ASSESSMENT OF GROUNDWATER INTRINSIC VULNERABILITY USING GIS BASED DRASTIC METHOD IN SOUTHERN PART OF DISTRICT KARAK, KHYBER PAKHTUNKHWA, PAKISTAN

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DEDICATION

I dedicate this thesis to my beloved parents and respectable teachers whose prayer and guidance has always been wheels for me that has always helped me to travel in this competitive era.

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ABSTRACT

The Study area lies in the Eastern part of the southern Kohat deformed fold and thrust belt. This part of the Kohat plateau, borders the southern extension of the Himalayan deformation, with the Salt range to the south most. The research is based on the DRASTIC model. Groundwater is vulnerable to contamination by anthropological activities. Vulnerability mapping is considered as a fundamental aspect of groundwater management. The aim of this study was to estimate aquifer vulnerability by applying the DRASTIC in southern part of district karak, Khyber Pakhtunkhwa, Pakistan. The DRASTIC model uses seven environmental parameters (depth to water, net recharge, aquifer media, soil media, topography, impact of vadose zone, and hydraulic conductivity) to characterize the hydrogeological setting and evaluate aquifer vulnerability, The information layers for models were provided via geographic information system. The results showed that the DRASTIC model. For DRASTIC model, the correlation coefficient between vulnerability index concentrations was 100% which is is highest vulnerability, 66% show medium vulnerability and 33% show low vulnerability, The Low vulnerable zone cover 1019.51 square km area, Medium vulnerable zone cover 375.12 square Km while High vulnerable zone cover 160.35 square Km area. The highest Nitrate concentration recorded in the area is 13.57 ppm and the lowest is 0 ppm. Around 45% of the samples surpassed the approved limit of PSQWA and NSQWQ standard. The concentration of Nitrate >10 ppm represent that some human action has contributed toward the highest concentration.

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LIST OF ABBREVIATIONS

D	Depth of water table
R	Net recharge
A	Aquifer media
S	Soil media
T	Topography/slope
I	Impact of vadose zone
C	Hydraulic conductivity
Dr	Assigned rating to range of depth of water
Dw	Weight of depth to the water
Rr	Assigned rating to the range of net recharge
Rw	Weight of net recharge
Ar	Assigned rating to range of aquifer media
Aw	Weight of aquifer media
Sr	Assigned rating to range of soil media
Sw	Weight of soil media
Tr	Assigned rating to range of topography
Tw	Weight of topography
Ir	Assigned rating to range of vadose zone
Iw	Weight of impact of vadose zone
Cr	Assigned rating to range of hydraulic conductivity
Cw	Weight of hydraulic conductivity

CHAPTER 1

INTRODUCTION

1.1 Background

According to Kahlown and Majeed (2005), water is the most important commodity for life on earth to survive and thrive. There is no doubt that subsurface water reservoirs are one of the most significant and essential sources of freshwater on earth (Villeneuve et.al., 1990). Due to the relatively tighter control of pollution on groundwater resources than on surface water resources, groundwater resources are most adversely affected by pollution and are depleting rapidly. As a result of its low susceptibility to contamination, groundwater is considered a "major drinking water resource" (US EPA, 1985). Although it is nearly impossible to determine the exact amount of subsurface water in aquifers around the world, a loose estimate suggests the earth's reservoirs contain 15.2--60 million cubic meters of water. According to Margat (2008), Approximately eight to ten million cubic meters of this groundwater are fresh, while the rest is brackish and saline. For daily life activities, groundwater is essential since it is easily accessible and has better quality than surface water. Groundwater is used for a variety of purposes in our everyday lives, including agriculture, industry, and domestic use. In this way, it becomes a strategic resource.

Globally, 4430-kilo cubic meters (km3) of water are withdrawn each year, of which about 70% is utilized in agriculture, while 25% and 5%, respectively, of the total amount, of pumped groundwater, is used for industrial and domestic consumption (Kinzelbach et al., 2003). Using Eurostat data from 2011, the global combined yearly withdrawal is estimated at around 1000-kilometer cubes cubic, or 22% of all groundwater pumps worldwide (EUROSTAT, 2011). In 2009, ISRAM estimated that nearly 2 billion people around the world rely exclusively on groundwater resources for their daily needs. Two hundred and seventy-three of these groundwater resources extend beyond international borders, fulfilling the needs of countries from around the world (ISRAM, 2009). The total population of the planet Earth, estimated at 6.9 billion in 2010, is rapidly increasing and is expected to reach 8.3 billion by 2030, according to a UN report (UNDESA, 2009). There is no evidence as to how socioeconomic and ecological factors will influence that figure, and rapid population growth poses a serious threat to depleting subsurface freshwater resources. As a result of industrial development, urbanization, and agriculture, subsurface water supplies are burdened and pressed, and their overall dominance is reduced. Groundwater, the main source of fresh water, is used to meet several industrial, domestic, and agricultural needs. There are more aquifers in that area that are vulnerable to groundwater pollution from domestic, industrial, anthropogenic, and agricultural activities, and all of these activities can affect the water in the short term. To prevent long-term damages or losses from groundwater contamination, remediation is a costly and complex task (Secunda et al., 1998). There is a serious deterioration in the quality of subsurface waters worldwide due to rapid urban expansion and industrial development, as well as increasing anthropogenic pressures (Foster, 2003). Subsurface aquifers containing groundwater that is contaminated disrupt the ecosystem and pose a health risk, in addition to causing damage to direct and indirect ecosystem processes (Milovanovic, 2007). Many factors contribute to groundwater contamination, including chemical factors (chloride, nitrates, sulfates, etc.), physical factors (turbidity, odor, taste), and biological factors (e.g. bacteria). To assess subsurface water quality, we must consider all the main causes, including chemical, physical, and biological factors (Thomas, 2003). As a result of the additional penetration hazards, ease of pollution, and various anthropogenic activities resulting in an enormous amount of harmful and poisonous chemical elements being discharged into groundwater, the chemical factor has gained greater significance in groundwater quality development. A greater emphasis is placed on these chemical parameters in the management of subsurface water. Human lives are at risk whenever groundwater containing hazardous substances, inorganic contaminants, and residues of heavy metals is provided to homes and used for drinking water. Infections linked to contaminated groundwater are common in the third world and emerging countries because of improper drinking water evolution and inadequate management practices. World Health Organization (WHO. 2008) estimates that about 3.3

million people perish in third-world countries as a result of inadequate water supplies, unsanitary living conditions, or inadequate sanitation systems, with drinking pathogen-contaminated subsurface water accounting for a significant portion of these deaths. Diseases associated with groundwater are mostly brought on by the fact that underground aquifers are more susceptible to contamination than surface-water bodies. Pakistan regards subsurface water as a trustworthy supply of water. It is utilized not just for drinking and agriculture, but also for several industrial sectors. Groundwater provides around 35% of what is required for agriculture. Furthermore, subterranean water is recognized as one of Pakistan's most significant sources of drinking water (Bhutta, 2005). With rising populations came unexpected and poorly controlled urbanization, industrialization, and agricultural development. These negative effects of the expanding population are threatening Pakistan's groundwater quality. The likelihood of groundwater pollution has increased due to the uncontrolled disposal of industrial, solid, and sewage wastes as well as the use of insecticides, herbicides, and chemical fertilizers in agriculture. The dumping of sewage has led to widespread groundwater pollution in Pakistan, and many shallow aquifers, especially in urban areas, are reportedly affected, according to BGS (BGS 2002). Industrial waste is the main contributor to groundwater contamination in the nation's major cities and metropolitan areas. Due to the high volume of the unprocessed toxic waste present, groundwater in industrialized areas and states like Lahore, Gujranwala, and Faisalabad is vulnerable to pollution. Additionally, wastes from nearby industries like textile, sporting goods, tanneries, paper, pharmaceuticals, leather, and chemical contaminate residents' drinking water (Mahmood et al, 2011). The toxic waste from many companies has poisoned the groundwater in the Karak region.

The Kohat Plateau, the primary Himalayan foreland fold and thrust belt, extends to the west of the Karak district, which is in the province of Khyber Pakhtunkhwa. The Indus River divides it from the Potwar plateau on its eastern border, and the Kurram strike-slip fault encircles it on its western side. It is bordered to the north by the major boundary thrust and to the south by the Shinghar range (Juam and Lillie, 1988). The most valuable natural resource is groundwater, which can be found at varying depths and in a variety of lithologies and ratios. Digging, karaze and open pits are just a few of the methods that have been used to harvest groundwater throughout human history (Morris et al., 2003). These methods of ground extraction differed according to location; for example, people in mountainous areas rely on natural springs to meet their needs. In addition to surface water resources, groundwater has been depleted due to increasing population and extraction to deep levels that are beyond the capacity of digging and open wells. To meet the needs, it becomes crucial to explore deep potential groundwater zones.

Every time it rains, groundwater, a renewable natural resource, recharge; this process is known as rainfall recharge (Seiler and Gat, 2007). Water levels in open wells are another example of this phenomenon; they rise after precipitation, indicating that the porous material has become saturated with additional water. Drawdown happens as a result of groundwater extraction, and continued pumping causes the well to dry out and the water level to rise. As a result, it is crucial to search for deep groundwater resources using various methods.

Everywhere, groundwater is not distributed equally. Groundwater can be found in different places depending on the formation. The worn and fractured zones determine the quantitative presence of groundwater in a typical crystalline hard rock landscape (Singhal and Gupta, 2010). Groundwater is more likely to exist in sedimentary terrain. In most regions, groundwater prospecting is a highly thought-provoking scientific endeavor. Understanding groundwater exploration techniques are important since it is a useful way to make decisions.

The available water resources in Khyber Pakhtunkhwa's Karak region are scarce and diminishing. Groundwater is also used by the agriculture industry for home reasons, which contributes significantly to the loss of this natural resource. It is crucial to investigate this natural resource's quantity and quality in this region due to the depletion, mixing, and contamination of salt and fresh water zones, as well as the contaminated groundwater caused by inadequate sewage systems.

Due to the absence of any perennial streams or canal canals, the study region receives its replenishment mostly from rainfall. The Karak area is divided into three distinct zones according to soil texture, temperature, and rainfall (Khan et al., 2018). The first Thal zone is located in the district's southwest corner, together with the second Banda Daud Shah and Tehsil Karak's center and northeastern regions. Sandstone and evaporites are sedimentary rocks that are present throughout the Karak valley (Cronin et al., 1989). There is a little amount of fresh groundwater that is available and is powered by the southeast watershed. The majority of the larger towns are situated in regions with easy access to water for residential purposes. Aquifers in the north receive saline water from an overabundance of rock salt.

1.2 Hydro Climate

Karak's climate varies seasonally. Hot summers and annual rainfall of less than 500 mm are characteristics of the Thal zone (Khan and Khan, 2015). In June and July, this region frequently achieves temperatures of up to 46 degrees. Pure sandy soil makes up the majority of this zone's soil, which is suitable for cultivation. Crops in this area rely on rainfall or water from tube wells for supply. Rainfall totals each year in Tehsil Karak's northeastern region range from 500 to 750 mm, and the soil there is mostly medium clay in texture.

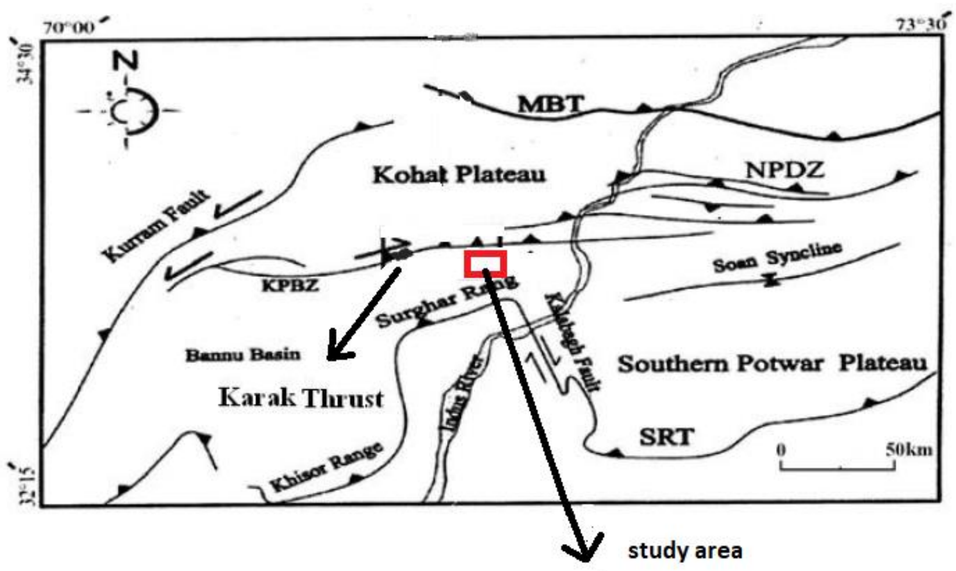

Figure 1.1 Geological map of the study area (Modified after Khan et al., 1986)

1.3 Aims and objective

The specific research targets to deliver an essential agenda for effectively averting and decreasing ground water pollution. The study aims to gather some key components essential for risk management regarding ground water.

The purpose of research is to identify and determine those specific hydrogeological sitting that offer considerable amount of resistance against outer situation beside detection and demarcation of those specific areas. Some of the precise aims of the research are mentioned below.

- **i.** To generate input thematic map layer of each hydrogeological parameter for DRASTIC model.
- **ii.** To execute susceptibility analysis for aquifer of district Karak southern part.
- **iii.** To recognize future approaches to control ground water contamination and susceptibilities.
- **iv.** To offer a basic framework and technique for resource allocation and land use planning.

CHAPTER 2

DESCRIPTION OF STUDY AREA

2.1 Introduction

In Pakistan's Khyber Pakhtunkhwa province's Kohat Division, the district of Karak is located. The study region is located in the Kohat Plateau, which is the westernmost portion of the main Himalayan foreland fold and thrust belt. It is divided from the Potowar plateau to the east by the Indus River, and to the west by the Kurram strike-slip fault. It is bordered to the north by the major boundary thrust and to the south by the Shinghar range. Three tehsils make up District Karak, and these tehsils are further divided into 23 union councils. At a height of 548 meters, Karak is a plain and hilly region (1,798ft). Karak is deemed to be districting in 1982.

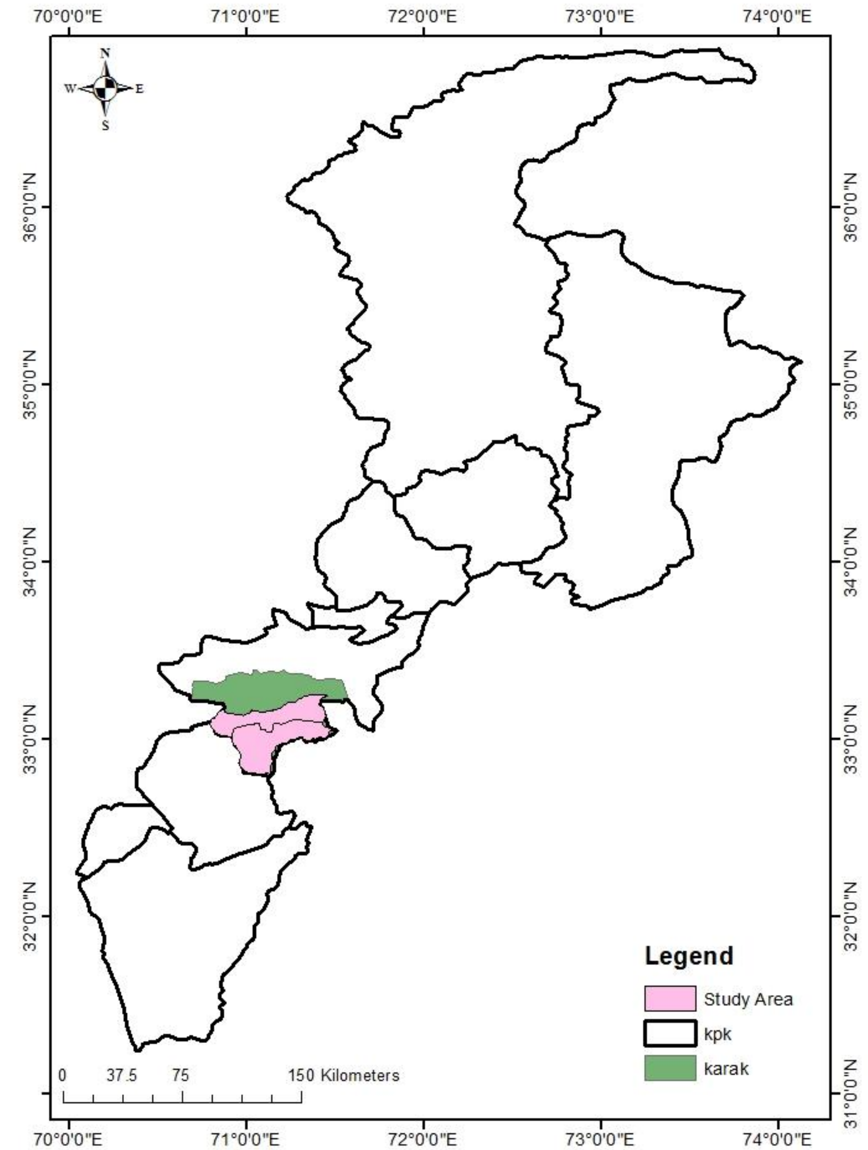

Figure 2.1 Study area map (pink color shows study area)

2.2 Geography

It is located on the main Indus Highway between Peshawar and Karachi, south of Kohat District, and north of Bannu and Lakki Marwat Districts. It is 123 kilometers from Peshawar, the province's capital. It consists of three tehsils: Banda Daud Shah, Karak, and Takhti-e-Nasratti. At 33◦71’2”N 71◦54’1”E, you can find Karak. Karak has a 3372 square kilometer total area.

2.3 Climate

Karak's climate changes every year. With his severe summers and low annual rainfall of less than 500mm (Khan and Khan, 2015). In June and July, the temperature in this region frequently gets up to 46 degrees. Pure sand makes up the majority of the soil in this area, which is suitable for cultivation. Crops in this area rely on rainfall or water supplied by tube wells. Rainfall in Tehsil Karak's north-eastern region ranges from 500 to 750 millimeters per year, and the predominant soil type is medium clay.

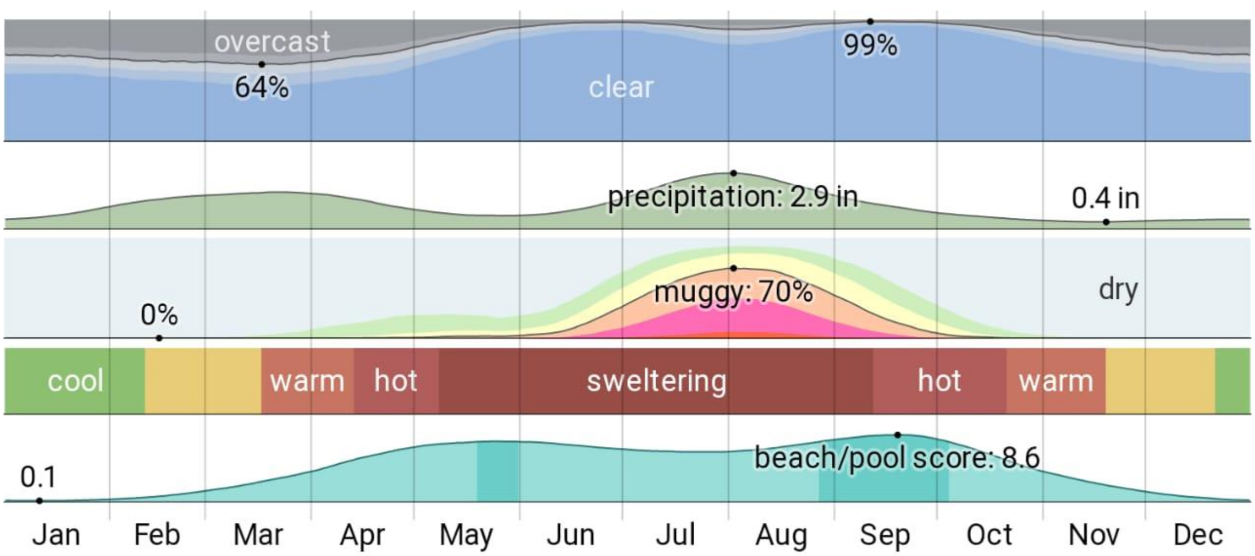

Figure 2.2 Climate change of district karak by weather spark

2.4 Geology

The study area has a very complex geology having different type of fold and faults which expose different lithologies.

Table 2.1 Geology of Study area

Age		Group	Formation
Pliocene	Early Middle Middle Late	Siwalik	Soan Dhok Pathan Nagri Chinji
Miocene	Middle Early	Rawalpindi	Kamlial Murree
Eocene	Late Middle Early Early	Charat	Kohat Kuldana Jatta Gypsum Bahadur Khel Salts

2.5 Regional Tectonic

The Indo-Pakistani, Arabian, and Eurasian plates connect in Pakistan, and their historical and current interactions have a significant impact on the country's structure. An intra-oceanic transform barrier, known as the Murray Ridge in the Pakistan offshore area, separates two composite plates made up of both continental and oceanic crust (Indo-Pakistan & Arabia). The Eurasian Plate is a composite formed by the fusion of three microplates in the Cretaceous to Paleogene region of Iran, Afghanistan, and western

Pakistan (Quad Report, 1994). The Afghan Block, the most easterly of these microplates, is bordered by the Herat and Chamman significant transform fault systems and makes up a sizeable portion of Pakistan's northwest boundary. Belts of ophiolite assemblages can be used to identify the borders between microplates.

The majority of Pakistan is made up of the Indus Basin, which is positioned in the mid-Tertiary collision zone established when the Indo-Pakistan Plate was obducted by Eurasia. This area encompasses the Kohat-Potwar Plateau, Hazara/Kalachitta Ranges, Kirthar, and Sulaiman ranges, which represent a foreland fold and thrust belt system. This collision zone contains many microcontinents, most of which are affine to Gondwana (Searle, 1991), as well as many Island arcs (Dietrich et al., 1983). . The Kohistan island arc came in contact with the system after the Afghan and Karakoram blocks collided with the southern border of the Eurasian plate (Ganser, 1964; LeFort, 1975; Windley, 1983). The massive Indian Shield lithosphere (25–30 km thick) is underthrusting in the north while higher crustal basement and sediments are being pushed south towards the convergence boundary.

Since the initial collision in the late Cretaceous-Eocene, this has caused the crust to shorten by about 500 km (Alleman, 1979; Searle, 1985; Coward and Butler, 1985; Dewey et al, 1988), which is accommodated in northern Pakistan between the Indian Shield and the Kohistan Island Arc terrain (Powell and Conaghan, 1973; Molnar and Tapponier, 1975)

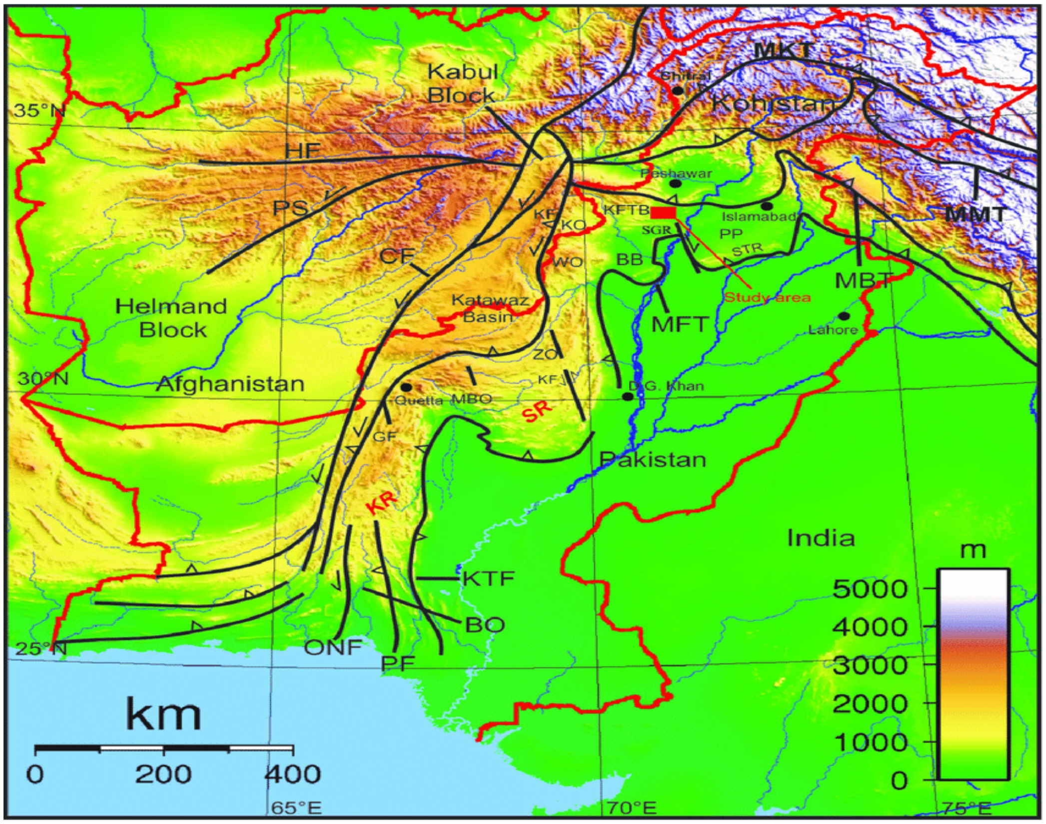

Figure 2.3 Generalized tectonic map of Pakistan showing Sedimentary Basins (Modified in GIS 10 after Farah et al. 23)

According to several studies (Gupta and Narain, 1967; Kono, 1974; Chaudhary, 1975; LeFort, 1975; Mattauer, 1975; Powell and Coneghan, 1973), the buoyancy of the doubled Sialic crust over the mantle material and imbricate stacking of the Indian crust during a collision are to blame for the uplift of the main Himalayan Ranges. The Kohistan Island Arc and Indo-Pakistani Plate would have collided and closed Paleo-Tethys (the Shyok Basin). The Tethyan Himalaya and the Indus Tsangpo Suture Zone both integrated NeoTethys' southern edge (LeFort, 1975; Molnar and Tapponier, 1977; Stocklin, 1977; Malinconico, 1986; Searle, 1983, 1985). However in the Zanskar Ranges of the High Himalaya, where even the Mesozoic-Cenozoic sediments of the passive edge have been barely deformed and metamorphosed in the interior zones of the Himalayas, much of the southern Tethyan margin has been preserved (Izatt, 1993). The Indo-

Pakistani Plate's upper crust delaminated and was moved south during the collision's latter stages, bearing passive margin sequences in its hanging wall. There are two significant zones of delamination in India. These include the Main Boundary Thrust (MBT) and the Main Central Thrust (MCT), which together shorten the Earth's surface by around 250 km (Izatt, 1993).

It is very debatable whether or not the Indian Craton's western border is subject to collision tectonics. The Chaman Fault, which connects the Owen Fracture Zone in the southwest of Makran with the Himalayan collision zone in the north, is generally considered to be the western boundary of the Indo-Pakistani plate. It runs from Kharan to Kabul for about 850 kilometers (Kazmi, 1979a; Lawrence et al., 1979). (Figure 2.1). The Indo-Pakistani subcontinent's Ninetyeast Ridge is situated in its southeast (McKenzie and Sclater, 1976).

2.6 Surface Hydrology

In the studied area, there are seasonal flood streams that flow during or after precipitation, i.e., when it rains or during the monsoons. In this location, the monsoon season lasts from March through April and July through August. These streams become active with upstream to downstream flow throughout these months. Annual precipitation is the main factor in aquifer recharging. The research area has semi-arid features year-round. The region experiences little, unpredictable rainfall that is concentrated during a brief rainy season, with the rest of the year being either very dry or completely dry. Much of the rainfall is lost due to runoff and evaporation as a result of high temperatures and intense rain, respectively (Farid et al. 2019). 68% of precipitation occurs in June through November, whereas 32% falls in December through May. (Khattak et al., 2014). While winter has low-intensity rainfall with extended periods, summer has high-intensity rains with short periods. Winter is excessively chilly due to the western winds, while summer is scorching with the monsoon in May through June.

Most of the time during flood seasons, surface water in the drainage system flows. Below is a diagram showing the research area's drainage system and other sources of surface water.

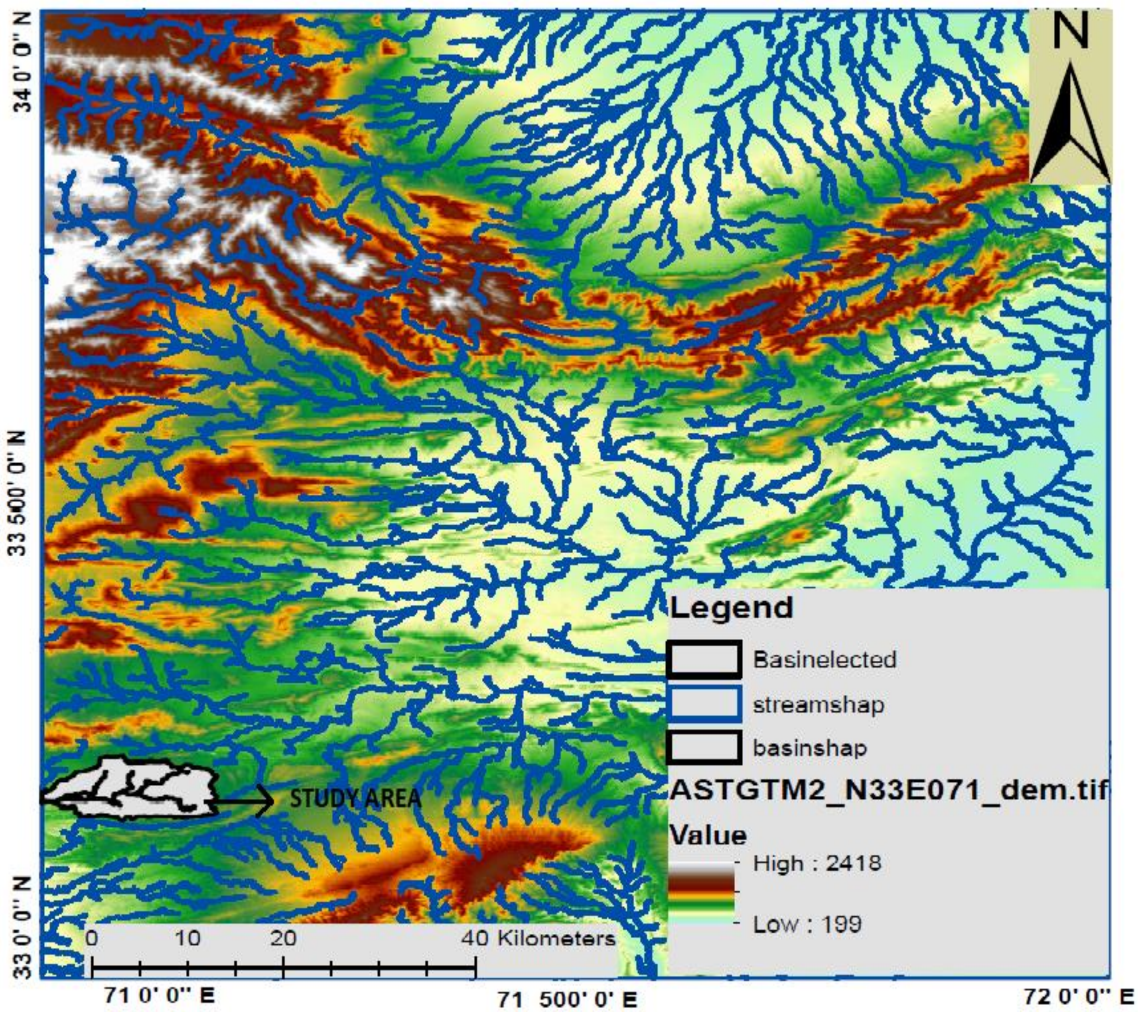

Figure 2.4 Map showing surface hydrology of the study area

2.7 Industrial activity

Different industrial activities are carried out in various parts of district Karak. and yet these industries are not contained in a suitable area that has been set out for them. Furthermore, many industries lack suitable waste management systems for disposal. It is a key contributor to water contamination.

2.8 Population

According to census 2017 total population of District Karak is 706299. In Total population males are 349433, female are 356863. Average annual growth rate is 2.63 from 1998 to 2017.

Table 2.3 Population of district karak

	Rural	Urban	Total
Population	655150	51149	706299
Male	323752	25681	349433
Female	311395	25468	356863
Household	67784	5360	73144

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Method

The study evaluates the groundwater contamination in the district of Karak, and to address this issue, the GIS-based DRASTIC model is used to identify and evaluate high-vulnerability locations. As mentioned in the previous chapter, the EPA and NWWA of the United States developed the GIS-based DRASTIC model in 1985. (Aller et.al, 1987). Due to its reliance on enthusiastically established information and its minimal indexing classification, the GIS-based DRASTIC technique has been gaining significant importance in the field of groundwater management. The main goal of the DRASTIC approach is to identify areas of shifting susceptibility to contamination in the form of a map and to use the susceptibility map for various ground water control tasks. According to Aller et al., Ter5m DRASTIC is utilized for this purpose since it has seven parameters, including hydrological and topographical features as specified by Aller et al (1987). These parameters consist of:

- **i.** (D) Depth of water table
- **ii.** (R) Net recharge
- **iii.** (A) Aquifer media
- **iv.** (S) Soil media
- **v.** (T) Topography/slope
- **vi.** (I) Impact of vadose zone
- **vii.** (C) Hydraulic conductivity

To determine the study areas subsurface water susceptibility, seven layers are developed and produced using these seven parameters. The DRASTIC model was developed by Aller et al. in 1987 using four rules.

- **i.** Pollutant is lead into the water at ground surface
- **ii.** Pollutant is introduced into earth by means of rainfall
- **iii.** Pollutant has agility and motion of water
- **iv.** Study area under assessment is 100 acres or bigger.

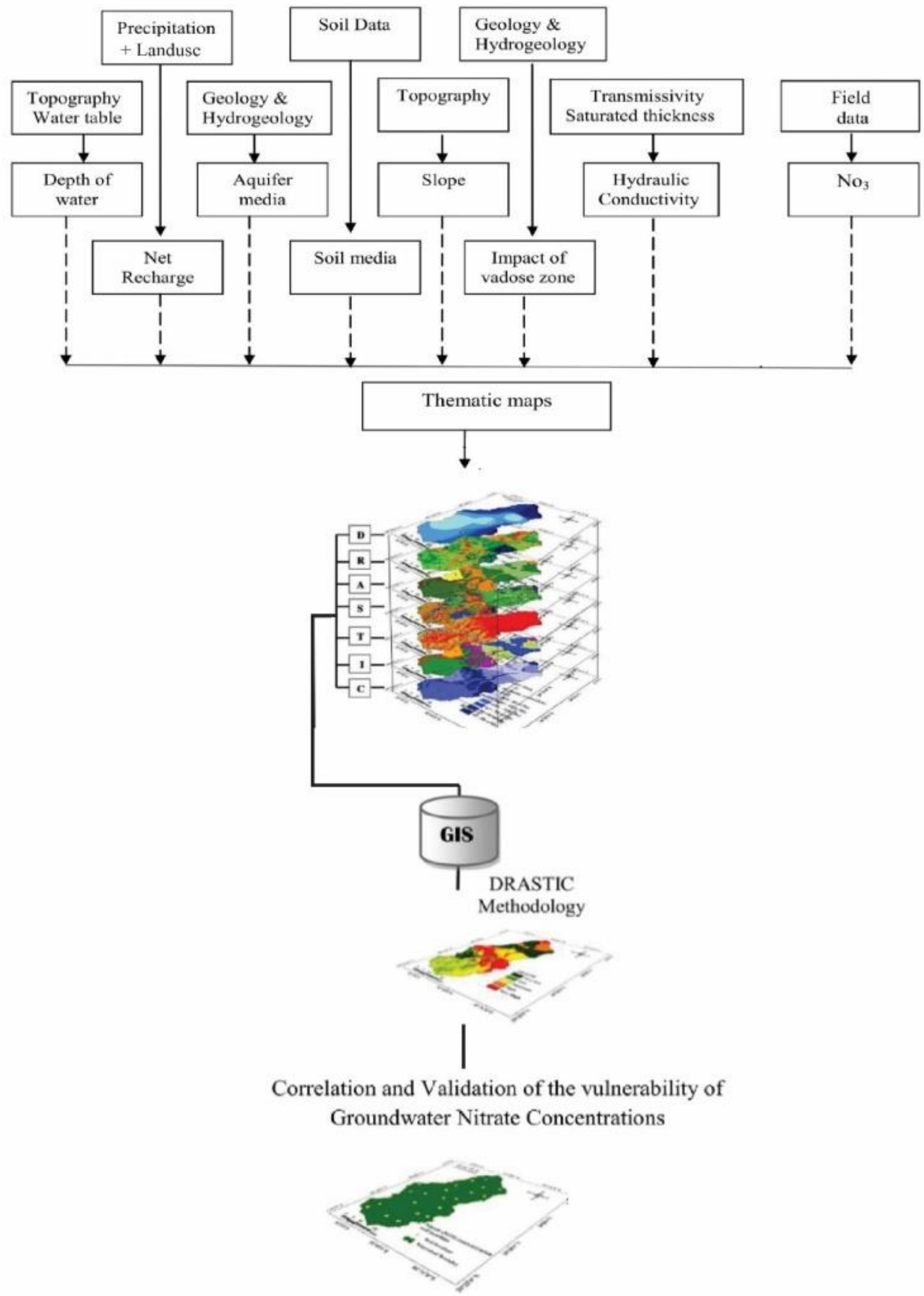

Figure 3.1. Work chart flow

The DRASTIC model was carefully selected because it has the ability to contain the accurate and operational symbolization of every conceivable parameter implicated in subsurface water susceptibility. As was previously discussed, there are various models and methods to assess ground water susceptibility. the index-generated help of any supplemental tool, such as GIG or LIWIS. Information accessibility is another reason why the DRASTIC technique was chosen.

The DRASTIC model is comprised of four chief part.

a. Weight
b. Ranges
c. Ratings
d. Drastic Index

3.2 Weight

Each individual element has been given a specific weight based on its importance, relative impact, and contribution to the transmission of pollutants to subsurface water reserves. The weight can range from 1 to 5, with similar values indicating factors that are minor contributors to subsurface water susceptibility while high values indicate factors that are major contributors (Babiker et al.,2005). For instance, component D, or water depth, has been given a high value of "5" because depth significantly affects subterranean water susceptibility. Although pollution would be more likely if the water were shallow and close to the ground surface, it would be less likely if the "D" depth of the water were greater. The topography parameter, which contributes slope, has been given weight "I" in accordance with its minimal impact on subsurface water susceptibility. Slope will control the overflow in some way. The chance of subterranean water pollution would increase with a softer slope because overflowing water can persist for a longer period of time.

By using the Delphi system, which considered the observations and views of multiple experts based on their expertise and capacity, the weight will be determined (Aller et al., 1987). Above diagrams shows seven factors and the predetermined weights for each.

3.3 Ranges

Each factor is categorized into a variety of media types, a category known as "Ranges." These specific classes or ranges are developed to allow for the evolution of susceptibility procedures in areas with shifting lithology, rock types, and hydrogeological features. To clarify the relative importance of each class in the probability of subsurface water pollution, separate class calculation has been carried out in combination with other classes.

3.4 Ratings

Any range of a particular element has been given a precise value illustrating its significance in relation to the likelihood of subsurface water contamination (Aller et al., 1987). "Rating" is the process of assigning a specific rock to a range rendering to its contribution to groundwater contamination. The range of the assigned Rating is 1 to 10. A range with a lower rating shows that a certain hydrogeological component has less potential to pollute underground water than a range with a higher rating, which shows that the particular media type has more potential. For instance, a rating of 8 has been assigned to depths up to 25 meters since shallow water has a higher potential for underlying pollution. On the other hand, depths greater than 45 meters have been given a Rating of 2, due to their high vulnerability to contamination.

Table 3.1 Hydrological Parameter of DRASTIC With Description and Assigned Weights (Aller et al., 1987)

Parameter	Description	Relative weight
Depth to water table (D)	Greater the depth, the less likely it would be for contamination to reach groundwater, while the situation would be the opposite for shallow aquifers. If the depth of ground water from the earth's surface and represent the depth of the material that would come into contact with the contaminant during its movement toward the ground water,	5
Net Recharge (R)	It is the total amount of water that percolates from the ground to the surface and gets to the water table. The level	4

	of leaching pollution is determined by recharge using a method of transportation or carrying agents.	
Aquifer Media (A)	It symbolizes the type of substance that exists in saturated zones and serves as an aquifer. The media act as a body that attenuates. If the grain size is large, permeability will be higher. The likelihood of the pollutant getting into groundwater would be higher, and the aquifer's ability to attenuate it would be lower.	3
Soil Media (S)	The topmost layer of unconsolidated material is displayed. The aquifer's permeability regulates the passage of contaminants as well as net recharge. The aquifer will be less vulnerable because smaller-grained soil is better able to obstruct the transport of contaminants than larger-grained soil.	2
Topography (T)	It is referring to the local slope. The slope will determine the type of runoff, the pollutants it transports, and how long it will stay on the earth's surface. The area's vulnerability will increase with slope since it will retain runoff for longer and percolate more.	1
Impact of Vadose zone (I)	It symbolizes the characteristics of the media in the unsaturated zone above the aquifer. Depending on its permeability, the composition of the material in the vadose zone will dictate its attenuation capability.	5
Hydraulic Conductivity (C)	Its indicate the rate of water transmission from the aquifer. Consequently, calculate the rate of polluted groundwater flow along a specific hydraulic gradient.	3

3.5 Drastic Index (DI) Calculation

With the aid of the simple linear equation listed below, the DRASTIC Index (DI) can be determined using the weights, ranges, and ratings that have already been assigned to each hydrological parameter;

Index DRASTIC Dr*Dw+Rr*Rw+Ar*Sw+Tr*Tw+Ir*Iw+Cr*CW = DI

Where;

Dr = Assigned rating to range of depth of water

Dw = Weight of depth to the water

Rr = Assigned rating to the range of net recharge

Rw = Weight of net recharge

Ar = Assigned rating to range of aquifer media

Aw = Weight of aquifer media

Sr = Assigned rating to range of soil media

Sw = Weight of soil media

Tr = Assigned rating to range of topography

Tw = Weight of topography

Ir = Assigned rating to range of vadose zone

Iw = Weight of impact of vadose zone

Cr = Assigned rating to range of hydraulic conductivity

Cw = Weight of hydraulic conductivity

The outcome of computing the DRASTIC Index using the aforementioned equation will represent the relative sensitivity of the subsurface water to any pollution. More susceptible areas are used when calculating the (DI) DRASTIC index since they are simpler to demarcate than less susceptible areas. The groundwater aquifer will be more vulnerable or susceptible to pollution the higher the susceptibility index, whilst a lower DI DRASTIC index score will indicate a relatively low sensitive area. One thing to keep in mind is that just because a certain zone in the research area has a low susceptibility index doesn't mean that subsurface water contamination is impossible and that zone cannot be depicted as an area that is unsusceptible. . The Infect Less Index result serves as evidence that a particular zone is in a region with comparatively lower susceptibility to pollution (Almasari,2008) In addition, depending on the purpose for which the susceptibility map is developed and the ground generated from the research area susceptibility range, the DI DRASTIC index can be classified into different ranges or classes, such as low, moderate, high, and extremely high.

3.6 Data collection

Preparing input data of DRASTIC factor participants is necessary for carrying out the susceptibility calculation technique, which requires handling a sizable amount of data. An effort was made to gather the data with regard to the DRASTIC method's factor. Each parameter's necessary data was of a different nature, and it was gathered from a variety of public and private institutions. To obtain and verify certain facts, such as the depth of the water or the geographic areas and placement of water wells, field examinations were conducted as part of the study. The types of data collected have been divided into primary and secondary data groupings.

3.6.1 Primary data

It was gathered from various field surveys conducted in the research region as well as from strata charts, well logs, and stratum and lowering charts collected from PHED, the Pakistan Soil Survey, and the Pakistan Survey.

3.6.2 Secondary data

The secondary data came from a variety of research papers, publications, census data, public records, and official and unofficial archives of different government agencies and organizations. The table below shows the many types of information and data associated with various hydrological factors. The table also includes a reference to the data's source.

Table 3.2 Type and Nature Of Data are Collected From Various Organization.

Number	Layer	Data format	Source/Organization
1	Depth to Water Table	Field data, Strata/lowering Charts, MS Excel Sheet	Field Surveys, PHED
2	Net Recharge	TRRM Raster Data, land use shape file	NASA, Literature Review
3	Aquifer Media	Well logs Strata/Lowering Charts	PHED
4	Soil Media	Map Raster Data	Soil Survey of Pakistan
5	Topography	DEM	SRTM
6	Impact Of Vadose Zone	Well log, Strata/Lowering Charts	PHED
7	Hydraulic Conductivity	MS Excel file	PHED

3.7 Desk study and professional judgments

Meetings with diverse scholars, experts, and authorities were planned to discuss the need for data, the documentation of data sources, and data analysis. Since the GIS-based DRASTIC model is built on the Delphi system, comments and explanations regarding the ranges of hydrological parameters were solicited from experts including hydrologists, hydrogeologists, and other professionals in the field

3.8 Field surveys

District Karak field trips were performed to identify the locations of water wells and discover the depth of the water column at various points. The purpose of the field visits was to locate water wells using GPS data and gather their geographic coordinates as the PHED data was useless without knowing where they were. Several water samples were also taken during the field survey to be tested for the nitrate parameter.

3.9 Literature survey

A thorough assessment of the literature was done in order to investigate the research issue and its fundamentals, and several research papers, reports, draughts, and official and unofficial statistics data were examined. In order to, a review of the literature was conducted.

- **i.** Assemble a basic framework for the GIS-based DRASTIC model.
- **ii.** Recognize the DRASTIC model's three types, functions, outcomes, and applications.
- **iii.** Acknowledge and comprehend the complexity of the research area
- **iv.** Assemble material and data to illustrate the study area.
- **v.** Collect information on the many aspects of the study process.

3.10 Software and tool

For this study, the spatial diffusion and distribution of the susceptibility index were envisioned using geographic information systems. To analyse and present the acquired data, many GIS applications were employed, including QGIS 3.2.3, Surfer Google Earth, and ArcGIS 10.4. Although the DRASTIC index can also be determined manually, in this study the data was collected and then translated into a thematic map layer using geographic information systems (GIS). All of the acquired information was tabulated using Microsoft Excel. During field trips, GPS was used to locate the exact location of water wells. Google Maps, Google Earth, and both tourist and topographic maps gathered from a survey of Pakistan were used as resources.

3.11 Generating Layers for DRASTIC Factors

Thematic map layers of DRASTIC factors were produced with the help of the acquired data. The generation of layers includes the analysis of available data and factors the layers in raster format. The tool used to express information in raster format is called GIS. To provide geographically scattered data about relevant hydrogeological parameters in GIS, a variety of interpolation techniques are available. Below, each layering process's specifics are covered.

3.12 Depth of water (D)

As stated, the Health Engineering Department of wells (PHED) provided the subsurface water data for the region research in the form of well logs, strata charts, and lowering charts.

The information collected from the engineering and public health departments was in written form, and each document included all specific information about the well, including its depth, location, the results of any tests that were undertaken, etc. In order to import this data into ArcGIS, it was first transformed into a tabular format in Microsoft Excel.

In an appendix, there is a detailed excel spreadsheet with data on water depth. Several interpolation methods, including (OK) ordinary kriging, (UK) universal kriging, and IDW inverse distance weight, were used. RMSE values were used to determine which technique was most appropriate. It mentions the methodology applied to their values.

3.13 Net Recharge (R)

The term "Net Recharge" refers to the total amount of water that has fallen as rain or come from other sources in the area and has penetrated the earth there. to determine the mean annual precipitation, land use, and net recharge rate. The information on land use was modified and converted to vector format after being taken from a report during a literature review. The appendix II contains the land use statistics. A number of variables, including LULC, DEM, slope, geology, and rainfall data, were used to compute the net recharge. As the aforementioned parameter plays a significant part in determining the net recharging of the area, a weighted overlay of these characteristics was used to produce a map of net recharge. Five categories were assigned to the thematic map layer that was produced.

3.14 Aquifer Media (A)

Due to the unavailability of subsurface geologic maps, a different method was adopted to gather data on the aquifer media. Strata log analysis, for example. The public health and engineering department Karak provided the strata charts and well logs. The subsurface information is shown on the strata chart. The depth to water column information was used to identify and note the aquifer media from the strata chart. For the aquifer medium of each well, a separate sheet was organized on MS Excel and included in appendix number III. A raster layer was created using the interpolation techniques of (OK) ordinary kriging, (SK) standard kriging, and IDW (inverse distance weighting interpolation method).. Since it has the lowest root mean square error, the inverse distance weighting interpolation approach was utilized for aquifer media (RMSE).

Using the Normal transformation, the data from the aquifer media were interpolated.

3.15 Soil Media (S)

A soil map of District Karak was compiled for this layer using information from a literature review. In ArcGIS, it was georeferenced and digitalized. and the pertinent soil report was obtained from Peshawar, Pakistan, soil study. A final soil media distribution map was created after using a soil report to determine and categories the soil texture of each class. The appendix contains a soil map of District Karak created with ArcGIS.

3.16 Topography (T)

Topography is the second factor the DRASTIC model takes into account. With the use of ArcGIS, the slope was derived from a digital elevation model (10-meter resolution) of the research region created using USGS (STRM) Landsat 9 satellite imagery.

3.17 Impact of vadose zone (I)

The vadose zone affects how vulnerable groundwater is to pollution. The engineering and public health departments collected the strata charts and good logs for the vadose zone data, which were then ranked by the different media kinds. Data sheets were produced on MS Excel following the examination of the well logs, and they are included in appendix V. Raster layers were created using the interpolation techniques of (UK) universal kriging, (OK) ordinary kriging, and (IDW) inverse distance weighting.

Thematic layer of aquifer media parameters were created using the kriging interpolation technique.

3.18 Hydraulic conductivity (C)

Hydraulic conductivity data was organized using various annual reports from the public health and engineering department and the water and power development authority (WAPDA). IDW, OK, UK, and SK interpolation techniques were employed. Root indicates that the square error served as the basis for choosing the most suitable interpolation technique. For hydraulic conductivity, the kriging interpolation approach was employed.

The ranges and rating was taken and inspired by Aller et al., (1987).

3.19 Overlay index analysis

Although the overlay and index approach was implemented in this study, the DRASTIC index can also be determined manually. The idea of integrating a layer of each DRASTIC element strengthens the overlay method. For the purpose of calculating the index, each factor or parameter is given a certain weightage according to the rating given to their features (NRC,1993). Additionally, several statistical analyses were used to evaluate the layer's rationality that was created using this method. Sensitivity analysis and different map removal techniques, for instance. Web technologies that deal with the spatial idea of massive amounts of information have enabled the deployment of this type of technique stress-free. The integrated land and water information system (ILWIS) and the geographic information system are two examples.

After giving each layer its proper rating and weight, the layer for each hydrogeological parameter was overlapped in the ArcGIS software. The parameter “Dr*Dw” was estimated by multiplying the weight of the relevant thematic layer by ratings given to various classes, where 'Dr' stands for the rating given to a particular factor and 'Dw' stands for the weight of the parameter. Each parameter's weighting and rating were examined, and their respective ranges were then totaled. 3.1.4 mentions that the DRASTIC index was produced using equation 1.

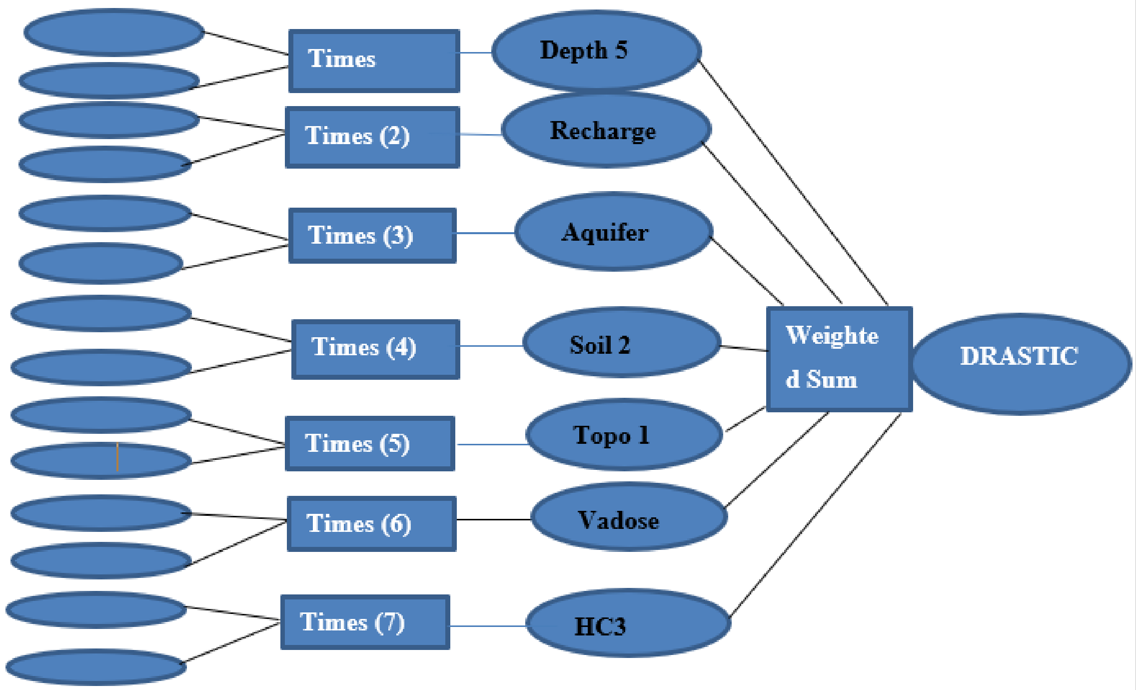

Figure 3.2 DRASTIC model in GIS environment

By categorizing the DRASTIC index into 5 ranges, zones with various contamination vulnerabilities were highlighted on the map to make it useful for a variety of purposes. Using DRASTIC Indices, a map with a fluctuating susceptibility zone was produced as the result of the overlay and index analysis.

CHAPTER 4

RESULTS AND DISCUSSION

In the preceding chapter of this study, there was a full discussion of the method used to gather, arrange, assemble, and compile data as well as the methodology used to apply and exploit this data in groundwater susceptibility evaluation. The DRASTIC model has been used to assess how vulnerable the shallow subsurface water is in the southern half of District Karak. The detailed examination of each thematic map layer will be covered in this chapter.

4.1 Depth to water

The hydrogeological parameter of depth to water is a key factor in the susceptibility of groundwater to pollution. Depth to water refers to the material that is present between the aquifer and the groundwater surface as a transitional layer. The extent, grade, and nature of biological, chemical, and physical advancement that result from collaboration between contaminants and material elements present above the aquifer are, respectively, controlled and determined by depth. Because depth plays a significant role in vulnerability, this criterion was given a weight of 5, which was already specified. According to the belief that an aquifer system with a water table shallower than the ground surface would be more vulnerable to contamination, a rating was given to each. The rating was given based on the ranges of the data that were available. The lower rating is subsequently given to the high ranges because they reflect deep aquifers, while the higher rating is given to the lower ranges since they are closer to the ground surface.

The groundwater depth in the research area was determined to be between 34 to 145 meters after gathering, organizing, synthesizing, and interpolating the depth to water table data in a GIS context using the standard kriging interpolation method. The depths were divided into four ranges, and a rating was given for each range. Aller et al. (1987)

The classes of depth to water along with allotted ratings are given below.

Table 4.1 Depth to water table

DEPTH TO WATER TABLE (METER)		
RANGES	RATING	WEIGHT
<25 METERS	8	5
25-35 METERS	6	5
35-45 METERS	4	5
45-55 METERS	2	5

The distribution of the water depth in the district under examination is shown on the map in the figure. The general distribution of water table depth indicates that a district is present in a region with a varying water table depth. Aquifers with shallow, deep, and intermediate depths can all be found in the research region. The groundwater system of the southern portion of district Karak is varied, with varying water table depths, as confirmed by the literature and field survey.

In the research area's tehsil Karak, the aquifer and water table were determined to be shallower, however there were deeper aquifers there as well. Due to extensive water extraction for various uses and very little net recharging in the area only from rainfall, the water table is significantly deeper than it should be.

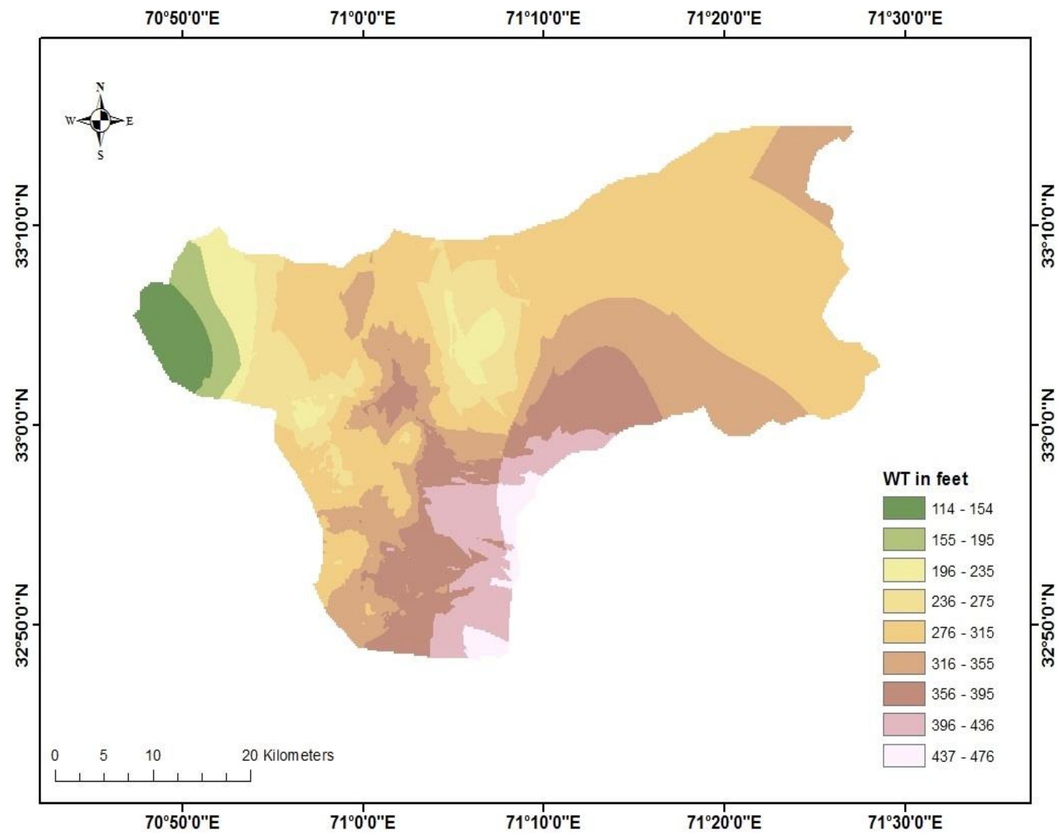

Figure 4.1 Spatial distribution of water table

4.2 Recharge

Hydrogeological factor net recharge in susceptibility assessment refers to the amount of water that the aquifer receives from rainfall or another artificial source after infiltration and percolation. The pollution may enter the aquifer as a result of water seeping down and replenishing it. The percolating water plays a crucial part in the susceptibility of subsurface water because it serves as a mechanism of delivering pollutants to subsurface sitting. The susceptibility of groundwater is closely correlated with the net recharge, therefore if more water is seeping into the aquifer, the likelihood of groundwater contamination increases. Due to its relative lesser impact on subsurface water vulnerability than depth to the water table and greater impact than other factors like aquifer, soil medium, and topography, the net recharge parameter has been given the weight of "4" in the DRASTIC weightage system.

Data on annual precipitation and land cover were used to determine the net recharge in the research area. The net aquifer recharge is greatly influenced by both of these variables. The net recharge is calculated using overlay analysis. The yearly precipitation provides information on the amount of rainfall that contributes to recharging, and the land use data provides information on the type of land cover that is present in a particular location of the study area. The net recharge is calculated using overlay analysis. Four categories of land use were established: water, vegetation, built areas, and barren land. The land use parameter has been given a weight of 2, and the ratings for each class are shown in the table below. While the average annual precipitation was classified into five categories: 551.8mm–583.6mm, 583.7mm–615.5mm, 615.5mm–647.3mm, 647.4mm–679.2mm, and 679.3mm–711mm. Annual precipitation is given a weight of 1, and the ratings for each range are shown in the table below.

Table 4.2 Land USE (Recharge Estimation)

LAND USE (Recharge Estimation)		
RANGES	RATING	WEIGHT
Vegetation	3	2
Water	8	2
Built Area	1	2
Barren Land	2	2

Table 4.3 Mean annual precipitation

MEAN ANNUAL PRECIPITATION(Recharge Estimation)		
RANGES	RATING	WEIGHT
551.8-583.6mm	1	1
583.7-615.5mm	2	1
615.6-647.3mm	3	1
647.4-679.2mm	4	1
679.3-771mm	5	1

The least recharging occurs in Karak City, Takhti-e-Nasratti, and Latamber since they are mostly built-up areas. The majority of the research area is made up of vegetation; hence the majority belongs to the recharge classes 3 and 4. Class "5" locations are those that receive the highest recharge because they are charged by both rainfall and percolation from the nearby water body. These regions are those that are closest to the water body. Figure 4.4 displays the map of this hydrogeological component created in GIS using the weighted overlay approach, along with the assigned ranges and spatial distribution of each class. The spatial distribution of mean annual precipitation and land usage are depicted in Figures 4.2 and 4.3, respectively.

Table 4.4 Net Recharge

NET RECHARGE		
RANGES	RATING	WEIGHT
1	2	4
2	4	4
3	6	4
4	8	4
5	10	4

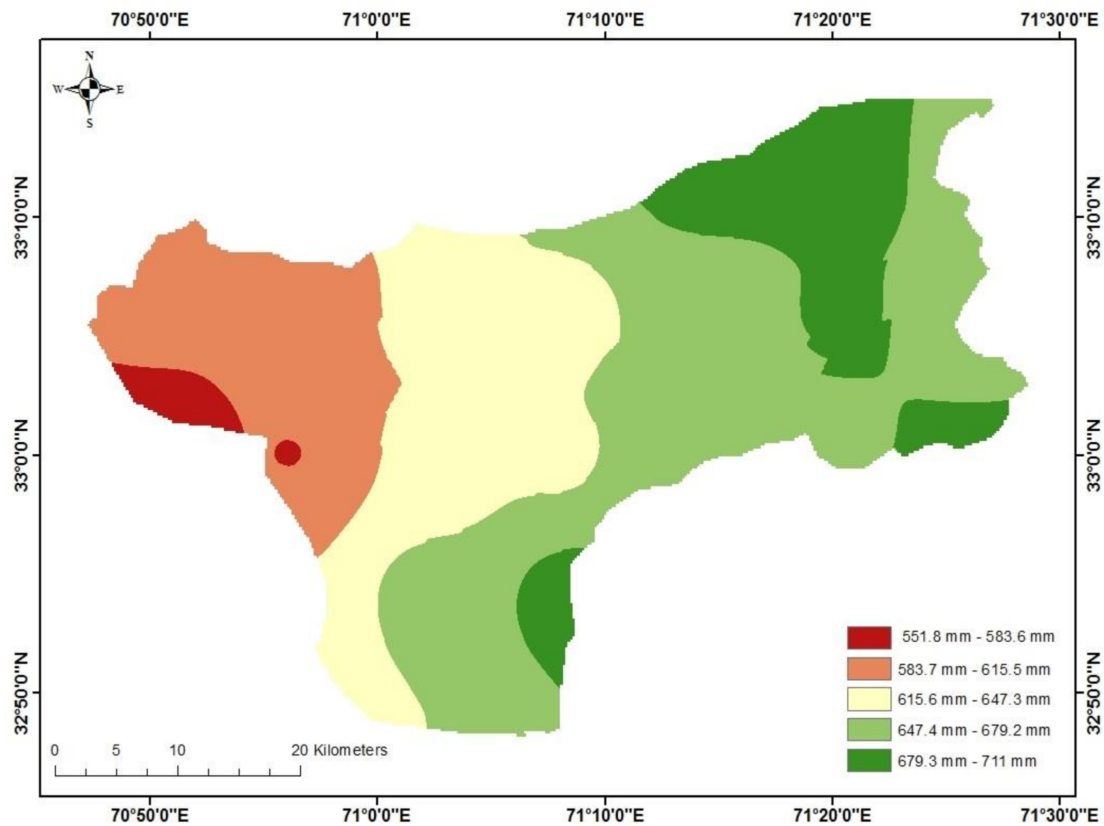

Figure 4.2 Mean annual precipitation in the study area

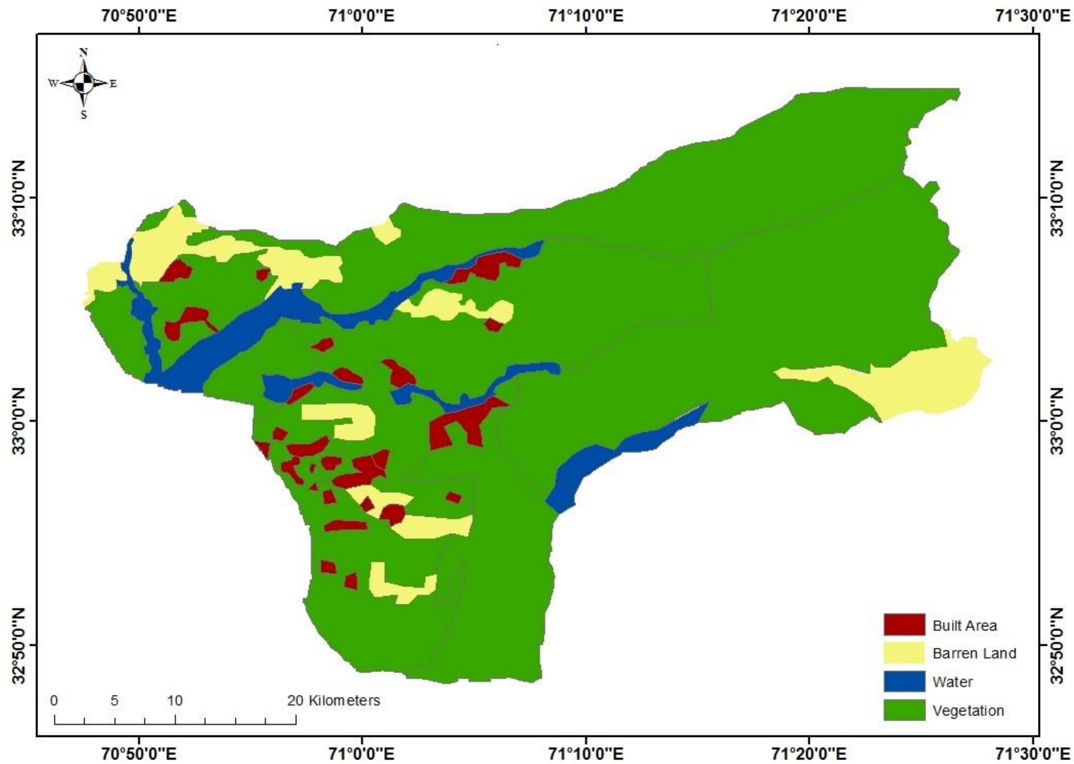

Figure 4.3 Land Use/Cover map of study area

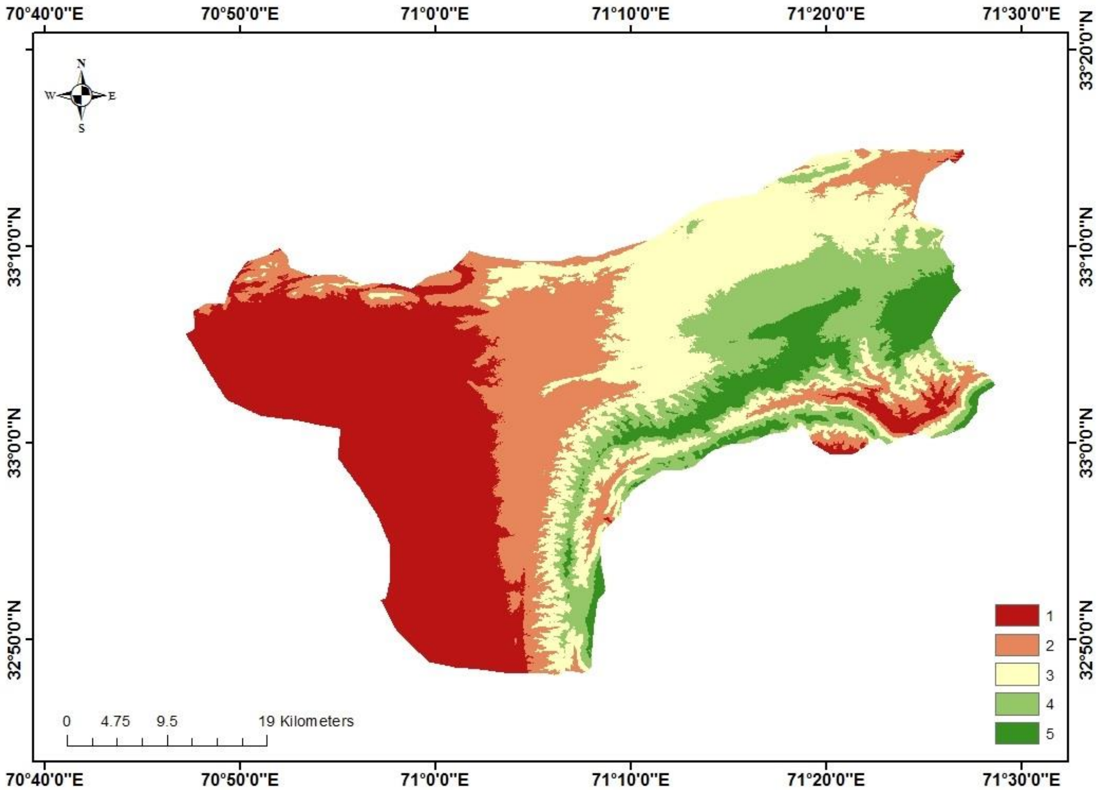

Figure 4.4 Net Recharge of study area

4.3 Aquifer media

The aquifer is a term used to describe an underground deposit of unconsolidated rock or unconsolidated geological material that supplies sufficient freshwater to a spring or surface well or tube well (Health, 1987). Aquifer media, the substance that makes up an aquifer, is significant in determining how vulnerable groundwater is because it has unique features of its own.

The primary function of the aquifer medium is to lessen, degrade, and capture the pollution that percolates into the groundwater reservoir. Regarding the susceptibility of the groundwater, the sedimentology of the aquifer media, namely the grain size and grain sorting, is particularly important. Aquifer media with larger grains and more fractures and openings will have greater permeability and a greater likelihood of becoming contaminated. Conversely, aquifer media with smaller grains and fewer openings will have lower permeability and a lower susceptibility to pollution.

The strata maps were used to derive the aquifer media's texture type, and PHED provided well-log data. The Ordinary Kriging interpolation method was then used to organise, assemble, and interpolate the data. The parameter of aquifer media has a weight of "3," and classes of aquifer media have been created using the information that is currently available. Following a thorough examination of the research area's aquifer media, 4 ranges are developed, each referencing Table 4.5 and indicating its corresponding rating. Gravel+Clay+Sand, Gravel+Sandstone, Gravel+ Boulder, and Sandstone are the ranges that are produced. Due to its ability to attenuate contaminants, the first range is given a relatively low rating value, whereas the last range is given the highest rating value due to its high permeability and less ability to restrict contaminants. The middle ranges, however, received a rating in accordance. Gravel+sandstone and gravel+boulder, which are intermediate in terms of attenuating impurities, make up the majority of the study area's aquifers, whereas safer aquifers made of gravel+sandstone are found in the heart of the tehsil Karak and in a few locations of the tehsil takhti-e-Nasratti.

Table 4.5 Aquifer Media

AQUIFER MEDIA		
RANGES	RATING	WEIGHT
GRAVEL+CLAY+SAND	2	3
GRAVEL+SANDSTONE	3	3
GRAVEL+BOULDER	6	3
SANDSTONE	8	3

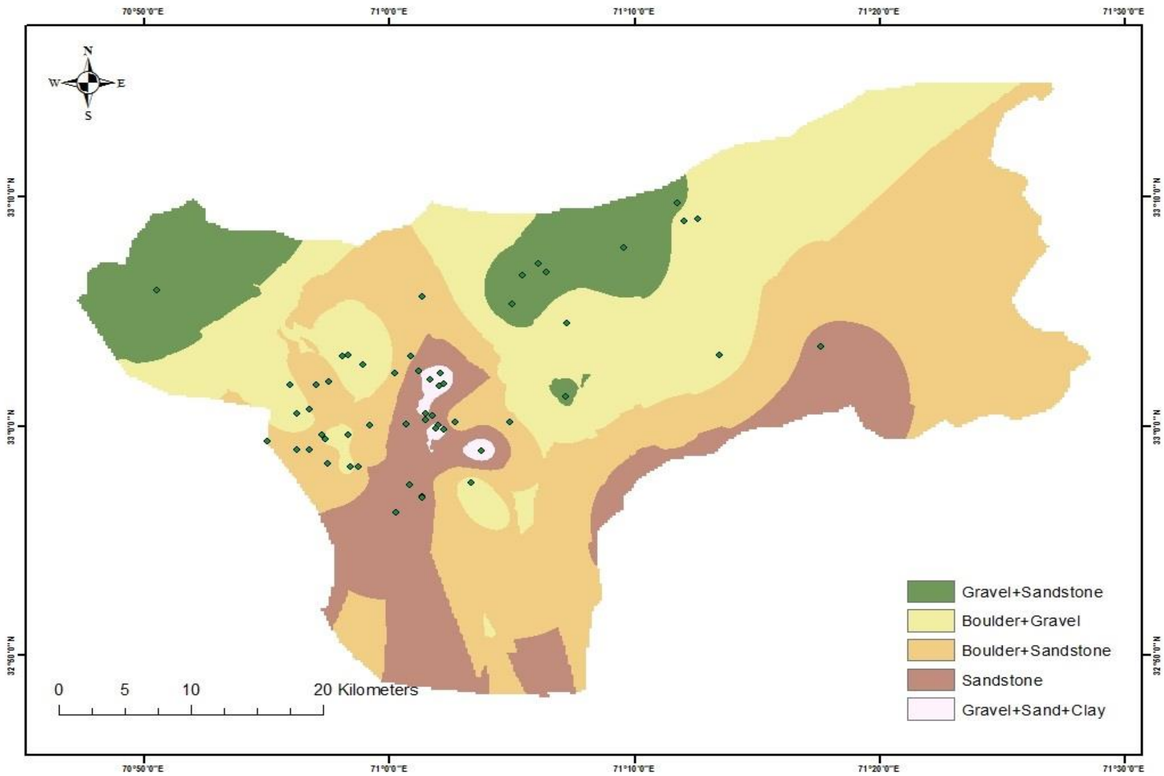

Figure 4.5 Aquifer Media distribution in Study area

4.4 Soil Media

On earth, soil is materially depleted and weather-beaten at the top. The vadose zone's top layer is the soil. This variable is crucial because it creates a setting for a variety of biological events.

The amount and rate of rainwater trickling down to the aquifer are influenced by the soil texture. The soil media also impedes the movement of contaminants and their ability to reach the aquifer. The type of clay present, its capacity for swelling and contracting, and ultimately the size of the soil's grain all have a significant impact on how contaminated the soil appears to be (Aller et al, 1987). As was mentioned in the aquifer media parameter, the larger the soil grain size, the greater the permeability and the greater the amount of pollution that will seep into the vadose zone. Additionally, soil with larger grain sizes won't be able to stop contaminants from migrating and won't be a good particle blocker. The names and spatial distribution of all soil series and associations were found on a map that was the result of a literature review. a thorough study outlining the map obtained from Peshawar, Pakistan's soil survey. Each series' and association's soil description was included in the report. Each series' soil texture was determined after being plotted on a triangle representing soil texture. To create a final thematic soil map, the soil series map was georeferenced, digitalized, and combined.

Various soil media are categorized based on their type. Loamy soil and clayey soil are the two categories that have been defined for soil media. The classes are created based on permeability; the permeability increases with grain size and decreases with vulnerability to contamination. So, a lower grade is given to soil with small grains, or clayey soil, and a higher rating is given to soil with large grains, or loamy soil. The soil media factor was given a weight of 2. The table below lists the ranges and assigned ratings for soil media. According to Aller's classification and rating system, the soil medium (1987). No interpolation method is required because the entire map of the study region is available.

All of the research region's tehsils are covered by loamy soil, which makes up a significant fraction of the area. On the western and southeastern sides of the study area, clayey soil is prevalent.

Table 4.6 Soil Media

SOIL MEDIA		
RANGES	RATING	WEIGHT
Clayey Soil	2	2
Loamy Soil	7	2

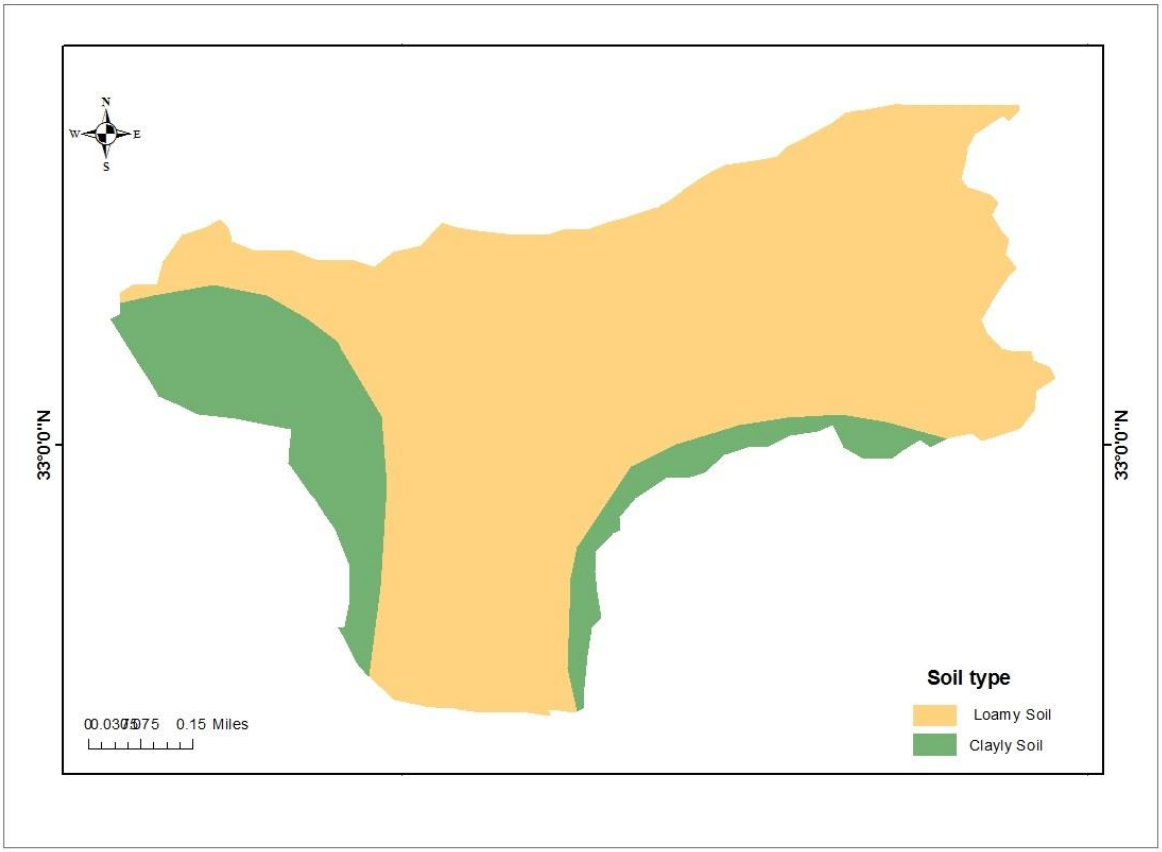

Figure 4.6 Spatial distributions of soil media in study area

4.5 Topography

An area's topography determines its slope (Rehman, 2008). The area's slope has an impact on groundwater susceptibility since it controls how long water is withheld and retained. For a place with a high gradient, water retention lasts for a shorter period of time. As a result, a high or steep slope can reduce the capacity of contaminants to percolate through soil and eventually leach into the vadose zone and groundwater. This reduces the vulnerability of groundwater. On the other hand, the area with the low angle of the slope allows for more water retention time, which increases the risk that contaminants may seep into the aquifer and cause contamination. As a result, a region with a steep slope will be less likely to be polluted since the water will run off more rapidly, giving less time for toxins to remain in the air. In contrast, an area with a mild slope or no slope will be more likely to be polluted.

The geography and landforms of the research region are diverse. There are both plains and mountains there. From the digital elevation model derived from SRTM, the slope of the study area is retrieved. Three ranges were determined for the extracted slope: 10°, 10°-35°, and 35°-70°. Each range received a suitable rating, which is listed in the table below. Because topography contributes less to groundwater contamination, it is given a weight of "1".

The majority of the research region's terrain has a slope angle of about 10° encircling the main populous area and the nearby agricultural land.

Table 4.7 Topography (Slope)

TOPOGRAPHY (SLOPE)		
RANGES	RATING	WEIGHT
<10°	10	1
10°-35°	5	1
35°-70°	1	1

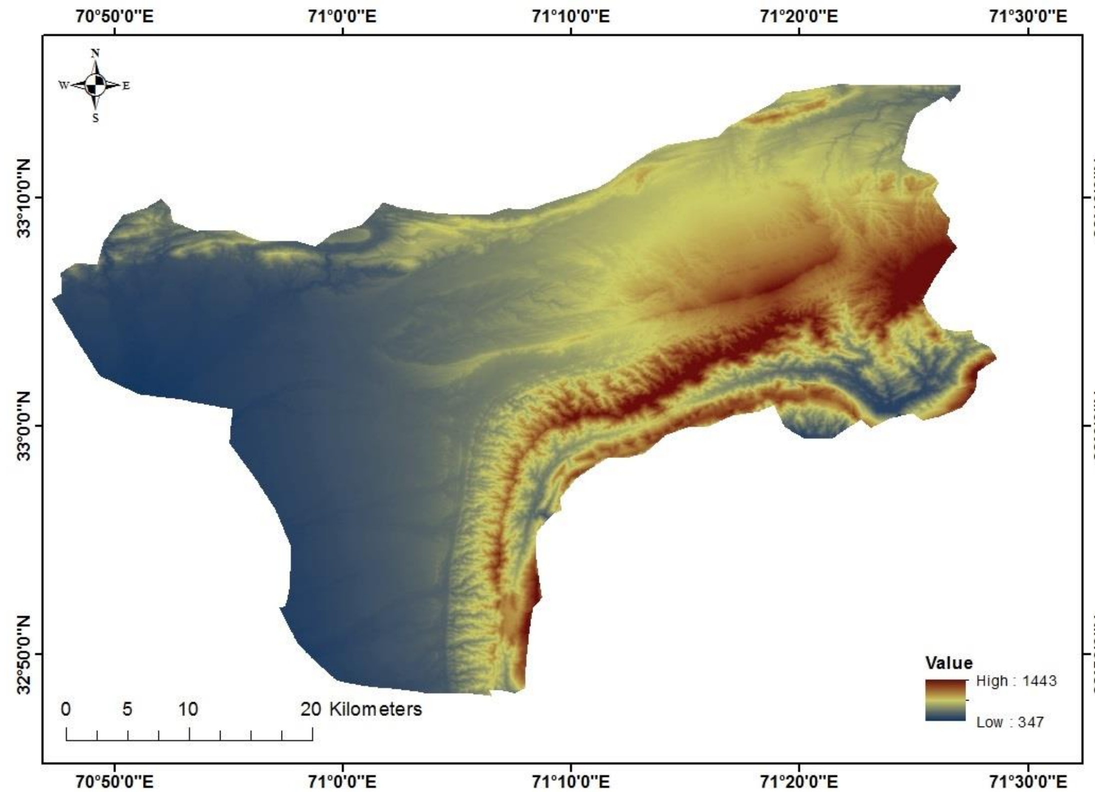

Figure 4.7 Topographic map of study area

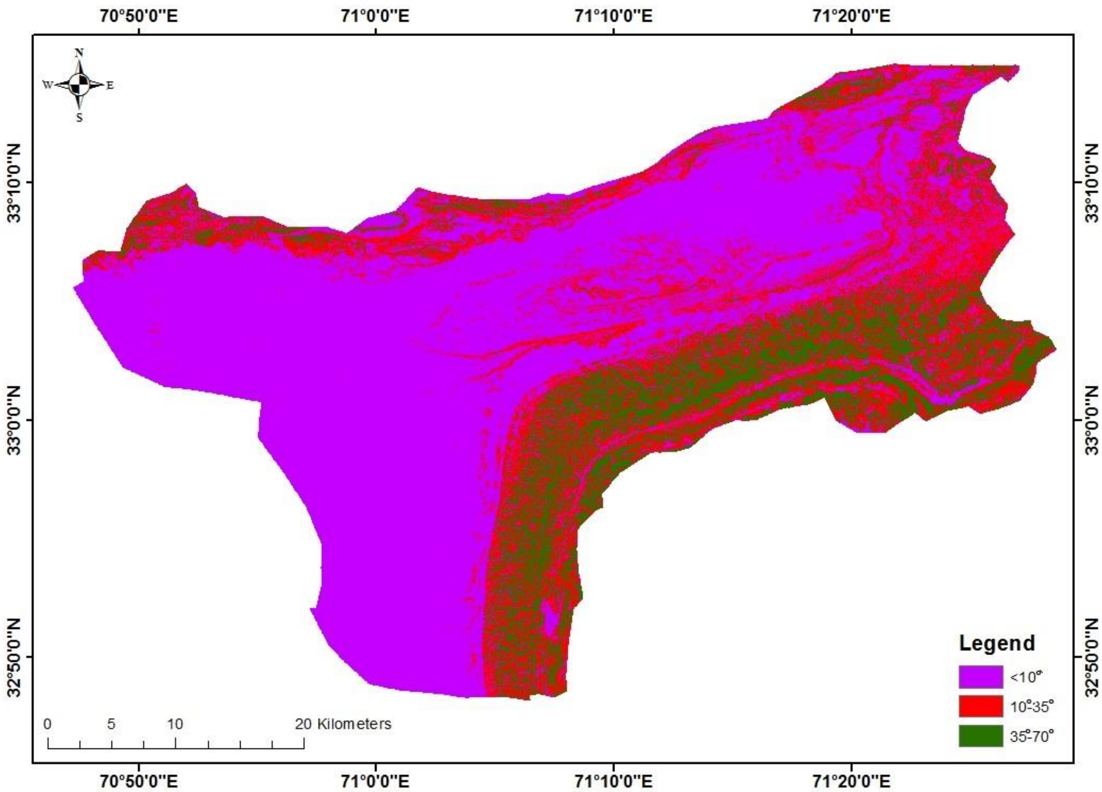

Figure 4.8 Slope Distribution of Study Area

4.6 Impact of vadose zone

The area between the soil medium and the aquifer is known as the vadose zone. The hydrogeological parameter of soil media and the vadose zone have nearly identical meanings and functions. The pollutant penetrating into the water is stopped by the vadose zone. The type of contaminants and the type of material making up the vadose zone impact how much pollution is captured.

Contaminant leaching is significantly regulated by the permeability of the material that makes up the vadose. Contaminants can be quickly leached down and the vadose zone won't be able to trap them, making it an ineffective barrier if it is made of a material with a big grain size and high permeability. On the other hand, the permeability of the vadose zone will decrease if the material's grain size is tiny. By capturing and limiting contaminants, the vadose zone will shield the underlying groundwater from

pollution.

Similar to soil media, the vadose zone experiences a variety of biological, chemical, and physical processes, such as volatilization, biodegradation, dispersion, mechanical filtering, neutralisation, etc (Aller, 1987). Together, these processes control how the pollutant behaves. The size and kind of the media that make up this zone between the aquifer and soil media, which controls the capturing and attenuation qualities of the vadose (Aller, 1987).

The ranges were created using the data that was readily available and the kind of material in the vadose zone. According to the grain size of each range, ratings were assigned to each range. Due to their high permeability and low capturing potential toward pollution, the range with large particle sizes was given a higher ranking. In contrast, the range with smaller grain sizes received lower ratings due to their poor permeability and strong attenuation capability toward contaminants. A weight of "5" is assigned to this element because the vadose zone's impact on groundwater vulnerability assessment is extremely strong.

A map was created to show the spatial distribution of vadose zone media after the data were collected, processed, organised, and interpolated in the GIS environment using the standard kriging technique of interpolation. The map that was developed is shown in the Figure 4.8.

For the vadose zone parameter, five classes or ranges were created: sandstone+gravel, sandstone+clay, clay+sand, and gravel+sand+clay. These ranges received a rating based on the importance of their grain size in determining susceptibility. The table below shows the rating given to each range.

Table 4.8 Vadose zone

VADOSE ZONE		
RANGES	RATING	WEIGHT
Gravel+Clay	6	5
Boulder+Gravel+Clay	7	5
Clay+Sand	8	5
Sandstone+Gravel	9	5
Gravel+Sand+Clay	10	5

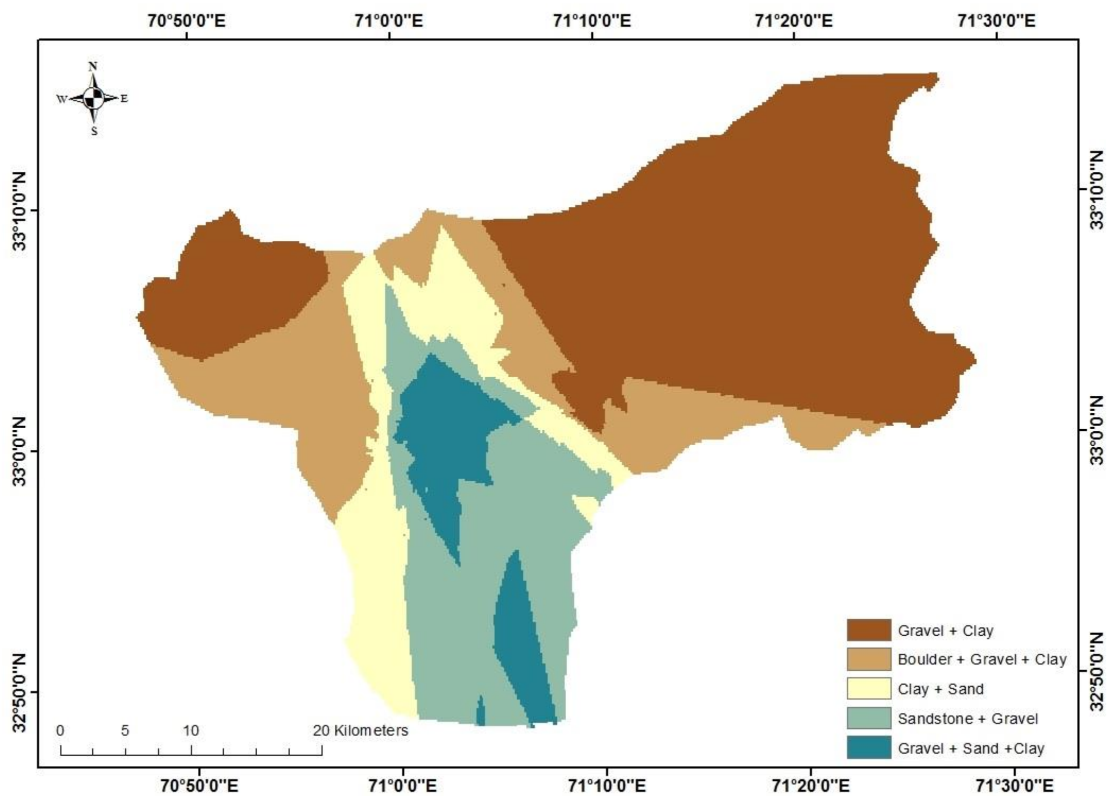

Figure 4.9 Spatial distribution of vadose zone

4.7 Hydraulic conductivity

The ability of the aquifer to transport or flow water across it is determined by its conductivity, particularly its hydraulic conductivity (Rahman, 2008). The rate at which water travels horizontally within the aquifer is measured by hydraulic conductivity (Almasri, 2008). The permeability or texture of the aquifer material and the level of saturation in an aquifer are key factors in the hydraulic conductivity parameter. Hydraulic conductivity controls water flow and pollutant migration in the vicinity of a given hydraulic gradient, making it a crucial element in assessing vulnerability. An aquifer's capacity to transfer contaminants from the point of discharge to the aquifer increases with its hydraulic conductivity.

Utilizing the standard kriging technique, the data was collected from PHED and assembled, categorised, and interpolated. The map that was produced is shown in the picture.

The Aller (1987) approach is used to assign the ranges and ratings. This metric has a weight of "3," according to Aller et al. (1987), because it is more important for evaluation than soil medium and topography. Four classes are specified for this parameter. Lower hydraulic conductivity ranges are rated less favourably than greater hydraulic conductivity ranges, which are rated well. The following table lists the ratings that were assigned.

In terms of conductivity, the range is 445 M/day to 2492 M/day. Hydraulic conductivity in the research area's main section ranges from 1986 M/Day to 2492 M/Day. although in the research area has the highest hydraulic conductivity.

Table 4.9 Hydraulic conductivity

HYDRAULIC CONDUCTIVITY		
RANGES	RATINGS	WEIGHT
445-943 m/day	4	3
943-1416 m/day	6	3
1416-1986 m/day	8	3
1986-2492 m/day	10	3

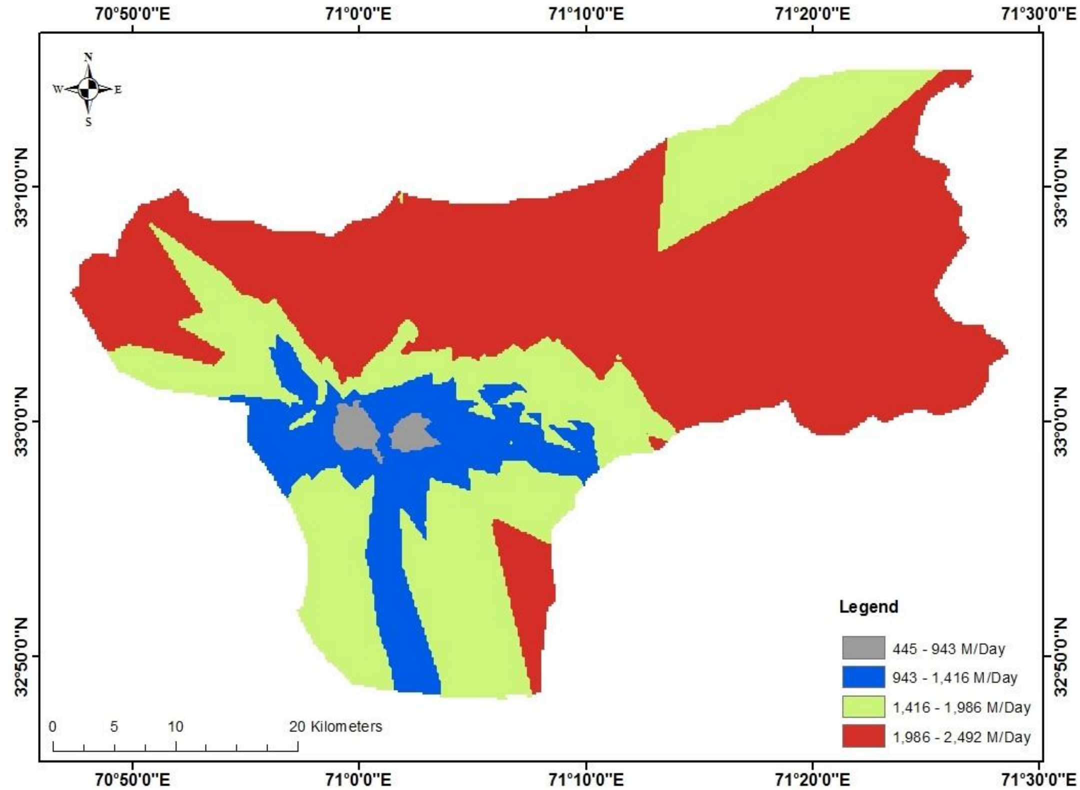

Figure 4.10 Map showing Hydraulic Conductivity of study area

4.8 Drastic-based intrinsic vulnerability assessment

Weighted overlay analysis is used to create a DRASTIC-based susceptibility map once the data has been divided into particular ranges for each parameter and given their appropriate rating ban weights. Equation 1 was applied in a GIS environment to create DRASTIC indices and a through-ground water susceptibility map of the study area by overlaying the thematic map layers of all seven parameters.

The percentages that were reached after performing the overlay analysis are 33, 66, and 100. The degree of susceptibility is indicated by the percentage of DRASTIC indicators. Conversely, if the percentage of DRASTIC indices is lower, the aquifer's vulnerability to pollution will be lower. Higher drastic index percentages indicate that aquifers will be more vulnerable to pollution. The DRASTIC indices were divided into three ranges or classes to efficiently differentiate the areas' varying susceptibility. The DRASTIC indices are classified into three categories: high, medium, and low. On the map, each class was given a distinct hue to help identify it, as seen in the figure.

Table 4.10 DRASTIC ranges and zoning

DRASTIC RANGES AND ZONING		
ZONE	RANGES (%)	COLOR
Low	0% - 33%	Blue
Medium	33% - 66%	Green
High	66% - 100%	White

The main cause to divide the area into 3 classes is:

- To make it simple for various business and public sector groups to decide on land use measures.
- This category can be applied to a variety of local residential, agricultural, and industrial activities.

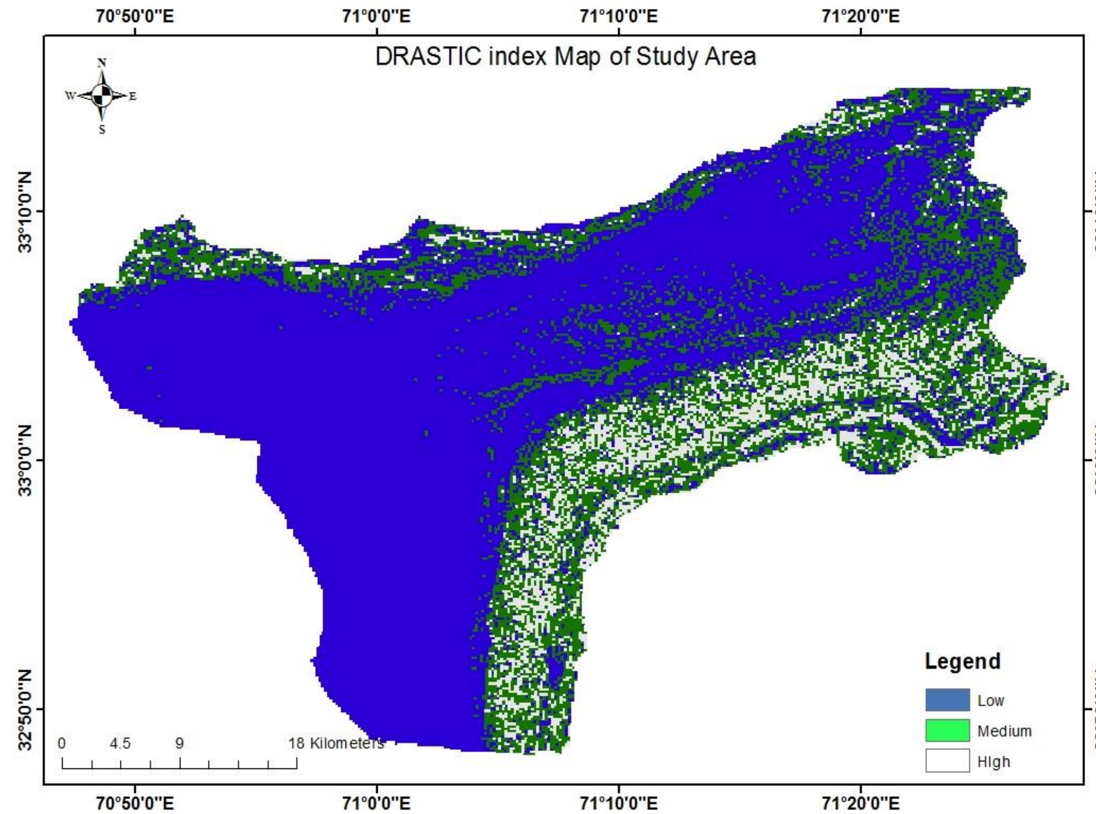

Figure 4.11 DRASTIC Indices map of study area

The graphic makes it abundantly evident that low susceptible zones make up the majority of the research region, followed by medium vulnerable zones. It should be noted that all high and medium zones, with the exception of the low vulnerable zone, are very critical in the susceptibility assessment due to uncertainties and potential outcomes surrounding the pollution process, the nature of subsurface water pollution procedures, and the difficulty of remediating contaminated groundwater.

4.8.1 Low vulnerable zone

A low vulnerable zone encircles 1019.51 square kilometers of the research region. and it become 65.57% of the total area. The low vulnerable zone almost completely encloses the study area's two tehsils. The area's low vulnerability index is caused by a variety of causes. Among the causes are;

The depth of the water table in the research region is the most crucial one. The water table is 450 feet deepest in the research region. The area is less prone to pollution leaching down when the water table is deeper.

The research area receives very little recharge, which makes it less vulnerable to surface contamination. This is the second crucial element.

The studied region is quite impermeable, which contributes to the area's reduced susceptibility to pollution.

Fine particles in the area cover the surface and prevent impurities from seeping through. The water is filtered by the tiny grain-size particles, which also prevent contaminants from migrating downhill.

The majority of the populace resided in a low-vulnerable area.

4.8.2 Medium vulnerable zone

The medium zone is more sporadic and occupies less space of 365 square kilometers on the DRASTIC index map. And it became 24.13% of the total area. The research area's southern portion, which is situated in the tehsil takhti-e-Nasratti, is covered by the medium zone. In comparison to the northern section of the research region, the southern portion is substantially more contaminated.

The region is fairly sparsely populated and is located in a medium-vulnerable zone. A shallow water table might be found in the medium susceptible zones. The soil is relatively tiny in size and has a limited permeability, and it is clayey on the surface. A contaminated particle moves downward just slightly because of low permeability. This zone's aquifer media has rather large-sized, highly permeable sandstone and gravel particles. can permit groundwater contamination.

4.8.3 High vulnerable zone

The study region has scattered points that make up the highly vulnerable zone. and it cover 160 square kilometers area. And it became 10.29% of the total area. This zone's territory is quite prone to pollution. A number of factors contribute to the high sensitivity. One of the primary causes is that, in comparison to other research areas, the area receives a very high recharge. Additionally, the locations in this zone contain strong vadose zones, high hydraulic conductivity, and highly permeable aquifer media. According to the weight and rating that each range is given, these elements contribute to making the area more vulnerable. The slope in this zone is fairly steep, but Aller (1987) gave this parameter a minimum weight of "1," therefore it is insufficient to lower susceptibility.

4.9 Calibration of the DRASTIC map with Nitrate concentration

To calibrate and confirm DRASTIC vulnerability map, map of Nitrate concentration was developed. In order to develop this map forty samples are collected from the accessible zone of the study area and analyzed for Nitrate parameter. The whole regions have an average concentration of 8.67 ppm whereas permissible limit set by Pakistan Standard Quality Control Authority (PSQCA) and National Standard for Drinking Water Quality (NSDWQ) is 10 ppm. The least concentration recorded was 0 ppm and the highest concentration recorded was 13.57 ppm. Around 45% of the samples surpassed the approved limit of PSQWA and NSQWQ standard. Figure …. Show the concentration of Nitrate in the southern part of district karak.

The concentration of Nitrate >10 ppm represent that some human action has contributed toward the highest concentration. (Spalding and Exner 1993). It is identified 24% of high nitrate sample are present in the very high vulnerable zone. Whereas the Nitrates values between 5-10 ppm lies in moderate and high vulnerable zone. These outcomes demonstrate a very accurate match among the drastic index map and the Nitrate concentration map. The Nitrate value also correlated with the depth of water table and impact of vadose zone parameter as they have the highest weight in the model. The reliable correlation exist among the Net Recharge , Aquifer media ,Hydraulic conductivity and Nitrate concentration showing the reliability of generated vulnerable map.

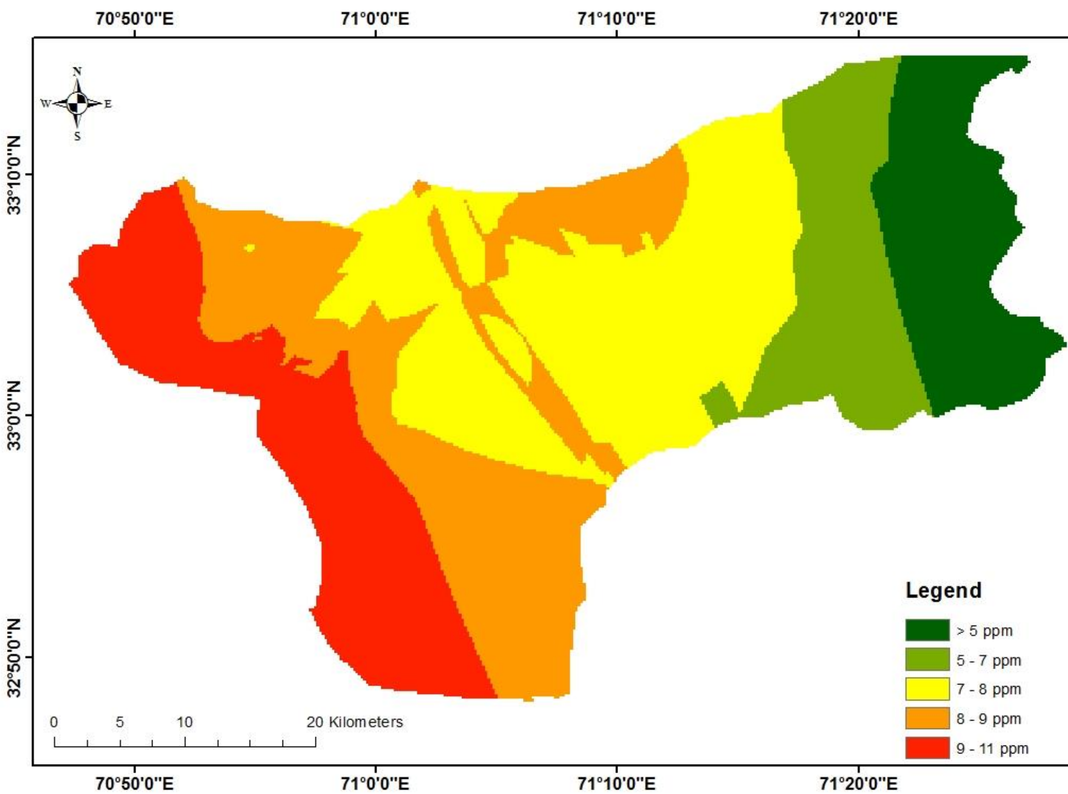

Figure 4.12 Spitial distribution of Nitrate concentration

CHAPTER NO 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this work, an effective weighted overlay-index method termed the GIS based DRASTIC model in GIS sitting was used to evaluate the inherent susceptibility of the groundwater system of the tehsils takhti-e-Nasratti and karak, of district karak. One of the key districts in the Kohat division is Karak. Natural resources like as salt, gypsum, and oil and gas are abundant in the district of Karak and contribute to the needs of the entire nation. The groundwater in the research area is at risk of contamination as a result of the steadily growing population in Karak, stabilised advanced industry, and other human activities. Because treating contaminated groundwater is an expensive and challenging task, By identifying regions that are susceptible to ground water pollution, a first step was done to reduce the likelihood of groundwater contamination. GIS-based DRASTIC model was chosen for this project due to its effectiveness, accuracy, and simplicity. The information required to assess the area's susceptibility was acquired from a variety of sources, including literature reviews and organisations. From the data, seven thematic map layers—Depth to water, Net aquifer Recharge, Aquifer media, Soil media, Slope/Topography, Vadose zone, and Conductivity—were produced (Hydraulic). These maps were produced in a GIS setting. These seven layers were used in a weighted overlay-index analysis to produce a susceptibility map of the study area.

Following the weighted overlay analysis, a set of DRASTIC indices with a range of 33% to 100% were created. Low vulnerable zone, medium vulnerable zone, and high vulnerable zone were the three categories into which this was divided. On the map, each zone was assigned a recognizable hue for quick identification. Below is the analytical point;

1. Low vulnerable zones were identified based on the DRASTIC index percentage of 0%-33%.

2. Medium Vulnerable Zones were defined as areas with a DRASTIC index percentage of 33%-66%.

3. The 66%-100% DRASTIC index percentage was made into a high-vulnerability zone.

5.2 Recommendations

After creating a vulnerability map and working on the DRASTIC model. Considering all of the DRASTIC model's key components, the following suggestions are suggested:

1. One of the main tools for managing water resources is the evaluation of groundwater susceptibility. Because of how this assessment will help with groundwater systems and threat analyses. This evaluation will also help in formulating suggestions for solutions and safeguards in this regard.

2. Based on the vulnerability index for each zone—Low, Medium, and High susceptible zones—the resulting map can be highly helpful for decision- and policy-making authorities in building monitoring and safety procedures. The DRASTIC index map can be used in source distribution and water management tasks as a screening tool.

3. When formulating land use policies, the susceptibility map and evaluation should be taken into consideration. The map can be used as a tool to inform and encourage the people to do their bit in preserving the groundwater in their particular region.

4. To reduce the likelihood of groundwater pollution and suggest appropriate preventive measures, a susceptible map of the entire country, particularly the industrial zones, should be created.

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APPENDICES

Water Table Of Study Area

Name of Pumping Schemes	Coordinate		Present Water Level (ft)
	Latitudes	Longitudes	
WSS: T/Nasrati Payan	33.00258	71.08146	230
WSS:Bogara	33.00003	71.03319	350
WSS: Gandari Khattak	32.98161	71.06253	450
WSS: Shaeedan Banda	32.9444	71.06483	545
WSS: Shah Salim	32.87027	71.03358	350
WSS:Wanki Siraj Khel	33.0213	71.11982	130
WSS: Muhabatti Killa	32.9935	70.95397	230
WSS: Mashan Khel	33.02996	70.93263	210
WSS: Hafiz Yasir Koroona	32.58156	71.3112	400
WSS: Odin Shah Dagar Sar	32.91741	70.97648	510
WSS: Warana Mir Hassan Khel	32.02996	70.23963	140
WSS: Kasteer Banda	32.85531	70.98774	250
WSS: Khada Banda	33.01149	71.06542	250
WSS: Khojaki Killa	32.97689	70.95661	210
WSS: Ibrahim Khel U/C Jehangiri	32.95408	70.98974	442
WSS: Late Wali Rehman Khojaki	32.97237	70.95762	180
WSS: Latamber Gharbi	33.01002	70.83776	25
WSS: Latamber Sharqi	33.07627	70.83268	130
WSS: Nusrat Abad	32.98855	71.044089	350
WSS: Qadar Khel Marwatan	32.99314	70.9718	210
WSS: Awal Khan Koroona Chowkara	32.93613	70.9633	350
WSS: Niaz Khel Alam Doz koroona	32.97111	70.98565	210
WSS: Ashraf Khan Koroona Chowkara	33.0371	70.925268	350
WSS: Ahmad Abad Hayat Khan Koruna	32.95845	71.0557	160
WSS: Alwar Payan	33.0025	71.069209	450
WSS: Badi Zuman Koruna Topi Killa	32.98971	71.01612	270
WSS: Paloski Banda T/Well at Aral	33.2074	70.97186	160
WSS: Mami Khel T/W No.2 Rasool	32.88739	70.97842	440
WSS: Narai Khwara	33.03675	71.02746	140
WSS: Jangrizi Ghulam Abad	33.00798	70.9421	430
WSS: Surati Killa Gul Malook	33.04673	70.99657	210
WSS: Zain No.2	32.88245	70.99381	200
WSS: Aziz Abad Usman Koroona	33.04174	70.99895	140
WSS: Ghulam Abad Mumbati Killa	33.009982	70.94421	150
WSS: Latamber Malay koroona	33.08637	70.85288	45
WSS: Aral Banda Latamber	33.05451	70.84048	180

WSS: Surati Killa Bala	33.044178	71.00687	275
WSS: Amberi Killa Islami Madrassa	33.094197	71.02242	260
WSS: Inzar Banda	32.95717	71.0145	320
WSS: Inayat Ullah Koroona	33.01149	71.06542	420
WSS: Zar khan Killa	33.01416	71.00328	270
WSS: Gandawo Karak			110
WSS: Bahadar Nawaz Said Ali Banda	32.98706	71.05128	430
WSS: Tanga Zani	33.0512	70.97182	210
WSS: Ghulam Khel Mambati	33.00898	70.9521	120
WSS: Dhab Sheikhan Akbar			235
WSS: Ghari Khel	33.031748	70.958706	160
WSS: Shadi Khel	33.03466	71.101087	110
WSS: Wali Khan Banda			120
WSS: Kanda Karak Syed Hassan Koruna	32.97221	71.92825	100
WSS: Topi Killa	32.98971	71.01612	320
WSS: Akar Wala	33.10847	70.87221	80
WSS: Walaki Muhabat Khel			130
WSS: Late Qadir Bakush Danger Wala	33.038682	70.9789	200
WSS: Nara Janda Khel	32.89552	71.01009	310
WSS: Ghundi Killa	33.058001	71.29286	310
WSS: Manja Khan Koroona	33.00418	71.02974	140
WSS: Yaghi Badi Khel	32.978742	70.97116	160
WSS: Zari Wala	32.98615	70.996271	270
WSS: Ayub Gul Koroona Eider Khel	33.14885	71.26095	165
WSS: Karim Nawaz Koroona Darsha	32.823755	71.047858	400
WSS: Mazari Payal	32.99062	70.95674	200
WSS: Said Ali Banda			430
WSS: Gardi Banda	33.00042	70.98626	235
WSS: Noor Qatal Koroona	32.83353	71.02014	370
WSS: Tanga Zani Dawala	33.2928	71.01624	250
WSS: Azam Khan Koruna Mambati	32.99594	70.93855	218
WSS: Mianki Banda Pajan Koroona	32.9485	71.022126	330
WSS: Kanda Baji Khel	33.01315	71.0597	320
WSS: Khojaki Killa Gul Adam	32.96986	70.97376	160
WSS: Gul Hassan Koroona T/Nasrati	33.00245	71.04499	210
WSS: Shoukat Zarin Killa	32.8822	70.99382	370
WSS: Molana Farooq Koroona Jarasi	32.81611	71.03032	360
WSS: Qasim koroona Tanga Zainay	33.05076	70.96821	90
WSS: Khan Bag Koroona Warana	33.04429	70.98161	140
WSS: Warana Latamber	33.09848	70.84194	100
WSS: Bahram Khel	32.865036	71.01961	385
WSS: Inzar Mir Hassan Koroona	32.93671	71.00453	350

WSS: Gul Mir Tattar Khel	32.98265	70.93733	110
WSS: Moona Khel	32.88729	70.98123	260
WSS: Mena Khel T/W 01	32.85035	71.04048	440
WSS: Amberi Killa	3305163	71.2239	170
WSS: Khadda Banda	33.0114	71.06544	320
WSS: Mulana Shabir Jarasi	32.82322	71.02855	210
WSS: Jehangiri Banda	32.495408	70.98974	315
WSS: Warana Mashan Khel	33.02996	70.93263	90
WSS: Dabli Lawaghar	33.07463	71.120498	190
WSS: Chapi Banda	32.92031	71.04847	435
WSS: Alam Gul Khel	32.97793	70.992	250
WSS: Mufi Sardar Koroona	33.0055	70.94711	180
WSS: Dr. Sherin Koroona Gari Khel	33.00376	70.96082	170
WSS:Jamal Khel(1996)	32.940348	71.033046	380
WSS: Chack Manzai2004	32.919	71.00393	210
WSS: MAnsoori Killa2004	32.92225	71.04035	435
WSS:Kari Dhand1999	32.87517	70.98371	275
WSS: Qureshan Banda 2008	32.96777	71.0593	470
WSS:Darsha Khel 2006	32.826829	71.0332	400
WSS:Khadda Banda Hassan 2008	33.00252	71.04488	360
WSS:Khadda Banda No,01 2007	33.00818	71.05984	370
WSS:Awazi Killa 2010	33.0627	71.01986	325
WSS:Bangi Killa 1999	32.93125	71.04446	475
WSS: Kabal Khel 1995	32.8804	71.00533	350
WSS:Babal Khel 2006	33.29539	71.0063	250
WSS:Shobli Banda 2009	32.99408	71.0544	395
WSS:Seirak No. 02 2006	32.92263	71.02211	350
WSS:Yaghi Musakan 1996	32.96974	70.97991	230
WSS:Lakki Banda 1997	32.94692	70.99513	260
WSS:Inzer Banda 1992	32.95717	71.0135	350
WSS:Hamid Ullah Shah Zarin 2015	32.88594	70.99232	260
WSS: Abdul Nawaz Zarin Killa 2014	32.88942	70.98935	270
WSS:Usman Koroona Meena Khel	32.88729	70.98123	360
WSS:Kari Dhand 1984	32.87517	70.83371	280
WSS:Zargaran Banda 1979	32.86132	70.98395	290
WSS: Painda Banda 1998	32.86097	71.00962	390
WSS:Meena Khel 1992	32.85531	70.98774	420
WSS:Pakki Ghudi Khel 1992	32.89518	71.04985	525
WSS: Darsha Khel 2006	32.82236	71.0465	425
WSS:Umer Din Killa	32.91311	70.97333	220
WSS: Machaki Banda	32.93133	71.02148	360
WSS:Koti Killa	32.90449	70.99297	210
WSS:Odin Shah	32.92116	70.97889	255

WSS: Khojaki Killa	32.96986	70.97854	290
Wss :Khan mire banda	32.86017	71.03705	430
Wss: Mena khil	32.85035	71.04048	450
Wss: Haji Gull sahib khan	328499	71.03866	430
Wss: hazrat Kareem 2	32.85075	71.04708	430
Wss: silab Din shnwa gudi khil 1992	32.87723	71.06137	480
Wss: khan Badsha khada Banda2016	33.00252	71.04488	350
Wss: Mohabat khil bogara2003	32.99753	71.03708	380
Wss:gul sha ali bogara 2009	32.99804	71.03165	385
Wss:shir Alam koroona	33.00813	71.02944	370
Wss:Shah Salim	32.87476	71.02529	510
Wss: Zarin banda No 2	32.88245	70.99381	315
Wss:Daraz khel khojaki	32.94483	71.012291	180
Wss: inzar banda	32.95717	71.0135	290
Wss:kareem Nawaz	32.98132	71.06725	390
Wss:lasti koroona	32.97538	71.020178	320
Wss:Jahangeri No 2	32.95666	70.9978	330
Wss: sharbat koroona	32.95527	71.00819	270
WSS: Yaghi Badin Khel	32.97873	70.97115	160
WSS:Nusrat Abad	32.99098	71.04173	350
WSS:Wagi banda No.01	32.9816	71.06247	460
WSS:Wali Rehman	32.97237	70.95762	180
WSS: Odin Shah Dagar Sar	32.88124	71.05497	510
WSS: Hafiz Yasir Koroona	32.58156	71.3112	415
WSS:Mianki Pajan Koroona	32.94785	71.02212	330
WSS: Noor Qatal Ghudi Khel	32.83353	71.02014	380
WSS:Wanki Siraj Khel	33.069573	71.161821	170
WSS:Topi Killa	32.9897	71.01612	310
Dost Muhammad Shaheedan	32.93305	71.06367	515
WSS: Khadda Banda	33.00249	71.0483	335
WSS: Khurshid Koroona	33.20246	71.06923	425
WSS: Ghanderi Khattak 1	32.98482	71.06586	435
WSS: Ghanderi Khattak 2	32.98507	71.06435	430
WSS: Chappi Banda	32.92031	71.04847	435
WSSBehram Khel Yousaf Koroona	32.86382	71.01685	370
WSS: Noor Warjan Mansoori	32.9282	71.062	400
WSS: Khadda Banda Usman Koroona	33.00809	71.06077	340
WSS:Dabaki Banda	32.92103	71.04235	445
WSS:Hamid Ullah Zarin	32.88594	70.99232	270
WSS: Bogara Manja khel	33.00418	71.2974	350
WSS: Mohallah.Charghi Khel Mianki	32.94589	71.02233	300
WSS: Islami Maddrassa	32.96392	71.5195	420
WSS:Sultan Abbad Khojaki	32.91324	71.03425	240

WSS: Gulay Malik Shaheedan	32.94833	71.06946	535
WSS:Hajat Ullah Behram Khel	32.87146	71.01581	350
WSS: Dakasi banda	32.85153	71.02115	420
WSS:Bogara Said Noor	3300461	71.02425	340
WSS: Rashid Abad T/N	32.99249	71.04479	410
WSS: Bogara Sher Alam	33.007	71.02949	340
WSS: Jalal Saddique	33.00859	71.02455	330
WSS: Sher Bahadar	33.00634	71.0248	330
WSS: Rangeen Khel	33.0048	71.0132	310
WSS: Dagar Sar	33.00113	71.01126	300
WSS:Inzar Banda	32.96136	71.01872	300
WSS:Lashti Koroona	32.97538	71.02017	320
WSS: Manzini	32.94197	70.96757	290
WSS: M.Ayaz Inzar Banda	32.96008	71.01346	415
WSS: Dar Ali Shaheedan	32.94064	71.07091	520
WSS: Gul Da Ali Shaheedan	32.93862	71.06765	530
WSS: Alam Gul Shaheedan	32.93305	71.06367	520
WSS: Hazrat Gul Jarasi	32.81718	71.0986	385
WSS: Mir Wali Alwar Banda	32.95845	71.055704	445
WSS: Awal Jan Koroona	32.93613	70.96333	390
WSS:Mehraban Shah Sheetaka	32.92254	71.02225	440
WSS:Sahib Zad Koroona Jattan	32.93546	71.00985	325
WSS: Jatan Banda	32.93321	71.00662	310
WSS: Malak Shah Jahan Jattan	32.93671	71.00453	320
WSS: Said Nawaz Koroona Mir Khawas	32.94439	71.00307	290
WSS: Lakki Mir Khawas	32.94508	70.99769	270
WSS: Lorha Lakki Banda	32.94692	70.99513	270
WSS: Ghulam Khel Mambati	32.97741	70.96926	250
WSS:Inzer Banda Altaf Banda	32.95812	71.01159	300
WSS:Nizam Abad Lakki Banda	32.95121	70.99532	270
WSS: Jahangeri	32.9561	70.99117	250
WSS: Nawaz Abad Lerha	32.94788	70.98023	240
WSS:Manzini Banda	32.95523	70.95298	240
WSS: Laghari Rajab Khel Mir Wali	32.9682	70.95153	230
WSS: Kabir Soli Khel	32.97756	70.96671	230
WSS:Badshah Noor Korrona	32.9709	70.98582	270
WSS:Alam Ghul Khel	32.97975	70.99414	260
WSS: Topi Killa Rab NAWAZ	32.98392	71.00016	260
WSS: Malak Pump Fateh Sheri	32.98253	70.977	260
WSS: Nazif Koroona Masti Khan	32.99257	70.96721	300
WSS:Qadar Khel	32.9922	70.97695	310
WSS: Sana Ullah koroona	32.96439	71.00806	310

WSS:Mir Dal Banda	32.97018	70.99896	260
WSS:Alam Ghul Khel 2	32.97493	70.992	310
WSS:Badi Zuman Toppi Killa	32.98856	70.99369	340
WSS: Shah Qaiser Banda 01	32.99874	71.00128	300
WSS: Shah Qaiser Banda 02	32.9999	71.00331	290
WSS: Bogara Dagar Killa	33.00112	71.01134	330
WSS: Sultan Abad Khojaki	32.97901	70.96105	280
WSS:Late Wali Rehman Khojaki Killa	32.97237	70.95762	280
WSS: Khan Malook Laghari Bogaran	32.96313	70.96247	210
WSS: Mir Adam Banda	32.96453	70.97481	320
WSS: Sher Bahadar Yaqoobi Killa	32.92312	71.01119	380
WSS:Badin khel	32.91311	70.97339	290
WSS:Bangi Killa Hazrat Khan	32.93368	71.03224	420
WSS:Bakhani Koroona Shawa Nasrati	32.91609	71.05698	475
WSS: Jan Shah Koroona Sheetaka	32.9146	71.05621	475
WSS:Shamadi Khel	32.93151	71.05853	470
WSS:Kaski Banda	32.9258	71.06396	480
WSS:Dar Ali Shaheedan	32.94063	71.07098	550
WSS:Mianki Ikram Koroona	32.95149	71.1906	385
WSS: Prof: Rasool Shah Ghanderi	32.97124	71.04916	415
WSS:Wagi Banda Saddique Koroona	32.9624	71.05645	400
WSS: Gul Maizar Koroona Ghanderi	32.98309	71.05533	440
WSS: Waqar Hussain Ghanderi	32.98565	71.06097	440
WSS: Haziq Rehman Ghanderi	32.99458	71.06814	450
WSS: Shobli Banda Baroz	32.99345	71.05584	390
WSS:Mudassir Shah Koroona Qureshi Nagar	32.95674	71.2583	400
WSS:Alawr Banda Noor Bashar	32.9582	71.06621	475
WSS:Idrees Koroona Gul Shan Zarki	32.97866	71.06703	445
WSS: Dagar Sar Sher Nawaz	32.8769	71.004283	460
WSS: Bait ullah Jan Shah Slim	32.87222	71.3289	420
WSS: Gul Zuman Jarasi	32.81611	71.03032	380
WSS:Ghulam Abad Jangrezi	32.8962	71.04639	410
WSS: Pakki Ghudi Khel	32.89533	71.04987	435
WSS: Mina Khel No 01	32.85028	71.04064	370
WSS: Gul Faraz Koroona Dersha Khel	32.82242	71.04647	360
WSS:Jarasi Banda 01	32.82324	71.02857	370
WSS:Jarasi Banda 02	32.81854	71.02381	370
WSS:Jarasi Banda Hazrat Gul	32.81718	71.02878	370
WSS:Ismail Koroona Dakasi Banda	32.81189	71.04011	390
WSS:Malik Muhammad Hayat Jarasi	32.81816	71.03352	370
WSS:Jarasi	32.82244	71.02278	370
WSS:Banjah Killa	32.83816	71.01517	360

WSS:Behram Khel Nazim Yousef Koroona	32.86384	71.01686	360
WSS: Painda Banda	32.85769	71.00956	360
WSS:Karri Dhand 03	32.86767	70.98161	370
WSS:Kasteer Banda	32.85534	70.98771	380
WSS:Karri Dhand Nawab Koroona	32.85926	70.97981	370
WSS:Kasteer Banda 02	3285702	70.97455	380
WSS:Karri Dhand 01	32.86139	70.98383	370
WSS: Karri Dhand 02	32.87521	70.98377	370
WSS:Zarin Killa	32.88245	70.99381	280
WSS:Jahanzeb Koroona Mosam Banda	33.00633	71.07621	330
WSS: Khadda Banda Mir Ali Khan Koroona	33.00975	71.06813	340
WSS:Rasool Muhammad Koroona Khadda	33.00808	71.05651	330
WSS:Khadda Banda 01	33.01315	71.0597	360
WSS:Khadda Banda 02	33.0114	71.06544	360
WSS: Hassan Koroona Khadda	33.00245	71.04499	370
WSS:Bahadar Sher Koroona Bogara	33.00643	71.02483	380
WSS:Jalal Manager Koroona Bogara	33.00852	71.02456	380
WSS:Doctor Syed Noor Koroona Bogara	33.00462	71.0243	390
WSS:Malik Sher Koroona Rangeen Khel	33.05532	71.01313	380
WSS:Gul Shali Koroona	32.99804	71.03165	380
WSS:Muhabbat Khel Bogara	33.00003	71.0331	380
WSS:Takht-e-Nasrati 02	33.00458	71.05918	340
WSS:Takht-e-Nasrati 01	33.00226	71.05926	340
WSS:Sher Alam Koroona Bogara	33.00813	71.02944	380
WSS:Zafar Ali Rasees Koroona	33.00591	71.06764	375
WSS:Warana Ghari Khel Bala	33.0295	70.95051	240
WSS:Ghari Khel Warana	33.03175	70.95871	240
WSS:Dadena Amail Shah Koroona	33.03633	70.94858	220
WSS:Warana Musakan 01	33.0122	70.94567	220
WSS:Warana Musakan 02	33.01168	70.94445	220
WSS: Naseer Ahmad Koroona	33.03424	70.92035	230
WSS:Tanga Zany	33.03864	71.00384	230
WSS:Muhmmad Subhan Koroona	33.03826	70.92555	280
WSS:Fazal Rehman Koroona	33.04198	70.91924	250
WSS:Muhmmad Farid	33.04824	70.92519	300
WSS:Darwesh	33.05454	70.94126	270
WSS:Aka Wala T/W at Shobli Banda	33.06951	70.94171	300
WSS:Saikot Amberi Killa	33.05102	71.01435	270
WSS:Salam Shah Koroona Tatter Khel	32.98894	70.91679	245

WSS:Awal Badshah Koroona	32.98851	70.93699	245
WSS:Lali Paya Koroona Mazar Pale	32.98852	70.95507	240
WSS:Mazri Payan Tatter Khel	32.99062	70.95674	240
WSS:Muhabati Killa Aziz Rehman	32.99935	70.95397	230
WSS:Doctor Sherin Koroona Ghari Khel	33.00376	70.96082	240
WSS:Javed Akhter Advocate	32.98877	70.95018	275
WSS:Akhya Jan	32.97906	70.94068	240
WSS:Karim Dad Khan	32.97908	70.94669	320
WSS:Mazhar Hayat Koroona	32.97205	70.93147	355
WSS:Alam Sheri Killa	32.9803	70.93256	40
WSS:Alam Sheri Tabib Koroona	32.98546	70.91942	230
WSS:Mazari Payan Tatter Khel	32.98284	70.94594	250
WSS:Gul Mare Koroona Tatter Khel	32.98265	70.93733	250
WSS:Haji Banda Khowaja Muhammad	32.94449	70.93428	300
WSS: Muhabbati Killa	32.99233	70.94189	275
WSS: Said Akbar	33.00567	70.92935	320
WSS:Khalil Rehman	33.00785	70.92658	325
WSS:Alam Sheri Sheikhan ShahenaBanda	32.99373	70.92113	290
WSS:Mohabati Killa Gharbi	32.99594	70.93855	230
WSS:Sahib Gul Koroona	33.00544	70.93698	285
WSS:Warana Mir Hassan Khel	33.00873	70.93745	170
WSS:Ghulam Abad Mohabati Killa	33.00808	70.94216	230
WSS:Mufti Muahhmad Sardar Koroona	33.00557	70.94711	325
WSS:Akami Koroona Warana	33.02475	70.94334	170
WSS:Nabi Koroona Warana	33.02923	70.94355	170
WSS:Moulana Abdul Aziz Koroona	33.04174	70.99895	260
WSS: Surati Killa	33.04673	70.99657	270
WSS:Gul Shahzad Koroona	33.04245	70.99293	295
WSS:Ahmad Wala Surati Killa	33.04429	70.98166	280
WSS:Surati Killa	33.0489	70.98572	285
WSS:Qasim Khan Koroona Tanga Zany	33.05076	70.96821	200
WSS:Tanga Zany	33.0512	70.97182	200
WSS:Zara Ghandi Badi Zuman Koroona	33.01978	70.97072	180
WSS:Paloski Banda	33.02074	70.97186	200
WSS:Chaman Abad	33.04377	70.99843	210
WSS: Awal Daraz Koroona	32.99953	71.079	330
WSS: Aral Banda	33.01102	70.9699	185
WSS: Lal Sardar	33.05546	71.05595	380
WSS: Muhammad Iskhaq	33.04502	71.01853	310
WSS:Essot Killa	33.04584	71.0597	205

WSS:Dabaki Killa Ghundi Killa	33.04018	71.02019	360
WSS: Mufti Younas Koroona	33.01525	71.03504	355
WSS: Ajab Noor Koroona	33.03491	71.06084	380
WSS: Haji Lal Badin Chowkara	33.03027	71.0368	395
WSS:Muhammad Iqbal	33.06064	71.02439	395
WSS: Rafique Koroona Chowkara	33.03867	71.03441	380
WSS:Painda Khel Chowkara	33.02896	71.03407	390
WSS: Mazi Addha	33.02936	71.04249	385
WSS:Allah Noor Khel Chowkara	33.03367	71.02746	385
WSS:Habib ur Rehman	33.03932	70.99752	360
WSS: Dengar Wala	33.038682	70.97798	290

Aquifer media

Latitude	Longitude	Aquifer Media
32.9935	70.95397	Sandstone
33.0213	71.11982	boulder + gravel
33.00003	71.03319	Sandstone
33.09848	70.84194	sandstone + gravel
32.98161	71.06253	Sandstone
33.0942	71.02242	clay +sand+gravel
32.93671	71.00453	gravel + boulder
33.058	71.29286	gravel + boulder
33.02996	70.93263	Sandstone
32.9485	71.02213	clay + gravel + Sand
33.0512	70.97182	gravel + boulder
33.00042	70.98626	sandstone + gravel
32.95845	71.0557	gravel + boulder
32.99314	70.9718	sandstone
33.00258	71.08146	boulder + gravel
33.00245	71.04499	boulder + gravel
33.03027	71.0368	gravel + sandstone
33.03867	71.03441	gravel+sandstone
33.02896	71.03407	gravel sandstone
33.03367	71.02746	gravel sandstone
32.99062	70.95674	Sandstone
32.98284	70.94594	boulder+gravel
32.98265	70.93733	boulder+gravel
32.98894	70.91679	boulder+gravel
32.99753	71.03708	Sandstone
32.99804	71.03165	Sandstone

33.00418	71.2974	Sandstone
33.00461	71.02425	Sandstone
33.007	71.02949	Sandstone
33.00112	71.01134	Sandstone
33.00852	71.02456	Sandstone
33.07463	71.1205	Sandstone
33.05163	71.2239	gravel+sandstone
33.05102	71.01435	clay sand+gravel
33.04018	71.02019	boulder + gravel
33.04429	70.98161	Sandstone
33.0295	70.95051	sandstone + gravel
33.00873	70.93745	sandstone + gravel
32.94785	71.02212	clay + gravel +sand
32.95149	71.1906	clay + gravel +sand
33.03864	71.00384	gravel + boulder
33.05076	70.96821	gravel + boulder
32.96986	70.97854	Sandstone
32.97237	70.95762	Sandstone
33.00245	71.04499	sand +gravel +clay
33.10944	71.09	gravel + sand+clay
33.15074	71.20967	Boulder+gravel
33.08861	71.08306	Sandstone
33.18472	70.88278	boulder + gravel
33.10944	71.09	boulder + gravel
33.11786	71.10118	gravel+sandstone
33.16191	71.19535	clay + gravel+sand
33.11175	71.10679	Sandstone
33.14897	71.20037	clay + gravel+sand
33.12994	71.15937	gravel + boulder

Vadose Zone

Latitude	Longitude	Vadose Zone
32.9935	70.95397	Clay+sand
33.0213	71.11982	Clay

33.00003	71.03319	Clay+sandstone
33.09848	70.84194	Gravel+boulder
32.98161	71.06253	boulder+gravel
33.094197	71.02242	gravel+clay
32.93671	71.00453	gravel+clay
33.058001	71.29286	boulder+gravel
33.02996	70.93263	Clay+sandstone
32.9485	71.022126	sand+gravel
33.0512	70.97182	boulder+gravel
33.00042	70.98626	Clay+sand
32.95845	71.0557	Gravel+boulder
32.99314	70.9718	sand+boulder+gravel
32.96986	70.97376	Clay+sand
33.00258	71.08146	boulder+gravel+sand
33.00245	71.04499	boulder+gravel+sand
33.03027	71.0368	boulder+gravel+clay
33.03867	71.03441	boulder+gravel+clay
33.02896	71.03407	boulder+gravel+clay
33.03367	71.02746	boulder+gravel+clay
32.99062	70.95674	Clay+sand
32.98284	70.94594	Clay+sand
32.98265	70.93733	Clay+sand
32.98894	70.91679	Clay+sand
32.99753	71.03708	Clay+sandstone
32.99804	71.03165	Clay+sandstone
33.00418	71.2974	Clay+sandstone
33.00461	71.02425	Clay+sandstone
33.007	71.02949	Clay+sandstone
33.00112	71.01134	Clay+sandstone
33.00852	71.02456	Clay+sandstone

33.07463	71.120498	sandstone
33.05163	71.2239	gravel+clay
33.05102	71.01435	gravel+clay
32.95717	71.0135	gravel+clay
33.04018	71.02019	boulder+gravel
33.04429	70.98161	Clay+sandstone
33.0295	70.95051	Clay+sandstone
33.03175	70.95871	Clay+sandstone
33.0122	70.94567	Clay+sandstone
33.00873	70.93745	Clay+sandstone
32.94785	71.02212	sand+gravel
32.95149	71.1906	sand+gravel
33.03864	71.00384	boulder+gravel
33.05076	70.96821	boulder+gravel
32.96986	70.97854	Sandstone
32.97237	70.95762	Sandstone
33.00245	71.04499	boulder+gravel+sand
33.1094444	71.09	Clay
33.1507361	71.20966944	clay+gravel
33.0886111	71.08305556	soft sandstone+clay
33.1847222	70.88277778	Clay
33.1094444	71.09	boulder+gravel
33.1178556	71.10117778	gravel+boulder
33.1619111	71.19534722	clay+gravel
33.1117472	71.10678889	sandstone+clay
33.1489667	71.20037222	clay+gravel
33.1299361	71.15936944	Gravel+boulder

Hydraulic Conductivity

Latitude	Longitude	Hydraulic Conductivity
32.9935	70.95397	5
33.0213	71.11982	2600
33.00003	71.03319	5
33.09848	70.84194	2700
32.98161	71.06253	5
33.0942	71.02242	3000
32.93671	71.00453	2700
33.058	71.29286	2700
33.02996	70.93263	5
32.9485	71.02213	3000
33.0512	70.97182	2600
33.00042	70.98626	2700
32.95845	71.0557	2600
32.99314	70.9718	5
32.96986	70.97376	3000
33.00258	71.08146	2600
33.00245	71.04499	2600
33.03027	71.0368	2700
33.03867	71.03441	2700
33.02896	71.03407	2700
33.03367	71.02746	2700
32.99062	70.95674	5
32.98284	70.94594	2600
32.98265	70.93733	2600
32.98894	70.91679	2600
32.99753	71.03708	5
32.99804	71.03165	5
33.00418	71.2974	5
33.00461	71.02425	5
33.007	71.02949	5
33.00112	71.01134	5
33.00852	71.02456	5
33.07463	71.1205	5
33.05163	71.2239	2700
33.05102	71.01435	3000
32.95717	71.0135	2600

33.04018	71.02019	2600
33.04429	70.98161	5
33.0295	70.95051	2700
33.03175	70.95871	2700
33.0122	70.94567	5
33.00873	70.93745	2700
32.94785	71.02212	3000
32.95149	71.1906	3000
33.03864	71.00384	2600
33.05076	70.96821	2600
32.96986	70.97854	5
32.97237	70.95762	5
33.00245	71.04499	3000
33.10944	71.09	3000
33.15074	71.20967	2600
33.08861	71.08306	5
33.18472	70.88278	2600
33.10944	71.09	2600
33.11786	71.10118	2700
33.16191	71.19535	3000
33.11175	71.10679	5
33.14897	71.20037	3000
33.12994	71.15937	2600

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by Muhammad Muneer

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