CHAPTER 1 INTRODUCTION

1.1 General

Groundwater is defined as freshwater that infiltrates the soil and resides in pore spaces, fractures and geological formations, plays an indispensable role in sustaining human life and fostering societal advancement worldwide. This invaluable and renewable resource is a vital component of the Earth's hydrologic cycle, facilitating the movement of water within the planet. Groundwater is primarily stored in porous geological structures called aquifers. An aquifer can be defined as an underground layer of rock or geological formation that contains an adequate supply of groundwater for wells and springs. Aquifers fall into two primary categories: confined and unconfined. Confined aquifers are reservoirs of water hidden within permeable rock layers, sandwiched between impermeable rock strata. In contrast, unconfined aquifers are typically located closer to the Earth's surface and lack layers of clay above the water table, although they may still be underlain by impermeable clay rock formations.

There is no denying that the use of groundwater benefited a lot of people. But in many regions of the world today, the groundwater table is declining at an extremely unusual rate of about one meter per year. And pollution is the primary cause of that. It is endangering the available supply more and more.

The ground has a lot of water that is stored. Ground water is the liquid that is found beneath the surface in the voids and fissures of rock, sand and soil. Even though it may be moving extremely slowly, the water is still moving and remains a part of the water cycle. Aquifer is another term for ground water, though it's typically used to refer to water-bearing formations that can produce adequate water for human consumption. People all across the world rely on ground water for their everyday needs and aquifers comprise a sizable reservoir of the planet's water.

Groundwater is an integral part of the hydrologic cycle, with no distinct beginning or end. It refers to the water present below the earth's surface specifically water that completely fills all cracks and pores. It serves as an important source of water for human consumption. In dynamic groundwater systems, water moves slowly and continuously down a gradient from places of recharge to areas of discharge.

1.2 Classification of Contamination Sources

Various human activities that alter the physicochemical properties of water lead to the degradation of groundwater quality and the resulting pollution of water resources. Groundwater pollution sources can be classified based on different parameters (origin, geometry of the source and transmission rate). Pollution sources as a result of origin could be natural or anthropogenic, geometry of the source could be point source (landfills, waste dumps, septic tanks, underground tanks), linear (roads) and diffused (nitro pollution, acid rain, uranium decay) while the transmission rate represents continuous and recurrent transmission of pollutant. The following are some of the various pollution sources that are threatening groundwater quality.

(i) Industrial Effluents:

Depending on the industry, such as chemical producers, metal processors, steel plants and textile producers, industrial effluents contain a variety of elements. Both organic and inorganic chemicals can be found in industrial wastewater. Industries include pharmaceutical, organic dye, cosmetics, glue, soaps, synthetic detergents, herbicide, insecticide, textile, paper plants, oil refining, metal processing and fermentation produce the organic industrial effluents (Mondal N C et al., 2005). The iron mining, electroplating, coal and steel industries are the principal producers of inorganic industrial effluents (Mohapatra U et al. 2005). Untreated industrial effluents posed a significant threat to the environment, human health and ground water resources (Shankar B S et al. 2008).

(ii) Agriculture Discharges:

Agriculture discharge is a non-point source of pollution that spreads over a wide area, making control and treatment more challenging. Agricultural runoff deteriorates both groundwater and surface water (Ramappa R et al. 2000). Surface and groundwater are reportedly severely contaminated by chemicals from fertilizers, pesticides, insecticides, farm waste, plant and animal debris, inorganic material and manure slurry. Regulation and mitigation of fertilizer pollution are challenging. It has higher concentrations of nitrogen and phosphorus and lower concentrations of potassium. Nitrate-containing nitrogen fertilizers can contaminate groundwater easily since they are highly soluble in water. Fertilizers are delivered to rivers, streams, lakes and seas through rainwater runoff (Deshpande S M et al. 2012; Sharma S K et al. 2002).

(iii) Sewage and Domestic wastes:

Sewage is a significant source of water pollution. Wastewater that frequently includes industrial and home pollutants is referred to as sewage. Water discharged after residential or commercial use is frequently referred to as sewage. Human waste, soap, detergent, glass, metals, garden trash and sewage sludge are all found in sewage. Domestic sewage carries used water from homes, while industrial sewage carries used water from chemical processes. Untreated sewage may be filled with nitrogen, phosphorus, organic waste, bacteria, viruses, protozoa, oils, greases, mercury, cadmium, lead, chromium, copper and a variety of harmful compounds. Human health is endangered by the sewage that is discharged into the lakes, rivers and oceans.

(iv) Fertilizers:

Fertilizer isn't a problem if it's handled properly, but if too much is applied at the wrong time, it can easily wash down storm drains and then flow untreated into streams or lakes. A fertilizer is a substance, either natural or manufactured, that supplies one or more nutrients to plants necessary for plant growth. Fertilizers are man-made or organic substances that have the potential to be quite harmful. Fertilizers are mostly used in agricultural fields since they contain high quantities of nitrogen and phosphorus, which harm the environment. Whenever nitrogen fertilizers are used at high levels, they contaminate groundwater that is poisonous to humans. The most significant change in algae populations occurs due to fertilizer pollution (algal blooms). Using too much fertilizer results in algae blooms in streams.

(v) Runoff from Urban Areas:

Urban runoff is a significant contributor to water contamination in urban areas. In urban areas, water is often unable to infiltrate into the soil as a result, urban runoff flows across roadways and urban landscapes. The pollutants from urban runoff include plant material, fertilizers, pesticides and household chemicals waste. Urban runoff pollution is caused when the runoff, while traveling across the urban environment, acquires contaminants that affect water quality. Urban runoff pollution is nonpoint source pollution.

(vi) Organic Chemicals:

In the chemical industry, a variety of organic chemicals are utilized. Drinking-water from various sources may contain a very small amount of chemicals that cause serious health problems (Wabaluti R. et al. 2013). Through a variety of human activities, synthetic organic chemicals are brought into the ecosystem. The majority of the harmful organic chemicals in water come from synthetic sources, including pesticides, food additives, detergents, medicines, insecticides, synthetic fibers, plastics, solvents and volatile organic compounds.

(vii) Inorganic Pollutants:

Human activities result in inorganic contaminants that seep into groundwater aquifers, including mineral acids, trace elements, inorganic salts, metals, metal compounds, cyanides and sulphates. Inorganic contaminants are persistent in the environment and do not biodegrade (Yadav S et al. 2010).The aquatic ecology and biological communities are negatively impacted by toxic inorganic pollutants. Inorganic substances that occur naturally primarily contaminate groundwater.

(viii) Toxic Metals:

Toxic metals like aluminum, arsenic, barium, cadmium, chromium, lead, mercury, selenium and silver may be damaging to human health and cause diseases like diabetes, hearing loss, hematologic and immunologic disorders, various types of cancer and developmental abnormalities. Human activity is mostly too responsible for the toxic metal contamination of water resources. Toxic metals extensively present in the environment, including the air, water and food. Toxic Metals in water sources can be a byproduct of contamination or might occur naturally. Naturally, when water comes into touch with rock or soil, metals dissolve in the liquid. Leakage from waste disposal sites and pipe corrosion are additional causes of metal pollution (Verma N. et al. 1995).

1.3 Groundwater quality issues in Indian/Gujarat Context

For India: Groundwater quality in India is currently facing a significant crisis, with a substantial portion of the population relying on it for domestic use. Approximately 80% of rural communities and 50% of urban areas depend on groundwater, making it a vital resource for over a billion people. However, alarming reports indicate that more than 33% of the country's groundwater resources are unsuitable for consumption (Times of India, 2010). This critical issue stems from a troubling combination of anthropogenic and geogenic contaminants.

Anthropogenic pollutants, originating from sewage disposal, agricultural practices and industrial activities, have contributed to the widespread contamination of groundwater. For instance, groundwater Nitrate (NO_3^-) contamination, primarily caused by agricultural runoff from excessive nitrogen fertilizer use and improper disposal of human and animal waste, exceeds the permissible level of 45 mg/L set by the Government of India (GOI) in 11 out of the total 28 states (Mehta M. et al. 2006). In Rajasthan, a staggering 22% of villages grapple with excessive Nitrate contamination (Gupta A. et al. 2010). Pesticide consumption surged dramatically during the Green Revolution, reaching a staggering 74.323 billion metric tons in 1995 (Chaudhary C. et al. 2002), leaving many areas, such as Howrah in West Bengal, with groundwater unfit for drinking due to elevated pesticide levels (Chaudhary C et al. 2002).

Industrial discharge compounds the problem, with major Indian cities like Delhi, Mumbai, Kolkata, Ludhiana, and Kanpur experiencing groundwater pollution due to industrial effluents (Bobba A. et al. 1997). In Kolkata, the production of the insecticide Paris-Green by a local factory led to arsenic contamination of hand tubewells used for drinking, affecting over 7,000 people and causing chronic arsenic poisoning (Chatterjee A. et al. 1993). Shallow tubewells are especially vulnerable to contamination in such cases. India is home to about 2.6 million small-scale industries (SSIs) concentrated largely in urban areas (Nair C. 1997), and a majority of these SSIs do not adequately treat their industrial discharge, further exacerbating groundwater pollution.

Additionally, geogenic contaminants, including fluoride and arsenic, pose substantial threats to public health. Fluorosis, affecting more than 66 million people in India, is a widespread issue, with 20 of 28 states grappling with some degree of groundwater fluoride contamination. This contamination impacts a overwhelming 85-97% of districts in certain states, with a total population of 411.4 million residing in 201 districts with known fluoride contamination.

Addressing these multifaceted challenges is not only essential for safeguarding public health but also for ensuring the availability of clean and safe drinking water for millions of people across India. Comprehensive and concerted efforts are urgently needed to mitigate the factors contributing to groundwater pollution and to secure a sustainable future for this critical resource.

For Gujarat: Groundwater quality in Gujarat, remains a dynamic concern due to the state's diverse hydrogeological conditions. Gujarat's heavy reliance on groundwater for various purposes, including irrigation, industry and drinking water supply, underscores the need for continuous monitoring. The CGWB conducts extensive studies to assess the state's groundwater quality parameters, including, Nitrate concentrations, iron content and the presence of geogenic contaminants like fluoride.

Gujarat faces specific challenges in maintaining groundwater quality. In some regions, high TDS levels are observed, affecting the suitability of groundwater for drinking and irrigation. The presence of fluoride in certain areas raises concerns about fluorosis, a health issue affecting communities. Additionally, Nitrate contamination is reported in pockets, posing health risks.

The state's increasing urbanization and industrialization have led to heightened concerns about industrial effluent discharges affecting groundwater quality in some urban areas. The regular monitoring and comprehensive assessments provide valuable data to guide policymakers and stakeholders in ensuring sustainable groundwater management in Gujarat. By fostering partnerships and employing suitable remedial measures, Gujarat aims to safeguard its groundwater resources for future generations while addressing the existing quality issues (CGWB Year book 2020).

Depth of groundwater level in Gujarat (May 2020)

In May 2020, water levels of 20 to 40 mbgl were observed in 8.9% of Gujarat wells. Kuchchh district recorded the shallowest water levels in Lilpuri village with 0.50 mbgl. Amreli district's Morjhar aquifer recorded 49.50 mbgl as the deepest level for unconfined aquifers. The deepest water level ever recorded in North Gujarat is 39.67 mbgl at Waliampura in Sabarkantha district, while the shallowest water level ever recorded is 0.55 mbgl at Shekhupura in Kheda district. In portions of Vadodara in South Gujarat, deeper water levels of more than 20 mbgl were mostly seen. At Dahli (bhilad) in Valsad district, the deepest water level was 49.20 mbgl, while at Luhara in Bharuch district, the shallowest level was 0.85 mbgl. In the Saurashtra area, Kadegi village in the Porbandar district reported the shallowest water level (0.55 mbgl) and Morjhar in the Amreli district recorded the deepest water level (49.50 mbgl). Kotada in the Kachchh area has the deepest water level, which is 37.00 mbgl, while Haboi has the shallowest, which is 0.62 mbgl.

Depth to water level in Gujarat (November 2020)

Unconfined aquifers range in depth from near ground level to 37.40 mbgl (Waliampura, Sabarkantha district) in November 2020. Water levels of more than 40 mbgl are not observed in any district of Gujarat State. The Kheda district's Shekhupura has the lowest measured water level (0.05 mbgl). The deepest water level in North Gujarat, 37.40 mbgl, was recorded at Waliampura in Sabarkantha district, while the shallowest level, 0.05 mbgl, was reported in Shekhupura in Kheda district. The deepest water level in South Gujarat is 29.10 mbgl at Sunderpura in the Narmada district, while the shallowest level is 0.10 mbgl in Huda in the Valsad district. The shallowest water level in the Saurashtra area was 0.15 mbgl at Dhrol in the Jamnagar district, while the deepest was 34.30 mbgl at Dharangani in the Amreli district. Water levels reach a maximum of 30.65 meters at Panchasar and a minimum of 0.19 meters at Haboi in the Kachchh region.

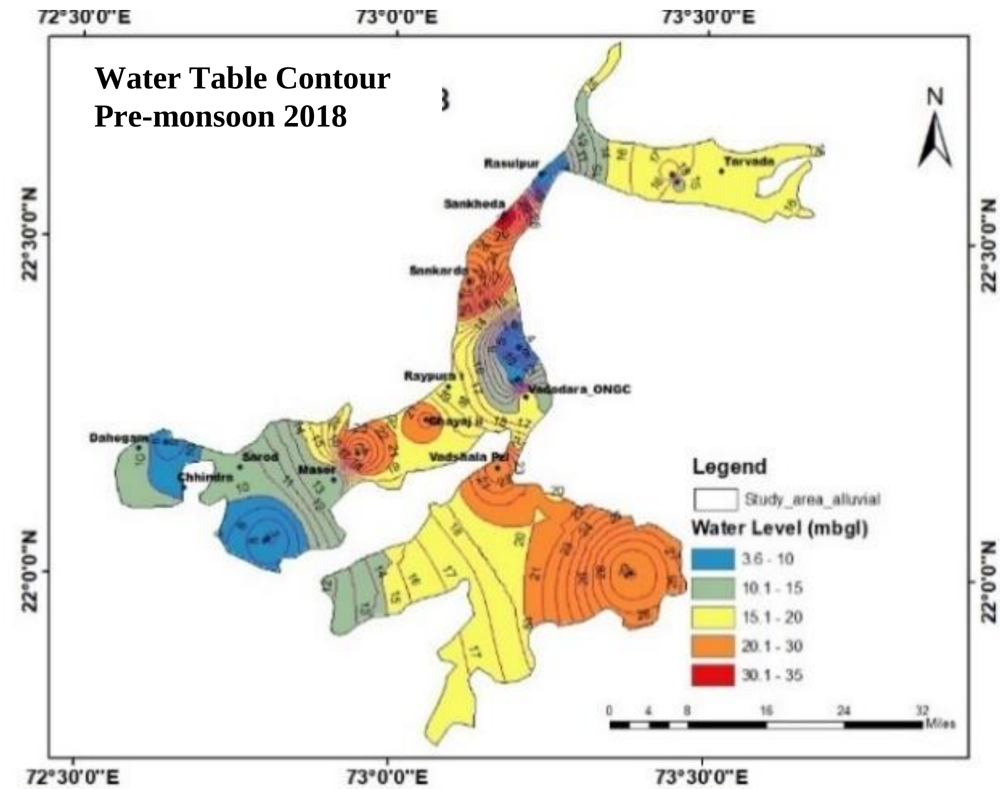

Fig 1.1 Water Table Contour Pre-monsoon 2018

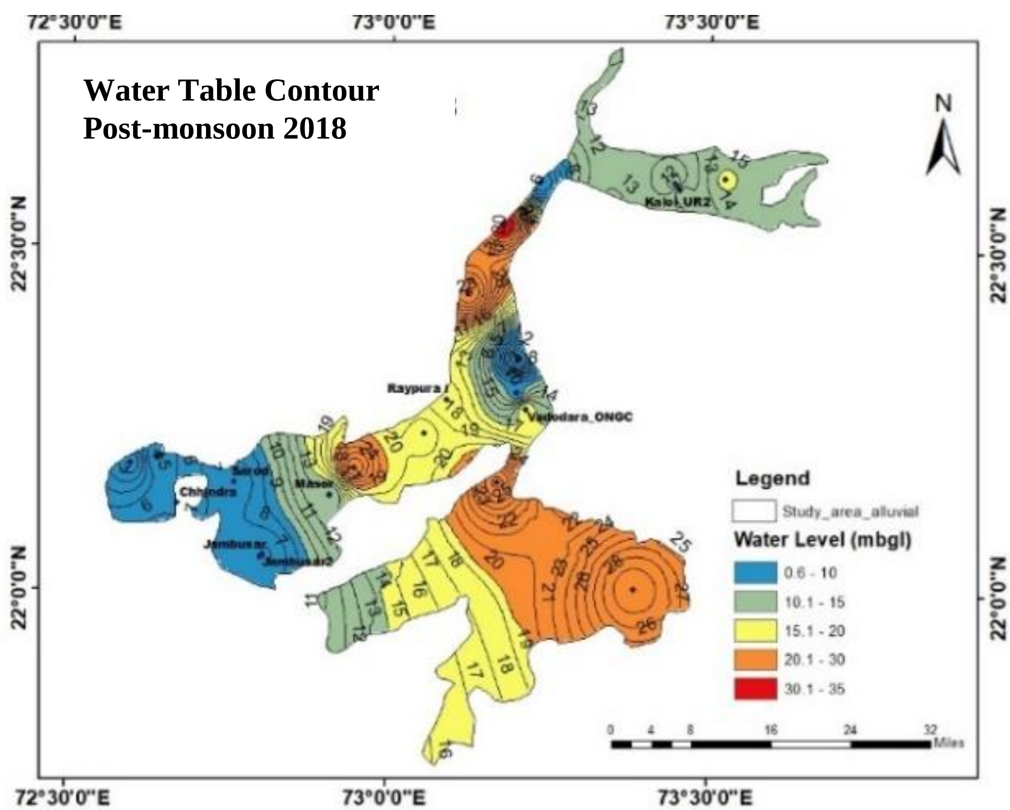

Fig 1.2 Water Table Contour Post-monsoon 2018

1.4 Groundwater Quality and Contamination

The term quality is used to define the chemical, physical and biological properties of water, generally in relation to its suitability for a certain use. It becomes required to give the word quality a dimension. Quality in water does not refer to an immeasurable quality. It is not only measured in mill equivalents per liter of various ions but it may also be adjusted to meet specific needs. In order to be accurately measured, the concept of quality must be applied to water. Although it may seem strange, water has the unique ability to measure quality.

A combination of natural landscape elements, including geology, topography and soils; contributions from the climate and atmosphere; and human activities associated with various land uses and land management techniques are responsible for the deterioration of ground water quality. Water is such a great solvent; it may have many compounds dissolved in it. Ground water has a lot of opportunities to dissolve materials as it travels since it passes through beneath dirt and rocks. Because of this, ground water frequently contains more dissolved materials than surface water.

When man-made harmful substances enter groundwater, they cause it to become dangerous and unsuited for human use, this is known as groundwater contamination. Contaminated groundwater may have negative health impacts. Contaminants are presumed to be either above or below ground (Kumar D et al. 2003, Kaplay R. et al. 2004). The contaminants are transported across a larger area by groundwater movement and aquifer dispersion. Surface water percolate through soil then it picks up minerals, salt and organic compounds (Agrawal V et al. 1997). As a result of the water migrating downward, the concentration of dissolved solids has increased (Saleem A. et al. 2012). Some places have mineral concentrations high enough to make groundwater unsafe for irrigation and drinking without treatment. Ground water pollution occurs when contaminated water seeps into the ground and reaches an aquifer (Meena A. et al. 2001, Mohan R. et al. 2010). Groundwater contamination comes from point and non-point sources. Septic systems, underground storage tanks and landfills are examples of point sources of contamination, whereas agricultural waste (pesticides and fertilizers) and urban garbage are non-point sources of contamination.

A point source of contamination occurs when the pollution comes from a single, identifiable source. There are many different kinds of point-source pollutants in streams, including those from industrial, agricultural and urban sources. Storage areas for animal waste and areas where fertilizers and pesticides are cleaned up can both be considered point sources of pollution from agriculture. Municipal point sources include waste water plants, landfills (Datta P. et al. 1996). Hazardous substances may be present in the raw materials as a result of all of these actions. Pollution from non-point sources spreads out over large areas. Water can deposit contaminants into rivers, wetlands, lakes and underground water when it flows over and through the ground. These contaminants can be both natural and man-made (Nirmala B et al. 2012). Additionally, sediments, septic tank seepage and fertilizer use can also be considered non-point causes of contamination. A prominent cause of groundwater non-point contamination is irrigated agriculture.

1.5 Concept of Groundwater Vulnerability

Different researchers interpret the concept of groundwater contamination vulnerability in diverse ways. In its broadest sense, groundwater vulnerability is a measure of how simple or difficult it is for pollution or contamination at the land surface to reach a producing aquifer. It also refers to whether or not, an underlying aquifer will become contaminated as a result of activities at the land surface. Vulnerability is high if natural factors provide little protection to shield groundwater from contaminating activities at the land surface and it is low, if natural factors provide relatively good protection and if there is little likelihood that contaminating activities will result in groundwater degradation (Harter and Walker, 2001).

A fundamental characteristic of groundwater systems that is based on how sensitive they are too anthropogenic and/or natural influences. Natural mechanisms are in charge of reducing the concentration of several pollutants, including hazardous microbes, when water penetrates the earth. The type of soil and aquifer properties, the kind of contamination and the related activity all affect how much attenuation takes place.

In general, the term groundwater vulnerability is used to represent the intrinsic characteristics of the aquifer which determine whether it is likely to be affected by an imposed contaminant load (National Research Council, 1993). There are two types of vulnerability: intrinsic vulnerability, which is purely dependent on the characteristics of the groundwater system and specific vulnerability, in which these fundamental characteristics are linked to a specific contaminant or human activity.

The concept of groundwater vulnerability, as expressed by Linda Aller (1987), revolves around assessing the susceptibility of groundwater resources to contamination or degradation.

She has considered a combination of geological, hydrological and hydrogeological factors that influence the potential for pollutants to infiltrate and impair the quality of groundwater. These factors include the characteristics of the overlying soil and rock layers, the depth to the water table or groundwater level and the rate at which water can flow through the subsurface.

Water travels from the ground surface to the water table in a predictable manner, which determines vulnerability. The chance for pollutant attenuation increases with increasing travel time. According to the governing criteria, aquifer vulnerability can also be measured using an appropriate mathematical framework and further split into broad classes like very high, high, low and very low.

1.6 Rationale of Present Study

Groundwater is one of the significant resources which is frequently used for a variety of purposes related to life. The level of ground water usage has significantly increased during the last few decades. The use of water has grown significantly during the past 50 years, along with the rate of development. The quality of ground water is under threat from a number of factors, including industrialization, increased urbanization, increased agricultural activity, unrestricted pesticide and fertilizer usage and expanding agricultural activity. Interest in the study and research in the field of ground water engineering in general and ground water quality in particular has been increased significantly in past few decades. The study in this area has become more diverse and well-liked as a result of innovation and the development of new approaches based on soft computing tools during the last 20 years or so. Studies connected to the problems with ground water quality are also gaining momentum in India, but this area is yet only lightly researched. Particularly in Gujarat, no significant work has been noticed in the literate survey carried out till date. At the India level also the work done is comparatively less, however among this few works, the work done by Prakash Gupte, Atiqur Rahman, JMI University, New Delhi; Prasant Kumar, CSIR, Chandigarah, Praveen Kumar Thakur, ISRO, Dehradun is worth referring.

Fig 1.3 Effluent Conveyance System (M/S Ecpl) For Nandesari Industrial Area And Industries Located near Vadodara, Gujarat

The possible effects of human activity on groundwater resources, such as changes in water quality and quantity, and the possible hazards associated with groundwater extraction, can be significantly better understood through groundwater vulnerability assessments. Such assessments can also help inform decision-making around sustainable groundwater management, providing key information on the location and magnitude of groundwater-related problems. A groundwater vulnerability assessment can also be used to establish policies and practices promoting the management and protection of groundwater. In addition to identifying areas that may require additional protection measures, groundwater vulnerability maps can also provide guidance for new management and protection measures.

The study area comprises the major districts of Gujarat namely Vadodara, Panchmahal, Dahod, Chhota Udaipur and some part of Bharuch, Narmada and Mahisagar districts between the left bank of Mahi river and right bank of Narmada river. This region covers rural area and highly populated urban area of Vadodara city. In and around Vadodara city, there are basic six types of industries vise Chemical and Petroleum, Spinning/Textile, Rubber and plastic, Machinery and vehicle parts, Electrical machinery and Tobacco producing industries. These industries release their effluents which has adverse effect on regional ground water quality. In addition to this there is also potential contamination sources from the agricultural, excessive fertilizers and pesticides and waste generated from the residential domestic activities. The ground water of the region is suspected to be vulnerable to a noticeable extent which needs due consideration.

Gujarati to English: Complaint against managers of Raicon Distribution Company for dumping hazardous chemicals in groundwater.

Gujarati to English: In Vishwamitri, the men escaped from the police raid when the chemical waste was dumped.

Gujarati to English: Polluted Groundwater is not suitable for use of irrigation-domestic use.

Fig 1.4 Frequent illegal land pollution activities by industry are caught by authority

The ‘precipitation’ and ‘recharge’ are the main factors which can reduce the effect of ground water contamination up to certain extent, this is true only in the case of when soil surface does not carry pollutants. On the contrary if the top soil contains contaminants, recharge can wash these pollutants into the groundwater, leading to a decline in water quality. As per CGWB report the, ground water level is decreasing 61% due to lack of recharge in urban area. Looking to the scenario of ground water contamination and lacking in ground water recharge in urban area, the study of ground water vulnerability assessment become essential for further course of action for Authority.

1.7 Aim and Objectives of study

A variety of methodologies are used in this study, including identification of the source area and vulnerability of groundwater contamination in the study area, determining the relationship between groundwater quality and vulnerability parameters, as well as implementing management strategies to reduce public health risks in critical areas based on human health risk assessment (HHRA).

The objectives of the research are,

1. To identify various sources of ground water contamination in study area.
2. To develop suitable model for ground water vulnerability.
3. To assess ground water vulnerability in study area.
4. To develop the relationship between vulnerability parameter with ground water quality.
5. To suggest the management strategy to minimize the risk on public health.

1.8 Organization of Thesis

This research work is structured considering the following chapters:

Chapter 1: Introduces key terminologies and describes the aim and objectives of present research.

Chapter 2: Reviews previous research works in the field of groundwater vulnerability and groundwater management strategies that minimize the health risk on public.

Chapter 3: Highlights necessary information about present study area such as Geohydrology, hydrometeorology, location specific characteristics and shows the collection of required data.

Chapter 4: Describes various methods used in present study.

Chapter 5: Identifies the sources of groundwater contamination for present study area based on multivariate statistical analysis.

Chapter 6: Describes groundwater vulnerability and groundwater quality assessments along with correlations between vulnerability parameters and groundwater quality.

Chapter 7: Explains various groundwater management strategies for reduction of most crucial parameter and minimizing public health risk.

Chapter 8: Summarizes entire research work and gives appropriate concluding remarks.