at their respective well locations and the chemical data maps were extracted through nearest neighbourhood method in GIS analysis.

3.1. Hydrogen Ion Concentration (Ph)

The most important chemical parameter used in the groundwater quality assessment is pH. It is assumed generally that naturally groundwater will have pH around 7 – 7.3. It may be regarded neutral pH [2]. In lithologies of Na and CO_3 areas very high pH values about 8.5 are observed. Bicarbonate (HCO_3) causes moderate to high pH values for surface as well as groundwater.

3.2. Total Dissolved Solids (TDS)

Total Dissolved Solids is one of the measures of groundwater quality. It indicates the total quantity of dissolved solids in mg/l. It is determined by two methods. In the first method the E.C. values of groundwater are multiplied with factor which usually varies from 0.55 mg/l to 0.75 mg/l depending upon the nature of ions present [3]. As the electrical conductance and T.D.S. are independent it is generally accepted that if the TDS are less than 3000 mg/l, the factor 0.64 can be used to multiply the E.C. values to obtain the TDS values. The TDS values can be determined by evaporation technique in other methods. In the evaporation tech-

nique the total solid material will be collected and determined gravimetrically.

3.3. Total Hardness (TH)

Total hardness can be described simply as the property of groundwater causing a white precipitate on the surface when it reacts with the soap. It forms leather from the soap. Groundwater which has the quality is said to be hard. It is generally agreed that compounds of carbonates and bicarbonates of calcium and magnesium initially cause the hardness of the water. Also the other minor constituents which contribute hardness to water to some extent are iron, manganese, aluminium, barium, strontium and free acids. The geological formations influence directly the hardness of groundwater which results in Cardiovascular diseases and Kidney problems. According to [4] and [5]. The hardness of water becomes objectionable when it exceeds 120 mg/l.

3.4. Calcium (Ca)

Calcium is the most important in the study of groundwater quality. Majority of the geological materials of aquifers will be composed of calcium. It is present in groundwater as a material of suspension calcium carbonate readily goes into solution. It is the prime cause of hardness in water. Groundwater from limestone terrain generally contains 10-300 mg/l calcium. The excessive amounts of calcium creates Urinary track problems of human beings.

3.5. Magnesium (Mg)

Magnesium is another chief cation of groundwater chemistry. Magnesium rich minerals are associated with basic and ultrabasic rocks and ultramafic rocks of igneous and metamorphic percentage, geologically. According to W.H.O the maximum permissible limit of magnesium is 150 mg/l. [6] suggested that river water contain magnesium content varying between 1 and 50 mg/l.

3.6. Sodium (Na)

The sodium content of groundwater is caused by the weathering of sodium bearing minerals like sodic, plagioclase and other minerals and dissolves in water. It is owing to the exchange of calcium ion and sodium ion on the surface clay minerals [7]. The weathering reactions generally contribute major part of the sodium content of the groundwater according to [8].

3.7. Potassium (K)

The potassium concentration is generally very low in most natural waters. The concentration of potassium in the groundwater is the result of disintegration of potassium bearing minerals like orthoclase microcline, biotite, leucite and nephelene in igneous and metamorphic rocks. The pollution from sewage water is caused by a considerable amount of potassium. Potable groundwater should contain less than 10 mg/l potassium. As suggested by [7] the increase in potassium will have no relationship whatsoever with the total dissolved solids. The general range of potassium in groundwaters is 0.1 to 98 mg/l and the average value is around 62 mg/l [9] and [8].

3.8. Chloride (Cl)

Chloride is the most common anion in the groundwater. Chloride concentrations vary widely in natural waters. It is directly related to mineral content of the water. Abnormal concentrations of chloride are present in the coastal aquifers which suffer the seawater intrusion. In the industrial area the pollution from industrial effluents is a source of chloride concentration. The desirable level chloride is 200 mg/l and maximum permissible level is 600 mg/l according to the standards of World Health Organisation (W.H.O.).

3.9. Sulfate (SO_4)

Sulphate is important when dealing with drinking water as excessive amounts of sulphate have different effects on the health of human beings. The sulphate concentration should not be more than 250 mg/l in drinking waters according to the U.S. Public Health Services (1962). Clays contribute sulfate ion, that clay and enter into the ground water will be effective by high sulfate content.

3.10. Fluoride (F)

Fluoride is another important chemical constituent of water. It belongs to halogen group. It has maximum electro negativity. It is partially soluble in most natural waters. It is generally present only in small quantities. Its occurrence in higher amount in the order of 1 mg/l is safe and effective in reducing the dental decay [2]. The concentration of fluoride varies from place to place depending up on the type of rocks and soils from which they originate [10] and [9]. According to [11] several places of India, groundwater is characterized by high fluoride contents.

3.11. Nitrate (NO_3)

The occurrence of nitrate in groundwater is also very common. Nitrate occurres owing to the aerobic decomposition of nitrogen from organic matters. Nitrate from other sources like fertilizers, industrial effluents and septic tanks contribute nitrates in the form of pollutants. Generally nitrate concentration in ground water ranges from 10 mg/l to several hundred mg/l. However, in unpolluted natural water the nitrate content will be generally 10 mg/l.

4. Data Base Organisation and Analysis

Suitable methodology was carried out in order to achieve the objective of the present study. It is inevitable to create a data which is equally compatible to the methodology in that way it is mandatory to thoughtfully organise the database to enable smoother analysis and trying out every possibility of inter thematic and inter class dependencies and variabilities operating in nature. This is an attempts to use capabilities of G.I.S. (ILWIS 2.2.3) along with Index overlay model to generate the output for groundwater exploration.

4.1. Index Overlay Model With Multi – Class Maps

In this case the map classes occurring on each input map are assigned different scores, as well as the maps themselves receiving different weights as before. It is convenient to define the scores in an attribute table for each input map (some GIS provide specialized template for inserting values in especially attribute table for all the maps being combined).

The averages score is then defined by

$$\bar{S} = \frac{\sum Sij\ Wi}{\sum Wi}$$

S is the weighted score for an area object (polygon, pixel)
Wi is the weighted score for the **i**-th input map and
Sij is the score for the **j**- th class of the **i**-th map, the values of **j** depending on the class actually occurring at the current location.

Each map must be associated with an editor, for access by the modeling procedure. The attribute table can then be modified without changing the procedure. Attribute table containing scores are shown in Tables 1 to 11 for the groundwater pollution zones.

4.2. Derivation of Weights

The weights for the 11 input maps for pollution vulnerability were assigned and added together. The table and is showing weights of individual class of the each map.

5. Analysis for Groundwater pollution Zonation

The input layers, which are considered for the analysis of groundwater pollution zonation are pH, TDS, TH, Ca, Mg, Na, K, Cl, SO_4, NO_3, and F. As mentioned above to locate polluted zones in the study area, index overlay model with multi- class maps method has been followed.

The weights for the 11 input maps for groundwater pollution zoning has assigned and added together. The Tables 1 to 11 is showing weights of individual class of the each map.

Table 1 pH

S. No.	Range	Class	Weight
1	7.0-8.0	Normal	1.0
2	8.0-8.5	Slightly alkaline	2.0
3	>8.5	Alkaline	3.0

Table 2 TDS

S. No.	TDS RANGE	Class	Weight
1	0-500	permissible	1.0
2	500-1500	Max .permissible	2.0
3	1500-2000	Slightly saline	3.0
4	>2000	Saline	4.0

Table 3 TH

S. No.	Range	Class	Weight
1	0-75	Soft	1.0
2	75-150	Moderately soft	2.0
3	150-300	hard	3.0
4	300-1000	Very hard	4.0

Table 4 Calcium

S. No.	Range	Class	Weight
1	0-75	Permissible	1.0
2	75-200	Maximum permissible	2.0
3	>200	Exceeding level	2.0

Table 5 Magnesium

S. No.	Range	Class	Weight
1	0-30	Permissible	1.0
2	30-100	Maximum permissible	2.0
3	100-150	Exceeding level	3.0

Table 6 Sodium

S. No.	Range	Class	Weight
1	0-300	Low value sodium	1.0
2	300-600	Medium value sodium	2.0
3	600-700	High value sodium	3.0
4	>700	Very high value sodium	4.0

Table 7 Potassium

S. No.	Range	Class	Weight
1	0-15	Low potassium	1.0
2	15-20	medium potassium	2.0
3	20-25	Moderately high potassium	3.0
4	>25	high potassium	4.0

Table 8 Chloride

S. No.	Range	Class	Weight
1	0-200	Permissible	1.0
2	200-600	maximum permissible	2.0
3	600-700	Exceeding level	3.0

Table 9 Sulfate

S. No.	Range	Class	Weight
1	0-150	Permissible	1.0
2	150-400	maximum permissible	2.0
3	>400	Exceeding level	3.0

Table 10 Nitrate

S. No.	Range	Class	Weight
1	0-30	Permissible	1.0
2	30-50	maximum permissible	2.0
3	50-100	Exceeding level	3.0

Table 11 Fluorides

S. No.	Range	Class	Weight
1	0-1.5	Permissible	1.0
2	1.5-2	maximum permissible	2.0
3	2-4	Exceeding level	3.0

5.1. Derivation of Weights

The weights for the 11 input maps for pollution zoning has assigned and added together. The following table showing weights of individual class of the each map.

Map weights

M1=8* (class (pH)
M2=6* (class (TDS)
M3=5* (class (TH)
M4=4* (class (Calcium)
M5=3* (class (Magnesium)
M6=2* (class (Sodium)
M7= 1* (class (Potassium)
M8=7* (class (Chloride)
M9=4* (class (Sulfate)
M10=6* (class (Nitrate)
M11=8* (class (Fluoride)

Calculate sum of weighted conditions and divided by normalization factor

New map =((*M1+*M2 +*M3+*M4+*M5+*M6+*M7+*M8+*M9+*M10+*M11))/SUM the new map is shown in Fig. 3.

6. Results and Discussion

Groundwater pollution may be caused locally either by release of effluents and by industries or by indiscriminate use of fertilizers and pesticides for agricultural purposes. Another important point is topping of groundwater resources is often higher in urban aquifer when compared to the rural areas. This affects the natural groundwater system in many ways like subsidence in the aquifer, salt-water intrusion in the coastal aquifers etc. The other important aspect is rapid industrialization and urbanization result impact on both the quality of the groundwater. The quality of groundwater will affected by the likely pollutants released by human and industrial activity.

As mentioned earlier the pollution of groundwater has been reported for a number of urban aquifers through world [12] and [13]. Naturally the pollutants are of a wide ranging variety including nuclear species, major elements, heavy metals, chlorinated hydrocarbons, phenols, Cyanides, pesticides and bacteria.

The pollution of urban groundwater is also big problem for Indian cities. Different workers have studied the groundwater quality from different cities of India.

Scientists has carried out the studies on pollution of groundwater from the city of Madras. Similarly the pollution aspect of another south Indian city Bangalore, Sabandam. The groundwater in Bangalore environs have high Mn, Si and total Fe content which exceed to maximum permissible limits for drinking waters.

In this study the groundwater polluted zones, vulnerable areas has been identified in Visakhapatnam urban and industrial area.
The results of the present study has been categorized in to three, which are presented below

1. Demarcation of groundwater polluted zones
2. Identification of vulnerable areas

6.1. Groundwater Pollution

Groundwater pollution has become an ever-increasing problem threatening all over the world. As human population is growing phenomenally the magnitude of the population also increased, As consequence, the environment has been adversely affected leading to the impairment of the health and degradation of the area. The international and national norms for drinking water have been presented by various organizations such as WHO, ISI and ICMR (Table 12).

Table 12: GROUNDWATER QUALITY STANDARDS

	WHO (1971)		ICMR (1975)		ISI (1983)	
	Max. Permissible	Max. Allowable	Max. Permissible	Max. Allowable	Max. Permissible	Max. Allowable
TH	100	500	-	-	300	600
pH	7.6-8.5	6.5-9.2	7.0-8.5	6.5-9.2	6.5-8.5	8.5-9.2
TDS	500	1500	-	-	500	1500
Ca	75	200	77	200	75	200
Mg	<30	150	50	150	30	100
Cl	200	600	250	1000	250	1000
SO4	200	400	200	400	150	400

(Except pH, all values are in mg/l)

In the present study the groundwater quality of Visakhapatnam urban and industrial area has been analysed the distribution of chemical parameters such as (Ca) magnesium (Mg), sodium (Na), potassium (K), and anions such as chloride (Cl), sulfate (So_4), fluoride (F), and Nitrate (No_3). Similarly the chemically related properties such as hydrogen ion activity, (pH), total dissolved solids (TDS), total hardness (TH) is determined for the groundwater samples.

The detailed results and GIS analysis indicated that relationship between the parameters and the extent of pollution in different parts of the Visakhapatnam is established. The sampling stations that are situated around the chemical industries namely HZL, AF, HPCL, CF and HP have shown higher rate of pollution. The pinot interpolation maps clearly showing this phenomenon. Among these areas some places are indicating moderate to high pollution marks.

In this investigation a detailed account of groundwater quality determinations have been undertaken and GIS is applied. Based on these GIS index overly analysis results, the distribution of different parameters and their ranges indicate that the areas situated around the chemical industries such as HZL, AF, HPCL, CF and HP shows high concentrations. The quality of groundwater from these areas is far from the standards set by national and international institutions. These areas are Mulagada, Natayya palem, Kapparada, Malkapuram, Akkireddypalem, Shriharipuram, H.S.colony, Venkatapuram, old town and Sheela nagar.

Based on the distribution diagram GIS analysis the study area has been classified in to four polluted zones, which are presented below in Table 13.

Table 13 : HEALTH HAZARDS DUE TO POLLUTION (BASED ON ICMR (1975) STANDARDS

Chemical parameters	Highest Desirable	Maximum permissible	Undesirable effect	Study area Chemical parameters range
pH	7.0-8.5	6.5-9.2	Taste, corrosion, scale formation	7.12-8.9
TDS	500	1500	Gastrointestinal Irritation	163.84-3392.0
TH	300	600	Taste, corrosion, scale formation	95 -1187.9
Ca	75	200	Taste, corrosion, scale formation	25 - 214.83
Mg	50	100	Taste, corrosion, scale formation Gastrointestinal Irritation in the presence of sulfate	7.3 – 174.0
Cl	200	1000	Taste, corrosion in the hot water system	83.33 -719.48
SO4	200	400	Gastrointestinal Irritation with magnesium or Sodium	14.08 -347.26
NO3	20	45	Taste, Odor	1.2 – 103.6
F	0.6	1.5	Fluorosis	0.76-4.92

Based on the ICMR standards the Table 13 has prepared with relation to present concentrations and following areas are described below.

Unpolluted water and safe areas

In this category the city areas like MVP colony, Dwarakanagar, Assillimetta, Waltair Sitammadhara, HB colony, Dabagardens and few places of Gajuwaka.

Area under permissible limit and safe areas

H.S colony, old town, Mulagada, Akkireddipalem, Natayyapalem, Madhava dhara comes under this zone.

Area under Maximum permissible limit and moderately vulnerable

Sheelanagar, someparts of Gajuwaka, Marripalem, NAD kotta road area, 104 area are showing maximum permissible limits.

Moderate to highly polluted area and highly vulnerable

The areas Mulagada, Sriharipuram, Natayyapalem, Malkapuram, Kapparada, Venkatapuram and some parts of Gopalapatnam are indicating high-polluted zones.

7. Conclusions

- Field information and pollution zone, vulnerable maps indicates the sources for pollution of groundwater is through chemical industries, which are situated in southern and northwestern sides of the city.
- The impermeable and massive Charnockite body occurring along the E-W direction of study area perhaps restricts the mixing of polluted. waters from south to the Northeastern unpolluted waters. These areas comes under safe areas
- The groundwater quality studies and pollution zonation map indicate that HZL, AF, HPCL and CF are polluted the areas Mulagada, Sriharipuram, Natayyapalem, Malkapuram and Kapparada. Whereas the area Venkatapuram and Gopalapatnam are polluted due to Hindusthan Polymers.
- The area old town although far away from the chemical industries, the pollution may be due to the sources of the con-

tamination poor sewage system, organic wastes and sea water intrusion.

- Based on the level of pollution the entire study area is classified into two zones.
    a) Unpolluted region: MVP colony, main city area, Kancharapalem, Sheelanagar.
    b) Highly polluted region: Sriharipuram, Malkapuram, and some parts of Gopalapatnam and Venkatapuram.

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