Groundwater Vulnerability and Pollution Risk Assessment of Jizzi Catchment,Sohar, Sultanate of Oman

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Abstract

The Sultanate of Oman has seen unprecedented development in the past three decades since renaissance. Recent economic development in the country, together with rapid expansion of the population has increased the demand for water, and increased waste generation. These demands exacerbate the over utilization of aquifers. It has been recognized the urgent need for the preparation of a comprehensive strategic plan for optimal development, and management of water resources for projected needs, in order to meet future demand of water, which requires extensive information of water quality, quantity, and water use.

A number of groundwater pollution incidents, originating from leakage of underground storage tanks and seepage of leachate from mine tailings have been reported. Leakage of septic tanks and agricultural developments utilizing inorganic fertilizers and pesticides are also a major concern of groundwater pollution. Increasing demand upon aquifers, and wellfields, coupled with the rapid infrastructure development, and agricultural expansion has emphasized the need to protect water resources of the Sultanate, and this has emphasized the need for adopting improved technologies of groundwater protection. Groundwater vulnerability assessment maps, potential pollution risk assessment maps, and training of Omani's staff to handle these subjects are becoming very efficient tools and indispensable in water resources planning and development, in the Sultanate and in different part of the world. It is noted here that all groundwater is vulnerable to contamination from land uses, which are becoming more intensive in rural and urban areas. Although most of groundwater could be considered vulnerable, hydrogeological setting may provide some protection. By determining which areas are relatively more vulnerable to contamination, strategies can be developed to implement stringent management options, or focus groundwater-monitoring efforts. Therefore, since the system has been developed on a selected pilot scheme, the Ministry of Regional Municipalities, Evironment and water Resources, can provide comprehensive information on selection of waste disposal sites, and licensing procedures. In addition potential risk assessment of contaminant sources could be achieved.

Some major areas of direct application of the aquifer vulnerability assessment system are evaluation of land development proposals for; residential, commercial, and industrial purposes; agricultural developments; above and underground storage

tanks, and salinity management.Groundwater protection for future water use is the main objectives of the country, aiming at protection of existing water resources from pollution, saline intrusion, and overabstraction of groundwater aquifers. Since most of the exploitable aquifers are vulnerable to contamination, therefore wellfied protection zones have been established within each catchment area ruled by laws restricting groundwater pollution. The Groundwater vulnerability ,and risk assessment mapping will facilitate the professionals and the decision-makers to perform many tasks on national level. Each decision at the higher integrated management level related to the wellfield and catchment's protection would be enhanced, improved, and uniquely more suitable for the Ministry. The technique will help the planner if necessary to perform any Socio-economic development's senarios in the region. It will demonstrate nearby potential contaminants and its impact on the surrounding environment pertaining to the existing wellfields, whole catchment and their potential risks. In order to achieve above objectives, Jizzi catchment has been selected as a pilot project. The ultimate goal of the project, is building a Groundwater vulnerability map, to play a significant role in Decision Support System (DSS)(utilising GIS,Autocad teqnique) ,that will pave the way to the decision-makers to deal, and manage water resources in the whole catchment areas throughout the sultanate of Oman Jizzi catchment is located at the western part of the town of Sohar, Albatina Region Of Oman, embraces the main surface watercourses and tributaries of Wadi Jizzi. Wellfields also exist supporting the Sohar regional center municipal water supply system. The results of the activities and potential pollution sites have enabled a Risk Assessment of the aquifer vulnerability map. The risk assessment evaluation for an array of activities in the catchment indicated that solid waste site, sewage-holding tanks and used oil products stored in drums from abandoned crusher camps (upstream of wellfield) and agricultural activities in the immediate vicinity of the wellfield pose a medium to high risk. The natural vulnerability of the aquifer is considered to be very high in the Red zone, high in the Orange zone, moderate to high in the Green, Light Green, and low to moderate in the Light Blue zones, of the catchment. Zone specific regulations for the wellfield protection have been proposed along with the best practices for the activities, which can potentially affect water resources. To implement Wellfield Protection Plan in each zone, acceptability, non-acceptability or conditional acceptability conditions have been suggested in respect of each generic category of activities. Therefore, protection of groundwater should remain a primary goal, due to its pivoted importance to the country.

1.0 Project Background

Oman lies in the arid region of the world with irregular and scant rainfall. There is very little availability of fresh surface water; the demand is predominantly met by the groundwater supplies. However, desalinated water in conjunction with groundwater is supplied to some of the major towns.

Traditionally, villages and towns in the semi arid climatic zones have developed close to the water sources, particularly in the wadi channels. Due to increase in population and enhanced living standards, new agricultural, industrial and commercial activities have emerged near these water sources and wellfields. These wellfields are increasingly required to produce more water to satisfy demand, sometimes leading to over-abstraction. This can reach unsustainable levels causing depletion in production and/or deterioration of the water quality which may render the water unsuitable for its intended use. The uncontrolled practices of waste disposal at inappropriate locations may cause inorganic, organic and bacteriological contamination of the groundwater resource.

Typically, groundwater sources are brought into production mainly via boreholes and dugwells. A group of production boreholes (located close to each other and in the same catchment) supplying water to a town/village is commonly referred to as a "wellfield". MEW operates several wellfields in the country. These are generally located in the wadi channels which are the natural conduits for occurrence and movement of water, on or below the ground surface.

The Ministry of Water Resources in the Sultanate of Oman used to manage precious water resources for municipal, industrial and agricultural uses. Recent economic development in the country, together with rapid expansion of the population has increased the demand for water. These demands exacerbate the over utilization of aquifers. A number of groundwater pollution incidents, originating from leakage of underground storage tanks, and seepage of leachate from mine tailings have been reported. Leakage of septic tanks and agricultural developments utilizing inorganic fertilizers and pesticides are also a major concern of groundwater pollution. Increasing demand upon aquifers and wellfields coupled with the rapid infrastructure development and agricultural expansion has emphasized the need to protect water resources in the Sultanate is a high priority area, and this has emphasized the need for adopting improved technologies for vulnerability assessment, and training of Omani staff on these aspects.

It is noted here that most of groundwater is vulnerable to contamination from land uses, which are becoming more intensive in rural and urban areas. Although all groundwater could be considered vulnerable, some protection may be provided by hydrogeological setting. By determining which areas are relatively more vulnerable to contamination, strategies can be developed to implement oriented management options, or focus groundwater monitoring efforts. For example, one of the direct applications of the vulnerability assessment system is for the development of land disposal of waste management program. At present most of the land disposal sites (solid and liquid waste) are located on flood plains and alluvial wadi beds. The municipalities that operate these sites do not have sufficient data or staff for the required hydrogeological assessment,characterisation ,and standardisation of waste disposal sites. Therefore, once the system is developed on a selected pilot scheme, the government can provide comprehensive information on selection of waste disposal sites and licensing procedures.In addition potential risk assessment of contaminant sources could be achieved.

Other major areas of direct application of the aquifer vulnerability assessment system are: evaluation of land development proposals for ; residential, commercial, and industrial purposes; agricultural developments; above and underground storage tanks, and salinity management.

1.1 Intoduction

Oman is a country with a different weather systems which are dominating in particular seasons. Tow distinct seasons are prevailing namely (November to April) and Summer(may to October) affected by various meteorological mechanisms throughout the country. The rainfall although scanty is the only source of natural water replenishment while groundwater is the essential natural source of water supply. Rainfall is ranging from 50 mm in the interior to 300mm in the north Oman Mountains while the general average is about 100mm.

All fresh groundwater in the Sultanate of Oman originates from local rainfall, The country's reserves of fresh groundwater are the Alluvium in the Northern Oman and the Tertiary limestone in the south. Significant amount of fossil water are contained in aquifers underlying the Nejd Southern Oman.

New groundwater basins have been discovered with appreciable potentiality of fresh water for long term domestic water use as well as brackish water for Agricultural use.

The fresh saltwater interface was detected along most of Albatinah coast, in north eastern Asharqiah,on the Salalah Plain, and in some areas of the Musandam Peninsula.

Albatinah has important reserves of groundwater which are heavily exploited for Agricultural use, where it is influenced by seawater intrusion(nonpoint contamination), and recirculation of irrigation returns.

Traditionally most of Omani communities are evolved adjacent to Aflaj systems(very sensitive to contamination) which are channels originates from a mother well intercepts the groundwater table or on the surface for collecting groundwater or natural spring water in order to be led away by tunnel for different uses, mainly for irrigation.

Surface water flow in the Sultanate of Oman is rare , in nearly all wadis, it occurs only for short period of time, hours or few days after the storm, in the form of flash flood incidents .However, there are some cases of periods of two or more dry years with no runoff. Fifteen major recharge dams have been built for recharge purposes, which contribute for more than 50Mcm ,additional annual recharge to aquifers on average, through the estimated 300Mcm of annual outflow to the sea and desert could be harvested.

The main non -conventional water resources in the Sultanate of Oman are desalinated water and treated wastewater. There are 54 desalination plants in all over the Sultanate,Muscat Governorate is accounted for approximately 90% of the total production of the desalination plants.

Approximately 23Mcm/yr. of treated wastewater is used for irrigation purposes. In general terms, the host country strategy is encouraging the diversification of its economy, focusing on agricultural development in order to achieve self-sufficiency in foodstuffs. Rationalization of existing water resources is a prerequisite to ensure sustainable socio-economic development, promotion of water conservation and metering with progressive introduction of tariffs in the agricultural sector (demand management), legal provision to control drilling. This strategy implies utilization of desalinated sea water for domestic and industrial use, whereas ground water resources to be utilized in irrigation purposes in order for the government to maintain the level of commitment to irrigated agriculture,and minimize the environmental impact on the deteriorating water quality caused by point non point contaminant sources namely the saltwater intrusion and soil degradation. It is believed that artificial recharge/aquifer storage recovery schemes in ad hoc conditions are an effective tool in groundwater management. The source of injected water could be from conveyed water, surplus of desalinated water or from treated wastewater to prevent saltwater intrusion in coastal areas .

Consequently,to fulfill ad hoc strategic tasks a complex of integrated studies and investigations should be carried out within the present context of seeking ways and means to manage the scarce groundwater resources of Oman and to enhance the environmental considerations in all possible development alternatives. The delineation of point-nonpoint pollution sources of Jizzi cacthment and along the coastal areas of the region ,preparation of potential groundwater pollution risck assessment ,groundwater vulnerability assessment have becoming indispensable at the time being due to the importance of groundwater conservation.

1.2 Project Justification

Groundwater system in Jizzi region is heavily overexploited mainly for irrigation purposes resulting in a severe deterioration of water quality and quantity accompanied in continuous saltwater intrusion wedge along the coast. Under recent conditions the sustainability of the agricultural sector would not be prevailed without rationalizing groundwater resources to maintain agricultural production, and to augment national groundwater reserves for emergency purposes. Augmentation of groundwater resources through artificial recharge, conjunctive use of water resources, and improvement of irrigation techniques for water savings are part of the well known procedures towards rationalizing and protection of the water resources in Oman.

The lower coastal plain of Jizzi, has led to a successive decline in ground water levels, and quality deterioration, and soil degradation.

Contamination may enter freshwater aquifers from at least 33 generic sources ,these sources may be classified broadly as either point or nonpoint sources. Point sources are derived from localized areas and include, landfills, surface impoundment's, underground storage tanks, spill of chemicals ,oil or brine during transport or transfer operations, injection wells, where as nonpoint sources actually consist of activities or processes that introduce contaminants over a broad area such as agricultural pesticides, and fertilizers, septic tanks, drainfields and cesspools, saltwater intrusion animal feed lots and mining operations.

The project has contributed to the delineation of groundwater vulnerability , potential risk assessment and control of contamination sources in order to manage hazardous materials and waste, the management of municipal solid waste, the control of underground storage tanks, nonpoint sources contaminant, and land uses; and the reduction of sources of contamination to enhance groundwater availability in the region.

In Oman, soil layer above the aquifer is relatively thin or absent in most areas. Therefore potential of natural attenuation of contaminants in the soil layer is very small and perhaps negligible. Fissures in the aquifer will allow faster movement of contaminants whilst rocks where inter-granular flow is predominant may act as an impediment to a significant degree. The most vulnerable strata in Oman are the uncemented coarse wadi gravels in active wadi channels(very sensitive to contamination), and fractured limestones. The depth to water table has a significant impact on the potential vulnerability of groundwater. Therefore, there is an urgent needs in adopting evoluted and well developed vulnerability, risk assessment system and mapping in Oman.

The proposed system is a knowledge based system, which are computer programs designed to assist non-experts to obtain solution to difficult problems that experts would handled. These programs have been developed combining the knowledge used by experts such as their decision-making skills, interpretive abilities, experience and judgement as well as factual information such as field derived data.

2.0 Geography and Population

The Sultanate of Oman occupies the south-eastern corner of the Arabian Peninsula and has a total area of 312 500 km2. It is bordered in the northwest by the United Arab Emirates, in the west by Saudi Arabia and in the south-west by Yemen. A detached area of Oman, separated from the rest of the country by the United Arab Emirates, lies at the tip of the Musandam Peninsula, on the southern shore of the Strait of Hormuz. The country has a coastalline of almost 1 700 km, from the Strait of Hormuz in the north to the borders of the Republic of Yemen in the south-west, overlooking three seas: the Arabian Gulf, the Gulf of Oman and the Arabian Sea.

Oman can be divided into the following physiographic regions:

The whole coastal plain. The most important parts are the Batinah Plain in the north, which is the principal agricultural area, and the Salalah Plain in the south. The elevation ranges between zero near the sea to 500 metres further inland.

The mountain ranges, which occupy 15% of the total area of the country. The mountain range that runs in the north close to the Batinah Plain is the Jebel Al Akhdar with a peak at 3000 metres. Other mountains are located in the Dhofar province, in the extreme southern part of the country, with peaks from 1 000 to 2 000 metres.

The internal regions. Between the coastal plain and the mountains in the north and south lie the internal regions, consisting of several plains with elevations not exceeding 500 metres.

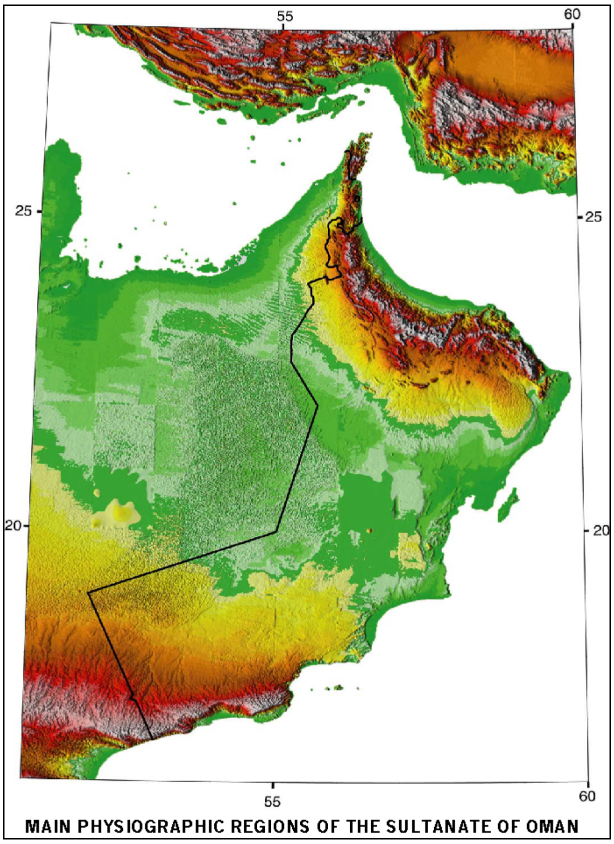


Fig:2.1 The Main Physiographic features of the Sultanate of Oman.

The cultivable area has been estimated at 2.2 million ha, which is 7% of the total area of the country.. Over half the agricultural area is located in the Batinah Plain in the north which has a total area representing about 3% of the area of the country.

The total population is about 2.256 million (1997), of which 87% is rural according to United Nations estimates. The annual demographic growth rate is estimated at 3.7%.

The Wadi Jizzi catchment area is inhabited by people living in small villages and towns. Most of the population lives on the coastal plains of the Batinah which have two important towns in the Wadi Jizzi catchment. They are Sallan and Sohar. The Sohar Wilayat Centre hosts all the Government offices, schools and a hospital. These facilities are located along the main road which passes through the centre of the Town. Sohar is the most important town in the Al Batinah region.

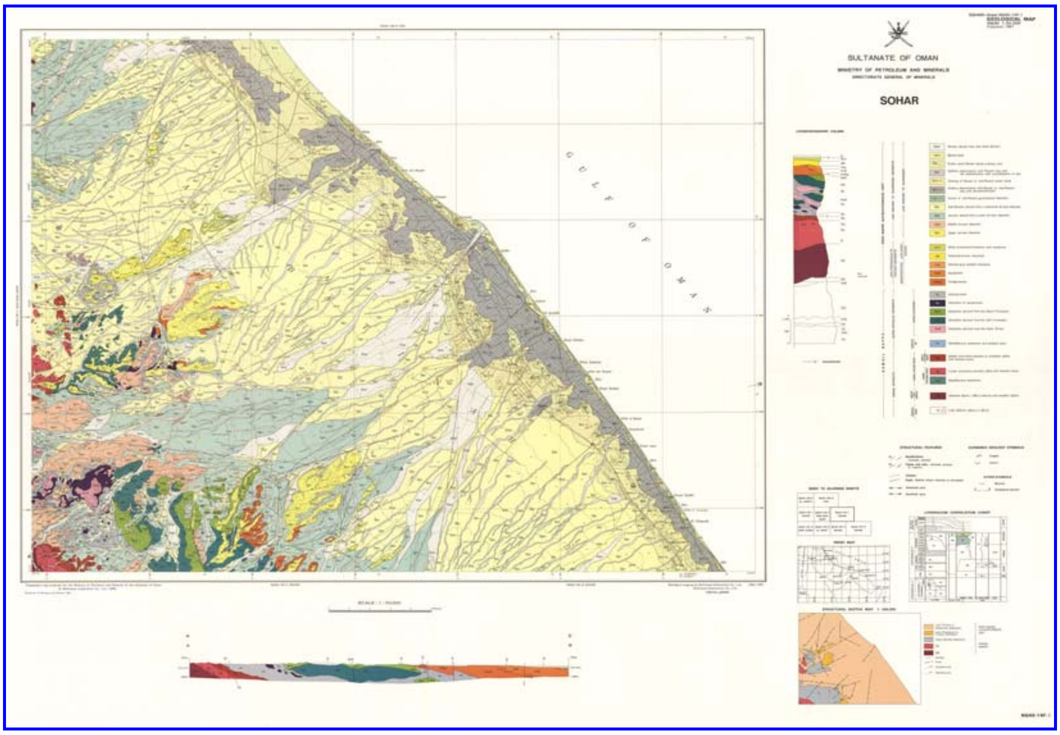


Fig:2.2 Detailed Geological Map of Sohar Region

The Northern Batinah Region stipulates major expansion in the industrial sector at Sohar. The major industrial sectors (BP Petrochemicals, Aluminium Smelter Plant etc), are located in adjacent toSohar Wilayat Centre. OMCO Township at Magan is supplied from the OMCO wellfield in Wadi Jizzi. It is envisaged that significantly large volumes of water will be pumped from Wadi Jizzi in future due to developmental activities in the region.

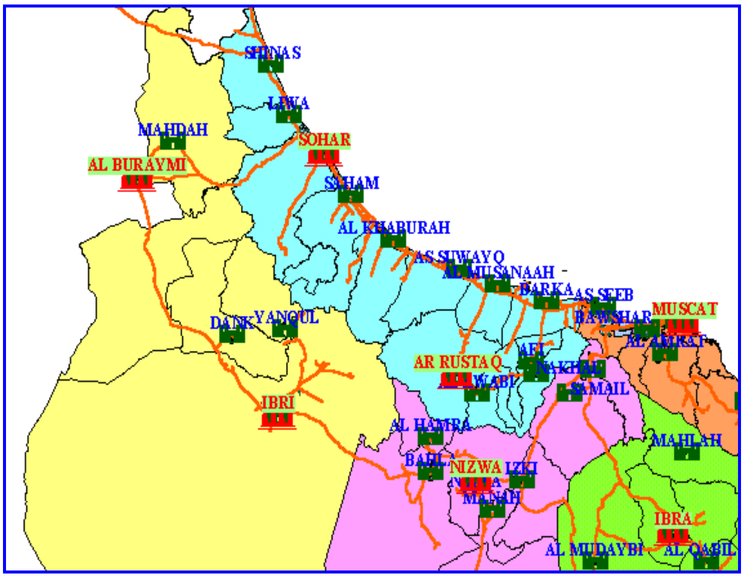


Fig:2.3 Location of Al Batinah Region

The important villages: within this catchment are Fasiqah, Al Waqaybah, Muwaylah, Falaj Al Awin Yanbu, Lasail, Al Mulaynah Suhaylah, Al Hayl, Ath Thuqbah, Farfar, Al Wasit and Kitnah. About 95% of the population lives in Sohar Wilayat Centre and the remaining 5% is the combined population of the villages in the catchment area. The combined population of the twenty five villages other than Sohar Wilayat centre in the study area was 4,300 at the end of 1996, which is projected to become 9,538 by the year 2,020.

The Sohar Industrial Estate located at Falaj Al Qabail is supplied by the potable water supply from the Government Borehole at Sallan where Wadi Jizzi crosses the National highway. Similarly OMCO Township at Magan is supplied from the OMCO wellfield in Wadi Jizzi.

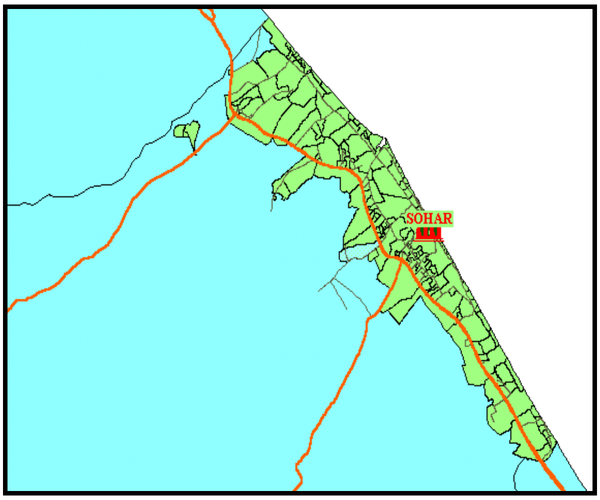


Fig:2.4 Sohar Town

3.0 Climatological Conditions

The present climate of Northern Oman Fig:3.1 is classified as 'arid province'(Schyfsma 1978) and is characterized by dry warm winters,very hot and sometimes humid summers,low and erratic rainfall, large variations in relative humidity and high rates of evapotranspiration.

Monthly mean temperatures for the study area are taken with reference to the nearest Meteorological Station at Sohar. Monthly temperatures are significantly very high during the Summer months, averaging over 35^0 C during the months of May to October. The winter spell is from November to April when temperatures are around 20^0 C (General Soil Map of Oman). Precipitation is highly variable in space and time.

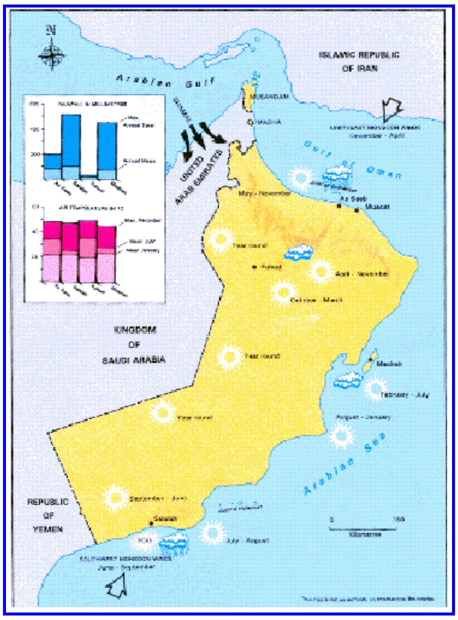


Fig:3.1 Generalised climate map of the Sultanate of Oman.

The average annual rainfall of Jizzi catchment ranges about 100 mm in the lower catchment to 120 mm in the upper catchment., Mountainous regions above 1000m receive in excess of 200mm/yr and more than 300mm/yr in areas located above 2000 m (Meteorological Reports; Ministry of Communications, Sultanate of Oman

The average annual rainfall for stations ranges from 100 mm to 164 mm in the catchment.The mountainous area of higher altitude attracts more rainfall than the surrounding areas.

Most of the precipitation occurs between December and March and is sourced by Mediterranean frontal systems approaching the area from the northwest. A second source for precipitation is local convective storm cells that form over the mountains during very hot summers and cause short and heavy rainfall mostly in the mountains (orographic rain). Tropical cyclones that originate either in the southeastern Arabia Sea or in the Bay of Bengal approach the area occasionally, causing heavy precipitation for several days. Because of the strong monsoon airstreams that parallels the Arabian Sea coastline during summer and winter, however, southeastern air masses normally do not reach the northern Arabian Coast. The frequency of southern cyclonic rainfall is estimated as once every 2-to5 years in southern and central Oman and once every 5to10 years in northern Oman. In July 1995, a tropical cyclone reached the Arabian Peninsula from the southeast, causing intensive rainfall all along the coast of Oman with decreasing rainfall intensity from south to north. At several coastal weather stations the total rainfall in July produced a new extreme record for the month. In southern Oman, a weather station near Salalah recorded a total rainfall of 135mm for July1995, compared to a long-term mean July value of 9.1mm.

As in most arid regions, evaporation rates are extremely high,with long-term mean daily evaporation rates estimated from open pan experiments as 5 to 15 mm/day, depending on altitude and surface exposure.(Gibb and Partners 1976, Stanger 1986).

4.0 Location And Physiographic Features of Jizzi Catchment

The catchment area of Wadi Jizzi (Pilot scheme) extends from the grid co-ordinates 409200E to 474900E and 2660200N to 2701500N and covers an area of approximately 1150 km^2

The Jizzi catchment region streches between the Gulf of Oman to the east towards Oman Mountains to the west and south-west. In the north it is bordered by Liwa Wilayat, in the west by two Wilayat Yanqul and Buraimi and in the south by Saham Wilayat.

The catchment embraces two major sections:

The Upper catchment area covers the western mountainous terrain of water to the Jizzi catchment (633 km^2).

The Lower catchment area embraces the Lower eastern piedmont and coastal plains of Wadi Jizzi (517 km^2). The Lower catchment comprises the Piedmont and the Coastal plain and has only two tributaries, namely Wadi Barghah and Wadi Yanbu.

5.0 Geological Conditions

5.2 Wadi Jizzi Geology And Hydrostratigraphic Features

The catchment of jizzi region is comprised of the folloing geological formations:

Samail Ophiolite Nappes,
Hawasina Nappes,
Tertiary Limestone and the alluvium.

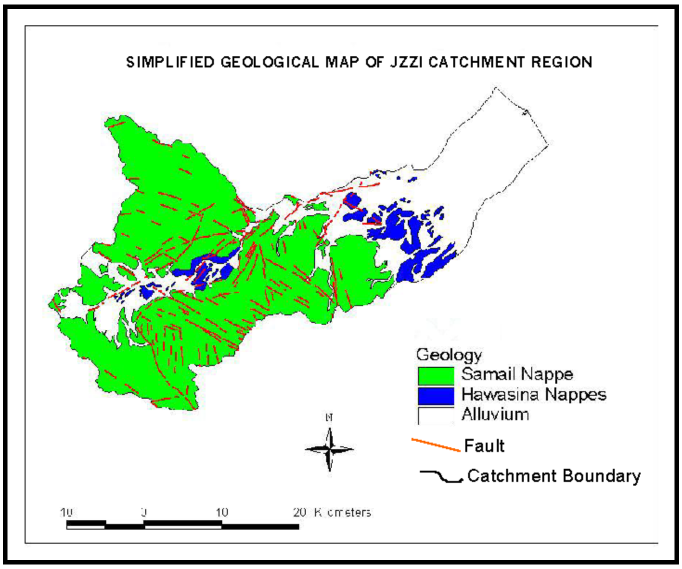


Fig 5.1 Presents the geology and the prevailing major leniaments of Jizzi catchment.

The alluvium is underlain by either of these rock types.

The upper catchment is composed of the following allochthonous units:

Sumeini Nappes,
Hawasina Nappe and
Samail Ophiolite Nappes and also post Nappe units.

Summarizing the geology of the study area, Figure 5.3 provides a schematic diagram of major stratigraphic units, including the pre –Permian basement and Hajar Supergroup of the Jabal Akhdar as well as the Samail ophiolite nappe.

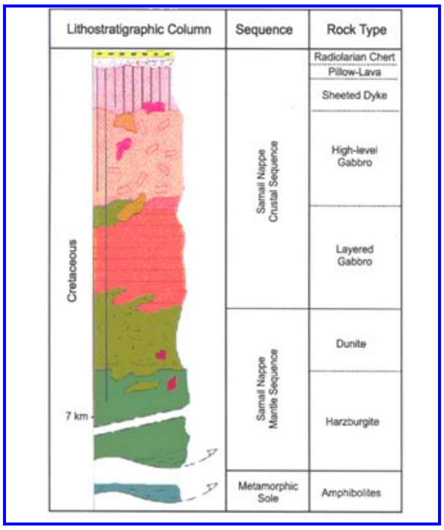


Fig 5.2 Schematic diagram showing the simplified stratigraphy of the northern Oman Mountains, including the Samail ophiolite nappe.Slightly modified after Hanna(1995).

The Samail Ophiolite nappe comprises of tectonised harzburgite, and serpentine with dunite forming the mantle sequence and has been highly tectonised. The crustal sequence consists gabbroic, and basaltic units which have also been affected by tectonic movements. Both the crustal and mantle sequences have significant secondary porosity.

The Post Nappes unit sequence comprises of the Aruma Group and occupies the limited outcrop area between the mountains and the Batinah Plains. This group consists conglomerate sequence, sandstone and shale and gritty limestone with marl (Mastrichtian) and Tertiary Sediments (Eocene-Miocene). The Tertiary sediments consist of Braccia with blocks of limestones, clayey limestone and inter-bedded with mudstone.Significant secondary porosity is present due to folding, fracturing and weathering.

The alluvial deposits of the Jizzi catchment are composed of sediments of Tertiary, Quaternary and Recent age. Based on the physiography, geology and lithology, the thickness and extent of the alluvium differ.

6.0 Groundwater Vulnerability Assessment

6.1 Introduction

The ultimate goal of the project is building a Groundwater vulnerability map to play significant role in the Decision Support System (DSS) that will pave the way to the decision-makers to deal and manage of water resources (resources protection), and wellfields (sources protection) in catchment areas throughout the sultanate of Oman. In this report we will describe the role of the GIS, AutoCAD, Surfer in designing and preparing groundwater vulnerability maps, which are considered an important part of the DSS. AutoCAD, Surfer and, ArcView systems were used in putting together various color-coded thematic maps that will be later on integrated with other special packages to construct the Groundwater vulnerability map, which is applied on a selected pilot catchment area of Jizzi region, located in the northern part of Al Batinah coastal plain. The design will describe and display the whole hydrogeological setting of the catchment's area that contains water points, and Jizzi catchment's that required protection.

Jizzi catchment area has been implemented as a pilot project. The work had been based on MWR data base and the final report data of Sohar Wellfield Protection Plan (source protection) produced by the Water Resources Protection Department. The wellfield protection plan aimed to protect the groundwater used for water supply from contamination, and overabstraction. Resources protection of catchments has also been prepared in order to cover the whole region. Various data collected and used in the project to perform different hydrogeological analysis. Different thematic maps representing the geology, soil type, potential contaminants, location of wells, rainfall stations, wadi gauges, protection zones, which have been produced in CAD, Surfer, and ArcView formats and presented in image version in the report.

The main databases of the groundwater vulnerability thematic maps of the project either in digital and non-digital formats had been used to prepare ad hoc maps. The Groundwater vulnerability mapping of resources protection techniques will facilitate the role of decision-makers at the MWR to be able to get the accurate information and data on the quality of water resources available for uses, existing wellfields in each catchment area, and other relevant itegrated information of the hydrogeological setting and groundwater protection on resources protection level, which play a significant role in the prospected Socio-economic development, and management in the country.

The Groundwater vulnerability mapping will facilitate the professionals and the decision-makers to perform many tasks on national level. Each decision at the higher integrated management level related to the wellfield and catchment's protection would be enhanced, improved, and uniquely utilised in the former MWR. The technique will help the planner if necessary to perform any Socio-economic development's senarios in the region. It will demonstrate nearby potential contaminants and its impact on the surrounding environment pertaining to the existing wellfields,in the whole catchment and their potential contaminant risks. An applied example of ad hoc maps Fig:6.1 is the preparation of characterization and standardization of suitability of waste disposal sites map in the sate of Qatar prepared by the author which has resulted in a map delineating suitability of areas for landfill purposes

Accordingly site evaluation report can be produced showing the coordinates of the selected site ,area affected by radius of influence in meters, the closest places, the underlying geology ,suitability according to the hydrogeo-environmental map prepared by Dr.Samir Kotoub, Qatar.MMAA, 1997, other sensitive features within the area of influence of the selected site are also reported as a result. On the basis of ad hoc observation ,the requested site is deemed suitable/unsuitable for the proposed project.

Files in digital and non-digital format had been used in the preparation of (Groundwater Vulnerability,and risk assessment Maps). Initially the obtained databases were available primarily in CAD and excel spreadsheet formats. The AutoCAD layers and the point features associated with coordinate system in excel formats were translated into dxf, and shapefiles, which is the GIS ArcView format. The converted files are in adequate quality and all of them projected into the same coordinate system, which is UTM zone 40.

Various color-coded thematic maps had been produced on the basis of the result of the analysis. The maps represent Jizzi catchment, wellfields, monitoring wells, aflaj, geology, soil classification, groundwater flow system, average change in static water levels, wadi flow, protection zones and other information necessary for building Ad hoc synoptic map's components .

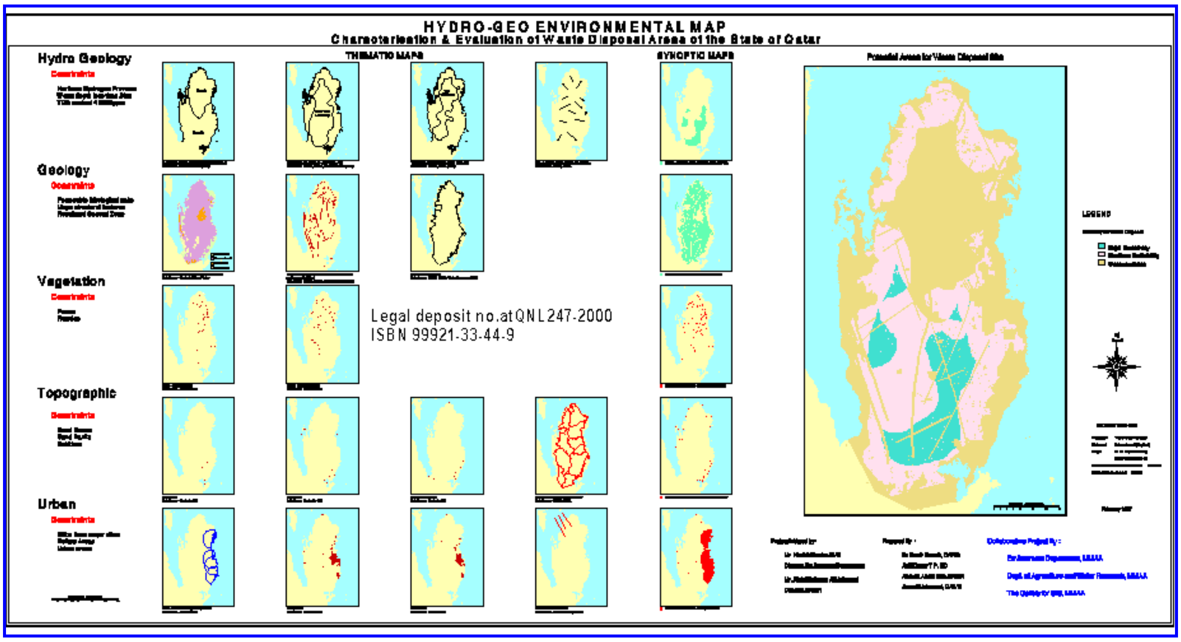


Fig:6.1 The Hydrogeo environmental map prepared for the State of Qatar in the field of national Characterisation and Standardisation of Waste Disposal Sites (Kotoub.S.1997etal.Qatar).

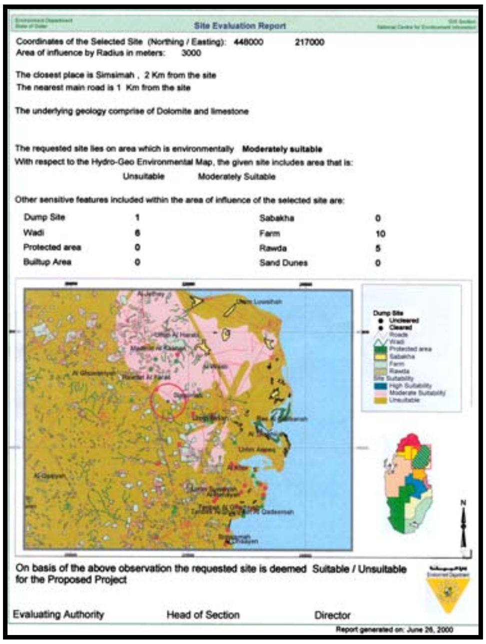


Fig:6.2 Site evaluation report,suitability areas
for Landfill usages.used Arc/Info,Avenue.

6.2 Groundwater Vulnerability And Mapping:

The initial vulnerability concept was based on the assumption that the sub-terrain material plays a significant role in the natural protection of groundwater. However, the potential for natural protection is extremely variable. Groundwater systems in different areas characterized by varying capacities for attenuating contaminants.

Vulnerability mapping is defined as the technique of quantifying the assessment of vulnerability and displaying it in a way that makes it useful in the decision–making process. The main objectives are to serve as guidelines for land use zoning, and for the development of policies for groundwater protection. (Vrba and Zaprozec,1994) have reported that groundwater system is vulnerable in terms of quality, and quantity. The quantitative aspects are particularly significant in arid and semi-arid zones.

An IHP/IAH joint working group on “groundwater vulnerability maps”, has reviewed previous work on the concept and definition of vulnerability, and on the basis of recent developments, defined groundwater vulnerability as ,“an intrinsic property of a groundwater system that depends on the sensitivity of that system to human,and/or natural impacts”. Thus vulnerability maps should encompass, regarding this definition; vulnerability to human impacts, as well as natural prevailing processes, and should cover both quantitative, and qualitative aspects of vulnerability maps. Published maps however, represent only the qualitative (contamination) aspects of vulnerability maps displaying the quantitative aspects (depletion) need to be tested in areas where such impacts are significant. Guidelines on both quantitative, and qualitative aspects of vulnerability were published by UNESCO.

Climate is considerd An important factor contributing to natural changes in arid zones

Evaporites are of common occurrence in the Quaternary and Neogene sediments. As groundwater flows from areas of recharge to discharge zones it dissolves minerals from rocks through which it moves. Due to low solubility of crystalline and pure sandstone's, groundwater transmitted through these rocks, e.g.,Nubian Sandstone is characterized by low total dissolved solids .Carbonate rocks and Lower Fars evaporites, which are of widespread occurrence in the Mashrek and Arabian peninsula, store and transmit water of relatively high TDS content.

However, the resident time water in contact with different types of rocks determines groundwater quality and characteristics. High calcification in the Mediterranean basins, for example, results in rapid groundwater flow and exceptionally freshwater is available in these coastal basins.Inland ,however, as in the Dammam carbonate aquifer of Arabian Peninsula,for example, low transmissivities and higher contents of marls and evaporites result in extensive occurrence of brackish and saline groundwater.

Groundwater deteriorates when its quality parameter changes beyond the natural variations. The type of human activity controls the type, limit, and duration of man-made changes of groundwater quality, pertaining to the geochemical, physical and biological processes occurring underground.

Since natural processes generally reduce the magnitude of groundwater contamination, several contaminants remain, essentially after entering the aquifer system, and some aquifers or parts of aquifer may be damaged beyond repair.

Sources of contamination include two broad categories, namely point and non- –point sources. Point sources comprise municipal, and industrial wastewater, landfills, oil storage tanks and other sources, which join water bodies through pipes and channels. Application of fertilizers , pesticides, and saline water bodies are non-point sources.

7.0 Factors Affecting Groundwater Quality And Vulnerability

The Nation's groundwater reserves consist of waters of various chemical quality contained in numerous, complex aquifers. The water in these aquifers can be affected by both natural and human activities, and the extent to which the quality is affected by either natural processes or human activities varies with the hydrogeologic and climatic setting. In aquifers unaffected by human activity, the quality of ground water results from geochemical reactions between the water and rock matrix as the water moves along flow paths from areas of recharge to areas of discharge. Thus, "natural" water is variable in quality, and in very large, regional aquifer systems the quality of ground water also can change as the result of the mixing of waters from different aquifers within the system. In aquifers affected by human activity, the quality of water can be directly affected by the infiltration of human-induced compounds or indirectly affected by alteration of flow paths or geochemical conditions.

This section describes the basic hydrogeologic principles that can affect the movement of chemical constituents in ground water and the quality of the water. It also serves as an introduction to several subsequent discussions of point and nonpoint sources of ground-water contamination, its influence and significant role as a background of groundwater vulnerability mapping and the assessment of potential groundwater pollution risk.

7.1 Hydrogeologic Factors

7.1.1 Ground-Water Flow Systems

A ground-water flow system includes aquifers (water-yielding units) and confining beds (units that restrict flow of water). Water enters the flow system in recharge areas and moves through the aquifers and confining units, according to their hydraulic properties and the hydraulic gradients, to discharge areas . Climate, topography, and geology determine the nature and location of natural areas of recharge and discharge. Movement of ground water normally is by flow through small openings, such as the pore space between sand grains or hairline fractures in granite. In some highly productive aquifers, movement occurs through larger openings, such as solution channels in limestone and tubular openings in basalt.

The stratigraphy and geologic structure determine the geometric arrangement of aquifers and confining units in an area (hydrogeologic framework).Geologic structure is concerned with folding and fracturing of rocks due to movements of the Earth’s crust. Folding of the rocks can cause jointing or cleavage that increases permeability, or it can close up primary openings and decrease permeability. ***Faults*** can disrupt the continuity of aquifers or confining units and thereby restrict ground-water flow. Alternatively, fault zones can be permeable and enhance ground-water flow.

A ground-water flow system can be simple-one aquifer with short flow paths to a nearby stream or spring. Conversely, a flow system might be complex-several aquifers and confining units and flow paths that range in length from hundreds of feet to a hundred miles or more. Water following the longer (regional) flow paths may cross river-basin boundaries in addition to several geologic formations and ultimately (after many years or centuries) discharge at a river or the ocean.

Recharge to aquifers tends to be spread over very large areas. Discharge from aquifers might occur over large areas as leakage into surface drainage network or the ocean, or it might occur as point discharge, such as the large springs or falajes. Before pumping of ground water by humans, an equilibrium condition exists in ground-water systems – that is, the long-term natural recharge rates and discharge rates are equal.

7.1.2 Rates of Groundwater Flow

Ground water moves very slowly, and most ground water always is moving along a flow path from where it is recharged to where it is discharged. Shallow ground water generally moves at rates that range from much less than a foot per day to as much as several feet per day. An exception to this is in aquifers that have conduit-like openings, such as basalt and karstic limestone, where water may move much faster. Deeply circulating ground water moves extremely slowly – sometimes as little as a few feet or less per century.

The velocity at which groundwater move depend upon the permeability, and porosity of the rocks along its route and the hydraulic gradient.

7.2 Hydrochemical Factors Affecting Groundwater Quality And Vulnerability Assessment

7.2.1 Chemical Processes

One or more combinations of three of the most significant natural chemical reactions and one physical process that affect ground-water quality, can explain water chemistry:

- Dissolution-precipitation (exsolution) reactions
- Oxidation-reduction (redox)) reactions
- Ion-exchange processes.
- Mixing of ground waters.

The Dissolution-precipitation (exsolution) process involves water-rock-gas relations. An important dissolution reaction is uptake of carbon dioxide (CO_2) in the soil zone to form carbonic acid (H_2CO_3); the reaction causes dissolution of aquifer materials. As a result, the chemistry of ground water often reflects the primary suite of minerals in an aquifer

Oxidation-reduction reactions occur throughout ground-water systems, although in many instances their effects are manifest in chemical constituents that may be present in low concentrations in ground water and, therefore, may be overlooked. Oxidation-reduction takes place when electrons are exchanged between electron-poor (oxidized) constituents and electron-rich (reduced) constituents. This type of process must, therefor, involve both oxidizable species, such as sulfide in pyrite (FeS_2) or carbon in peat or lignite, and reducible species, such as sulfur (+6) in gypsum ($CaSO_4.2H_2O$). Groundwater near areas of recharge might contain some dissolved oxygen and therefore be in an oxidizing geochemical environment. Dissolved oxygen in ground water is common in unconfined aquifers, and it has been observed in some confined aquifers. In parts of aquifers where oxygen has been depleted and the ground-water system is closed to atmospheric oxygen, reduction of certain chemical species is accompanied by the, oxidation of other chemical species. For example, the bacterial reduction of sulfates (SO_4^{-2}) to sulfide (S^{-2}) can occur as organic matter is oxidized to CO_2. Many redox processes involve bacteria that “catalyze” a specific reaction, using available organic matter.

The dominant form of ion exchange is the exchange of cations in the aquifer material for cations in the water, although anion exchange has been documented. The most common cation exchange process in aquifers involves the exchange of aqueous calcium ions for adsorbed sodium ions, or natural “softening” of the water. Mixing of ground waters is largely a process of physical alteration where waters from different sources mix as a result of hydrogeologic controls on ground-water movement. When the chemical make-up of waters differs, the process of mixing can produce dramatic change in the water chemistry. Mixing of groundwater that at equilibrium with their respective aquifer minerals can alter equilibrium and cause extensive rock-water interactions. Mixing of ground waters, especially fresher ground water with saline, is most common in downgradient parts of aquifers (for example, in coastal areas or deep sedimentary basins where salty water usually is present downgradient) or where groundwater flows from one aquifer into another .

7.2.2 Geologic Environment

As described in the section on chemical processes(7.2.1) , the nature of the geologic units in an area directly affects the chemical constituents in ground water. The mineral composition of rock is a very important influence on the water quality. Equally important is the hydrogeologic framework; that is, the sequence, thickness, and arrangement of the aquifers and confining units. This framework and the topography determine the paths that ground water follows, affect the rates of groundwater flow, and determine sequence in which ground water moves through different rock types.

7.3 Effects of Human Activities on Qualitative and Quantitative Groundwater Vulnerability

7.3.1 Groundwater Pumpage

Large withdrawals of ground water have profoundly altered the flow systems of the major aquifers in the Coastal plain. The decline of ground-water levels due to pumping from wells has caused changes in the location and size of some recharge areas, large reductions in natural discharge, and in aquifer storage.

The location of recharge areas can be very important in the protection of aquifers from water-quality degradation. Therefore groundwater protection should be based in addition to the wellfield protection policy groundwater vulnerability mapping should be adopted for long term water resources development and protection strategy of the nation.

7.3.2 Contaminants And Groundwater Vulnerability

Ground-water contamination refers to any degradation of ground-water quality resulting from human activities. To provide guidance for water use, the U.S. Environmental Protection Agency (1986a, b) established water-quality criteria that include-

Recommended concentration limits for certain, not particularly harmful constituents, such as chloride, iron, and dissolved solids.

Maximum permissible concentrations for highly toxic substances, such as some pesticides, certain metals, and radionuclides.

The most serious problems of ground-water contamination generally have resulted from the introduction into the ground water of organic chemicals (especially pesticide residue or byproducts, oils, phenols, and solvents) and metals (especially chromium, lead, and mercury) from a variety of human activities. Fortunately in only a small part of the Nation’s ground-water supply. However, such contamination often is in areas of heaviest ground-water use. Cleaning up an extensively contaminated aquifer is expensive and time consuming; the best cleanup strategy may be difficult to determine because of the complexities of the hydrogeologic framework and uncertain results of aquifer cleanup make the prevention of ground-water contamination whenever possible a very desirable national goal (Conservation Foundation, 1987, p. 13).

7.3.3 Sources of Contaminants

Contaminants may enter freshwater aquifers from at least 33 generic sources (Office of Technology Assessment, 1984, p.43). These sources may be classified broadly as either point nonpoint sources. Point sources are derived from localized areas (a few acres or less in size) and include:

Landfills (industrial and municipal)
Surface impoundments (lagoons, pits, and ponds)
Underground storage tanks (petroleum, toxic Chemical, and wastes)
Spills of chemicals, oil, or brine during transport or transfer operations
Injection wells (hazardous waste and brine disposal) or abandoned oil wells

The first four point sources are considered to be major contamination problems by the EPA (U.S. Environmental Protection Agency, 1984, p.13) on the basis of information supplied by State agencies. However, EPA stated (p.16) “information on the current extent of contamination is far from adequate to quantify the severity of the problem”.

Nonpoint sources actually consist of activities or processes that introduce contaminants over a broad area, rather than in a specific area. Nonpoint sources can range in size from several acres to hundreds of square miles and can consist of multiple point sources such as septic tank drainfields. Significant nonpoint sources include:

Agricultural pesticides and fertilizers
Septic tank drainfields and cesspools
Encroachment of saline water
Road salt applications
Animal feed lots
Mining operations

The above nonpoint sources also were indicated as being intermediate significant contamination problems (U.S. Environmental Protection Agency, 1984, p. 13). Contaminants can enter aquifers by five basic mechanisms as described below.Fig:7.1

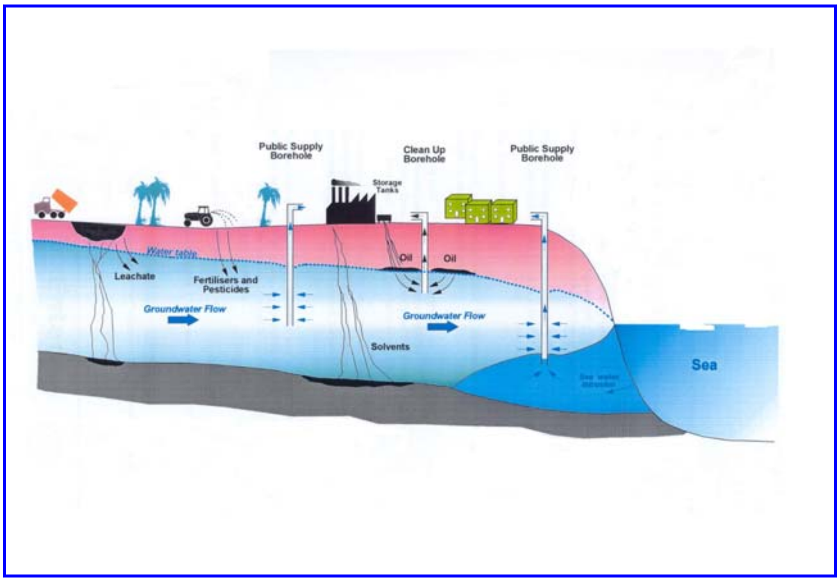


Fig:7.1 Sources of Groundwater Pollution

Movement of contaminants between aquifers by short-circuiting natural flow paths.-

A short-circuiting mechanism might occur in a well or along a natural Geologic feature such as a fault. In either situation, the well or fault zone acts as a conduit for transmitting poor-quality water from one aquifer to another. Movement via wells might occur either outside the well casing of a well open to more than one aquifer through screen or perforation. Pumping from a freshwater aquifer might induce poor-quality water to move from a contaminated or saline aquifer into the freshwater aquifer.

8.0 Vulnerability of Aquifers To Contamination

The flow system, the hydrogeologic framework, and the climate control the vulnerability of an aquifer to contamination from pollutant sources at or near the land surface. Specific factors that affect the degree of contamination of ground water include:

Length of and residence time in the flow path from the contaminating source to the aquifer. Short flow paths decrease the opportunity for adsorption, chemical reactions with soil minerals, and biodegradation and, thus, increase the potential for contamination. Conversely, longer flow paths from land surface to the water table lessen the potential for contamination.

Mineral composition of the soil and rocks in the unsaturated zone between land surface and the water table. High clay content and presence of organic materials increase adsorption and thus lessen the potential for contamination.

Potential for biodegradation (transformation of contaminants by reactions caused by microbes). This process depends upon the microbe species present.

Precipitation. Low amounts of precipitation result in small amounts of recharge to aquifers and thus, lessen the potential for recharge to aquifers and pollutants whose mobility is dependent on entrainment in or flushing by recharge water.

Evapotranspiration. High evapotranspiration rates reduce recharge and thus, lessen the potential for contamination from pollutants whose mobility is dependent on entrainment or flushing by recharge water.

The vulnerability of aquifers to contaminants from landfills, surface impoundments, spills, and underground storage tanks is of special concern. Consequently, investigations of the suitability of sites for waste disposal or for evaluating the vulnerability of aquifers to contamination are concerned primarily with surface and near-surface sources. However, problems caused by short-circuiting mechanisms (those that bypass natural geologic barriers), although difficult to identify, should not be overlooked in assessing aquifer vulnerability. A multiaquifer well that is abandoned and covered over or an unmapped geologic fault can easily escape detection.

In general, shallow, permeable, unconfined aquifers with high recharge rates are most vulnerable to surface contamination because the short flow paths from the land surface to the water table decrease the potential for adsorption, chemical reactions between contaminants and minerals in the soil, and biodegradation. Deep, confined aquifers tend to be much less vulnerable to contamination from surface sources because they are protected by confining beds. However, in some regionally extensive aquifer, hydrologic conditions can be such that some parts of the aquifer are very vulnerable to contamination, whereas other parts are much less vulnerable.

The vulnerability of aquifers to contaminants introduced directly in the subsurface is more difficult to characterize. However the volume of aquifer that is ultimately contaminated is dependent upon the aquifer properties and on the location from which the contamination is introduced into the flow system. Contaminants introduced in recharge areas or within the influence of pumped wells will migrate and spread more rapidly than contaminants introduced into deep, unpumped parts of an aquifer where ground-water flow is more sluggish. The principal features of hydrogeologic frameworks and ground-water flow systems that affect an aquifer's vulnerability to contamination are summarized in Table.8.1

Table:8.1 Principal geologic and hydrologic features that influence an aquifer's vulnerability to contamination

A. Feature determining Aquifer vulnerability To contamination	Low vulnerability	High vulnerability
A.Hydrogeological Framework		
Unsaturated zone	Thick unsaturated zone Containing clay and Organic materials.	Thin unsaturated zone in sand, gravel, limestone and basalt.
Confining unit.	Thick confining unit of Clay or shale above aquifer	No confining unit.
Aquifer properties	Silty sandstone or shaly Limestone of low permeability	Cavernous limestone, sand and gravel, or basalt of high permeability.

B. Groundwater Flow System

Recharge rate	Negligible recharge rate,as in Arid regions	Large recharge rate ,as humid regions.
Location within a flow system (proximity to recharge or discharge area or point).	Located in the deep sluggish part of a regional flow system.	Located within a recharge area or within the cone of depression of a pumped well.

Aquifers highly vulnerable to contamination from surface sources are especially common in many parts of Oman.

Several detailed examples of contamination in these types of highly vulnerable aquifers of Jizzi region are given later in this report. One example is a sand-and-gravel aquifer on coastal plain, which are very shallow occurrence, high permeability, and low adsorption characteristics coastal-plain aquifers have been studied to determine if the chemical quality of shallow ground water is related to the type of land use.

In many parts of the arid west, low rainfall, high topographic relief, low recharge rates, and the presence of a deep aquifer with a topographically low discharge area result in deep-lying water tables. Such conditions favor the protection of aquifers against contamination, and thick confining beds above the aquifer in most areas provides great natural protection against surface contaminants reaching the carbonate aquifer.

8.1 Site Evaluation Of Potential Grounwater Vulnerability To Contamination

Site evaluation for potential groundwater vulnerability to contamination is an approach that estimates the possibilities for ground-water contamination at a site for given contaminants. Application of site evaluation is desirable to assist in locating sites (for example, waste-disposal sites)Figs,6.1,6.2 that might prevent or minimize the effects of contaminants on ground-water systems. Site evaluation is best conduct with detailed, accurate, local hydrologic information: however, obtaining that information for large areal evaluation is expensive. Anumber of screening reconnaisance methods have been proposed for evaluating the contamination potential of aquifers using information on the geology, hydraulic properties, and groundwater flow. These methods generally use a relative numerical rating system for evaluating the local hydrogeologic conditions. One of the earliest methods proposed is based on weighted values for five factors whose relative significance can be evaluated from measurements or estimates made at the sites, LeGrand, 1964,p, 962. The five factors are:

Depth to the water table
Sorption capacity of shallow deposites
Permeability of shallow deposites
Water table gradient
Distance to point of use

Low point values are assigned where the factor at a site will provide little or no protection to an aquifer; high values are assigned where the factor provides high protection. For example, a shallow depth to the water table (less than 3m) receives zero points, whereas an extremely deep lying water table (30m), receives 10 points. Total counts (sum of the 5 factors) are interpreted as follows: 0-4, contamination imminent: 4-8 contamination probable; and so forth with counts about 25 indicating that contamination is very unlikely.

More recently, a system for evaluating the vulnerability of aquifers to contamination was prepared by Aller and others1985. This method is called the DRASTIC INDEX and it is intended to evaluate the pollution potential for any hydrogeologic setting in the United States. The DRASTIC method consists of two parts:

Heath 1984 identifies 1-The hydrogeologic setting of a site on the basis of a classification of the major groundwater regions of the United States.

2-The DRASTIC index for site is evaluated by assigning point values to mappable physical characteristics that form the acronym drastic as follows:

Depth of water
Recharge (net)
Aquifer media
Soil media
Topography (slope)
Impact of the vadose zone
Conductivity (hydraulic) of the aquifer.

Each of these characteristics is assigned a point value: a higher point value indicates greater vulnerability and lower value indicates less vulnerability to contamination. Weighting factors also are used to give greater or lesser importance to each characteristic (Aller and others, 1985.p31-126). The typical values given to materials or conditions may be accepted, if more accurate local information is available. A summary rating fore a site is simply the sum of point values for the seven characteristics. Applying the DRASTIC method to an area resulting with different drastic indexes, when applying numerical rating methods ,such as the LeGrand or DRASTIC method, that rely upon estimating geologic characteristics, several factors should be kept in mind:

- Numerical rating methods are useful primarily for evaluating potential contamination from surface or near surface sources such as landfills and shallow underground storage tanks UST.
- Groundwater development can change the hydrologic characteristics such as depth to the water table, directions of groundwater flow, recharge rates, and locations of recharge areas. Thus hydrologic information based on current groundwater withdrawals must be used.
- Numerical rating methods applied over regional areas might not account sufficiently for local variation in hydraulic properties and geohydrologic conditions,or might not take into account all factors affecting the potential for contamination, therefore possibly underestimating the potential for contamination.

- Numerical rating methods are not strictly applicable for evaluating contamination from sources in the deep subsurface, especially where natural geologic barriers have been short-circuited.

  Although numerical rating methods are useful for preliminary screening of potential waste disposal sites, or to estimate the potential contamination over large areas, the final selection of a major waste-disposal site or evaluation of an existing one requires field hydrogeologic data collection and an analysis of the groundwater flow system. Once data are in hand, analysis of groundwater flow system is best accomplished by computer modeling that simulates predevelopment conditions, present-day groundwater pumping, and future projected development. In recent years, a variety of computer models have been developed for simulating the transport of contaminants by groundwater.

9.0 The Preparation of Groundwater Vulnerability Maps

9.1 Methodology And Approach:

A vulnerability map depicts the spatial variation of an object's vulnerability to a specific risk. Groundwater vulnerability map includes in addition to strata vulnerability map, parameters of depth to water, soil cover drainage pattern flow gradient, geological characteristics, native water quality, as well as the strata vulnerability to hydraulic conductivity and attenuation capacity, and other logistical activities influencing the overall environmental activities prevailing in the region.

The efficiency and reliability of ad hoc maps depends largely on the adequate availability and accuracy of above-mentioned parameters. Previous study was essentially performed on the basis of strata vulnerability maps ignoring one of the most essential factors pertaining to the depth of water level, consequently the procedure of assessing groundwater vulnerability then becomes a two or three stage process to be combined with site-specific information to produce groundwater vulnerability map. This issue has been avoided so that all above categories were utilized in the preparation of Jizzi groundwater vulnerability map as a pilot scheme of regional groundwater vulnerability map's project.

The essential purpose of the map is a subdivision of an area into several classes, showing the potential response for different uses under variable environmental conditions .It is time dependent, and should be updated following to the improvement and understanding of the prevailing environmental, and potential contaminants categories in the region.

Two types of groundwater vulnerability mapping could be approached, general, and specific. General, or intrinsic vulnerability maps are used to estimate the natural vulnerability of groundwater without reference to specific contaminant or contamination source; Mott MacDonald in its project Master plane for Groundwater Protection in The Sultanate of Oman contract B8/95 MWR .97. Has produced strata vulnerability maps at a regional scale with no data relevant to depth of water level, or soil attenuation categories which needs more specific site information and data for ad hoc detailed and comprehensive vulnerability delineation of a site in small scale manner. The maps produced for GWPPMP, are only appropriate for planning purposes at regional level, and for making rough estimate of site-specific developments. Detailed site-specific survey should always be performed.

Recent Groundwater vulnerability map preparation of Jizzi region has considered all available geological, hydrological, hydrogeological, soil classification, environmental, and logistical information, to produce the specific vulnerability map of the area. Which means that data are referenced to specific source (or sources) of contamination, and specifically including characteristics of contaminants and their attenuation potential and vertical hydraulic conductivity of the study area.

Assessment and mapping of vulnerability entails the consideration of individual factors or attributes and their capacity for attenuating contamination.

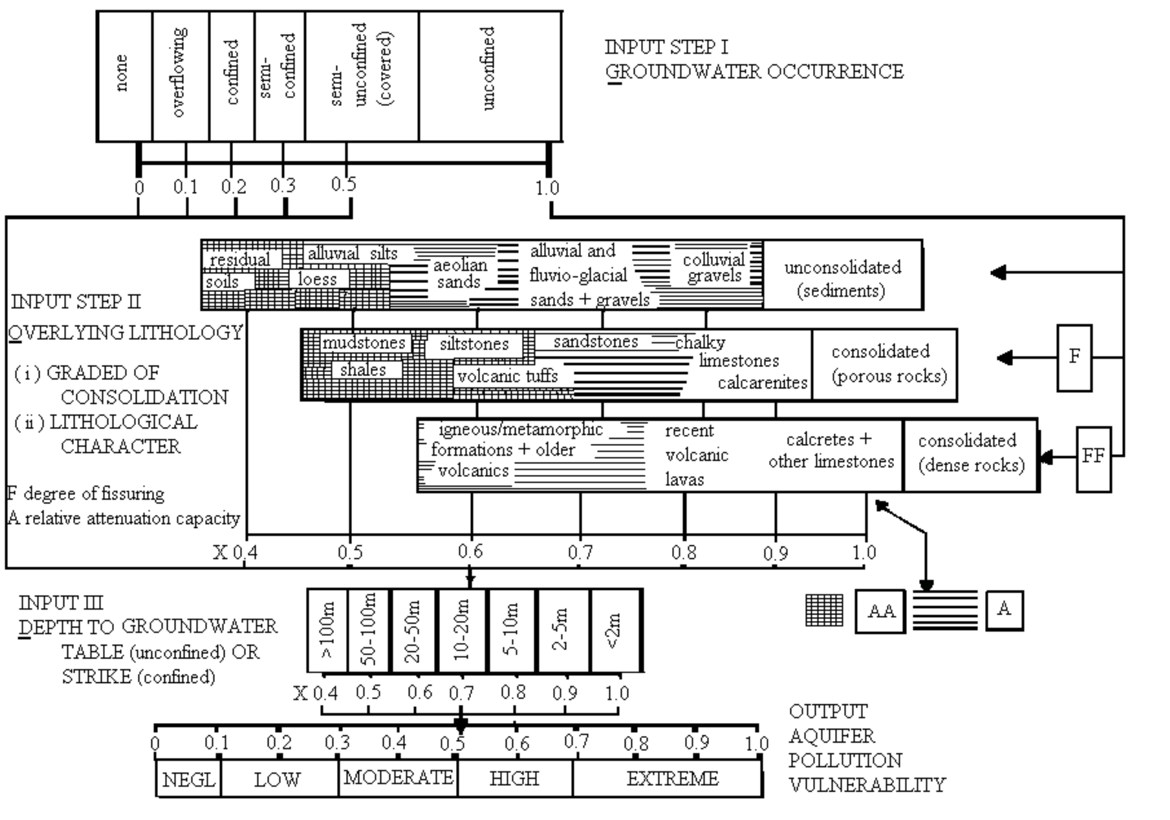
The preparation of *vulnerability maps* is based on the assessment of important attributes such as recharge, soil, the unsaturated zones, and the aquifer. As regards specific groundwater vulnerability, hydrogeological factors, as well as land use practices and contaminant loading are taken into account.

There are several methods for the assessment of intrinsic (or natural) vulnerability of groundwater (Civita, 1991). In general the widely used methods could be classified into 4 groups (Civita 1991,1993;vrba and Civita 1994):

1-Hydrogeologic setting methods.
2-Parametric system methods.
3-Analogical relations methods.
4-Numerical methods.

As indicated above drastic is widely used method. An example that illustrates the use of this method is given in table **(*GOD*).** Fig:9.1

Figure 4.1 GOD Empirical System (Foster 1987)



The main proposed methods adopted for the assessment of groundwater vulnerability, are based on the assumption that groundwater occurs under temperate climatic conditions. It should be taken into consideration that assessment of groundwater vulnerability under arid conditions, should however, recognize the impact of parameters such as extreme dryness, high temperature and evaporation, on the process that influence the transport and fate of contaminants.

In addition to the contamination factors, important human impacts in arid and semi arid regions include depletion and salinization. Drought is also an important factor, which should be considered whenever the vulnerability of aquifer is assessed, in terms of quantity. The sensitivity to drought, generally, increases with increasing aridity.

A drought is usually considered to be a period in which the rainfall consistently falls short of the expected amount (E.Shaw, Hydrology in Practise, page 225). Periods of droughts are defined as shortages in rain, below the mean. Based on hydrological data available for thirteen rainfall stations, the yearly average rainfall for Jizzi catchment is 132 mm. Serious droughts were when the rainfall does not exceed 20% of the average value. This happened twice in 22 years. Mediocre drought occur when rainfall received is between 20 and 50% of the average value. This happened six times in 22 years. Mild droughts occur when rainfall received is between 50 and 80% of the average. This happened seven times in 22 years. Drought Frequency analysis is presented in **Table.9.** (MWR,Sohar protection plan,1999).

Table 9.2 Drought Frequency for Jizzi Catchment.

Drought Intensity	Percent	Frequency
Mild	32	7 times in 22 years
Mediocre	27	6 times in 22 years
Serious	9	2 time in 22 years

The results of vulnerability assessment are portrayed on maps, which show areas characterized by different levels of vulnerability. A large variety of vulnerability maps has been proposed during the last decades. The experience gained and lessons drawn from the compilation and use of these maps have contributed to the development of principal concepts of vulnerability.

Vulnerability maps are constructed manually or generated by computers, and GIS has been increasingly used for the preparation and updating of such maps.

Vulnerability maps are utilised mainly as a planning aid to tackle problems of undesirable activities having adverse impacts on groundwater quality. They support also managerial, decision-making activities *DSS.*

The scale plays an important role in the applicability of vulnerability maps. Small-scale maps are used for formulating strategies for protection of groundwater resources, as the national and regional level. Maps of specific groundwater vulnerability are used for decision making in environmental protection.

Vulnerability maps can be combined with land use maps, groundwater quality data and contamination source inventories for integrated vulnerability studies to delineate an overall prevailing sensitivity conditions in a specific region, targeting management efforts to the most vulnerable aquifer to both contamination and depletion.Consequently,potential groundwater pollution risk, and risk classification of contaminant sources are also prepared.

10.0 Groundwater Protection Strategy of Vulnerable Aquifers

Groundwater protection strategy must be preventive and protective. Accumulated experience gained in many countries has shown that remediation is far too expensive to be the main approach to manage the quality of groundwater resources. Instead, preventive contamination measures are becoming more effectively in environmental protection programs. Consequently regulatory and technological measures must cover all major categories of point and non-point contaminant sources.

10.1 Resources Protection

The comprehensive protection of groundwater resources requires a sound information base to determine existing and potential groundwater contamination problems. Part of this information needs to be presented on vulnerability, land suitability, and groundwater protection maps.

The natural and specific vulnerability of groundwater systems needs to be assessed and mapped. Aquifer vulnerability is a function of inaccessibility of the saturated zone, in a hydraulic sense, to the penetration of contaminants and attenuation capacity of unsaturated zone, as a result of physico-chemical, retention or reaction of contaminants.

A specific vulnerability map of groundwater system depends on the contamination scenarios. Vulnerability maps should be compiled for individual contaminants and specific pollution scenarios. This approach to vulnerability is the basis of groundwater protection policy in several countries, which have developed or applied this technique. Both small and large-scale maps are required for planning and management of groundwater quality.

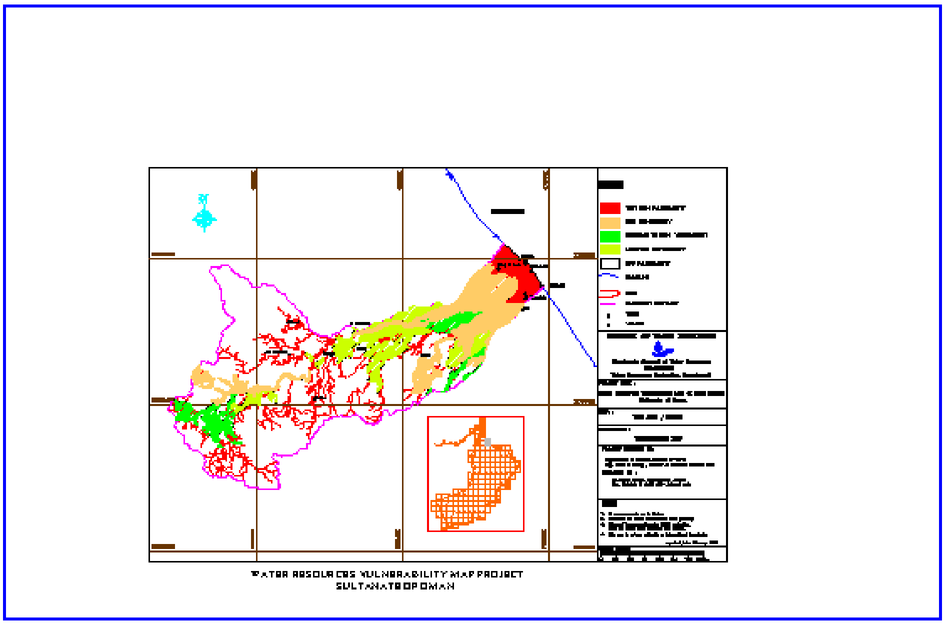


Fig:10.1 Initial Groundwater Vulnerability Map Of Jizzi Catchment.(Resources).
(Kotoub.S.et al 2001.Oman)

10.2 Source Protection

The aim of source protection strategy is to provide additional ways and means for the protection of selected groundwater sources (boreholes, wellfields, springs, aflaj, etc…), which supply water to rural and urban communities.

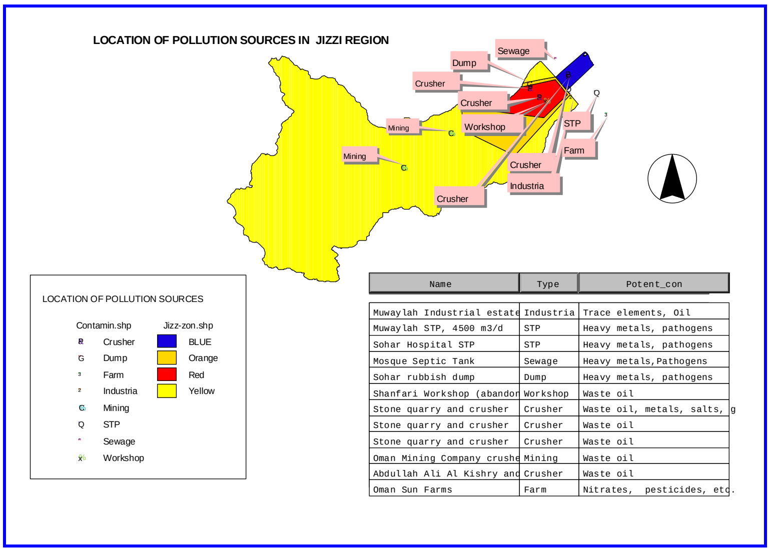
As mentioned above, resources protection is achieved by classifying land surface on the basis of vulnerability of the underlying aquifer(s) to contamination. Source protection is achieved by subdivision of the capture zone of individual sources into several source protection zones (Adam and Foster, 1992;Wyssling, 1979).

The recharge capture zone of a source is defined as an area within which all aquifer recharge is captured at that source. In order to eliminate the risk of source pollution, all potentially polluting activities have to be controlled to the required level in this zone. This is generally untenable due to economic consideration. The recharge capture zone needs to be subdivided into a number of protection zones. The level of groundwater protection varies with the distance from the source.

For general application, horizontal flowlines and distance are considered appropriate criteria for such subdivision (Adam and Foster, 1992).

A system of three protective zones around domestic supply wells has proved to be workable in a number of countries (EPA, 1967;Adam and Foster, 1992;Wyssling, 1979).

Example of source protection system that has been developed in 29 catchment areas in the Sultanate of Oman(MWR) for the purpose of source protection is shown on Fig: 10.2



Name	Type	Potent_con
Muwaylah Industrial estate	Industria	Trace elements, Oil
Muwaylah STP, 4500 m3/d	STP	Heavy metals, pathogens
Sohar Hospital STP	STP	Heavy metals, pathogens
Mosque Septic Tank	Sewage	Heavy metals,Pathogens
Sohar rubbish dump	Dump	Heavy metals, pathogens
Shanfari Workshop (abandon	Workshop	Waste oil
Stone quarry and crusher	Crusher	Waste oil, metals, salts, g
Stone quarry and crusher	Crusher	Waste oil
Stone quarry and crusher	Crusher	Waste oil
Oman Mining Company crushe	Mining	Waste oil
Abdullah Ali Al Kishry and	Crusher	Waste oil
Oman Sun Farms	Farm	Nitrates, pesticides, etc.

Fig:10.2 Shows Jizzi catchment area, source of contaminants, rain and wadi gauges, and the four protection zones,(Kotoub.S.2001,Oman).

The protection zones map represents 4 areas; red, orange, blue and yellow . The 1-year and 10-year wellfield capture zones for the wellfield generated my groundwater model are used to define the red and orange groundwater protection zones. The yellow zone was defined to be the total surface water catchment upstream of the orange zone. The blue zone was defined to be the wadi channel area downstream of the orange zone to the coast.

A Flowpath model was run by the former MWR, and has enabled to the definition of Wellfield Protection Zones(source protection) for the Jizzi wellfield. The number of zones has been simplified to three and kept to reasonable size in order to facilitate planned development and at the same time ensure safe, clean domestic water supplies.

Four zones are defined:

Red Zone - based on one year travel time
Orange Zone - based on ten year travel time
Yellow Zone - total capture zone (rest of the surface water catchment)
Blue Zone - the wadi channel area downstream of the Orange zone to the coast (Saltwater intrusion).

11.0 Groundwater Vulnerability Assessment of Jizzi Catchment Pilot Scheem

11.1 Introtuction

The population of Sohar one of the biggest towns in the country was estimated to be around 95,000 in 1997. Sohar town is located in the lower part of Jizzi catchment at Northern Batinah along the coast of the Gulf of Oman and located at a distance of 230 km from Muscat.

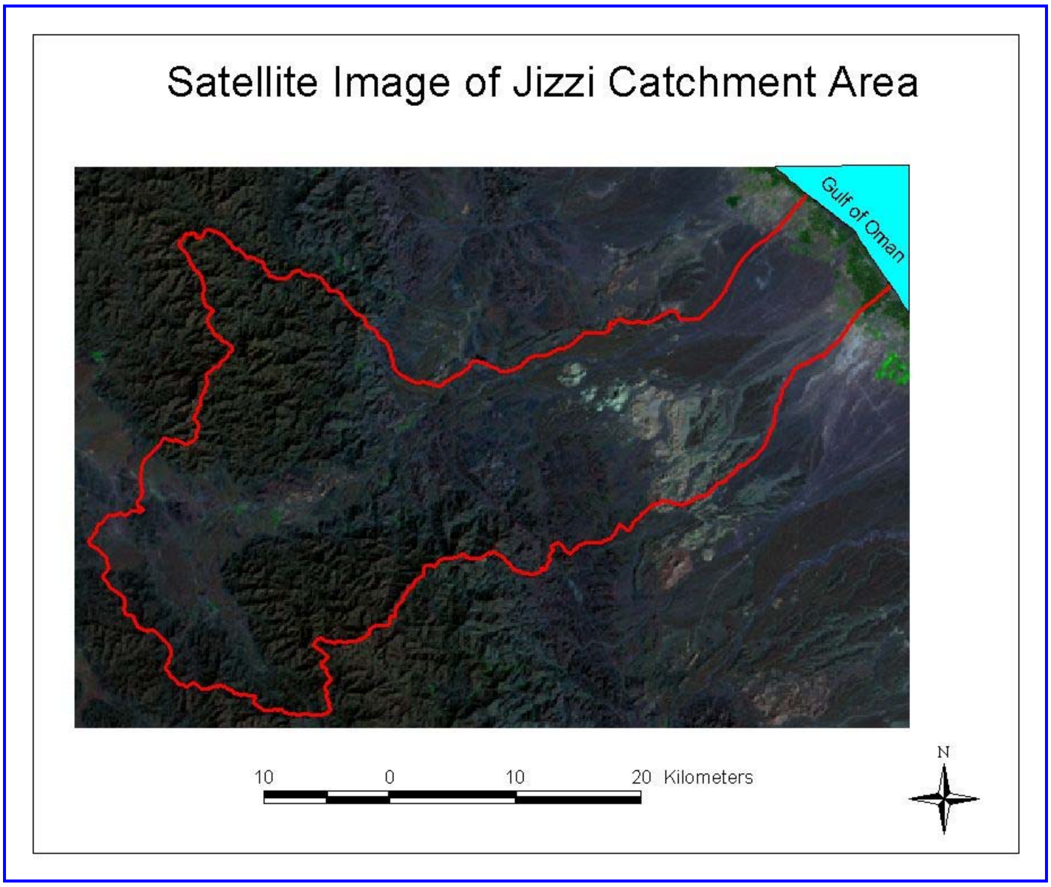


Fig :11.1 A satellite image of the Jizzi catchment area.

Fig :11.1 (Image) a satellite image of the Jizzi catchment area, showing the hydrological features, surface drainage, the outcropping geological formations, and the cultivated areas of the catchment. The image shows that Wadi Jizzi originates from the eastern slopes of Jabal al Hajar al Gharbi (Northern Oman mountains) and flows in the northeasterly direction in the Batinah Plain. It also shows tributaries of main wadi Jizzi, which discharge into the Gulf of Oman.

11.2 Aflaj in Wadi Jizzi Catchment's Area

A total of twenty-five aflaj exist in the study area, of which only two are currently monitored. All of them provide irrigation water to the nearby agricultural areas. There are two types of aflaj in Wadi Jizzi catchment; the Ayne type in the upper catchment, and the Daudi type in the lower catchment. The aflaj flow is highly variable and depends predominantly upon rainfall intensity.

They considered very vulnerable areas to weather changes and contamination.

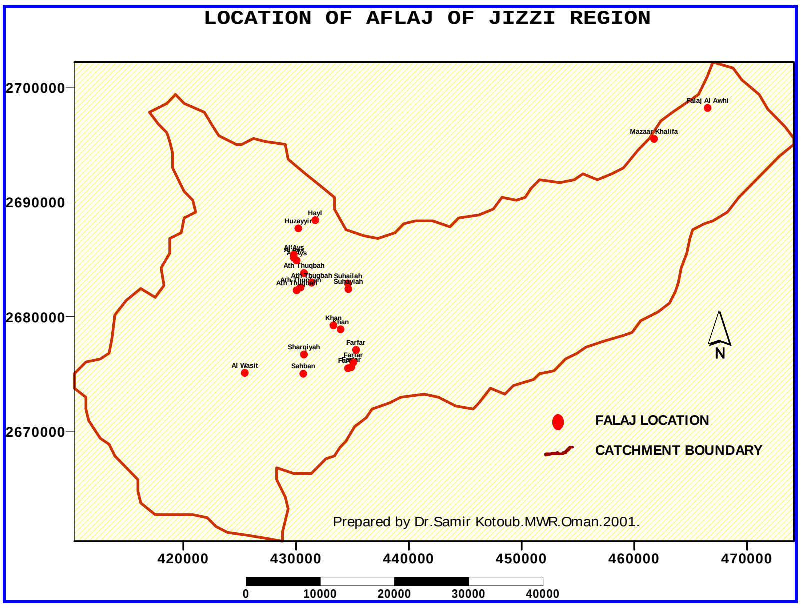


Fig:11.2 The distribution of Aflaj in Jizzi catchment area. There are twenty-five aflaj existing and they used mainly for irrigation.

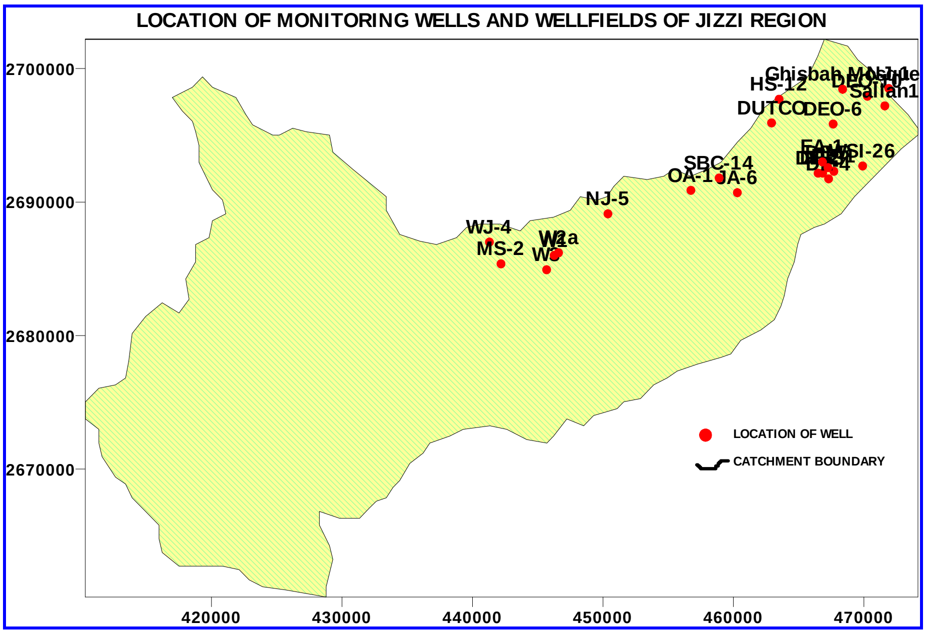


Fig:11.3 The location of the wellfields in the catchment, the Sohar Development Office (SDO), Ministry of Defence (MOD) and Oman Mining Company (OMC) wellfields .

A full assessment of groundwater vulnerability of Jizzi region has been achieved, however, the intrinsic vulnerability of the major geological ,and hydrogeological environment of Jizzi region, is based on strata vulnerability ,and unsaturated zone thickness. Following to the intrinsic assessment, specific groundwater vulnerability assessments were performed.

11.3 Specific Groundwater Vulnerability Of Jizzi Wellfield Source

The vulnerability map of lower Jizzi catchment was produced based on three criteria; the groundwater occurrence, the water bearing formation, and depth to water (Sohar wellfield Protection Plan - final report). Based on the above criteria the vulnerability map (source vulnerability) was produced and the zone of influence found to be divided into two parts; zone of aquifer vulnerability high, and zone of aquifer vulnerability moderate (Fig.11.4).

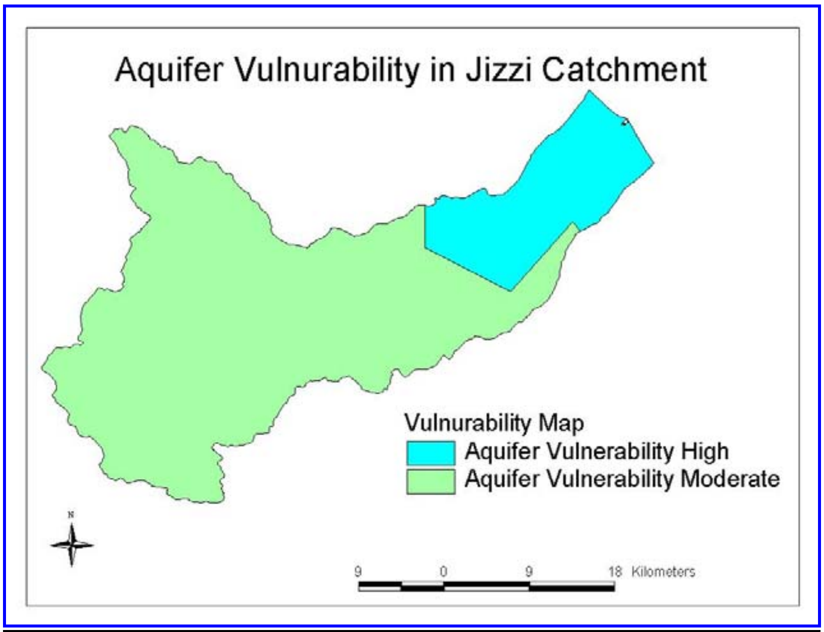


Fig.11.4 Groundwater Vulnerability Map of Jizzi Wellfield Source

The map shows that the three wellfields are located inside the zone of high vulnerability to contamination. In addition it is reported that more than 1040 wells are also located inside this zone. As we observed earlier other sources of potential contaminants are also located in this particular zone. This could lead to further complication in term of groundwater contamination if the aquifer has not been managed properly and protected from the contaminant sources.

11.4 Intrinsic Groundwater Vulnerability Assessment of Jizzi Catchment:

11.4.1 Strata Vulnerability Classification:

The major geological formations according to matt macdonald have been classified following to the major characteristics listed below:

- Primary and secondary or dual porosity, and permeability.
- Ability to store and transmit water.
- Importance as a potential water resource.
- Water quality.

The intrinsic strata vulnerability classification has been used as an input parameter in the thematic specific vulnerability map components of Jizzi region.

Emphasis where made on the above-mentioned characteristics for final vulnerability mapping.

Quaternary:

-Surficial deposits
-Recent alluvial fans and wadi alluvium:(very high vulnerability).
-Poorly cemented, major recharge areas.

These deposits comprise the major aquifers in jizzi region. Batinah Plain deposits are very heavily exploited.

After rainfall runoff will concentrate in wadi channels, increasing potential of contamination.

Deposits close to the coast and in the interior may contain saline water and thus classed as having low groundwater vulnerability from quality point of view in the interior, but at the coastal region it would be classified as a **very high vulnerable** area from quantity point of view and its susceptibility to saltwater intrusion and the prevailing hydrodynamic process.

-Sub-recent deposits (moderate vulnerability)

Partly to well cemented; so less vulnerable to contamination than active/recent deposits; recharge may occur through these. Groundwater exploitation from these deposit often considered as an important sources of water supply.

Mid-Late Cretaceous

Samail Nappe

-Early magamatic: Samail volcanics/cumulates.
-Tectonics: harzburgites and dunites.
-Late magmatic: intrusives and cumulates.

Localy important resource, and source of recharge to quaternary aquifers and baseflow to wadi channels. Late magmatics often massive and poorly joint so less vulnerable to contamination.

-Metamorphic Sole: (low vulnerability).

Generally very poor aquifer characteristics. Might be locally important in places, but not frequent, Natural water quality likely to be poor.

-Hawasina Nappe (low vulnerability).

Generally poor aquifer potential. Might provide local minor sources of water, but generally regarded as a non-aquifer. Often find springs located along contact between Hajar Supergroup and Hawasinah. Only very limited use as local water source.

Fig:11.5 shows the main outcropping formations in the area of the Samail Ophiolite Nappes, Hawasina Nappes , the alluvium,and corresponding thematic strata vulnerability classification.

The mountainous terrain is mostly made up of Samail and Hawasina Nappes. The Hawasina Nappes is late Permian to late Cretaceous and contain volcanic rocks, basaltic pillow lava, and shale with radiolarian chert with limestone. The Hawasina Nappes is highly fractured and have been affected by tectonic movemnet.

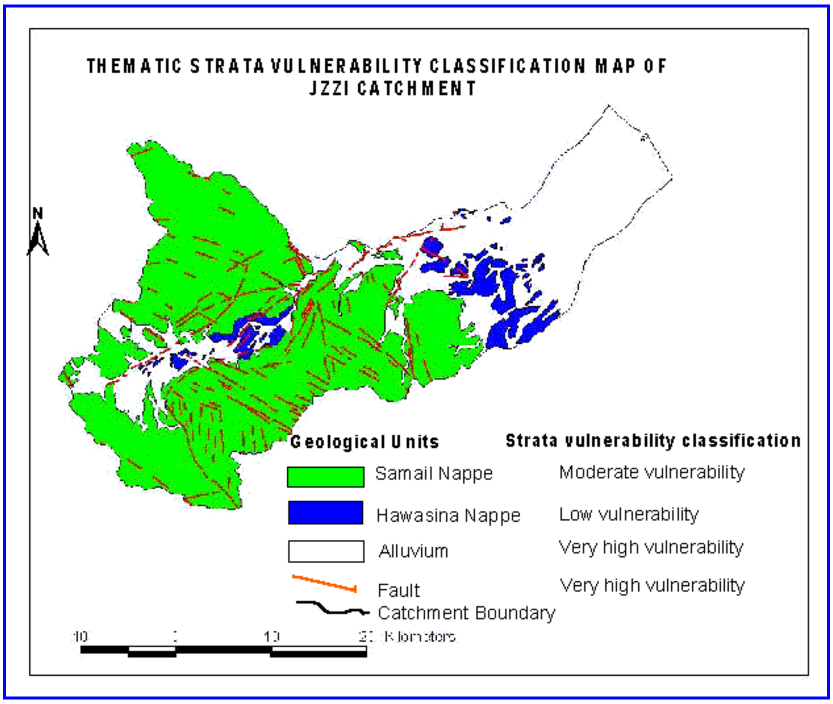


Fig.11.5 Geology of Jizzi Catchment Area,and Strata Vulnerability Clasification

The alluvial deposits of the Jizzi catchment are composed of sediments of Tertiary, Quaternary, and recent age. The alluvium thickness is different from place to another within the catchment due to the physiography, geology, and lithology.

The Coastal Zone is located between the tertiary outcrops and the Gulf of Oman. Toward the coast the plain flattens and is covered by finer sediments of sand and silt. The alluvial sediments comprise gravel sands, and silts that have variable cementation. The coastal alluvium has been proved to depth of up to 237 m.

11.5 Specific Grounwater Vulnerability Assessment Of Jizzi Catchment

In order to prepare Groundwater vulnerability map of Jizzi region several specific thematic maps were prepared on the following subjects, and steps were undertaken combined with GOD procedure adopted by the author in the field of ad hoc assessment has been explained herewith:

Geological information
Strata assessment (as explained in the previous section).
Depth to water level.
Soil classification data of the area.
Drainage pattern.
Gradient of regional groundwater flow.
Background of water quality.
Logistical, and aquifer importance to local users in the form of management context.

Geological, Strata, and depth to Water level have been combined to delineate the essential parameters and factors influencing the accuracy and efficiency of Jizzi groundwater vulnerability map. Soil data was classified,sorted out, and utilized in order to classify the soils into different hydraulic conductivity ,and attenuation capacity values rating the region into different vulnerability classes.

The natural water quality was assessed bearing in mind that the coastal region has been considered as a very vulnerable region, due to the prevailing overexploitation, and saltwater intrusion in the area. So vulnerability is related to the quality of water resources , rate of abstraction ,and relevant environmental consequences.

The assessment has taken into consideration the importance of aquifer as a source of water from the management perspective, delineating the most important areas to be protected, and the prevailing hydrological ,and hydrogeological problems of the region, so that the groundwater vulnerability might be increased accordingly.**Fig:11.6**

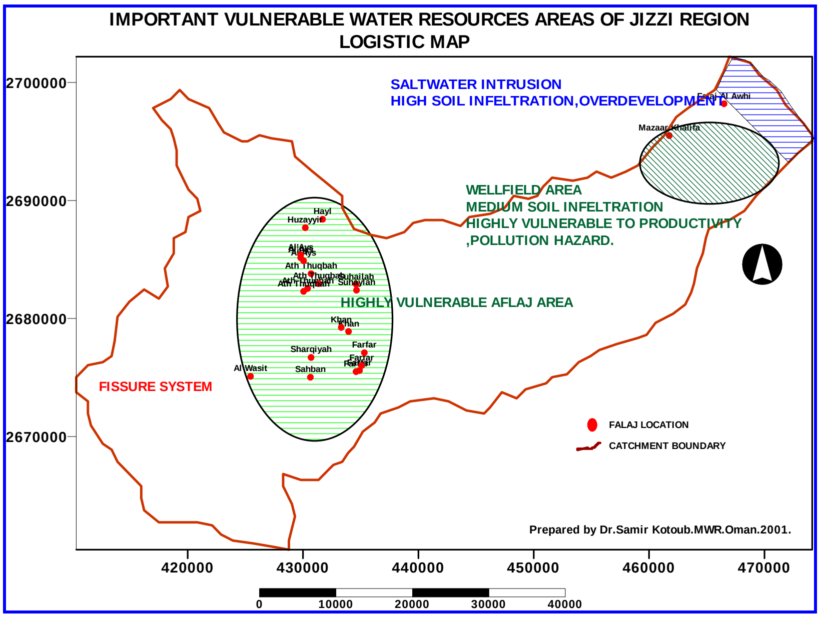


Fig:11.6 Important Vulnerable Water Resources Areas of Jizzi Catchment.

Groundwater classified as very high vulnerable is mostly located beneath active wadi channels, or beneath ground that is close to active channels. In addition many of the hard rock formations classed as being moderate to low are usually in mountainous areas with deep water tables, these areas are not proposed for development activities due to the dangers of flood risks, remoteness and topography features.

In assessing specific groundwater vulnerability, consideration have been given to the fact that despite that some areas are of poor quality, it should be dealt with in the same manner of remaining areas, due to the fact that these areas could be subjected for water resources development, or for irrigating saltwater tolerance plants. Therefore protection of aquifers of certain salinity limits from contamination should be adopted as a general policy, since water may be of a great significance to the local development programes.

It has been reported that Hawasinah Nappe is characterized with highly fractures, and Transmisive *fault* zones which are considered as active conduits of water at many places, therefore caution should be given during any proposed development in areas characterised with intensive faulting or prevailing fractures, and joints, prior granting an environmental permit, due to its very high vulnerability classification.Fig. 11.5

Logistical consideration has been enrolled in the classification and rating of the groundwater vulnerability of the region taking into consideration the importance,and prevailing hydrogeological conditions from the overall integrated development, and management of available water resources in the region. The most prevailing activities are the existing wellfields, Aflaj, irrigation ,and associated saltwater intrusion, copper mining, pollution sources, surface tributaries .Fig.11.6.

As explained earlier the present study area has adopted simple rating system, largely derived from Legrand's system (1963, 1988), and proposed by Foster (1987) with the acronym GOD, has been used due to its simple, and pragmatic structure, taking into account above hydrogeological, and soil rating parameters of ad hoc subjects and thematic maps of the region.

The parameters, and rating used in the GOD empirical system for the rapid assessment of aquifer vulnerability are shown in Figure 9.1. In this system, the data is rated according to the groundwater occurrence (nature of aquifer), over all aquifer classes (nature of aquifer sediments) and ,the depth to water table. In addition it has been found practical,and beneficial to utilize available data on the region's soil parameters, and strata in order to be included in the rating process to enhance the overall approach of the map. Final ratings of the Synoptic Map has been prepared. All the four ratings are multiplied to get the output in the form of a value, which is translated, into Groundwater synoptic vulnerability map.of the following classes :

- Very high
- High
- Moderate to high
- Low to Moderate
- Low

Specific thematic groundwater vulnerability maps were prepared on ad hoc subjects in order to generate the synoptic maps.

Average Groundwater fluctuation:

DE-2 well demonstrates the long-term water table trends between January 1989 up to January 1998. The fluctuation reflects the response of the well to the recharge events and abstraction from the groundwater in the vicinity area. It is of great important in order to see the general trend of the water level fluctuation, which is directly related to the storativity of the aquifer, its behavior and vulnerability to depletion and contamination.

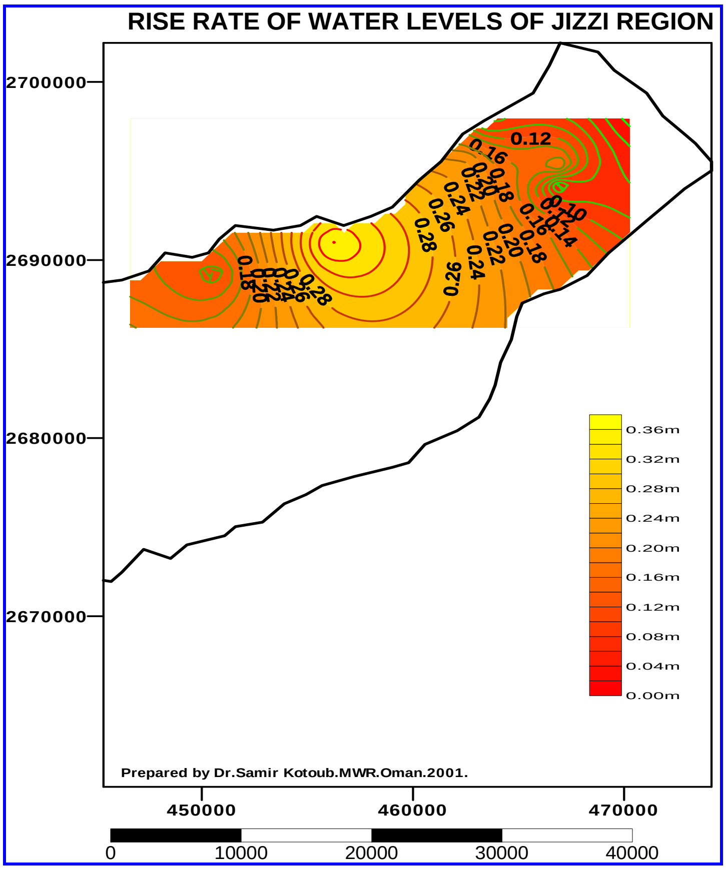


Fig:11.7 Average groundwater rise

Depth to Water level

The depth to water level in the Wadi Jizzi catchment area is shown on Fig.11.8 ranges from 2 m to over 21m in December 1996. It also presents the average (time series) water table as calculated from monitored data. The elevation for monitoring borehole WJ-4 is approximated at 300 m.
presents the shallowest ,and deepest depth to water levels, and static water levels in monitoring wells.

Water Table Gradient

Generally groundwater flows from SW to NE. The groundwater gradient in the upper catchment is steeper becoming gentler in the downstream direction. It becomes steady in the Batinah coastal plain. The groundwater gradient in lower catchment is 0.008.

Groundwater flow

The direction of the flow is from southwest to northeast. The average water table in the western part is deep and reaches up to 250 m, while the water table in the eastern part and along the coast is shallow and reaches up to 5 m.

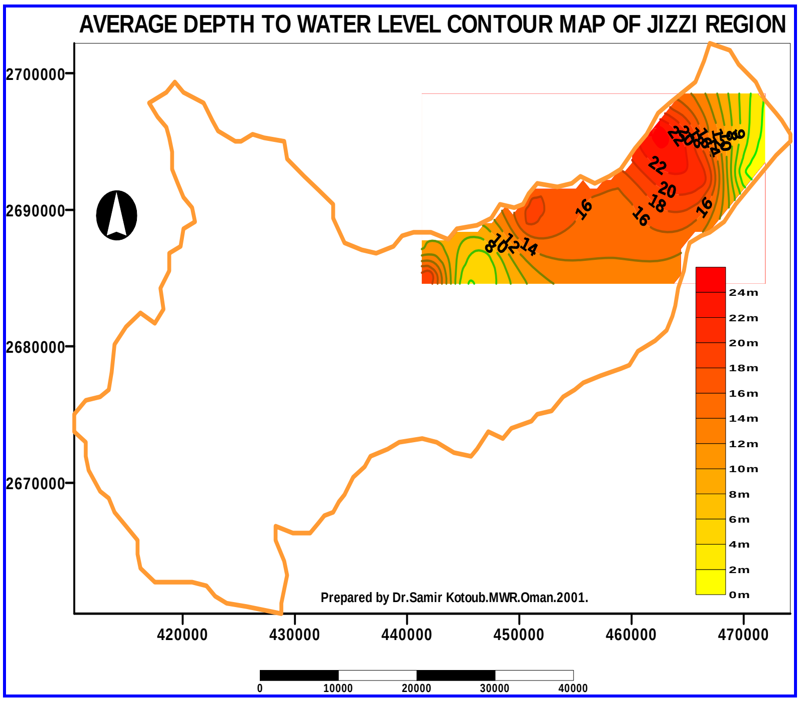


Fig:11.8 Average depth to water levels contour map of lower Jizzi catchment.

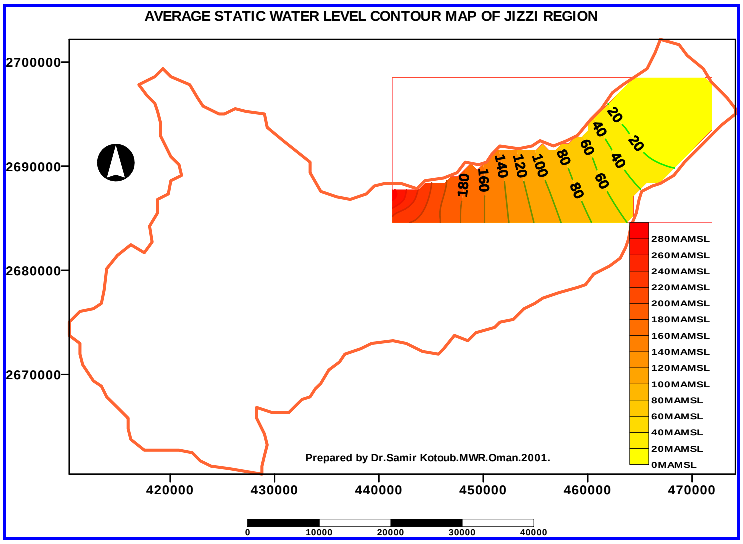


Fig:11.9 The average static water level contour map of the area.

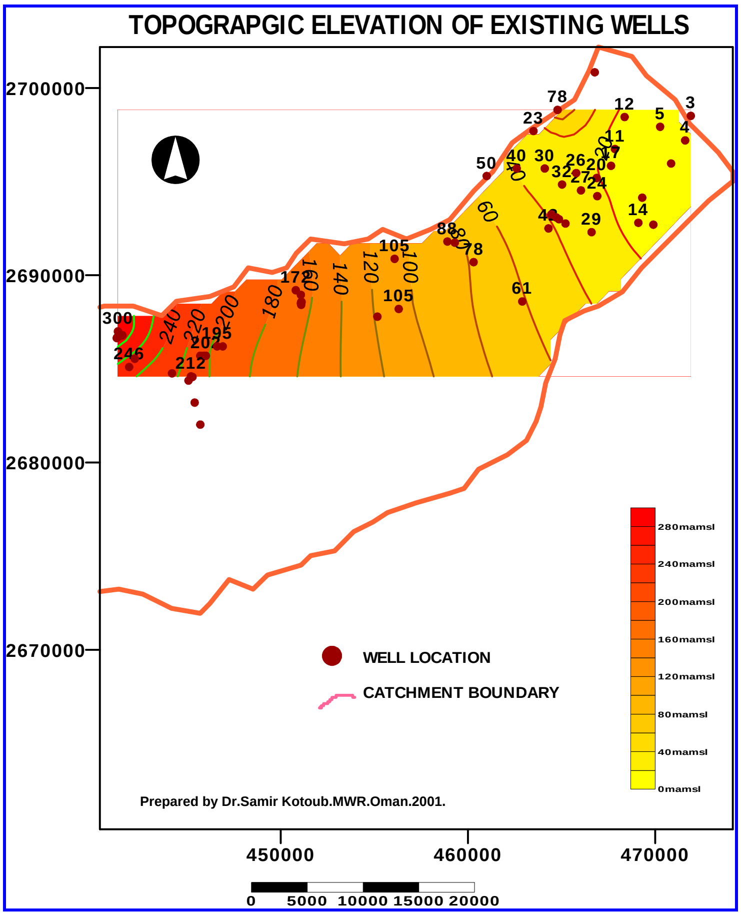


Fig:11.10 The prevailing topographic elevation of existing wells and gradient in the lower part of jizzi catchment

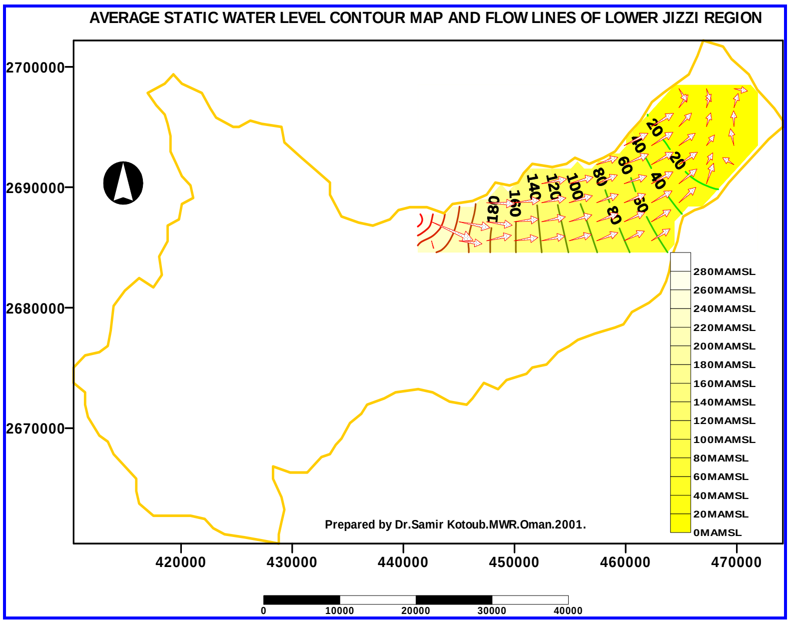


Fig:11.11 The general direction of flow.

Soil Characteristics and Interpretation

The soils of Wadi Jizzi have been classified into ten groups on the basis of the Soil Taxonomy, the Soil Classification System of the United States of America (USDA-SCS, 1975). These are numbered as Map units R, W, 17, 21, 26, 36, 38, 42, 43 and 48 and are shown in **Figure 11.12**Generated from the “General Soil Map of the Sultanate of Oman” (MAF, 1990). The units have been classified, and unified according to its vertical conductivity’s property as an input to the final synoptic Groundwater Vulnerability Map as follows:

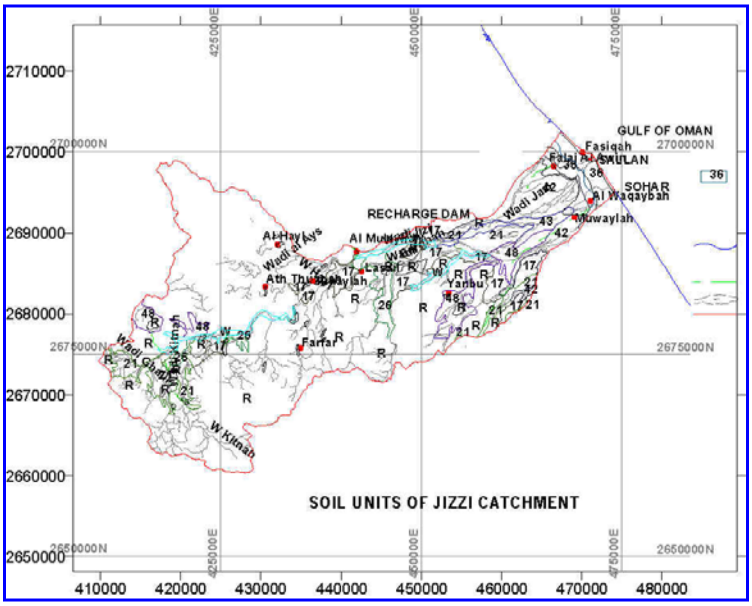


Fig: 11.12 Soil classification of wadi Jizzi catchment.

Unit ‘R’

This soil map unit comprises 70% rock outcrops,
20% Torriorthents, calcareous, very gravelly, loamy to sandy and 10% minor soils.
The vertical conductivity is high.
Water retention difference is low.
High to moderate vulnerability.

Unit ‘W’

Wadi beds, sandy-skeletal, shallow to deep soils, strongly flooded, 0-1% slopes.
This covers 2% of the catchment area and is 75% calcareous, very gravelly and extremely gravelly sandy,
High gravel content and severe flooding.
Very high vulnerability.

Unit ‘17’

75% Gypsiorthids and 25% minor soils.
Covers 7.5% of the catchment area, with a slope of 0 to15%.
Gypsiorthid soil is deep, very gravelly to gravelly, loamy
The vertical hydraulic conductivity is moderate
Water retention difference is moderate to high.
Moderate vulnerability.

Unit ‘21’ and 20% minor soils.

- Covers 5.6% of the catchment area
- The Gypsiorthids 80% are deep, very gravelly- sandy, 20% minorsoils.
- The vertical hydraulic conductivity is moderate to high
- Water retention difference is low.
- Moderate to high vulnerability.

Unit ‘26’ comprises 55% Gypsiorthids, 35% rock outcrops and 10% minor soils.

- Covers 2.2% of the catchment
- Gypsiorthids 55% are moderately deep, very gravelly loamy, calcareous, slightly.
- The vertical hydraulic conductivity is moderate;
- Water retention difference is moderate to high.
- Moderate vulnerability.

Unit ‘36’

- Covers 2% of the catchments. of irrigated farming alluvial plains and flood plains of major streams
- Torrifluvents 80% and similar soils 20% are on flood plains and alluvial plains.
- The vertical hydraulic conductivity is high to moderate.
- The water retention difference is moderate to high.
- Moderate to high vulnerability.

Unit ‘38’

- Covers 1.2% of the catchment. Irrigated farming in flood plains and coastal plains.
- Torrifluvents 30% are deep, gravely sandy, stratified, clacareous, and slightly saline soils.
- The vertical hydraulic conductivity is moderate to high:
- Torriorthents 25% are deep, gravelly sandy, calcareous, slightly saline soils.
- The vertical hydraulic conductivity is high
- Water retention difference is low.
- High vulnerability.

Unit ‘42’.

- Covers 6.9% of the catchment area
- Torriorthents comprises 75% sandy skeletal Torriorthents and 25% minor soils
- The vertical hydraulic conductivity is high
- Water retention difference is low.
- High vulnerability.

Unit ‘43’

- Covers 1.7% of the catchment area. Comprises mainly of Torriorthents.
- The vertical hydraulic conductivity is high
- Low water retention difference.
- High vulnerability.

Unit ‘48’

Covers 4.4% of the catchment, comprises 60% Torriorthents, 30% Gypsiorthids and 10% minor soils.
The vertical hydraulic conductivity is high
Water retention difference is low.
High vulnerability.

The resulting soil map shows that the soil units in the catchment can be classified according to its vertical conductivity’s parameters into five-soil classes; very high, high, moderate to high,moderate,and low to moderate,taking into consideration that Wadis and faults are considered as a very high vulnerable areas,presented in red color on the final synoptic map. Nevertheless, the majority of occupied ,and cultivated areas are located in the northwest of the vulnerable Jizzi catchment’s .

Accordingly, the soil map units have been classified and categorized according to the degree of vulnerability; Autocad program was utilized in the preparation of vulnerability classes of the vertical soil conductivity map.(Soil Thematic Map).

Fig:11.14 shows the results of five – vulnerability classes of the vertical soil conductivity as follows:

Red color: wadi beds,Faults, Coastal plain,Aflaj plains: very high vulnerability
Orange color:soil units, 38,42,43,48.:high vulnerability
Green color: soil unit21: moderate to high .
Yellow: soil units 26: moderate vulnerability
White: R unit: low to moderate vulnerability

Table 11.3 shows a summary of the soil map units in the catchment, their soil name and their physical properties and vulnerability

Table 11.3 Soil Unit’s and Vertical hydraulic properties of Jizzi Catchment

Soil Unit	Hydraulic Properties and Vertical conductivity	
Rock outcrop	Fractures,	low to moderate vertical conductivity
Torriorthents	Calcareous, gravel,	high vertical conductivity
Minor soils	Clayey,	moderate vertical conductivity
Gypsiorthids	Gravel,	moderate vertical conductivity
Torrifluvents	Gravel, sand,	moderate vertical conductivity

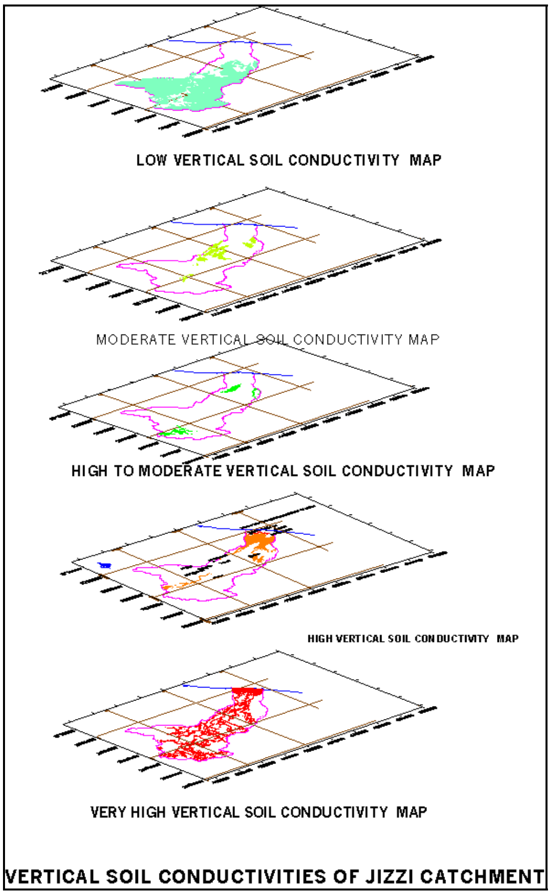


Fig: 11.13 The results of five – vulnerability classes of the vertical soil conductivity

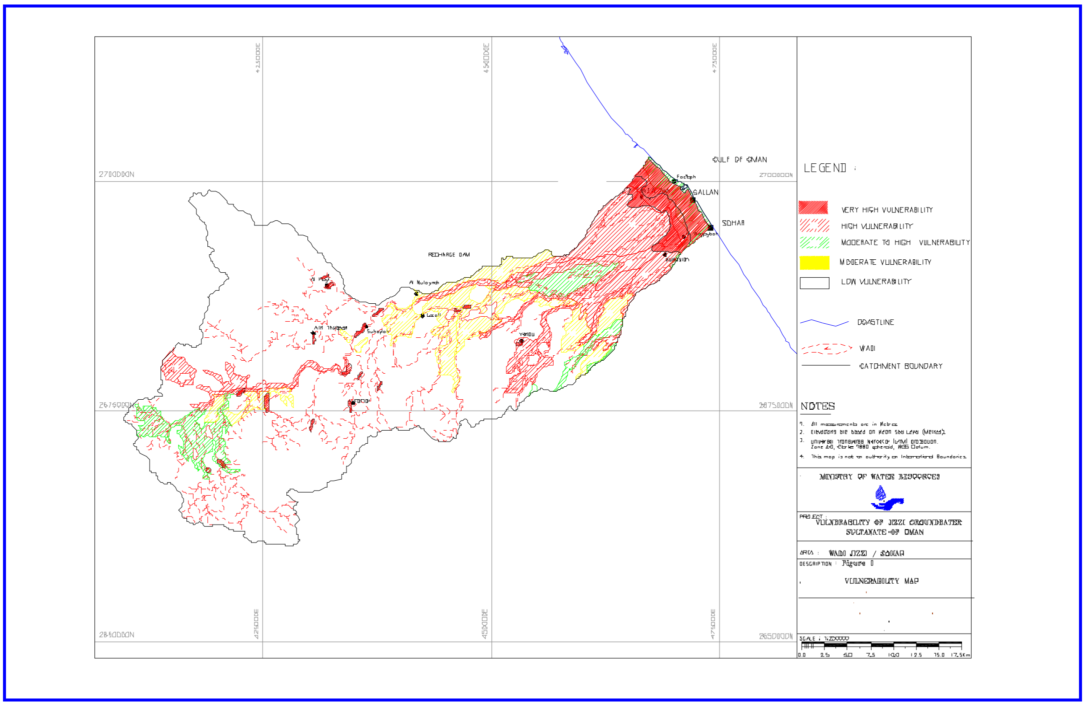


Fig:11.14 The Thematic Map results of five – vulnerability classes of the vertical soil conductivity.

12.0 Groundwater Vulnerability Mapof Jizzi Catchment

Based on above criteria , the Aquifer Vulnerability Classes were worked out in detail as shown on Fig: 12.1, and on the basis of the thematic maps prepared for the construction of the final synoptic map, bearing in mind that no distinctive sharp boundaries are encountered in the real nature. In the Wadi Jizzi catchment the vulnerability classes have been simplified as shown in Table 12.1 The results of ad hoc classes are represented spatially in detail as an Aquifer Vulnerability Map of Wadi Jizzi catchment as shown on Fig 12.2 the ultimate goal of this study and step forward for the preparation of Groundwater Potential Pollution Risk Assessment in the region.

The resulting Groundwater Vulnerability Map shows that the catchment can be classified into five classes; very high,high,moderate to high,moderate,low to moderate and taking into consideration that Wadi and faults are considered as a very high vulnerable areas presented in red color on the map.

Accordingly, the map units have been classified and categorized according to the degree of vulnerability; AutoCAD program was utilized in the preparation of the specific vulnerability synoptic map.

Fig::12.2 shows the results of five vulnerability classes where assigned as follows:

- Very high.
- High.
- Moderate to high.
- Moderate.
- Low to Moderate.

Red color: wadi beds unit, faults, coastal plain, aflaj plains, and very high vulnerability
Orange color: soil units, 38,42,43,48.high vulnerability
Green color: soil unit21 moderate to high vulnerability
Light green soil units 26 moderate vulnerability.
Light blue R unit low to moderate vulnerability.

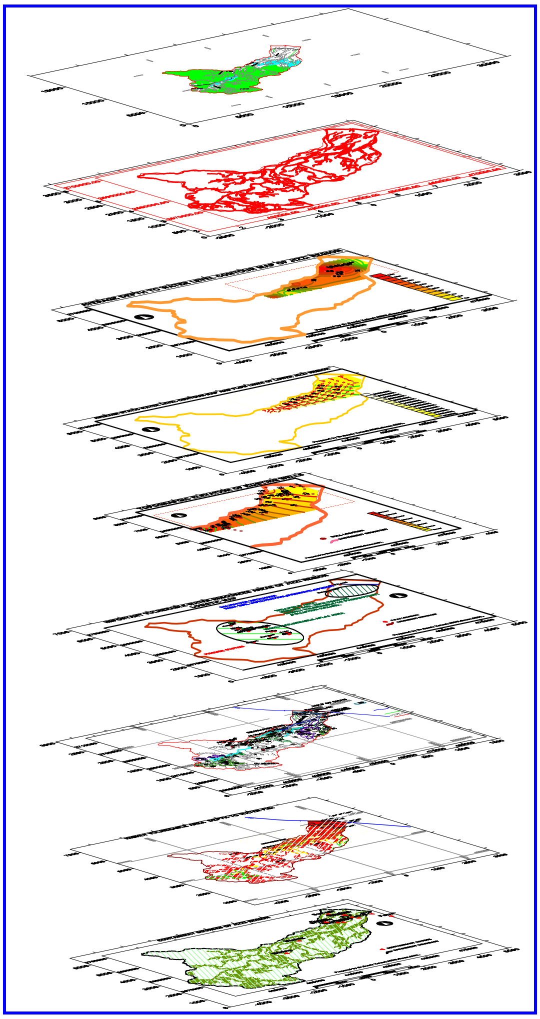


Fig: 12.1 Thematic Maps For The Preparation of GroundwaterVulnerability Synoptic Map of Jizzi Catchment

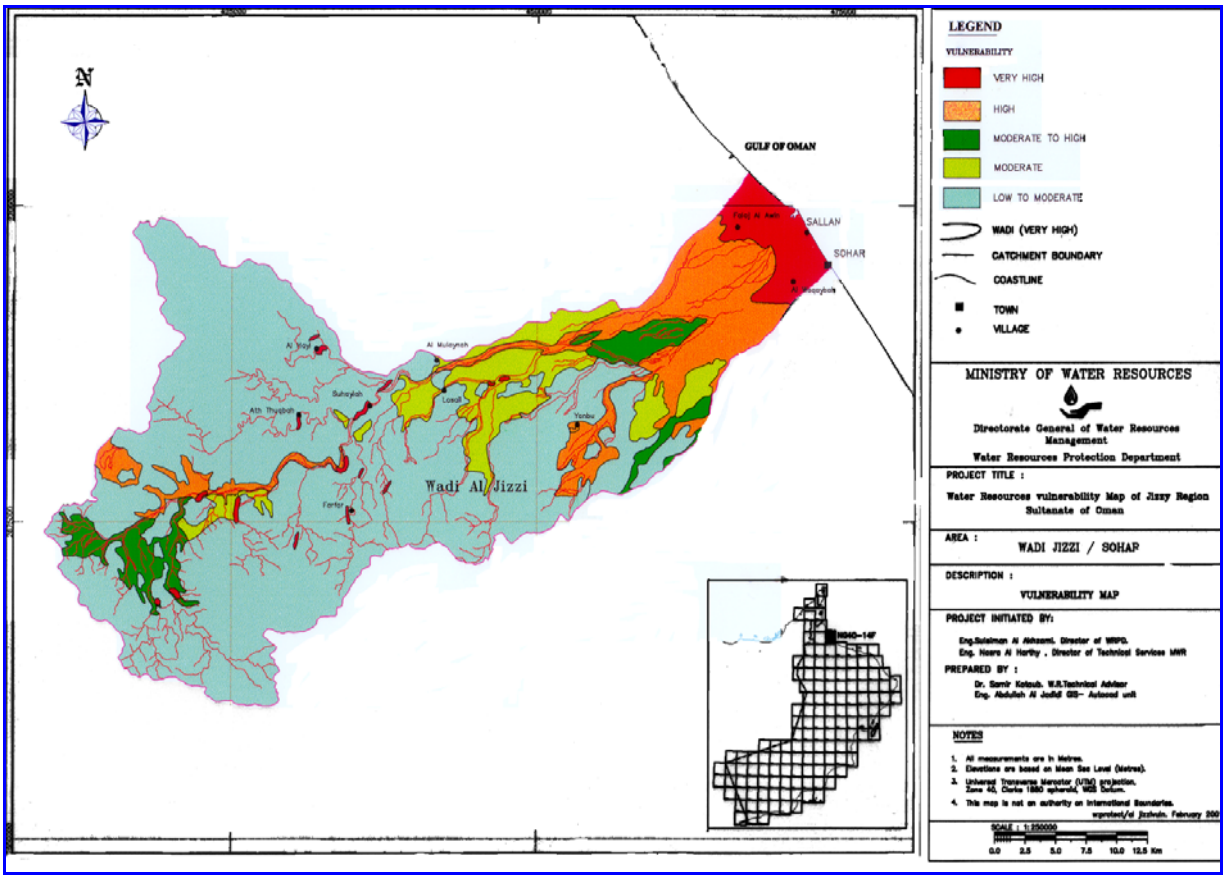


Fig:12.2 Groundwater Vulnerability Map of Jizzi Catchment.

Table 12.1 Aquifer Vulnerability Wadi Jizzy Catchment

Protection Zone	Groundwater Occurrence	Rating	Type of Aquifer	Rating	Depth to Water Level	Rating	V. Conductivity Soil Rating	Vulnerability Index	Aquifer Pollution Vulnerability
Orange	Unconfined	1	Unconsolidated Colluvial Gravels	0.8	10 to 20m	0.7	0.8	1 x .8 x .7x0.9=0.504	High
Green to light Green	Unconfined	1	Unconsolidated Colluvial Gravels	0.8	10 to 20m	0.7	0.8	1 x .8 x .7x.9=0.504	High
Light Blue	Unconfined	1	Igneous/ Metamorphics	0.6	20 to 50m	0.6	0.6	1 x .6 x .6x0.6=0.36	Moderate
Red	Unconfined	1	Unconsolidated Alluvial	0.75	2 to 5m	0.9	1	1 x .75 x .95x1=0.71	Very High

13.0 Potential Pollution Sources of Jizzi Catchment

A comprehensive inventory of activities and potential pollution sources (point and diffuse) was conducted by the Ministry of Water Resources, through the implementation of regional wellfields protection program in the sultanate of Oman. Part of the data has been utilized in the study of jizzi catchment to avoid redundancy.

13.1 Activity matrix

The site specific generic activity matrix in respective protection zones in Wadi Jizzi catchment is presented in Table 13.1.which has been prepared to match the vulnerability classes adopted in the region as follows: Green, Orange, Light. Blue and Red Zones have been delineated and shown in Figure: 12.1

Table 13.1 Activity Matrix of Specific Sites: Jizzi Catchment

Site Specific Activity Matrix

CATCHMENT AREA JIZZI

SN	CATEGORY	ACTIVITY	GREEN, L.GREEN ZONE	ORANGE ZONE	L.BLUE ZONE	RED ZONE
1	AGRICULTURE	LIVESTOCK	Y	Y	Y	Y
		ARABLE/VEGETABLE	N	N	Y	Y
		TRADITIONAL	N	N	Y	Y
2	BURIAL GROUND (REJECT WATER)		N	N	N	Y
4	DAMS		N	N	Y	N
5	DOMESTIC	RESIDENTIAL SEWAGE	N	N	Y	Y
6	FUEL STORAGE	SURFACE	N	N	N	Y
		DRUM STORE	N	Y	N	Y
7	INDUSTRIAL ESTATES	HIGH POTENTIAL RISK	N	N	N	N
		LOW POTENTIAL RISK	N	N	N	N
8	MINING	MINES/CRUSHERS/QUARRY	N	N	Y	Y
		GAS PIPE LINE	Y	Y	Y	N
10	ROADS	PROTECTED	Y	Y	Y	N
		UNPROTECTED	Y	Y	Y	Y
11	SEWARAGE SYSTEMS	SEPTIC TANKS	Y	Y	Y	Y
		CESS PITS	N	N	N	Y
12	SMALL BUSINESSES	HIGH POT. POLLU.	N	N	N	N
		MEDIUM POT. POLLU.	N	N	N	N
		LOW POT. POLLU.	N	Y	Y	Y
14	WASTE DISPOSAL	SOLID	N	N	Y	Y
15	WELLS	OPEN AND DUG	N	N	Y	Y
	BOREHOLES	BOREHOLES	Y	Y	Y	Y
16	SURFACE WATER	WADI	Y	Y	Y	Y
17	AFLAJ	AFLAJ	Y	Y	Y	Y

13.2 Potential Pollution Sources

A variety of human activities stemming from agricultural, industrial, community, and residential sources, as well as natural processes can contaminate groundwater. In Oman there are wide variety of materials have been identified as contaminants in groundwater such as synthetic organic chemicals, hydrocarbons, inorganic cations & anions, and pathogens. These contaminants could originate from under storage tanks (UST), oil pipeline, septic tanks, municipal landfills, saltwater intrusion, oil injection wells and others. Nevertheless, some of these potential sources pose much threat to groundwater than others. Hydrocarbon leakage through UST or oil pipeline is extremely of great threat to the groundwater in different areas.

A more detailed inventory of potential pollution sources resulting from generic activities, defined in Table 13.1, was conducted and is summarized in Table 13.2 and shown in figure 13.1

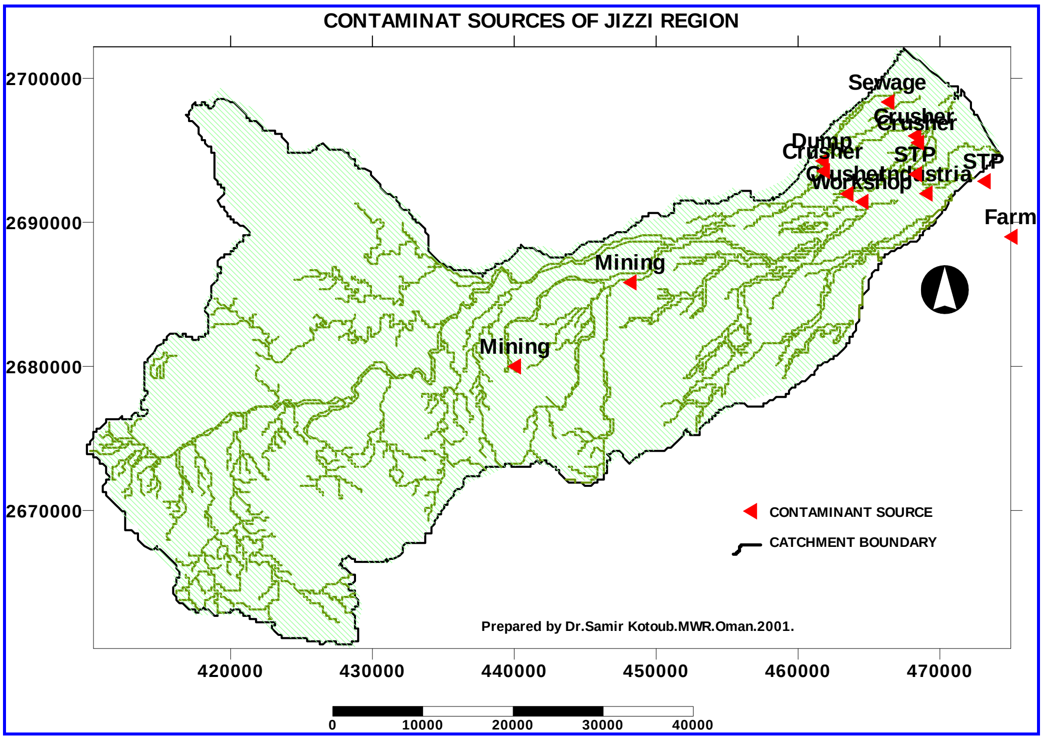


Figure 13.1

Figs. 13.2,13.3 Show the concentration of Nitrate contaminants along the coastal region of Jizzi Catchment of very intensive cultivated area, such practices have led to excess discharge of agricultural pollutants (e.g. Nutrients (N, P), Pesticides) to groundwater resources .In respect to human health, nitrate is primary concern, the suggested World Health Organization (WHO) limit of NO3 being 50 mg/l in drinking water. Fig .13.2 shows the distribution of well points and concentration of nitrates ranging from 0-10,10-45, and above 50 mg/l of Nitrates in the irrigated coastal areas which have been affected by saltwater intrusion processes, caused by the over development activities taking place in the region. MWR has indicated that the groundwater levels along the coastal aquifer are falling in a range of up to 0.2 m /year. As a result, saltwater intrusion is prevailing in many parts of the region at levels beneath seawater. Fig.13.4 Shows the delineation of saltwater intrusion in the northern part of Al Batinah region.

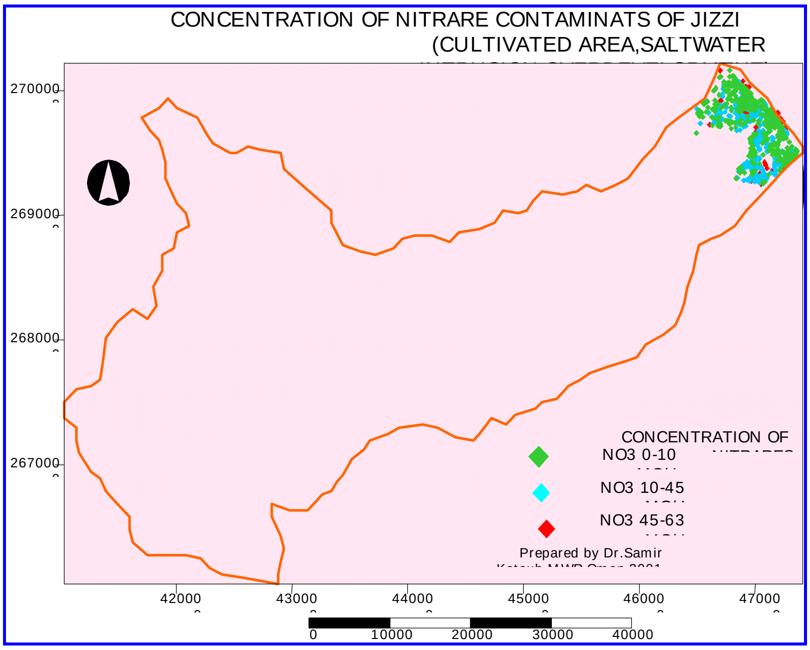


Fig. 13.2

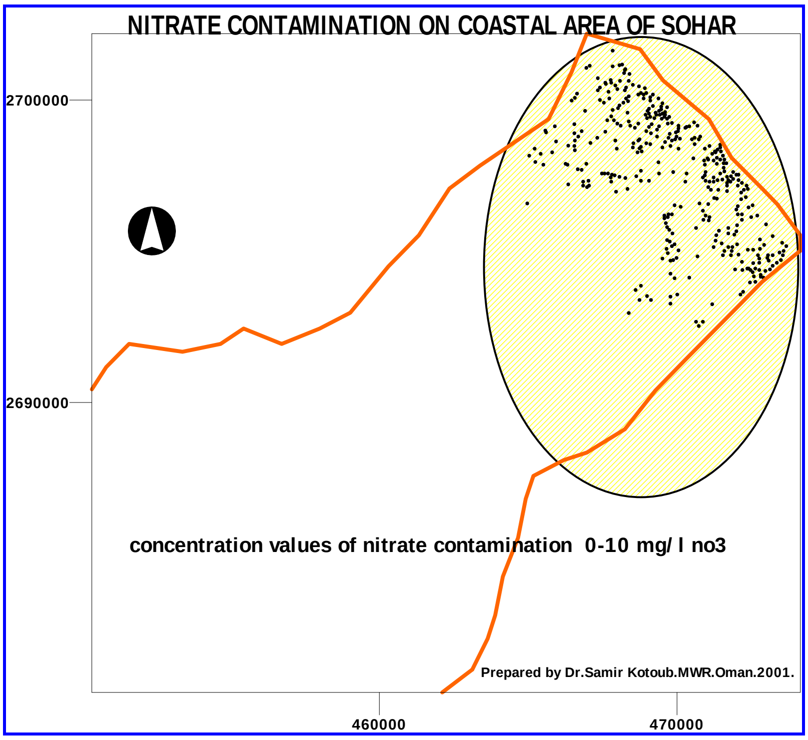


Fig.13.3

Four salinity surveys of Albatinah coast were carried out; the first being 1983-84.They covered ten years of monitoring and sampling of wells. The 1993 survey involved sampling of 1075 wells, it is reported that out of 870 wells sampled in both surveys, salinity had risen in 675 wells 78% and fallen in 22%. (MWR).

The reports delineated the hydrogeological conditions of the area; some agricultural crops on Albatinah coast are being deteriorated due to Stalinization of soils. Agricultural activities in the study area are generally limited to date farming orchards and growing alfalfa grass as fodder. Most of the farms are located on the Red and Orange zones.

As in Albatinah the prevailing overabstraction of water resources and application of inorganic fertilizers and pesticides have resulted in the overall nonpoint pollution hazards in Al Jizzi catchment.

Groundwater system in Jizzi region is heavily overexploited mainly for irrigation purposes resulting in a severe deterioration of water quality and quantity accompanied in continuous saltwater intrusion wedge along the coast. Under recent conditions the sustainability of the agricultural sector would not be prevailed without rationalizing groundwater resources to maintain agricultural production, and to augment national groundwater reserves for emergency purposes. Augmentation of groundwater resources through artificial recharge, conjunctive use of water resources, and improvement of irrigation techniques for water savings are part of the well-known procedures towards rationalizing and protection of the water resources in Oman.
The lower coastal plain of Jizzi, has led to a successive decline in ground water levels, quality deterioration, and soil degradation.

Enforceable Policies and Mechanisms*.* The area needs to ensure the implementation of the management measures. Mechanisms may include, for example, permit programs, zoning, bad actor laws, enforceable water quality standards, and general environmental laws and prohibitions. Voluntary approaches like economic incentives if they are backed by appropriate regulations could be used.

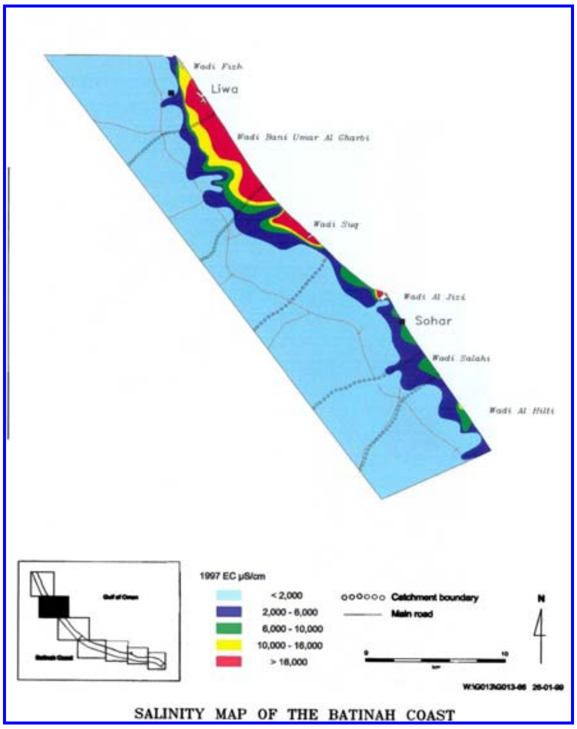


Fig.13.4.Delineates the saltwater intrusion in the northern part of Al Batinah, Sohar region.

All around the catchment in the Green and Orange zones, there are several septic tanks of residential / industries / government offices. Unprotected roads also pass through the Green and Orange zones. The Muwaylah Industrial Estate, falls in the Green, and o

Table 13.2 Potential Polluting Sources and Expected Contaminants: Jizzi Catchment's

Polluting Sources	*Grid Reference*	*Potential Contaminant*
Muwaylah Industrial estate.	469000E:2692000N	Trace metals, heavy metals, chemicals, oils, solvents,
Service stations, Petrol stations		Hydrocarbons, Heavy metals, solvents
Muwaylah STP, 4500 m^3/d	468257E:2693345N	Heavy metals, pathogens
Sohar Hospital STP	473100E:2692854N	Heavy metals, pathogens
Mosque Septic Tank	466305E:2698354N	Heavy metals,Pathogens
Sohar rubbish dump	461679E:2694271N	Heavy metals, pathogens
Shanfari labour camp Workshop (abandoned)	464486E:2691427N	Waste oil
Stone quarry and crusher	463418E: 2691973N	Waste oil, metals, salts, grease
Stone quarry and crusher	468201E:2695992N	Waste oil
Stone quarry and crusher	468404E: 2695533N	Waste oil
Oman Mining Company crusher	Limestone - 449486E:268565N Silica stone - 448138E:2685833N	Waste oil
Abdullah Ali Al Kishry and Partners crusher	461765E:2693560N	Waste oil
Oil Industries	Gas pipeline to OMCO	Methane Gas
Oman Sun Farms	47500E:268900N (farm building)	Nitrates, pesticides, etc.
Agricultural Farms	Mainly in the coastal region	Nitrates, Phosphates, Pesticides, fertilisers
Sohar copper mine (OMCO).	440000E:2680000N	Metals, sulphates, chlorides
Coastal Region (MWR,1999).	Coastal Strip	Saltwater Intrusion

Both the Muwaylah STP (sewage treatment plant) and the Muwaylah industrial estate are at a distance of 2-4 km downstream of the wellfield. Treated effluent is used for irrigation, while the sludge is used as fertilizer. The rest is drained through soak pits in the wadi beds since the STP is closed to the wellfield, the possibility of contamination of the ground water due to pathogens cannot be ruled out.

Great deal of care should be taken to ensure that the effluent is properly disinfected and does not carry any pathogens. It is best to avoid using treated sewage to irrigate farms in the Green and Orange zones of the catchment.

The dumpsite is located upstream of the wellfield, therfore any leachate formed as a result of waste decomposition and water washing through the waste could carry organic and inorganic pollutants to the wellfield. This is one of the major potential pollution hazards with respect to the underlying groundwater, especially as the site is located on a wadi bank. (Red zone).

Hydrocarbon wastes, (Oil and grease, solvents, engine oils, and metals), which contain heavy metals, require proper management and good housekeeping. All could pose potential risks to the ground water. All petroleum products and oils should be prevented from entering the groundwater.

It is reported that the Copper mines and smelter which based at Lasail has begun operation in 1980, the wellfield located 27-28 km upstream, have been impounding processed sea water from the smelter in the tailing dam on a tributary of Wadi Souq, and the mine seepage water (highly acidic) on the banks of a tributary of Wadi Lasail. Monitoring program should be implemented in order to record any possible pollution incident in the region. (MWR.1999)

Due to rains, flooding of the Lasail acid ponds has been observed many times over the years. Contamination indicated by high levels of sulphates, sodium and chlorides in Wadi Lasail. This is a potential polluting hazard in the Wadi Jizzi catchment, and needs to be properly remedied.

Fig: 13.5 shows various sources of potential contaminants. The potential contaminants are the sewage treatment plants, crusher, industrial, workshop, Sohar copper mine, septic tanks ,filling stations, and farms, which are all exist within the catchment area.

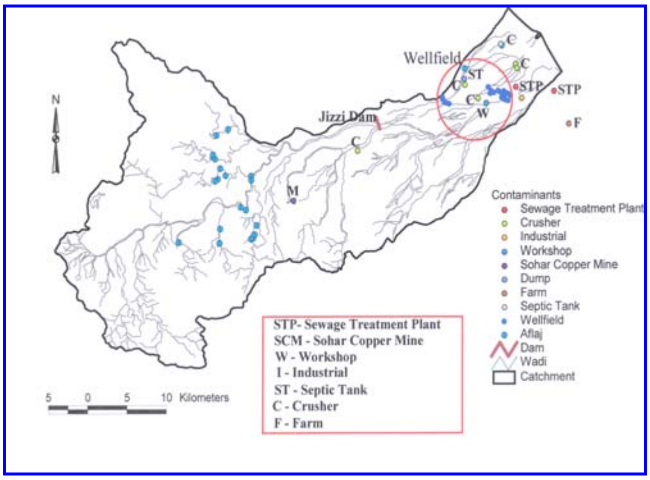


Fig. 13.5 Potential Contaminants in Jizzi Catchment area

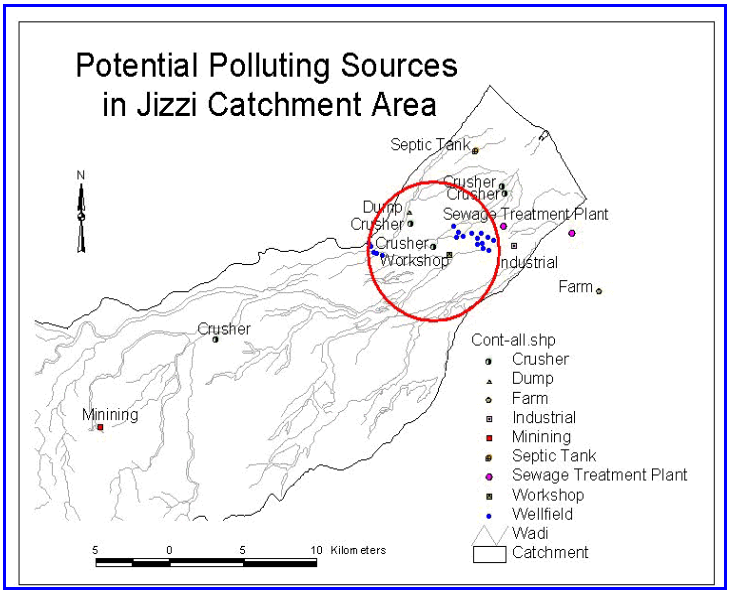


Fig: 13.6 Potential pollution sources adjacent to the existing wellfields in the lower catchment region of Jizzi.

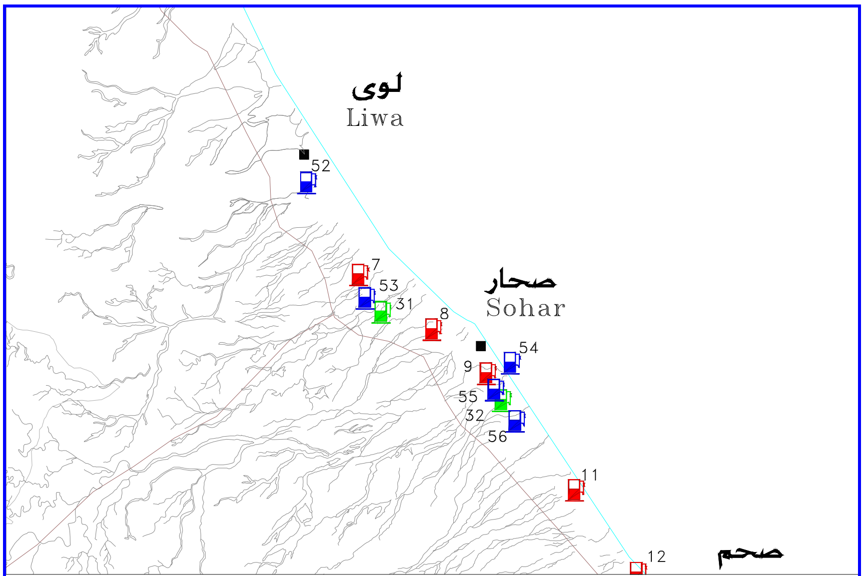
Some of the potential contaminated sources are located within 1 to 5 km distances from the SDO, OMCO, and MOD wellfields.

The expected contaminant from the SCM is metals, sulphates, and chlorides. The SCM location is around 25 km upstream from the wellfields and around 14 km from Jizzi dam.

The mine is in operation for almost twenty years (1980), and produce acidic water as seepage.

High acid water usually influences the mobility of many trace elements in groundwater and accelerates the dissolution of carbonate water bearing formation. This process could lead to build up the salinity and increase the concentration of some trace elements in groundwater.

The rest of the points represent the potential contaminants that can be generated from other sources such as Filling Stations located in the lower catchment of Jizzi along the coastal zone Fig 13.7. The image is also demonstrates the proximity of these sources from the location of the existing wellfields.



LOCATION OF FILLING STATIONS OF SOHAR REGION
POTENTIAL POLLUTION HAZARDS

FIG: 13.7

14.0 Risk Classification of Contaminant Sources

The potential contamination sites have been analysed for risk rating with respect to the catchment area. The classification criteria for each individual site or group of sites are:

- The sites vulnerability oning (as determined by the zones classification). A score is allocated according to which zone that activity takes place in, as shown in Table 14.1.

Table 14.1 Vulnerability scoring indicator

Zone	Score	Vulnerability
Red	10	Very high
Orange	4	High
Green to light green	2	Moderate to High
Light Blue	1	Low

- Hazard rating (level) i.e. the nature of contaminants that may be released. The hazard ratings depend on the contaminants that may be released and are shown in Table 14.2.

Table14.2 Hazard Rating(MWR, 1999).

Pollution Sources	Hazard Rating	Comments
Leachate	4	
Hospital waste	2	
Sewage	2	
Septic Tanks	2	
Biological (graveyards)	2	
Dairy waste	2	
Animal products (abattoir)	2	
Manure	2	Diffuse source
Chlorinated solvents	5	
Hazardous chemicals	5	
Welding & steel workshop	1	
Fertilizers, pesticides	2	Diffuse source
Petroleum products	3	See below*
Diesel and other waste oil	3	
Lubricants	3	
Oil and condensate leakage	3	
Transformer oil	3	
Aviation fuel	3	
Dyes, textile wastes	5	
Plastic wastes	4	
Metalwork's wastes	1	
Other wastes	1	

- Likelihood of contaminant release taking place. The scoring system is shown in Table 14.3.

Table 14.3 Score System for Likelihood of Release of Pollutants

Point Source	Diffuse Source	Score
Rare release and low quantity (e.g. tanker spill)	Occasional	**1**
Rare release with high quantity (e.g. pipe line)	Continual	**2**
Occasional release or continuous release in low quantity		**3**
Release very likely		**4**
Definite continual release		**5**

In order to derive the risk rating the three numbers are then multiplied together according to the following equation:

Risk = vulnerability indicator x hazard rating x likelihood of release

Accordingly, Risk Rating is classified as low, moderate, high or very high as shown in Table 14.4.

14.4 Risk Level

Risk Rating Range	Risk Level
0 – 10	No Risk
11 – 40	Low
41- 80	Moderate
81- 100	High
> 100	Very High

A risk assessment for the Jizzi catchment (resources) was performed, and results are presented in Table 14.5.

Table 14.5 Risk Assessment: Jizzi Catchment

Category	Activity	Potential Hazards	Vulnerability Indicator		Hazard Rating	Likelihood of Release	Risk Rating	Risk level
			Zone	Score	Score	Score		
Roads	Unprotected	Spills. Petroleum products	Orange	4	1	3	30	Low
Recharge Dams	Siltation, infiltration		Green	10	1	3	30	Low
Fuel Storage	Surface, UST, Drum	Hydrocarbons, solvents	Green	10	3	1	30	Low
Fuel Storage	Surface, UST, Drum	Hydrocarbons, solvents	Orange	4	3	1	12	Low
Crusher	Workshops,	Metals, salts, oil and grease	Green	10	3	3	90	High
Crusher	Workshops,	Metals, salts, oil and grease	Orange	4	3	3	36	Low
Agriculture	Fertilizer/pesticide	Nitrates, pesticides, phosphates	Red,	10	3	3	90	high
	Fertilizer/pesticide	Nitrates, pesticides, phosphates	Orange	4	2	4	32	Low
Roads	Unprotected	Spills, petroleum products	Red	10	1	3	30	Low
Waste Disposal	Solid	Nitrates, metals, bacteria	Orange	4	1	4	16	Low
STP	Treated effluents	Biological, nitrates, sulphates, heavy metals	Orange	4	4	2	32	Low
Domestic	Residential Sewage	Biological, nitrates, sulphates, heavy metals	Red, Green	10	3	3	90	High
	Residential Sewage	Biological, nitrates, sulphates, heavy metals	Orange	4	2	4	32	Low
Mining	Sohar copper mine (OMCO).	Metals, sulphates, chlorides	L.Blue	3	4	4	48	Moderate
Mining	Oman Mining Company crusher	Waste oil	L.blue	3	4	4	48	Moderate
Filling St.	Surface, UST	Hydrocarbons, solvents	Red	10	3	2	60	Moderate

15.0 Potential pollution Risk assessment Map:

Potential risk assessment map of contaminants has been prepared on the basis of groundwater vulnerability synoptic map superimposed on the potential contaminants and the results obtained from the risk assessment table: 14.5 indicated above.

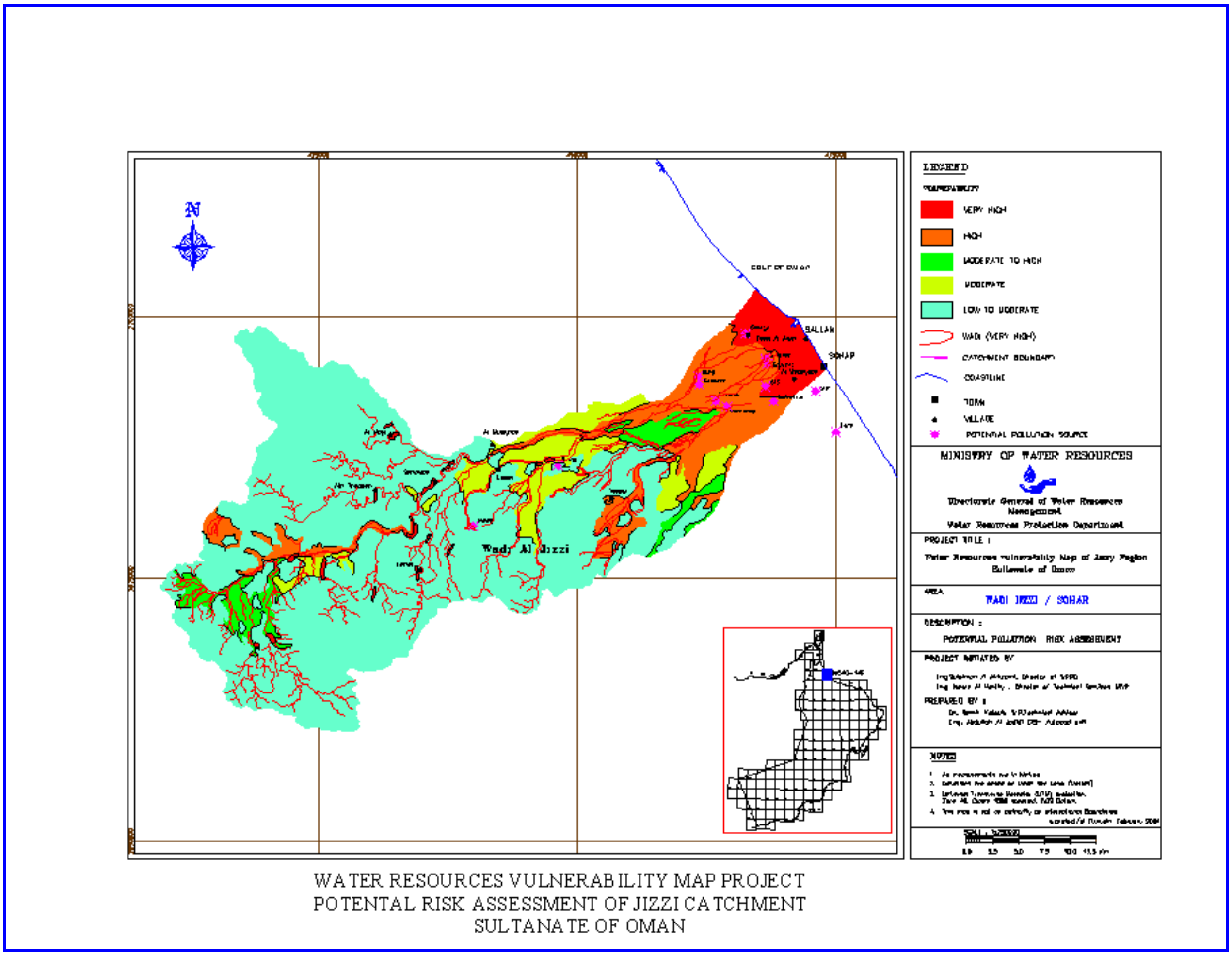


Fig: 15.1 The resulting risk assessment of pollutants potential hazards in the region.

Conclusions

In view of the increased interest for groundwater in the Sultanate of Oman, to meet the rapidly growing demands to water resources, the need to protect the groundwater from deterioration is becoming indispensable. However, there is one agreed-upon issue, in regards to groundwater protection policy, which implies preventing the components involved in groundwater deterioration, or at least mitigating their impacts. This is rather due to the fact that preventing or mitigating deterioration is always less expensive than post-treatment and rehabilitation of the deteriorated groundwater resources.

Groundwater is continuously threatened by unwise utilization and inadequate management, which will ultimately lead to serious deterioration both quantity and quality. If such behavior continues in the same trend, development of groundwater cannot be sustained, while dangerous impacts, unavoidable risks, health hazards, and soil degradation may arise. Therefore, protection of groundwater should remain a primary goal, due to its pivoted importance to the country.

Deterioration of groundwater resources may be due to depletion in regards to the prevailing water exploitation system and/or water levels, or due to contamination of groundwater chemically, biologically or by radioactivity. Both forms would render groundwater resources out of standard uses. The agricultural expansion and continues need for establishing irrigation projects are particularly responsible for both depletion and contamination of groundwater, whereas the industrial, domestic, and commercial activities are evidently the main reasons for contaminating both the groundwater and surface water alike. Overabstractions, and uncontrolled disposal of all types of liquid wastes into the groundwater, besides the prevailing phenomena of saltwater intrusion, constitute the major actions leading to the deterioration of groundwater in the region.

The most serious problems of ground-water contamination generally have resulted from the introduction into the ground water of organic chemicals (especially pesticide residue or byproducts, oils, phenols, and solvents) and metals (especially chromium, lead, and mercury) from a variety of human activities. Fortunately in only a small part of the Nation's groundwater supply. However, such contamination often is in areas of heaviest ground-water use. Cleaning up an extensively contaminated aquifer is expensive and time consuming; the best cleanup strategy may be difficult to determine because of the complexities of the hydrogeologic framework and uncertain results of aquifer cleanup make the prevention of ground-water contamination whenever possible a very desirable national goal.

The vulnerability of aquifers to contaminants from landfills, surface impoundments, spills, and underground storage tanks is of special concern. Consequently, investigations of the suitability of sites for waste disposal or for evaluating the vulnerability of aquifers to contamination are concerned primarily with surface and near-surface sources. However, problems caused by short-circuiting mechanisms (those that bypass natural geologic barriers), although difficult to identify, should not be overlooked in assessing aquifer vulnerability. A multiaquifer well that is abandoned and covered over or an unmapped geologic fault can easily escape detection.

The Groundwater vulnerability mapping will facilitate the professionals and the decision-makers to perform many tasks on national level. Each decision at the higher integrated management level related to the wellfield and catchment's protection would be enhanced, improved, and uniquely utilized in the MWR. The technique will help the planner if necessary to perform any Socio-economic development's scenarios in the region. It will demonstrate nearby potential contaminants and its impact on the surrounding environment pertaining to the existing wellfields,in the whole catchment and their potential risks. An applied example of ad hoc maps is the preparation of characterization and standardization of suitability of waste disposal sites map in the sate of Qatar prepared by the author, which has resulted in a map delineating suitability of areas for landfill purposes, and later on has been adopted by the government for licensing operation, program based on arc/info was prepared and linked to the system to protect the existing water resources and sources.

A vulnerability map depicts the spatial variation of an object's vulnerability to a specific risk. Groundwater vulnerability map includes in addition to strata vulnerability map, parameters of depth to water, soil cover drainage pattern flow gradient, geological characteristics, native water quality, as well as the strata vulnerability to hydraulic conductivity and attenuation capacity, and other logistical activities influencing the overall environmental activities prevailing in the region.

Two types of groundwater vulnerability mapping could be approached, *general, and specific*. *General, or intrinsic vulnerability maps* are used to estimate the natural vulnerability of groundwater without reference to specific contaminant or contamination source; detailed site-specific survey should always be performed.

Jizzi catchment is located at the western part of the town of Sohar, embraces the main surface watercourses and tributaries of Wadi Jizzi. Wellfields also exist supporting the Sohar regional center municipal water supply system.

The area of Wadi Jizzi occupies approximately 1150 $km^{2.}$. It is bounded in the west by Al Hajar Al Gharbi of the Northern Oman Mountains and in the east by the Gulf of Oman. The catchment consists of the upper western mountainous terrain (633 km^2) and the lower eastern piedmont and coastal plains (517km^2).

Average annual rainfall in the catchment is 132 mm and net average annual wadi flow from the area recorded at Mulayinah was approximately 15.20 Mm^3. Severe drought occurred only twice in 22 years period of recorded data from 1975 to 1996.

The thickness of alluvium ranges from 3m to 50 m. The average (time series) depth to water (spatially) ranges from 2 to 25 m below ground level and the long-term average saturated thickness is 33 m. The boreholes tap the alluvium where yields range up to 68 lps.

The results of the activities and potential pollution sites have enabled a Risk Assessment of the aquifer vulnerability map. The risk assessment evaluation for an array of activities in the catchment indicated that solid waste site, sewage-holding tanks and used oil products stored in drums from abandoned crusher camps (upstream of wellfield) and agricultural activities in the immediate vicinity of the wellfield pose a medium to high risk. The natural vulnerability of the aquifer is considered to be very high in the Red zone, high in the Orange zone, moderate to high in the Green, Light Green, and low to moderate in the Light Blue zones, of the catchment.

Some of the activities are considered to pose a potential risk of contamination, which could be a major risk on the ground water quality, especially the crushers, workshops, garages, filling stations and solid waste disposal site all within the Red zone of the catchment and the wellfield protection zone defined by the studies implemented by the Ministry of Water Resources.

Zone specific regulations for the wellfield protection have been proposed along with the best practices for the activities, which can potentially affect water resources. To implement Wellfield Protection Plan in each zone, acceptability, non-acceptability or conditional acceptability conditions have been suggested in respect of each generic category of activities.

Recommendations

The study also included recommendations that would support the Ministry of Water Resource's efforts in protecting and managing the catchment. The recommendations included:

Groundwater protection strategy must be preventive and protective. Accumulated experience gained in many countries has shown that remediation is far too expensive to be the main approach to manage the quality of groundwater resources. Instead, preventive contamination measures are becoming more effectively in environmental protection programs. Consequently regulatory and technological measures must cover all major categories of point and non-point contaminant sources.

The UNESCO working group on integrated Land-use Planning and Groundwater Protection in Rural Areas (1991) proposed a similar approach. The group recognized two categories of groundwater protection management." General protection of groundwater resources" and comprehensive protection around public water supplies.

Although aquifer–based protection strategy is the ultimate approach because it encompasses all usable groundwater resources, the most effective approach is to give greatest protection to those areas that supply recharge to public drinking water sources .The source protection program meet the mandate of Agenda 21 in " prevention of aquifer pollution through the establishment of protective zones in groundwater recharge and abstraction areas" (Agenda 21,Rio de Janeiro, 1992).

Regulations, Acceptability levels of activities, Best Practices, Penalties and Action Plans of the Ministry OF water Resources carried out in 1999 in the rregion should be implemented and adapted according to the evolving needs to protect and conserve the wellfields .and the catchment area as a whole.

A review of the existing monitoring network should be undertaken after a comprehensive evaluation of the type and nature of information which is currently required or might be required in future (at least until the year 2020) by the MWR or various users of data related to fluctuations in water table, groundwater quality and potential pollution status. While doing so, current and future plans of municipal water supply (MEW), agricultural expansion of MAF, structural town plans of MOHg, planned industrial areas of MCI and waste disposal and management plans of MRME and MOH should be taken into consideration.

Monitoring wells, specifically designed for monitoring water table responses and water quality parameters, should immediately be installed in each Wellfield Protection Zone.

Monitoring network should be established in the upper catchment to monitor water levels and water quality. Special emphasis should be directed to the protection and monitoring of existing Aflaj water resources.

A water sampling and analysis programme for the bacteriological, trace metals, nitrites and ammonia analyses, should be initiated immediately on a monthly basis in the Red, and Orange zones on a quarterly basis in the Green, Light Green zones of Jizzi Catchment's in general and in the Wellfield Protection Plan in particular.

A salinity profile-monitoring programme on a quarterly basis at the dedicated monitoring wells in the Red zone should be immediately formulated and implemented.

On the basis of monitoring data collection, Groundwater balance of the catchment should be updated and modified accordingly further refine the catchment's (Resources) and, Wellfield Protection Zones (Sources).

The solid and liquid waste disposal sites should be properly engineered and planned waste disposal sites located in less sensitive areas.

The results of this study should be integrated, with other studies, to formulate a rational, strategic national water resources master plan.

A public awareness programme should be initiated to encourage the public to conserve water, especially drinking water, to increase the use of organic fertilizers and minim use of inorganic fertilizers and pesticides.

The resulting Groundwater Vulnerability Map and corresponding Groundwater Pollution Risk Assessment Map should be utilized for any prospected socioeconomic planning or development in the region.

The impact of rapid development on the utilization of water resources became very acute. Demand increased substantially, surpassing the availability of water resources in a region deprived of perennial surface water, and led to the reliance on desalination as the main source of water. The environmental impact of this is difficult to measure, but is already reflected in loss of agricultural land due to salinization. The need for the careful conservation and efficient use of groundwater resources is therefore of vital importance to continued economic progress.

Policies have to be addressed to conserve groundwater as a strategic reserve and to ensure its replenishment in order to be available as national strategic resource. Prohibit new agricultural land use and provide incentives for the installation of highly efficient irrigation systems such as drip irrigation for licensed farms. After installation meter each farm that uses groundwater to determine its consumption on daily basis and to ensure farm operation on the basis of selected and adequate and different crops to different parts of the country.

There is ample evidence that increasing allocations from oil revenue will be directed towards appropriate industrial developments in the region. The advantage of expanding industrial sector is that, unlike the agricultural sector, its water supply could be reused so as to reduce the water demand.

The other major source of water in the region is sewage effluent. This new source of water is increasing with the increasing demand for potable water. TSE is shown to be for limited extend a significant resource for agricultural use. Treated effluents from the STP should be brought to acceptable standards before their use in the Red and Orange zones.

The management of water supply schemes and demand management of more desirable levels and patterns of water use by increasing the efficiency of its use is becoming indispensable.

Additional source of water is the accumulated leaking water beneath large cities which could be utilized for some extent in resolving rising water levels and as a resource in irrigation purposes.

In order to make sound planning possible and to avoid the squandering of water resources, the present institutional set-up needs to be restructured. A high degree of CO-ordination is required which could be achieved by a single authority responsible for water production, distribution and reuse.

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