ASSESSMENT OF GROUNDWATER INTRINSIC VULNERABILTY USING GIS BASED DRASTIC MODEL IN HARIPUR AREA, KHYBER PAKHTUNKHWA, PAKISTAN

By

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ASSESSMENT OF GROUNDWATER INTRINSIC VULNERABILTY USING GIS BASED DRASTIC MODEL IN HARIPUR AREA, KHYBER PAKHTUNKHWA, PAKISTAN

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2020

AUTHOR'S DECLARATION

I, solemnly hereby state that my MS thesis titled

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ABSTRACT

Study was conducted to assess the intrinsic susceptibility of the groundwater system using a weighted overlay – index approach known as GIS based DRASTIC model in GIS setting in District Haripur. Haripur is a major district of Pakistan's Hazara division, which is famous for its agriculture. The district Haripur has a major industrial state i.e. Hattar Industrial State which contributes to needs of whole country. Due to the increasing population, rapid industrial growth and other human activities the groundwater is under risk of contamination. Therefore, study was designed to avoid the exposure of population to contaminated water by identifying areas vulnerable to groundwater pollution. For this purpose, GIS based DRASTIC model was applied because of its efficiency, accuracy and easy execution. The data and information needed for assessing the vulnerability of the area was gathered from numerous organizations and from literature survey. Using GIS, seven thematic map layers were generated from the data gathered which are Depth to water, Net Aquifer Recharge, Aquifer Media, Soil Media, Slope/Topography, Vadose zone and Conductivity (Hydraulic). A weighted overlay- index analysis was carried out using these seven layer to obtain a susceptibility map of the study area. Results of the Weighted overlay analysis indicates a range (88-190) of DRASTIC Indices. Which was further classified into five smaller classes i.e. Low vulnerable zone (88 - 109), Medium vulnerable zone (110 - 129), Moderate vulnerable zone (130 - 149), high vulnerable zone (150 - 169) and very high vulnerable zone (170 - 190). Each zone was allotted a distinctive color on the map for easy identification. A dominant area of 965 kilometers square was covered by moderate vulnerable zone. Both medium and high vulnerable zone covers an area of 506 kilometers square. Low vulnerable zone covers an area of 118 kilometers square. Lastly very high vulnerable encompass the least area i.e. 66 kilometers square. The study recommends that the susceptibility map and assessment should be incorporated while making policies regarding land use.

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ABBREVIATIONS

NWWA	National Water Well Association
GIS	Geographic Information System
PHED	Public Health and Engineering Department
GPS	Global Positioning System
DEM	Digital Elevation Model
SRTM	Shuttle Radar Topography Mission
EPA	Environmental Protection Agency
WHO	World Health Organization
AF	Attenuation Factor
BAM	Behavior Assessment Model
LR	Logistic Regression
ILWIS	Integrated Land and Water Information System
RMSE	Root Mean Square Error
DI	Drastic Index
OK	Ordinary Krigging
SK	Standard Krigging
UK	Universal Krigging
IDW	Inverse Distance Weight
WAPDA	Water and Power Development Authority
PSQCA	Pakistan Standard Quality Control Authority
NSDWQ	National Standard for Drinking Water Quality

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CHAPTER 1
INTRODUCTION

1.1 General Overview

Among several other necessities to sustain and survive on earth, water is the most important commodity (Kahlown and Majeed, 2005). On the globe the most crucial and significant source of fresh water are subsurface water reservoirs (Villeneuve et al., 1990). There is more burden on the groundwater and it is depleting very quickly as compared to surface water because of the relatively less the groundwater is less prone to the pollution than the water resources present on the surface and because of this low susceptibility of groundwater it is considered "Major drinking water resource" (US EPA, 1985). Although it is very difficult and almost theoretically impossible to assess precisely amount of subsurface water present in aquifers around the globe, but conferring to loose assessments made in this regard, total amount of water in the earths reservoirs is between 15.3 – 60 million kilometer cubes. Among this whole amount of groundwater, only 8 to 10 million kilometer cubes of water are considered to be fresh water where the remaining portion of is brackish and saline water. (Margat, 2008). Groundwater is vital to for the daily life activities because it is easily available and has good quality as compared to surface water. The groundwater is termed as a commodity of strategic importance because of the rising demand of it in various needs like industries, agriculture and domestic life.

From a worldwide viewpoint, a yearly withdrawal of around 4430 kilometers cubes is documented around the globe, of which a large share is consumed in agriculture which is approximately 70% whereas industrial and domestic consumptions are of 25% and 5% respectively of over-all pumped groundwater (Kinzelbach et al., 2003). The combined yearly universal withdrawal is assessed as 1000 kilometer cubes cubic by 2010 which is around 22% of the whole yearly pumped groundwater globally. (EUROSTAT, 2011). Globally, almost 2 billion individuals hinge exclusively resources of groundwater to satisfy daily needs Among these groundwater resources, 273 spreads beyond the international border of the neighboring countries fulfilling the requirements of the different nations (ISRAM, 2009). Rendering towards a report of Department of

Economic and Social Affairs of United Nations (UNDESA, 2009), total human residents of planet earth, which were estimated to be 6.9 billion in the year 2010, is increasing rapidly and is expected to grasp an overall huge figure of 8.3 billion total populations in the year 2030. Alongside additional socio-economic and ecological influences, the rapid surge in the total human population is a grave hazard to the depleting subsurface fresh water assets because the growth in population would generate industrial development, expansion in urban areas and enhanced agricultural actions, creating burden and pressure upon amount of subsurface water and is also decreasing overall eminence of subsurface water.

Several industrial, domestic and agricultural needs are fulfilled by groundwater which is a main source of freshwater. Due to domestic, industrial, anthropogenic and agricultural activities, the aquifers of that area have a greater threat and are more vulnerable regarding groundwater pollution and the effects triggered in the result of all these activities can end in short-term or these effects permanent and everlasting damage or loss of groundwater, the remediation of the subsurface water to purify it from the contaminants is a quite expensive and complex task. (Secunda, et al., 1998). The growing tendency of anthropogenic pressures on subsurface water has made it susceptible and the rapid surge in urban expansion and industrial development is producing a severe difficulty regarding the subsurface water pollution globally (Foster, 2003). The pollution of subsurface aquifers containing groundwater disturbs the ecological systems and is a hazard to human health beside the damaging direct and indirect socio-economic effects of groundwater contamination, (Milovanovic, 2007). All main causes which include chemical (chlorides, nitrates and sulfates etc.), physical (turbidity, odor and taste,) and biological (e.g. E. coli, microbes) can contaminate the groundwater. The quality assessment of the subsurface water examines all the main causes i.e. Chemical, Physical and biological (Thomas, 2003), but due to additional penetrating chance, easiness of pollution, and type of various anthropogenic actions causing an enormous quantity of harmful and poisonous chemical elements as effluents, the chemical factors have acquired relatively more significance in evaluation of groundwater quality and these chemical parameters are given more importance in subsurface water management practices. Human lives are exposed to risks and hazards when groundwater containing toxic elements, inorganic pollutants and traces of heavy metals is supplied via water supply systems for domestic and drinking needs. The polluted groundwater associated infections are wide spread in the third world and developing nations due to absence of appropriate evaluation of drinking water groundwater and also because poor management procedures. A report of the United Nation's World Health Organization (WHO. 2008) reflects that around 3.3million people dies in the third world and developing nation due to poor water supply, unhygienic or poor sanitation arrangements and huge share of these demises is because of the contaminated subsurface water intake as drinking water. The main cause of the surging groundwater associated ailments is linked to the point that the aquifers are relatively more susceptible to contamination triggering events as compared to the water bodies on surface.

In Pakistan, the subsurface water is considered as a dependable mean of water which is used for agriculture and drinking purpose but also for the industrial division. The groundwater satisfies around 35% of agricultural necessity. Additionally, the subsurface water is thought to be the most important mean of drinking water within Pakistan (Bhutta, 2005). The increase in human population caused unintended and mismanaged urbanization, enlargement of industrial and agricultural activities. Due to these consequences originating from surging population, the groundwater quality is under risk and threat in Pakistan. The dumping of industrial and solid waste along with sewage waste without any management and the use of insecticides, pesticides and chemical fertilizers and in the field of agriculture has amplified the probability of pollution of groundwater. The pollution of groundwater due to dumping of sewage is very common in Pakistan and due to this many shallow aquifers are compromised, particularly in cities (BGS, 2002). The condition severely serious in bigger cities and metropolitans of the country, where the major reason of groundwater contamination is industrial waste. The groundwater of industrial areas and states in various districts like Lahore, Gujranwala, Faisalabad and Haripur (Hattar Industrial State), is prone to pollution due to huge volume of contaminated unprocessed expulsion of toxic waste from various industries like textile, sports, tanneries, paper, pharmaceutical, leather, chemicals and garments etc. These metropolises and zones solely rely upon groundwater for consumption and the wastes from industrial sector contaminates the drinking water of people living in nearby areas (Mahmood et al., 2011).

The Haripur Plain in Hazara Division of Khyber Pakhtunkhwa is confined by the river Doar in the north, mountain ranges in the east and west, whereas the Haro river streams a little away from its southern border. The two rivers along with their several tributaries recharge the aquifers of the study area. Tarbela Dam also recharge the aquifers in its vicinity (Akram et al., 2011).

Because shallower reservoirs of groundwater are more susceptible to external events and vulnerable to pollution from the above unsaturated areas, the top strata of the study area are infested by toxic industrial seepages (World Bank, 2006; David, 1996). The study area i.e. District Haripur has been selected keeping in mind the susceptible nature of aquifer system presents in the area and industrial development producing toxic wastes which pollute the groundwater of the area. The groundwater contamination is very hard to identify and control as compared to the water pollution on surface (Todd, 1980). The groundwater pollution is a very serious issue which needs to be addressed immediately because when the groundwater is contaminated, the pollution is obstinate and it is very hard to reverse the effects due to the huge storage, extended residential times and unapproachability of underground aquifers (Foster, 2003). In this study an effort has been made to evaluate the susceptibility of the study area and to demarcate and outline the susceptible regions in the area that are more susceptible towards pollution.

1.2 Background

Although the aquifer is not polluted easily but if gets contaminated it is very hard to reverse the effects. The replacement of a deteriorating groundwater reservoir is usually very high and the damage may affect nearby local aquifers considered as alternatives. Remediation of local aquifers is next to an impossible task especially in developing countries, so it is very imperative to figure out which groundwater reservoirs are more susceptible to pollution (Kaur and Rosin, 2007). Additionally, flexible and undetectable feature of subsurface water pollution, the time taking, expensive purification methods and trouble of approachability towards polluted groundwater aquifers may bound the efforts to recover and remediate groundwater (Causape, 2006). Therefore, single promising task is to detect and identify the most vulnerable zones which are susceptible to contamination and to take steps to protect the aquifer. This task is achievable by following various aquifer vulnerability assessment methods and models.

Chilton (2006) and Margat (1968) introduced the term "Vulnerability" in France. Idea of susceptibility was founded upon main idea that "specific areas remain relatively extra susceptible towards pollution regarding subsurface water as compared to the other areas" (Vrba and Zaporozec, 1994). A new debate started regarding the natural obstacles present in the form of environmental and hydrogeological situations, to the aquifer pollution. However, numerous tries have been conducted to describe and explain the word susceptibility, but the clearest description is of Margat (1968) "The susceptibility towards pollution is probability of filtration plus dispersal of pollutants and impurities from surface to the groundwater level, in normal circumstances" (Vrba and Zaporozec, 1994). In 1993, word groundwater susceptibility was explained by the National Research Council as " ability and probability for pollutants to attain a certain and specific place in groundwater aquifer after entering at some locality from topmost aquifer".

The groundwater susceptibility may or may not be definite to a particular pollutant or contaminant. Regarding the groundwater susceptibility is depending on contaminant or not, the term vulnerability has been categorized in " specific/integrated" and "Intrinsic" or "natural ". According to a study of the European Community, Vrba and Zaporozec (1994) and Natural Research Council (1993). Term "natural vulnerability" or "intrinsic vulnerability" has been recognized as "the normal and vulnerability to pollution according to the physical features of area and environment" and "specific/integrated susceptibility" as "contamination reliant susceptibility or susceptibility of groundwater to a certain pollutant or land cover" (Ligget and Talwar, 2009).

The idea of susceptibility performs a significant role in evaluation of hazards especially in evaluation of subsurface water by polluted by human activities. Susceptibility is also milestone in advancement of water administration procedures (Worrall et al., 2002). Susceptibility evaluation offer an appropriate remedy for the pollution and provide a decision making instrument founded on appropriate quantitative as well as qualitative information of the primary aspects and parameters accessible at local level, in existence of professional conclusions and estimations. Susceptibility evaluations help mainly to determine the subsurface water security measures such as most ecological and public health benefits are accomplished at minimum price. Groundwater susceptibility evaluation gives a platform, combining the main e metrological, environmental and hydrogeological elements, in order to reform the information in the shape of a susceptibility map which acts as an instrument, useful for policy makers and town developers and is valuable for other government, private institutes/organizations. The practice of subsurface water susceptibility evaluation in decision making, development and strategy analysis differs and shows various characteristics as mentioned below:

(i) Counseling policy and decision makers about necessity of implementing precise management decisions to improve and lessen the groundwater contamination.

(ii) Clarifying the consequences and significances of decision making administration.

(iii) Providing help and direction regarding assigning water ration.

(iv) Informative judgements regarding land use procedures.

(v) Enlightening the community regarding pollution of subsurface water with the help awareness drives (National Academy of Sciences, 1993).

GIS has been combined by the susceptibility evaluation models to fix the problem of controlling and handling such a large sizes of data and in order to crack spatial distribution of several parameters. GIS is a tool that works and deals with huge quantity of data and assist in handling, controlling, mapping, evaluating and spatially arranging the information to help the course of susceptibility evaluation. Several groundwater susceptibility models like DRASTIC, SINTACS, EP1K, MODFLOW and GOD which are based on GIS act as important tool in susceptibility evaluation (Masoudi et al., 2009; Almasri, 2006; Samake et al., 2011; Breaban et al., 2012; Kuisi et al., 2006; Gin et al., 2012; Babiker et al., 2005; Lasserre et al., 1999; Awawdeh et al., 2008 and Lake et al., 2003)

Susceptibility assessment provides a thematic resultant map, representing various zones with changing susceptibilities. Regions with high, moderate and low susceptibilities are demarcated on the map according to the position of various parameters with the help of GIS tool. Such maps are easily readable and can represent the data more efficiently. The application of Geographic Information System as instrument can made it stress-free to deliver data to all strategy makers, town developers and geological and environmental scientists etc.

1.3 The Groundwater susceptibility evaluation methods.

The groundwater susceptibility evaluation is built on elementary concept that the physical setting can offer aquifer some shelter from pollution (Ligget and Talwar, 2009). Numerous methods have been established in order to assess susceptibility of groundwater, including Process based, numerical and overlay - index procedures (Ravinder et al). In process based methods, recreations of methods have been considered, these simulation models are used for the detection and approximation of pollutant movement and relocation (Barbash and Resek, 1996).

1.3.1 The Process based methods

The process based methods are considered very useful to evaluate susceptibility of subsurface water. The process based methods include enormous number of intricacies while measuring the susceptibility of any region. These methods keep in work on and contemplate intricate chemical and physical procedures at comprehensive level. These models use deterministic methodologies to calculate travel time, pollutant absorption, and duration of pollution to compute regions of high and low susceptibility in spite of providing simple comparative standards as an answer.

These models are distinguishing from other vulnerability assessing approaches as they calculate pollutant passage and transport in space and time, because of the integration of various chemical, physical and microbiological procedures that govern outcome or passage of pollutants in saturated and unsaturated areas. (Almasri, 2008).

The process based methods may comprise of mathematical models (For example MODFLOW SAAT and SWAT) or analytical solution (Ligget and Talwar, 2009). Likewise, other models such as Attenuation Factor (AF) (Rai et al, 1985) or Behavior Assessment Model (BAM) (Jury and Ghodrati, 1998) may also be implemented for assessment of subsurface water susceptibility.

Normally, it is the task and concern of scientists and researcher to use, simulate and develop these process based models and these scientists then recommend the appropriate method to be implemented to the decision makers.

1.3.2 The Statistical methods

Statistical techniques rely on ambiguity. These techniques vary from regression analysis to descriptive statistics refined (Mair and El-Kadi, 2013). Statistical techniques effort to represent a quantitative threat framework illustrating a numerical association among a set of factors and existing information, and are measured essential in the susceptibility evaluation of groundwater, also termed as "response variables" i.e., detected pollution, ecological situations, land cover/use configuration, aquifer conditions etc. In statistical methods, presentation of contaminants beyond threshold standards are associated to some likely disturbing parameters with possibilities.

Teso et al., (1996) generated a Logistic Regression (LR) method which is the most common model of this type and has been implemented broadly around the globe in the field of susceptibility assessment to tackle a variety of pollutants e.g. nitrates, chlorinated solvents, and insecticides both separately (Tesoriero and Voss, 1997; Frans et al., 2012; Nolan et al., 2002) otherwise else applied with further process-centered simulations (Mair and El-Kadi, 2013).

1.3.3 The Overlay-index methods

The overlay-index techniques are among very frequently used approaches in assessment and evaluation of groundwater susceptibility. The overlay procedures apply a collection of main causative parameter and develop map of each parameter separately.

Afterwards the separately developed maps are overlaid on one another to generate an ultimate and final map, showing and depicting zones with variable susceptibilities. On the other hand, in Index techniques, the most related parameters disturbing subsurface water susceptibility are nominated, then they are allotted particular rating with respect to various classes inside specific parameter along with weight given to related parameter rendering its rank and to yield an index, called the "vulnerability index". The approaches are determined by accessible information from various respective government or private departments. These approaches rely on proficient results as the ranking and weighing of ranges of parameters and their respective sub groups are not sufficiently effectual without knowledgeable estimations. The approval of index techniques is because of the price efficiency, as calculations are built on freely accessible information, categorizing outcomes and easy execution. Numerous approaches are developed by various institutes. For example, DRASTIC method devised by Aller et al in 1987, SINTACS developed by Civita in 1993, GOD formulated by Foster in 1987 and EPIK created by Doerfliger et al in 1999.

The mentioned methods and models have been used extensively (Jessica et al,) but DRASTIC has received more approval in the susceptibility evaluation since its establishment and development by Aller et al, in 1987 due to its reliance on the data available, rating and weighing structure and relatively easy execution of outcomes.

The GIS based DRASTIC method, established in result of a joint contract among the NWWA and EPA and in United States of America (Aller et al.,1987) remains among the very frequently applied approaches to evaluate groundwater susceptibility of groundwater to pollution (Babiker et al., 2005; Masoudi et al., 2009; Samake et al., 2003; Girt et al., 2012; Breban et al., 2012). DRASTIC is an overlay-index technique, so it depends on the accessible information and data of several hydrogeological parameters. Focal model behind the DRASTIC technique was availability of natural obstacle with some contaminants reduction capability in the shape of hydrogeological situations, which are demarcated by Aller et al study in 1987 " a compound explanation of main parameters which influence or regulate the movement of subsurface water into and out of a region". The word DRASTIC is basically an abbreviation demonstrating the factors;

- Depth to water table
- Net recharge
- Aquifer media
- Soil media
- Topography
- Impact of vadose zone
- Hydraulic conductivity

Since the preparation of DRASTIC model, it has been implemented extensively all over the globe for marking out the region and areas with variable susceptibilities concerning the surface pollution. DRASTIC has been used for various evaluations stretching from a susceptibility evaluation of town to whole geological basin. Samake (2003) applied this method to estimate core susceptibility of near surface aquifers in the Linfen basin. Evaluation executed by information gathered from well boreholes, interpolation of yearly net recharge of aquifers, metrological data, and the Topography data. Confirmation of resultant map attained by using DRASTIC model was accomplished by the factor analysis and map removal sensitivity analysis were implemented. In Japan, the Kakamigahara heights groundwater system was evaluated for its susceptibility with the help of DRASTIC method along with Geographic Information System applied for a technique (Babiker et al., 2005). DRASTIC index was generated through merging numerous map layers. The data examination and model execution were accomplished by help of a GIS tool. The study region was separated in 3 sectors which are high, moderate and low. The western region of study area was termed high, due to extraordinary susceptibility of aquifer whereas the area in the east was termed as moderate. Ratings allotted were between 1 to 7 where the highest rating were given to the east region of Kakamigahara heights. The Drastic model with the application of GIS has been implemented in China's Beijing area in order to assess susceptibility of ground water (Wang et al., 2012). The DRASTIC method is implemented in various parts of Punjab in Pakistan like Sialkot and Lahore. Khan et al., used Drastic model in Sialkot, Punjab. However, no research has been conducted on aquifer vulnerability evaluation by

DRASTIC model in Khyber Pakhtunkhwa Pakistan. used GIS based DRASTIC method is implemented by Jha et al., (2005) for susceptibility calculation in Ranchi, Jharkhand, India. DRASTIC model is implemented in various areas by Indian experts.

GIS based DRASTIC method was applied in order to evaluate near surface and shallow aquifer susceptibility in the area of Aligarh, a susceptibility map was generated as a product research. Due to the accumulation of excess and rainwater in low land regions of the area because of absence of a natural mechanism of drainage, the specific area was nominated for susceptibility evaluation of the aquifers. For analysis, the weighing and rating system for each parameter was adopted from Delphi system established by the research of Aller et al. (1987). Professional's estimations considered for determining the risk level. Sensitivity analysis with subsurface water pollution examination were among approaches embraced for confirmation (Rahman, 2008).

1.4 Aims & Objectives

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

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

1. To generate input thematic map layers of each hydrogeological parameter for DRASTIC model.
2. To execute susceptibility analysis for aquifers of District Haripur.
3. To recognize future approaches to control groundwater contamination and susceptibilities.
4. To offer a basic framework and technique for resource allocation and land use planning.

CHAPTER 2

DESCRIPTION OF STUDY AREA

2.1 Introduction

Haripur District lies in Hazara Division of Khyber Pakhtunkhwa province in Pakistan. The Haripur Plain is surrounded by the river Doar in the north, mountain ranges in the east and west, whereas the Haro river streams away from its southern border. Presently, Haripur District is distributed into three tehsils, these tehsils are further partitioned into 45 Union Councils among which 15 Union Councils are urban. Haripur is the central city of the District, having Buner and Swabi to the west, from 65 km north of Islamabad . It is in a hilly plain region at an elevation of 1,706 feet. Haripur was declared as district on July 1, 1991.

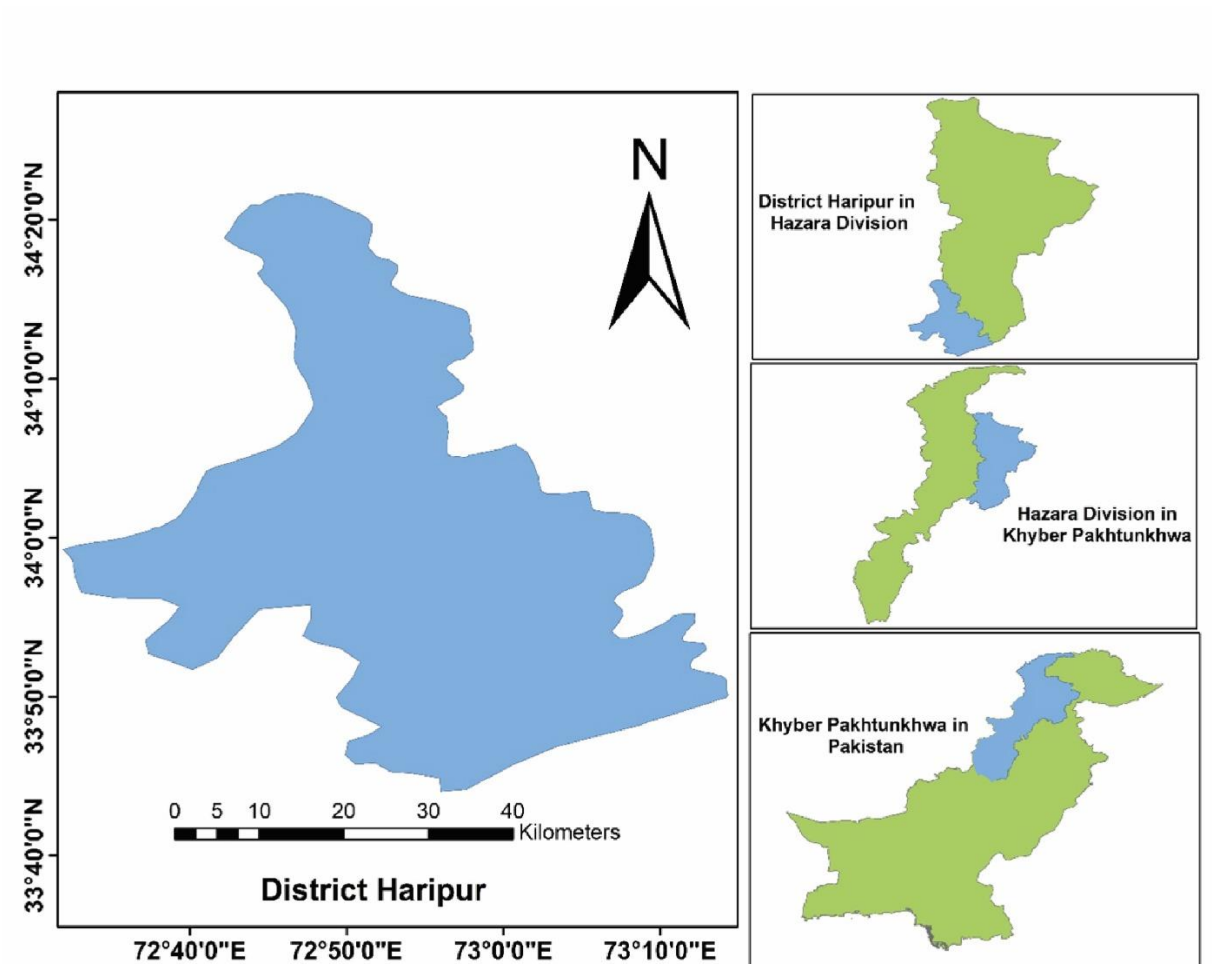

Figure 2.1. Location Map of District Haripur

2.2 Geography

Haripur district is a small valley bounded by highlands from north and east. In its south Khanpur Dam and in the west world's biggest earthen dam, Tarbela Dam and Ghazi Barotha canal are situated. Haripur has 3 tehsils, Haripur, Ghazi and Khanpur. Abbottabad district is in the East whereas Margalla Hills Range is in the South, Swabi district is in the west whereas Buner and Mansehra districts are in Northwest and Northeast respectively. Haripur District is located at latitude 33º 44' to 34º 22' north and longitude 72º 35' to 73º 12' east, and is about 610 meters above the sea level. The total area of Haripur is about 1938 kilometers square. (Calculated by GIS unit, Soil survey of Pakistan, Regional Office, Peshawar).

2.3 Communication

The study area is linked by good metaled road system with surrounding major cities. The area lacks air service. The Taxila-Havalian railway line, diverging off the Peshawar-Karachi main railway line, delivers the rail linkage. The area is joined by road with Abbottabad, Rawalpindi, Attock, Nowshera, Swabi and Tarbela Dam. Central settlements of the district are generally connected with metaled roads, however a network of unmetaled roads joins minor villages.

2.4 Climate

Climate of Haripur differs from sub humid to humid subtropical continental. In the hilly region of study area, it diverges from place to place dependent upon the elevation. Main share of the yearly precipitation is received during monsoon, whereas snowfall and winter rains are received from December to March. The normal rainfall fluctuates from 770 .7 mm in the central and western parts to about 1366.18 mm in the hilly territory from north east to south east of the region. Frost come about commonly during the months of December, January and February and damages the fruit orchards, vegetables and fodder fields. Average monthly climatological figures of temperature and rainfall of the Haripur is given in Table 2.1.

Table 2.1. Annual Mean Temperature and Precipitation

Parameters	**Monthly means**													
Mean Maximum temperature (°C)	Jan.	Feb.	Mar	Apr.	May.	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Mean Annual	Total
	16.3	19.4	24.4	29.2	35.7	40.7	37.2	34.6	34.1	30.7	24.9	19.8	28.9	-
Mean Minimum temperature (°C)	3.9	6.3	10.4	14.9	19.4	24.7	25.0	24.0	21.7	15.8	9.4	5.8	15.1	-
Mean temperature (°C)	10.1	12.8	17.4	22.0	27.5	32.7	31.1	29.3	27.9	23.2	17.1	12.8	22.0	-
Precipitation (mm)	65.5	38.4	65.0	40.6	23.1	5.8	163.6	187.2	106.4	25.1	16.5	33.5	-	770.7

2.5 Geology

The study area has a difficult and complex geological history of erosional/depositional cycles and orogenic disturbances, which have resulted in the estimation of five main landforms and eleven key soil-geological mapping units.

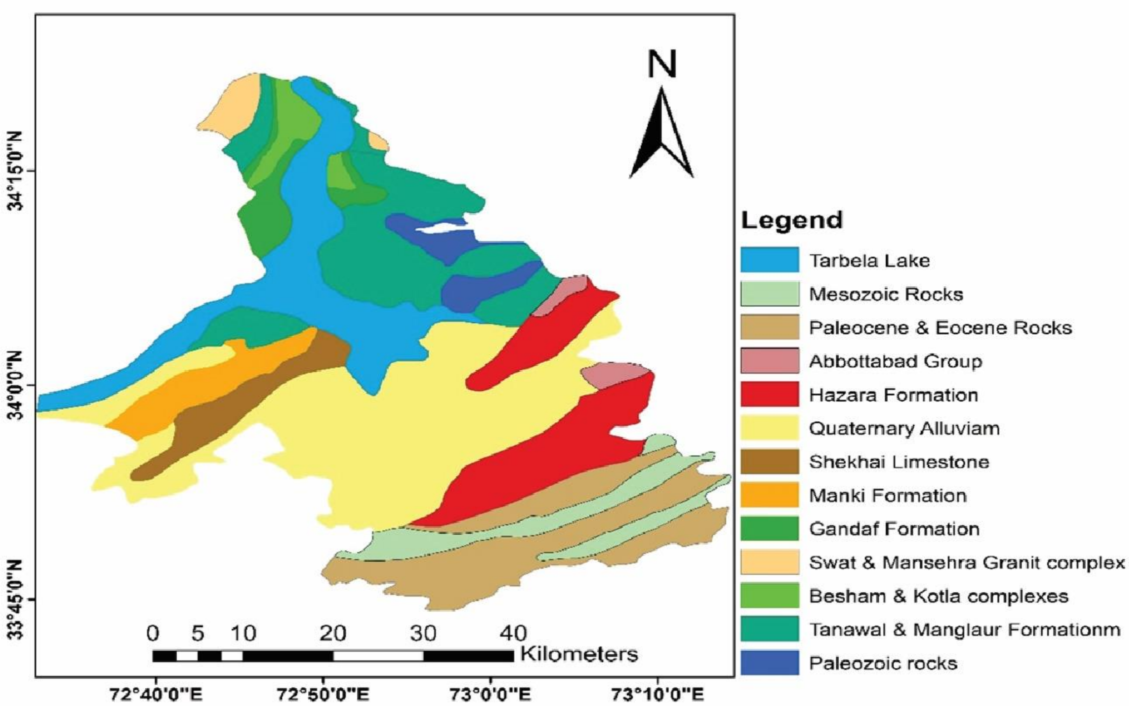

Figure 2.2. Geological Map of District Haripur

Table 2.2. Generalized stratigraphic section of Hazara Basin, Khyber Pakhtunkhwa, Pakistan (After Latif, 1970a)

Age		**Formation**	**Lithology**
Cenozoic	Miocene	Murree	Sandstone, Siltstone and Claystone
	Eocene	Kuldana	Shale, gypsum with interbeds of limestone
		Chorgali	Limestone with interlayers of shale/marl
		Margalla Hill Limestone	Nodular limestone with interbed shale/marl
	Paleocene	Patala	Marly shale with few thin limestone beds
		Lockhart	Nodular limestone with occasional marl/shale
		Hangu	Siltstone, sandstone, shale, bituminous shale
Mesozoic	Cretaceous	Kawagarh	Sandy limestone with shale interbeds
		Lumshiwal	Sandstone, siltstone with shale interlayer
		Chichali	Gluconite shale, sandstone
	Jurassic	Samanasuk	Limestone with intraformational conglomerate
		Datta	Calceraous sandstone with fireclay and shale
Paleozoic	Cambrian	Abbottabad	Dolomite with sandstone, shale and conglomerate
Pre-Cambrian		Hazara	Slate, Phylite and shale with minor Limestone.

2.6 Regional Tectonic Setting

The Tethys Ocean was closed and the evolution of the Himalayan orogeny happened due to the result of the collision of Indo-Pakistan plate with the Kohistan island arc and the Eurasian plate (Bender and Raza, 1995). The consequential mountain is ranging from Nepal to Afghanistan and about 3500km long (Bender and Raza, 1995). In Pakistan this mountain belt is known as NW-Himalayas Fold-Thrust Belt (Shah, 1977). A variation of sedimentary, metamorphic and igneous thrust up to the surface in the form of inflated mountain peaks due to the impact. These rocks sequences are highly faulted and folded. Towards north in the Himalayas, the force of deformation increases. These rocks have age ranging from Precambrian to Recent (Shah, 1977).

Higher Himalayas, Lesser Himalayas and Sub- Himalayas are the three main parts of the Himalayan Mountain range. In the NW-Himalayas Fold-Thrust Belt, these units are based on the bounding thrust faults (MMT, MCT, MBT, SRT) and the nature of rock association. Sub Himalayas is known to be the bottommost part of the Himalayas. In the north, it is surrounded by Main boundary thrust (MBT) whereas in the south there is Salt Range Thrust (SRT). Sub-Himalayas is mostly entailed of sedimentary rocks that differs from Precambrian-Recent in age. Lesser Himalayas lies to the north of the sub-Himalayas which is circumscribed in the north by Main Central Thrust (MCT) and in the south by Main Boundary Thrust (MBT). Ranging from Cambrian to Miocene, the sedimentary and metamorphic rocks make this region of Himalayas. Higher- Himalayas is the northern most part of the Himalayas which is bounded to the north by Main Mantle Thrust (MMT) and to the southward by Main Central Thrust (MCT). Cambrian metasedimentary rocks and Precambrian-Cambrian igneous rocks are mainly present in this part of the Himalayas (Shah, 1977).

Among Indian and Eurasian plates, Kohistan Island Arc was arbitrated during the collision. Above the higher Himalayas, the Kohistan Island Arc is present, and it consists of plutonic and metavolcanics rocks. Kohistan Island Arc and Karakoram block in the north is disconnected by Main Karakoram Thrust (MKT) (Shah, 1977).

Southern Hazara Basin has historical and very multifaceted structural geology. Many thrust faults forced older rocks over younger rocks. Variation of microscopic to mesoscopic faults and folds have mixed the sedimentary successions of the area and resulting in a rough topography (Aman Ullah, 2017).

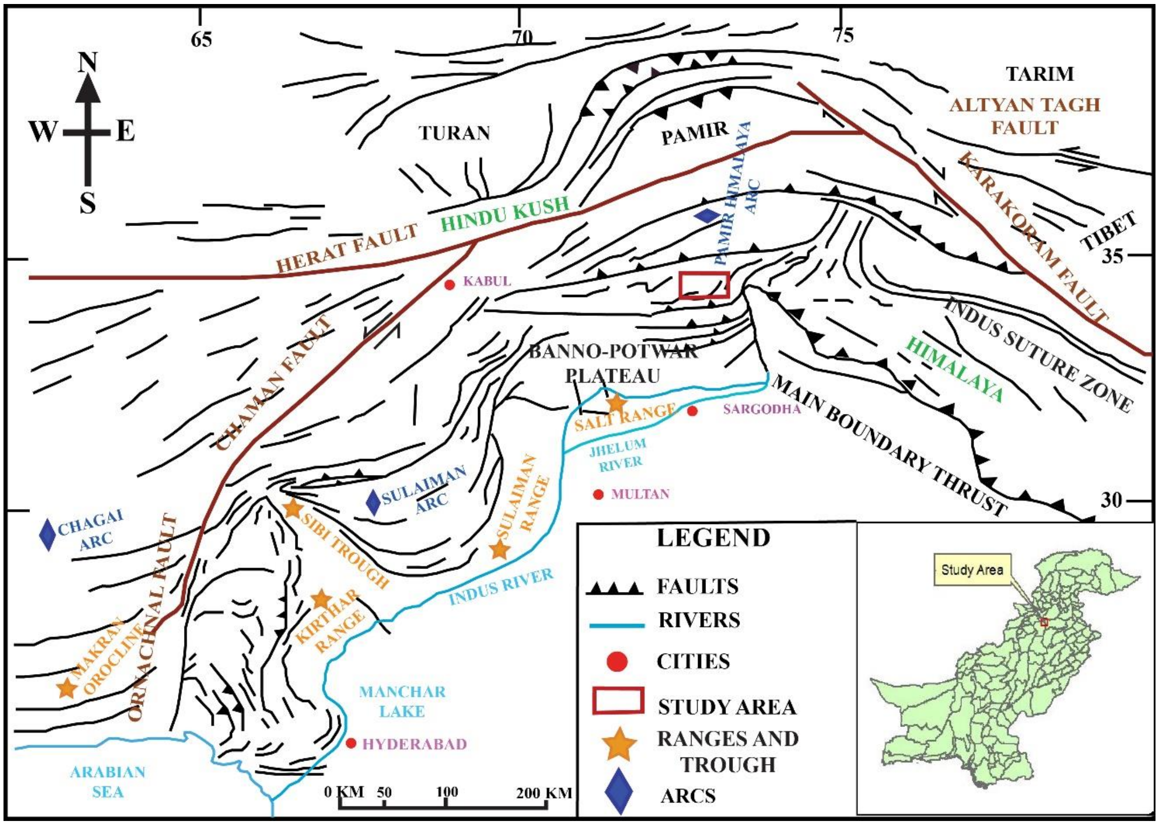

Figure 2.3. Regional Tectonic Map of Pakistan (Modified after Rahman and Ali, 2016).

2.7 Residuum

From the soil point of view minerologically alike rocks regardless of their age. could yield one type of soil. Thus, several types of rocks in the study area have been assembled into eight units, each of which comprises of minerologically related rocks. These units are as follows:

1. Granite etc.
2. Limestone, schist etc.

3. Sandstone, quartzite etc.
4. Sandstone, limestone and phyllite
5. Quartz schist, marble, graphitic schist and gneisses
6. Sandstone, shale and phyllite
7. Shale, slate and phyllite
8. Marl and calcareous red shale

2.8 Landforms

There are five main landforms in the study area which are as follows:

i. Mountains
ii. Piedmont plains
iii. Loess plains
iv. Redeposited loess plains
v. River plains

2.9 Hydrogeology

Key source of the recharge to groundwater aquifers is the precipitation dropping on the watershed of study area. The recharge happens due to filtration from streams, straight infiltration of the precipitation, groundwater influx from the consolidated rocks and discharge from irrigated land. The groundwater in the area is generally safe for livestock consumption, irrigation and domestic use. for agricultural use tube wells, open wells and canals are used, which offer water primarily for irrigation and partially for livestock. In relatively drier regions, water is stored in pools for the requirements of the native residents. Springs and tributaries are the central source of water for drinking and other local necessities. Extended dry season cause water scarcity in some regions of the area, particularly the loess plains and the upper mountain slopes. The energy of the water flowing down hill is applied at various places for running turbine which runs small flourmills.

2.10 Hydrology

The chief sources of surface water in the region are streams and tributaries originating from the highlands in the northeast and flowing from northeast to southwest in plains. The Haro River and its offshoots primarily drain the study area in the south. The Haro river originates as two major branches i.e. Dhand Haro and Karral Haro, rising near Muree and Nathiagali respectively. The two branches of Haro river junction near the Jabri Forest Rest House and flow as one westward. Haro river has a deep bed due to nonstop down cutting to regulate its gradient with the level of the Indus River into which it drains. A dam has been built up on the Haro River at Khanpur. The deposited dam water is utilized for irrigation and also provides for the drinking and industrial necessities of the Islamabad. The catchments area in the north and southeast is completely mountainous. With time, the hydrological forces along the precipitation slope have caused development of various deeply cut nullahs along north-southern direction. All these nullahs discharge into Indus River. The study area is ultimately drained by Indus River which rises in the Himalayas and is linked by various tributaries before and through its flow through the area. The river Indus has been dammed at Tarbela to build a reservoir spreading over about 260 Km^2. It is one of the major storage reservoir on earth.

2.11 Industrial Activities

Majority of the industrial Activities of District Haripur occur in Hattar industrial State. It was established in 1985-86 and covers an area of 1,063 acres. The industrialized state is composed of 215 active, 378 closed, 162 under construction and 98 industrial divisions. There are various industries including chemical, marble, poultry feed, textile, cement, vegetable oil manufacturing, paper, steel, pharmaceutical, and beverages industries.

These manufacturing businesses are major cause of contamination in the region according to a report of EPA. Apart from dangerous emanations by marble, fiberglass, cement, poultry feed and steel industries, majority of the industrial units do not have waste management services. Due to the absorption of water by the land, the residents are at a larger threat of dangerous ailments such as bronchitis, brain tumor, bone deformation, kidney, lung and skin diseases. Inhabitants also protest about bad smell of the water, because of decay of solid waste and unstable organic combinations. (Sadaqat, 2011).

2.12 Population

Rendering to the Pakistan Bureau of Statistics and US Bureau of Census, the district Haripur of Khyber Pakhtunkhwa KPK population is as follows:

Table 2.3. Population Data of District Haripur

NAME	STATUS	POPULATION (Census 1972-09-16)	POPULATION (Census 1981-03-01)	POPULATION (Census 1998-03-01)	POPULATION (Census 2017-03-15)
Haripur	District	417,561	479,031	692,228	1,003,031

As per 2017 census, 50.3% of the total population is female, where as 49.4% are male (Statistical Bureau of Pakistan, 2017).

Table 2.4. Population Data of District Haripur (Statistical Bureau of Pakistan, 2017)

GENDER (2017)	
Males	498,481
Females	504,483
Transgender	67

Table 2.5. Population Data of District Haripur (Statistical Bureau of Pakistan, 2017)

URBANIZATION (2017)	
Rural	870,007
Urban	133,024

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Method

The study assesses the subsurface water contamination in the district Haripur and regarding this problem a GIS based model i.e. Drastic model is adopted for delineating and assessing high vulnerable areas regarding groundwater pollution. As stated in earlier chapter, the GIS based DRASTIC model was generated and developed by EPA and NWWA of United States in 1985 (Aller et al, 1987). GIS based DRASTIC method has been acquiring serious significance in the field of groundwater management due to its dependency on enthusiastically established information and its modest indexing classification. Chief purpose of DRASTIC method is to demarcate zones of changing susceptibilities regarding contamination in shape of map and to employ susceptibility map for numerous groundwater controlling tasks. Term DRASTIC is given to proposed model due to 7 parameters used in this model which are hydrogeological and topographical features, as specified by Aller et al (1987). These parameters include:

1. (D) Depth to water table
2. (R) Net recharge
3. (A) Aquifer media
4. (S) Soil media
5. (T) Topography/ Slope
6. (I) Impact of Vadose zone
7. (C) Hydraulic conductivity

Seven layers are generated and produced from these seven parameters and are converted in the form of a maps to assess subsurface water susceptibility in study area. Aller et al., (1987) has established the DRASTIC model by means of four rules:

I. Pollutant is led into 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

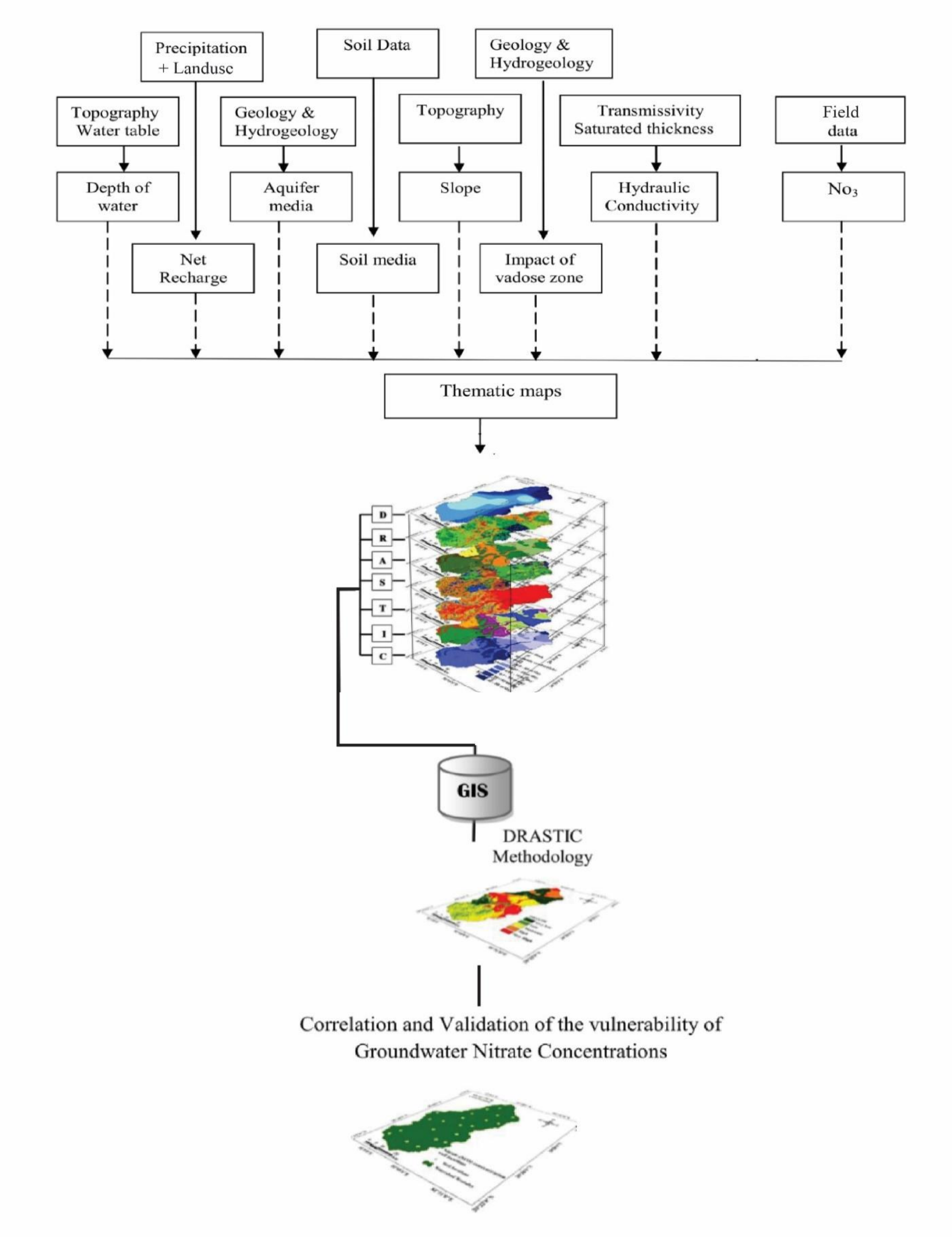

Figure 3.1. Flowchart of Methodology.

There are various models and methods to assess Groundwater susceptibility as discussed earlier but the DRASTIC model is carefully chosen due to its capability to manage various factors and parameters for evaluating susceptibility of groundwater, confirming the accurate and operational symbolization of all conceivable parameters implicated in subsurface water susceptibility. Additionally, the index generated cannot simply be classified into various classes but they can also be plotted with the assistance of any aiding instrument e.g. GIS or ILWIS. Accessibility of information is similarly one of the motives for the choice of DRASTIC method.

The DRASTIC model is comprised of four chief parts.

3.1.1 Weights

A certain weight has been allotted to every separate factor rendering to its significance and relative impact and part in pollutant transference to underground water reserve. The weights vary from I to 5, though the smaller value of weight will signify that the factor is of less importance and has a meek part in subsurface water susceptibility, however the high value of weight is depiction of more importance (Babikcr et al., 2005). For instance, a high value of "5" has allotted to factor D, i.e. depth to water due to motive that depth has significant part in subsurface water susceptibility. If the D, depth to water is larger, then there would be less possibility of pollution nevertheless it would be polluted more if water is shallow and close to ground surface. Correspondingly weight "1" has been allotted to topography parameter, which denotes slope, due to its small influence in subsurface water susceptibility. Slope will command type of overflow. Gentler the slope, higher would be likelihood of subsurface water pollution as overflowing water will withstand for a long duration of time.

These weights were established by means of Delphi system, in which observations or opinions of numerous specialists were taken on basis of their knowledge and capability (Aller et al., 1987). Table 3.1 is demonstrating 7 factors with their pre assigned weights.

3.1.2 Ranges

Each factor is classified in diverse media type, a class identified as 'Ranges'. These specific classes or ranges are defined to enable susceptibility evaluation procedure for regions with changing rock types, lithology and hydrogeological features. Calculation of separate class has been executed in association with others to elucidate relative significance of each class in subsurface water contamination possibility.

3.1.3 Ratings

Every individual range of specific factor has allotted a specific number, demonstrating its importance in accordance with subsurface water contamination possibility (Aller et al., 1987). The procedure of allocating specific rank to a range rendering to its part in groundwater contamination is identified as "Ratings". The values of Ratings allotted varies from 1 - 10. Small value indicates that certain range of a hydrogeological factor has little ability to contaminate subsurface water as associated to a range with greater rating that displays that the specific media type has additional capability to pollute subsurface water. e.g. Rating 8 has been allotted to depth stretching up to 25 meters because there is more probability of pollution in subsurface water if water is shallow. Conversely, a rating of 2 has been allotted to depth larger than 45 meters due to its minor vulnerability to contamination.

Table 3.1. Hydrogeological Parameters of DRASTIC with description and assigned weights. (Aller et al., 1987)

Parameter	Description	Relative Weight
Depth to Water Table (D)	It is the depth of groundwater from the earth surface and represents the depth of material that would come in contact with the contaminant during its movement towards the groundwater. Greater the depth, lesser would be the likelihood of contaminant to reach groundwater while the situation will be inverse for shallow, aquifers.	5
Net Recharge (R)	It is the total amount of percolating from surface to ground and reaching to the water table. Being a mean of transportation or transporting agent, recharge decides the amount of leaching contaminants.	4
Aquifer Media (A)	It represents the nature of material present in the saturated zone, acting as an aquifer. This media behaves as an attenuating body. If the grain size is large, Permeability will be higher; larger would be the certainty of pollutants reaching the groundwater and lower would be attenuating capacity of the aquifer.	3
Soil Media (S)	It shows the top most layer of unconsolidated material. The permeability of the material not only controls the net recharge but also the movement of pollutants. The soil material with smaller grain size will be more able to hinder the pollutants movement as compared to material with larger size, hence making the aquifer less vulnerable.	2
Topography (T)	It refers to the slope of the area. The slope will decide nature of runoff, carrying pollutant, and its retaining duration on the earth surface. Steeper the area, greater will be the runoff retaining duration and more will be the percolation resulting in the higher vulnerability.	1
Impact of Vadose Zone (I)	It represents the properties of media present in the unsaturated zone lying above the aquifer. The nature of material in the vadose zone will determine the attenuation capacity, depending on its permeability.	5

Hydraulic Conductivity (C)	Its represents the rate at which the aquifer transmit the water, hence determining the rate of polluted groundwater flow under some particular hydraulic gradient.	3

3.1.4 DRASTIC Index (DI) Calculation

DRASTIC index (DI) can be estimated with help of the already assigned weights, ranges and ratings allotted to each hydrogeological parameter with the help of simple linear equation mentioned below:

DRASTIC Index DI=Dr * Dw + Rr * Rw + Ar * Aw + Sr * Sw + Tr * Tw + Ir * Iw + Cr * Cw (1)

Where:

Dr = Assigned rating to range of depth to water

Dw = Weight of depth to 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 the 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

By calculating DRASTIC index with above equation the result will symbolize the comparative susceptibility of the subsurface water concerning any pollution. When the (DI) DRASTIC index is calculated, more vulnerable areas towards contamination becomes easier to demarcate as compared to areas which are less susceptible. The greater the susceptibility index, more will be the vulnerability or possibility of the underground aquifer towards contamination whereas the DI DRASTIC index with smaller values will represent relatively low susceptible areas. One point should be kept under consideration that, if the susceptibility index of some specific zone in study region is low, it doesn't imply that there is no possibility of subsurface water contamination and specific zone cannot be reflected as unsusceptible area. In fact, less index value is demonstration of the fact that specific zone is in the area having relatively less susceptibility to pollution (Almasri, 2008). Additionally, the (DI) DRASTIC index can be classified into several ranges or classes e.g. low, moderate, medium, high and very high, relying on the result generated from the DI of study area, susceptibility index range and the task for which susceptibility map is generated.

3.2 Data collection

In order to perform the susceptibility calculation procedure, preparing input data of factors involved in DRASTIC is essential and this procedure needs handling of huge quantity of data. Conferring to the factors involved in the DRASTIC method, efforts were made to gather the data. The required data was of different types for each parameter and was obtained from various government, semi government as well as private establishments. Thorough field examinations were carried out in the study to gather and to confirm some information e.g. depth to water or geographical locations and locations of water wells. Type of data gathered has been distributed in two groups which are primary and secondary data.

a. Primary data

It was gathered from numerous field surveys in the study area and by strata charts and well logs. The well logs, strata and lowering charts were obtained from PHED, Soil Survey of Pakistan and Survey of Pakistan.

b. Secondary data

The secondary data was obtained from various research articles, reports, census, government data, official and non-official archives of various administrations and organizations. Below table 3.2 is presented which illustrates the type and nature of information and data of certain type of hydrogeological factor. The source of data is also mentioned in the table.

Table 3.2. Type and nature of Data collected from various organizations.

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	TRMM Raster data, Land use shape file	NASA, Literature Review
3	Aquifer Media	Well Log, 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

3.2.1 Desk study and professional judgments

Gatherings were organized with various researchers, specialists, and authorities concerning data acquirement, documentation of data source and analysis. As the GIS based DRASTIC model is founded upon Delphi system, therefore remarks and explanations were reserved from experts like hydrologists, hydrogeologists and other professionals of the subject regarding outlining the ranges of hydrogeological factors.

3.2.2 Field surveys

Field visits were held in District Haripur to pinpoint positions of water wells and to learn about depth of water column on several positions. The field visits were conducted to obtain geographical coordinates of water wells and to identify them as the PHED data was of no importance without the location of wells with GPS data.

Several water samples were also collected during the field surveys to test them for Nitrate parameter.

3.2.3 Literature survey

In order to study about the research topic and its basics a comprehensive literature review was conducted and numerous research articles, reports, drafts, and official and nonofficial statistical data were studied. The literature review was conducted in order to:

1. Gather a basic outline for GIS based DRASTIC model
2. Recognize and realize the complication of the study area
3. Apprehend the kind, function, achieving and application of the DRASTIC model.
4. Gather information and data for study area depiction
5. Gather data for numerous factors involved in the research process

3.3 Softwares and tools

For this research the Geographic Information Systems was employed to envision spatial dissemination and distribution of susceptibility index. Numerous GIS tools were used including QGIS 3.2.3, Surfer, Google Earth and ArcGIS 10.4 to analyze and visualize the gathered information. However, the DRASTIC index may also be evaluated manually nonetheless in this study as an alternative of manual estimation, data gathered was transformed in thematic map layers by means of GIS. MS Excel was employed to organize all gathered information in tabularized manner. The use of GPS was applied in field visits in order to pinpoint precise site of water wells. Assistance was taken from Google Maps, Google Earth and both tourist and topographic maps, obtained from Survey of Pakistan.

3.4 Generating Layers for DRASTIC Factors

With help of gathered data, thematic map layers of DRASTIC factors were created. Procedure of generating layers contains the analyzing of accessible data to produce factors layers in the form of raster format. GIS is the instrument applied to express information in raster format. In GIS numerous interpolation methods are available to generate the spatially dispersed data about respective hydrogeological factor. Details of each layer generation process is discussed below.

3.4.1 Depth to water (D)

Subsurface water data of the area of research was gathered in the form of well logs, strata charts and lowering charts from various sources including (PHED) Public Health Engineering Department as stated in the table 3.2 above.

The data obtained from Public Health and Engineering Department was in documented form and all essential information regarding the well like depth, Geographical Coordinates, test conducted etc. were mentioned on each document. This data was then converted into tabular form in Microsoft Excel in order to import it into ArcGIS.

The comprehensive MS Excel sheet comprising information of depth to water is included in appendix. Numerous interpolation techniques were employed containing (OK) Ordinary krigging, (SK) standard krigging, (UK) Universal krigging and (IDW) Inverse Distance Weight. The most appropriate technique was chosen according to RMSE values. Technique used with their values is mentioned.

3.4.2 Net Recharge (R)

The (R) Net recharge denotes whole quantity of water from precipitation or other source in the area and penetrating to groundwater of the area. In order to calculate the Net Recharge rate, Land Use and Mean Annual Precipitation. The Land Use data was obtained from a report during literature survey and was refined and converted into vector format. The Land use map is attached in appendix II. The net recharge was calculated by using two parameters i.e. land use data and mean annual precipitation data. Weighted overlay analysis of these two parameter was executed to obtain a resultant map of net recharge as the land cover and mean annual precipitation both play a very important role in determining the net recharge of an area. The resultant thematic map layer was classified in 5 classes.

3.43 Aquifer media (A)

An alternate approach was used in order to get information of the Aquifer media due to unapproachability of subsurface geological map i.e. strata log analysis. The strata charts and well logs were acquired from Public Health and Engineering Department Haripur. The strata charts contained the subsurface data. The aquifer media was extracted and noted from the strata charts with the help of depth to water column information. Separate sheet was organized on MS Excel for aquifer media of each well and is given in appendix III. The interpolation procedures of (OK) Ordinary Kriging, (SK) Standard Kriging, (UK) Universal Kriging and (IDW) Inverse Distance Weighting, were used to generate raster layers. Inverse Distance Weighting Interpolation method was used for Aquifer media as it has the least root mean square error (RMSE).

The data of Aquifer media was interpolated using Normal transformation.

3.4.4 Soil Media (S)

For preparation of this layer, Soil map of district Haripur was obtained from literature survey. It was georeferenced and digitized in ARCGIS and the relevant soil report was attained from Soil Survey of Pakistan, Peshawar. Soil report was used to calculate and classify the soil texture of each class and a final soil media distribution map was generated. The Soil Map of District Haripur prepared in ARCGIS is given in the appendix.

3.4.5 Topography (T)

The next parameter involved in the DRASTIC model is Topography. Slope was extracted from Digital Elevation Model (30-meter resolution) of the study area obtained from USGS (SRTM) Shuttle Radar Topography Mission data. Using ArcGIS slope was extracted from Digital Elevation Model.

3.4.6 Impact of Vadose Zone (I)

The Vadose Zone has an impact on Groundwater pollution susceptibility. The Vadose zone data is obtained from the well logs and strata charts gathered from Public Health and Engineering Department and ranged in accordance with media types. After analysis of well logs, Data sheets were created on MS Excel and are attached in in appendix V. The interpolation methods of (OK) Ordinary Kriging, (SK) Standard Kriging, (UK) Universal Kriging and (IDW) Inverse Distance Weighting, were used to generate raster layers. Kriging Interpolation method was used to generate thematic layer of Aquifer media parameter.

3.4.1 Hydraulic Conductivity (C)

Various Annual reports of Public Health and Engineering Department and Water and Power Development Authority (WAPDA) were used in order to get Hydraulic conductivity of various wells. The hydraulic conductivity data was organized in MS Excel sheet. Interpolation methods i.e. IDW, OK, UK and SK were used. Root mean square error was the reason behind the selection of best appropriate interpolation method. The kriging interpolation method was used for hydraulic conductivity.

The ranges and rating method was taken and inspired from Aller et al (1987).

3.5 Overlay index analysis

DRASTIC index can be calculated manually but the Overlay and Index method was used in this study. The overlay method is reinforced by notion of integrating layers of each factor of DRASTIC. Each factor or parameter is assigned a specific Weightage with the ratings allotted for their characteristics for index calculation (NRC, 1993). Additionally, rationality of layers generated with the help of this technique are assessed by numerous statistical analysis e.g. Sensitivity analysis and various Map removal methods. Application of this type of techniques have been made stress-free by web tools that deal with spatial conception of huge loads of information. For example, (ILWIS) Integrated land and water information system and (GIS) Geographic Information System.

The layers of each hydrogeological parameter were overlapped in ArcGIS software after allotment of weightage and rankings to each layer and their respective attributes. The weightage of respective thematic layer was multiplied with ratings allotted to different classes in order to estimate the parameter 'Dr * Dw' where ' Dr ' is the rating allotted to specific factor whereas 'Dw' is the weightage of parameter. The weight and rating was analyzed for every parameter and for their respective ranges after wards they were summed up. The equation 1, mentioned in the section 3.1.4 was used in order to generate an index called DRASTIC Index.

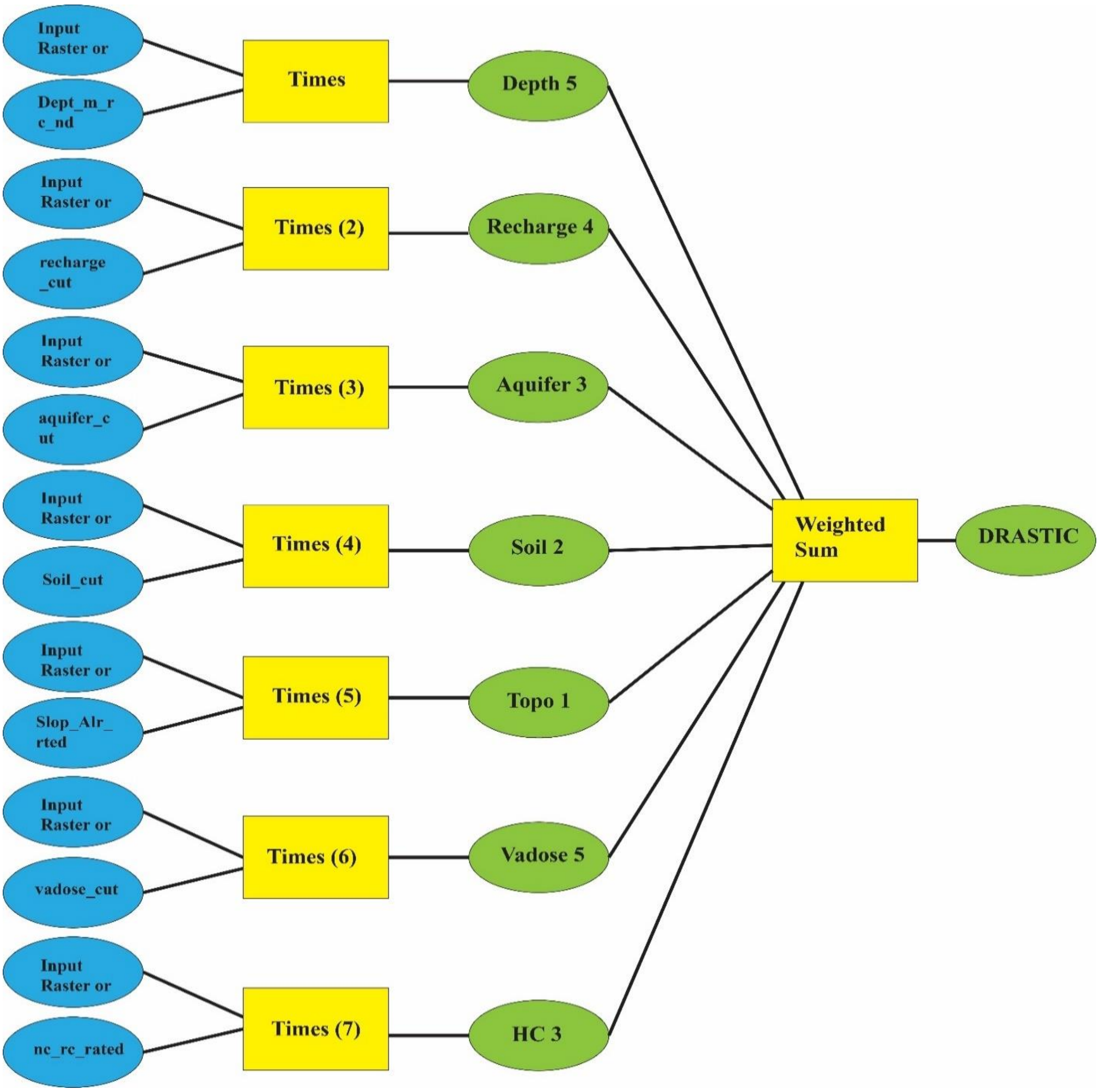

Figure 3.2. DRASTIC model in GIS environment.

In order to make the map serviceable for multiple uses, zones with diverse vulnerabilities concerning contamination were outlined by classifying the DRASTIC index into 5 ranges. Ultimate outcome of overlay and index analysis was a map with fluctuating susceptibility zones characterized through DRASTIC Indices.

CHAPTER 4

RESULTS AND DISCUSSION

The procedures regarding collection, arrangement, assembling and compilation of data and the methodology implemented to in order to use and utilize this data in groundwater susceptibility evaluation were discussed thoroughly in the previous chapter of this study. DRASTIC model is the adopted method to evaluate the susceptibility of the shallow subsurface water of District Haripur. This chapter will address the analysis of each thematic map layer in detail.

4.1 Depth to water

Hydrogeological parameter of depth to water is a chief parameter having a major character in groundwater susceptibility towards pollution. Depth to water signifies the transitional and in-between material present in the middle of the groundwater surface and the aquifer. Depth, respectively, command and determine the scope, grade and nature of biological, chemical and physical progressions occurring in response of collaboration amid pollutant and constituents of materials present above the aquifer. Due to Depth's important part in vulnerability, weight allotted to this parameter was 5 which is already predetermined. The ratings to each range have been allotted according to perception that aquifer system having water table shallower to the ground surface would be more prone towards pollution. The ratings are assigned according to the data available and their ranges. So consequently the higher ratings are allotted to the lower ranges as they are close to the ground surface and lower rating are allotted to high ranges as they represent deep aquifers.

After collecting, arranging, compiling, organizing and interpolating the Depth to water table data in a GIS environment using ordinary kriging interpolation method, the ground water depth in the study area was found to be in between 25- 55 meters. The depths were classified in four ranges and ratings to each range was allotted. (Aller et al, 1987).

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

Table 4.1. Ranges & Ratings of Depth to water table (D).

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

The map in figure 4.1 displays the dissemination of depth of water within the district under consideration. General dissemination of depth of water table represents that district is present in a region having variable depths of water table. The study area has both shallow and deep aquifers along with intermediate depth aquifers. The literature and field survey also confirm that the groundwater system of district Haripur is variable with varying water table depths.

The water table and aquifers were found shallower in the tehsil Khanpur of the study area whereas deeper aquifers were also present in the Tehsil Khanpur at Hattar Industurial State and populated regions. The relatively more depth of water table is due to excessive water extraction rate for various purposes and relatively less net recharge in the area due to builtup area does not allow water to percolate down and recharge the aquifers. The deep aquifers of whole district are due to the reason that the study area is revived by the rainfall as well as by the Tarbela lake, Khanpur lake, Doar river, Haro river and other canals and water bodies flowing in the vicinity.

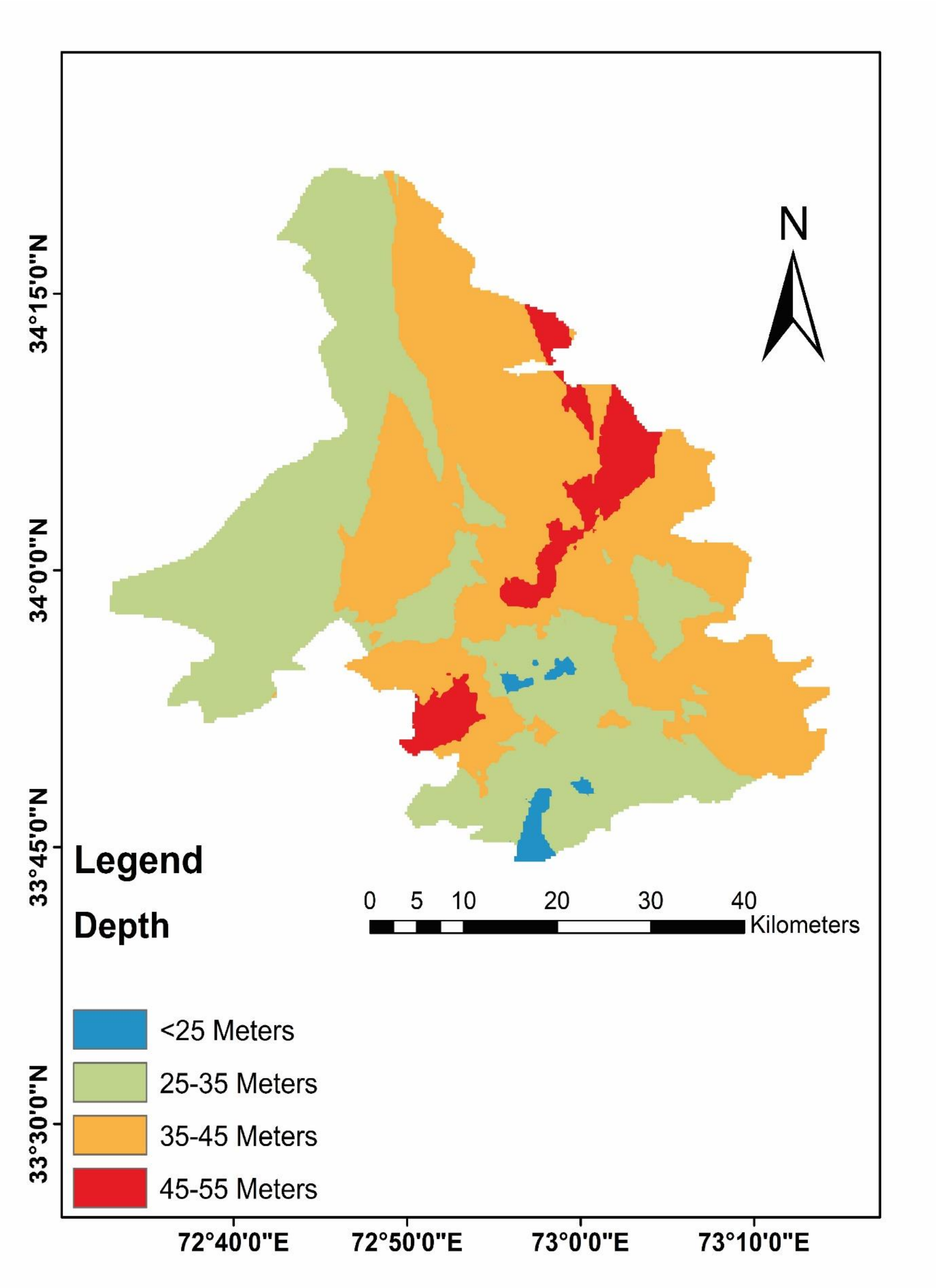

Figure 4.1. Spatial Distribution of Depth to Water Table

4.2 Recharge

In susceptibility evaluation, hydrogeological factor net recharge signifies the quantity of water which the aquifer receives in the form of rainfall or some other artificial source after infiltration and percolation. The water seeping down and recharging the aquifer can bring the pollutants with it. The percolating water acts as a transporting means, containing pollutants to subsurface setting and therefore shows a significant role in subsurface water susceptibility. The net recharge is directly relative to vulnerability of groundwater which means that more will be the chances of groundwater contamination if more water will be seeping down to the aquifers. In DRASTIC weightage system, weight of '4' has been allotted to net recharge parameter due to its comparatively less impact in subsurface water vulnerability as compared to Depth to water table and more impact than the other factors like Aquifer and Soil media and topography.

The net recharge in the study area was assessed by using annual precipitation and land cover data. Both these factors play an important role in determining the net aquifer recharge. The annual precipitation tells about the amount of rainfall contributing towards recharge and the land use data tells about the nature of land cover present in a specific region of study area. An overlay analysis was carried out to calculate the net recharge. The land use was classified into 3 classes namely Water Bodies, Open/Cultivated Land & Vegetation and Built-up Area. A weight of ‘2’ has been given to the Land use parameter, the ratings assigned to each class is given in the table 4.2. Whereas mean annual precipitation was divided into 5 classes. <1450mm, 1451-1850mm, 1851-2250mm, 2251-2750mm and 2751-3150mm. A weight of ‘1’ was allotted to Annual Precipitation and the Ratings allotted to each range are given in the table 4.3.

Table 4.2. Ranges & Ratings of Landuse.

LAND USE (Recharge Estimation)		
RANGES	**RATINGS**	**WEIGHT**
Built-up Area	1	2
Vegetation	3	2
Water Bodies	8	2

Table 4.3. Ranges & Ratings of mean annual precipitation.

MEAN ANNUAL PRECIPITATION (Recharge Estimation)		
RANGES	**RATINGS**	**WEIGHT**
<1449 mm	1	1
1450 – 1849 mm	2	1
1850 - 2249 mm	3	1
2250 – 2749	4	1
2750 – 3150	5	1

The cities and populated area of Ghazi, Haripur and Khanpur receives the least recharge as they are mainly built-up areas. The major portion of the district is composed of open/cultivated land & vegetation so a major portion of the district lies between the 2,3 and 4 recharge classes. The areas surrounding the water bodies receives the most recharge as they are charged by both Rainfall as well as percolation from the water bodies in their vicinity, these areas are represented by class '5'. This hydrogeological factor's map developed in GIS by Weighted overlay method is shown in figure 4.4 with allotted ranges and spatial distribution of each class. Figures 4.2 and 4.3 illustrates the spatial distribution of mean annual precipitation and Landuse respectively.

Table 4.4. Ranges & Ratings of Net Recharge.

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

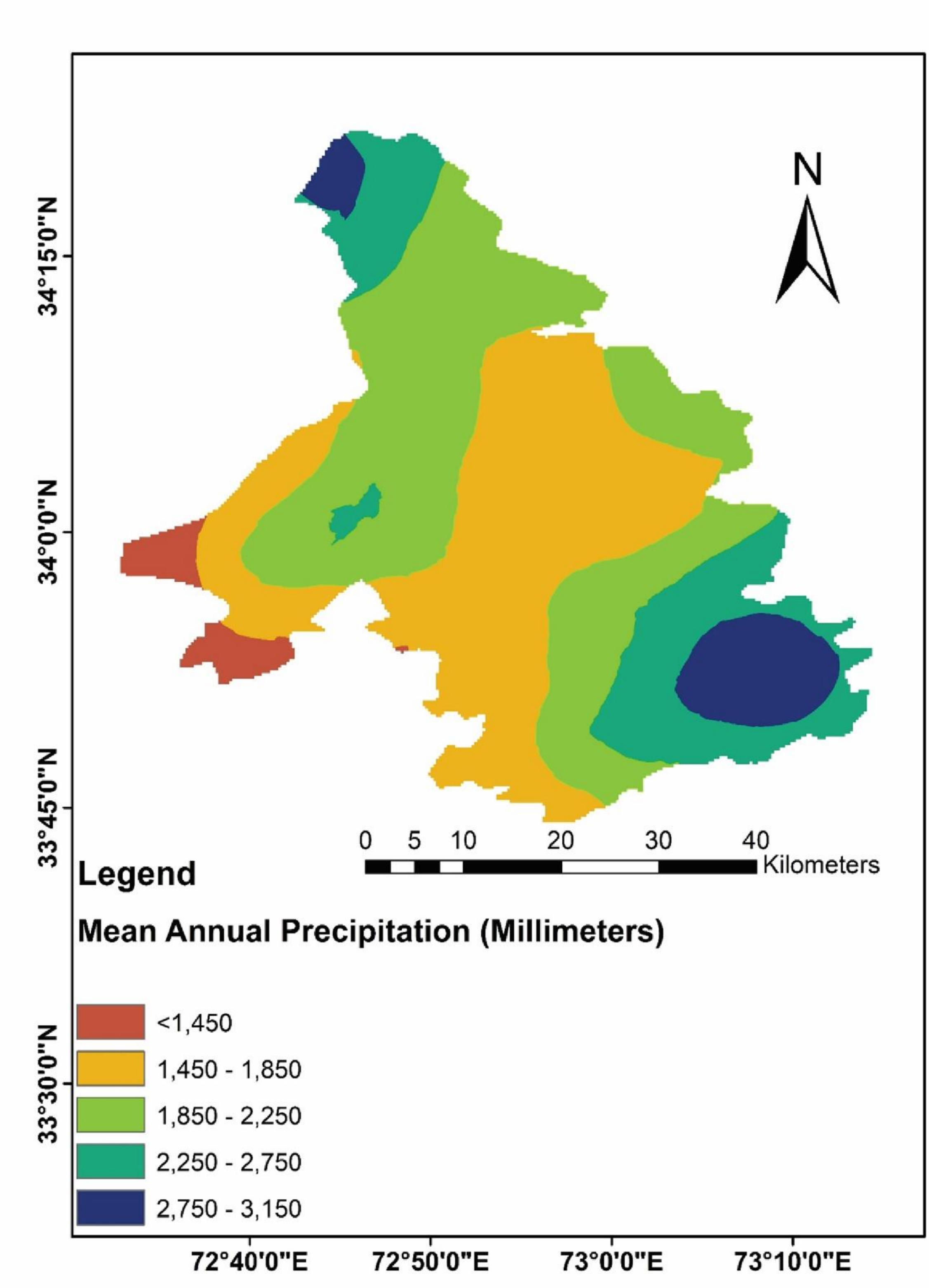

Figure 4.2. Mean annual precipitation in study area.

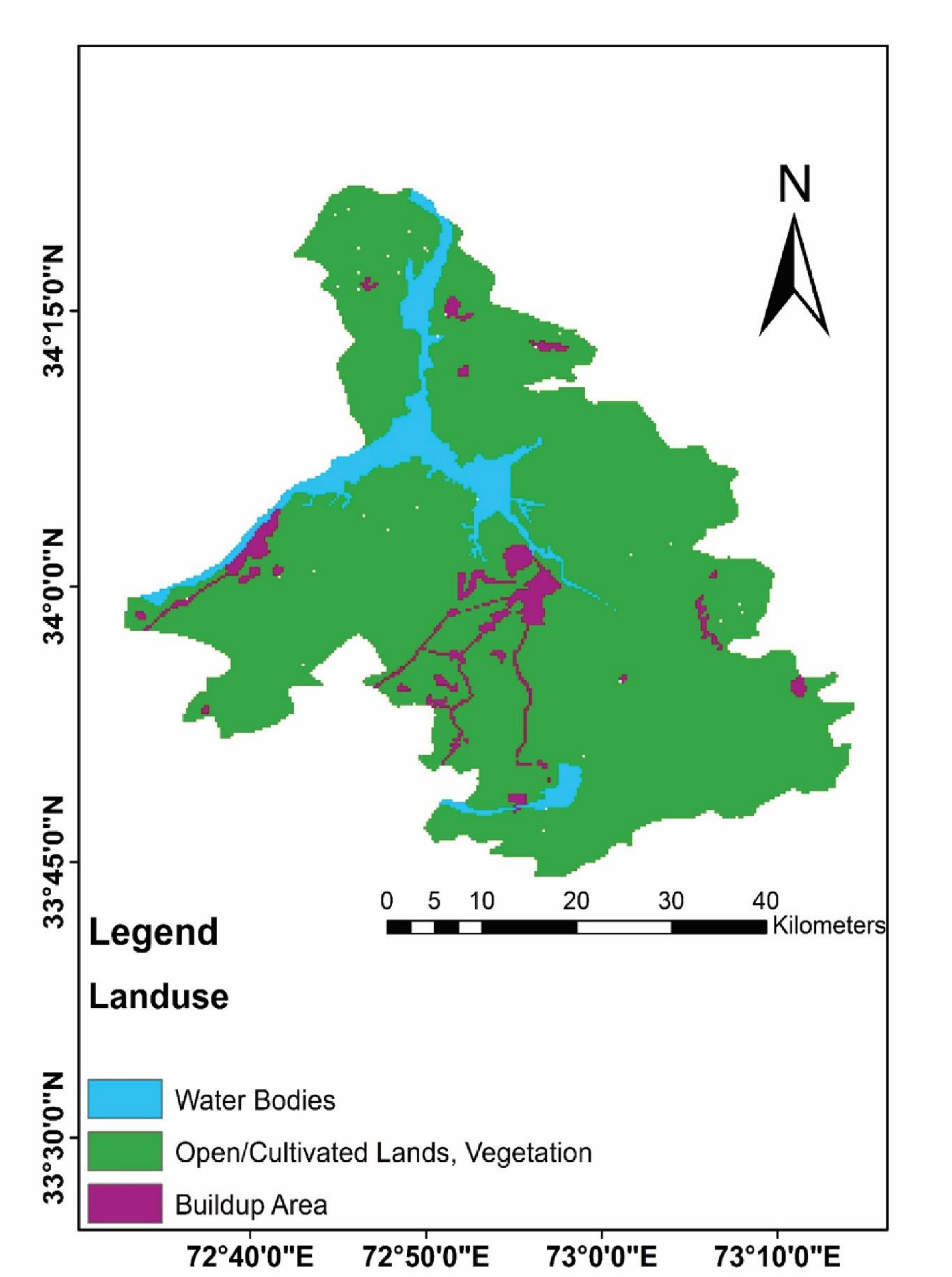

Figure 4.3. Landuse map of study area.

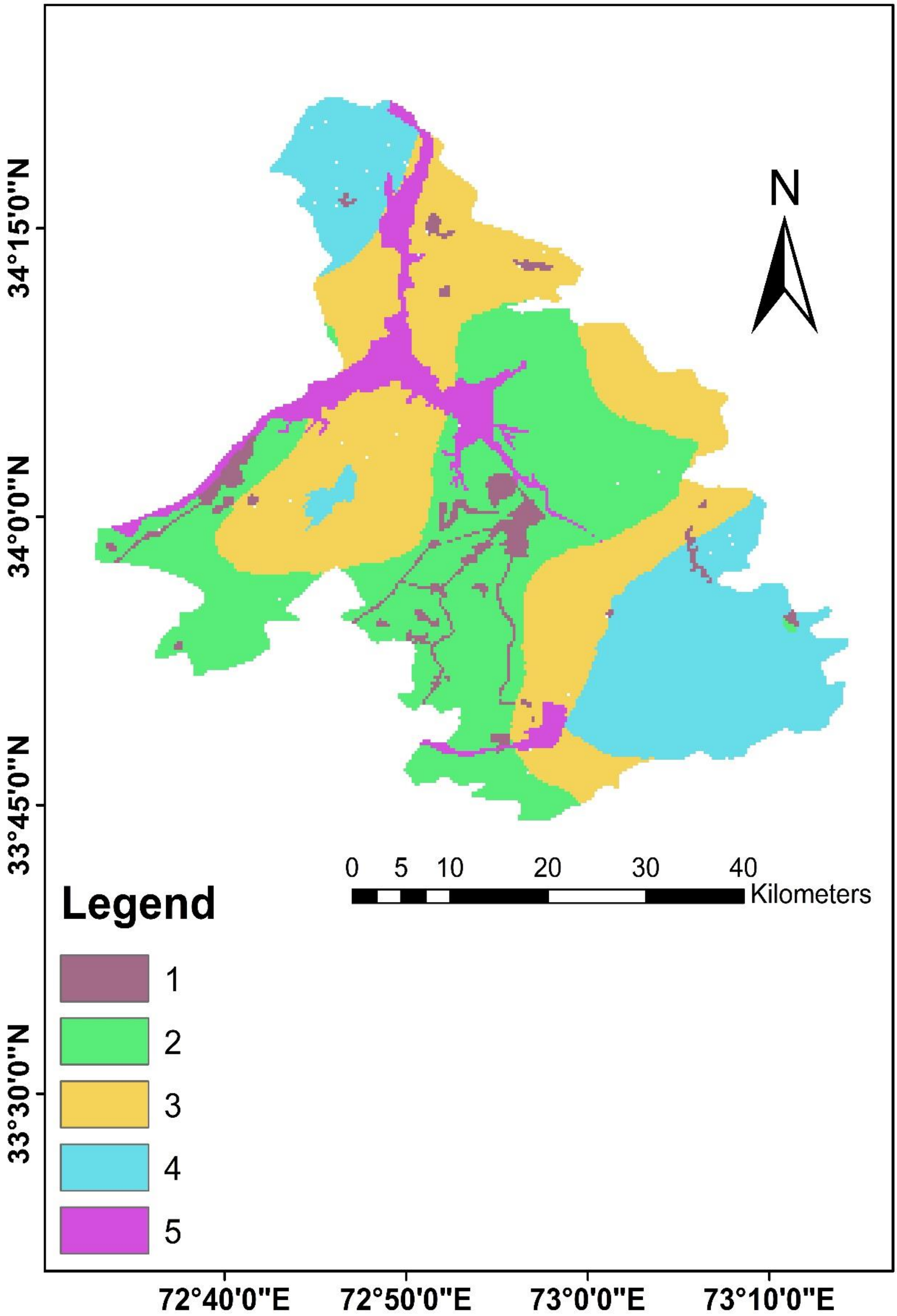

Figure 4.4. Spatial distribution of Net Recharge.

4.3 Aquifer media

The definition of aquifer is a underground geological or lithological formation of unconsolidated material or rocks that provide an adequate amount of water to a spring or surface well/ tube well in the form of fresh water (Heath, 1987). The material which makes up an aquifer has certain properties of its own, is called aquifer media and play an important role in vulnerability assessment of groundwater.

The key task of the aquifer media is to diminish, weaken and seize the pollutants that percolate to the groundwater reservoir. The sedimentology of the aquifer media i.e. grain sorting and grain size is very significant regarding the groundwater susceptibility. More the grain size of aquifer media and more the number of fractures and openings, more will be the permeability of aquifer media and more will be the chances of it getting contaminated will be, and the aquifer media will be more prone to contamination. In such case the aquifer's vulnerability will increase. Whereas smaller grain size, less number of openings and fractures within aquifer media will restrict contamination as it will have less permeability, and it will be less susceptible towards pollution.

The type and texture of the aquifer media was extracted from the strata charts and well log data obtained from PHED. The data of them arranged, compiled and interpolated using ordinary kriging interpolation method. Weight allotted to the parameter of Aquifer media is '3'. Classes of the Aquifer Media were developed according to the available data. After studying in detail about the aquifer media in the study area 4 ranges were created, mentioned in table 4.5 along with their respective assigned rating. The ranges created are Sand + Gravel, Gravel, Sand + Boulder and Gravel + Boulder. The first range is allotted a relatively low rating value due to its capability to attenuate contaminants whereas the last range is allotted the highest rating due to its high permeability and less capability of restricting contaminants. Whereas the middle ranges were given rating accordingly. Majority aquifers of the study area are composed of gravel and sand + boulder which are intermediate in terms of attenuating contaminants whereas safer aquifers comprising of sand + gravel are present in southern portion of Tehsil Ghazi and in some areas of Tehsil Haripur. The relatively vulnerable aquifers of study area comprising of gravel + boulder are present in Tehsil Khanpur and adjoining portion of Tehsil Haripur.

Table 4.5. Ranges & Ratings of Aquifer media.

AQUIFER MEDIA		
RANGES	**RATINGS**	**WEIGHT**
Sand + Gravel	2	3
Gravel	3	3
Sand + Boulder	6	3
Gravel + Boulder	8	3

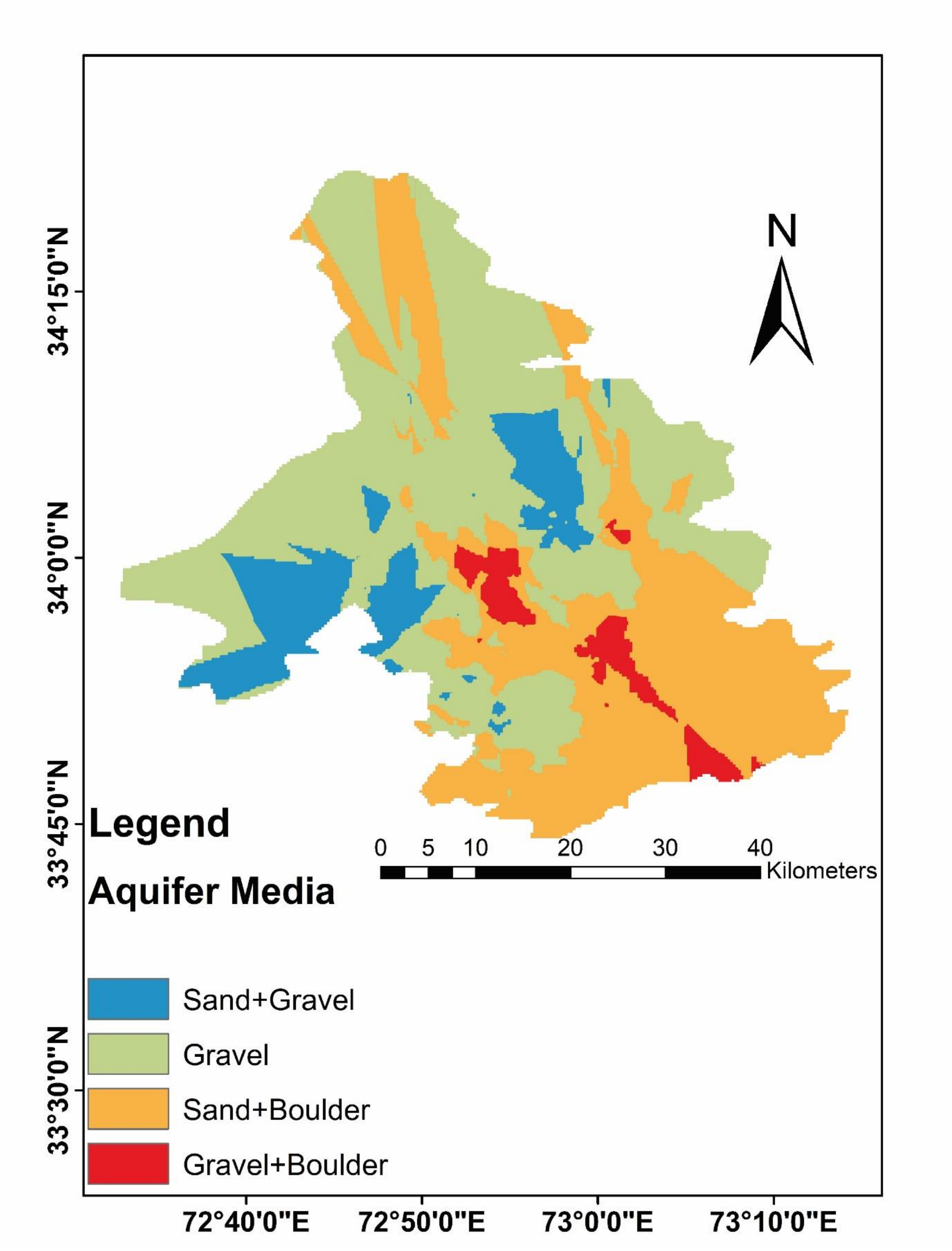

Figure 4.5. Spatial Distribution of Aquifer media.

4.4 Soil Media

Soil is upper weather beaten and loose material, on the earth. The soil is top part of vadose zone. This parameter of is very important as it provides an environment for various biological happenings.

The soil texture influences quantity and degree of rainwater percolating down to the aquifer. The soil media also effect the migration of pollutants to the aquifer and acts as an obstruction against pollutants. Mostly, soil contamination prospective is altered mainly by the kind of clay present, its swelling & shrinking capability and lastly grain size of soil (Aller et al, 1987). As discussed in aquifer media parameter the more is the grain size of the soil higher will be the permeability and more pollutants will seep down to the vadose zone. Additionally, the greater grain size of soil will not be capable to restrict the migration of contaminants and will be a poor blockade against particles. The soil data was obtained from literature survey in the form a Map, containing names and spatial distribution of all soil series and associations. A detailed report explaining the map was acquired from the Soil Survey of Pakistan, Peshawar. The report contained the soil description of each series and association. The soil texture of each series was calculated after plotting it on soil texture triangle. The Soil series map was geo-referenced, digitized and merged to obtain a final thematic soil map.

The soil media are ranged according to its type. Six ranges regarding Soil Media are developed, Clay Loam, Silty Clay Loam, Silt Loam, Loam, Sandy Loam and Water Bodies. The classes are developed according to permeability, less the grain size less is the permeability and less will be the vulnerability towards contamination and vice versa. So low rating is allotted to smaller grain size of soil i.e. Clay Loam and high rating is given to the most course grain size i.e. Sandy Loam. However highest rating is allotted to the areas comprising of water bodies. The weight allotted to Soil Media factor was ‘2’. The ranges and allotted ratings of the soil media are given in table 4.6. The Soil media is classified and rated according to Aller's (1987). Due to the accessibility of full map of the district, there was no need of using interpolation technique.

A major portion of the area is comprised of the Silt Loam soil, encompassing all three tehsils of the study area. Loam is present on the northern side of the area.

Other soil textures are distributed all over the district. The largest grain size is of Sandy Loam and it is present at the boundary of Haripur and Ghazi tehsils as well as at the eastern boundary of Tehsil Khanpur. Silty clay loam and clay loam are scattered in the form of patches. The Water bodies of the study area are also given an appropriate rating regarding soil media parameter.

Table 4.6. Ranges & Ratings of Soil Media.

SOIL MEDIA		
RANGES	**RATINGS**	**WEIGHT**
Clay Loam	2	2
Silty Clay Loam	3	2
Silt Loam	4	2
Loam	6	2
Sandy Loam	7	2
Water Bodies	9	2

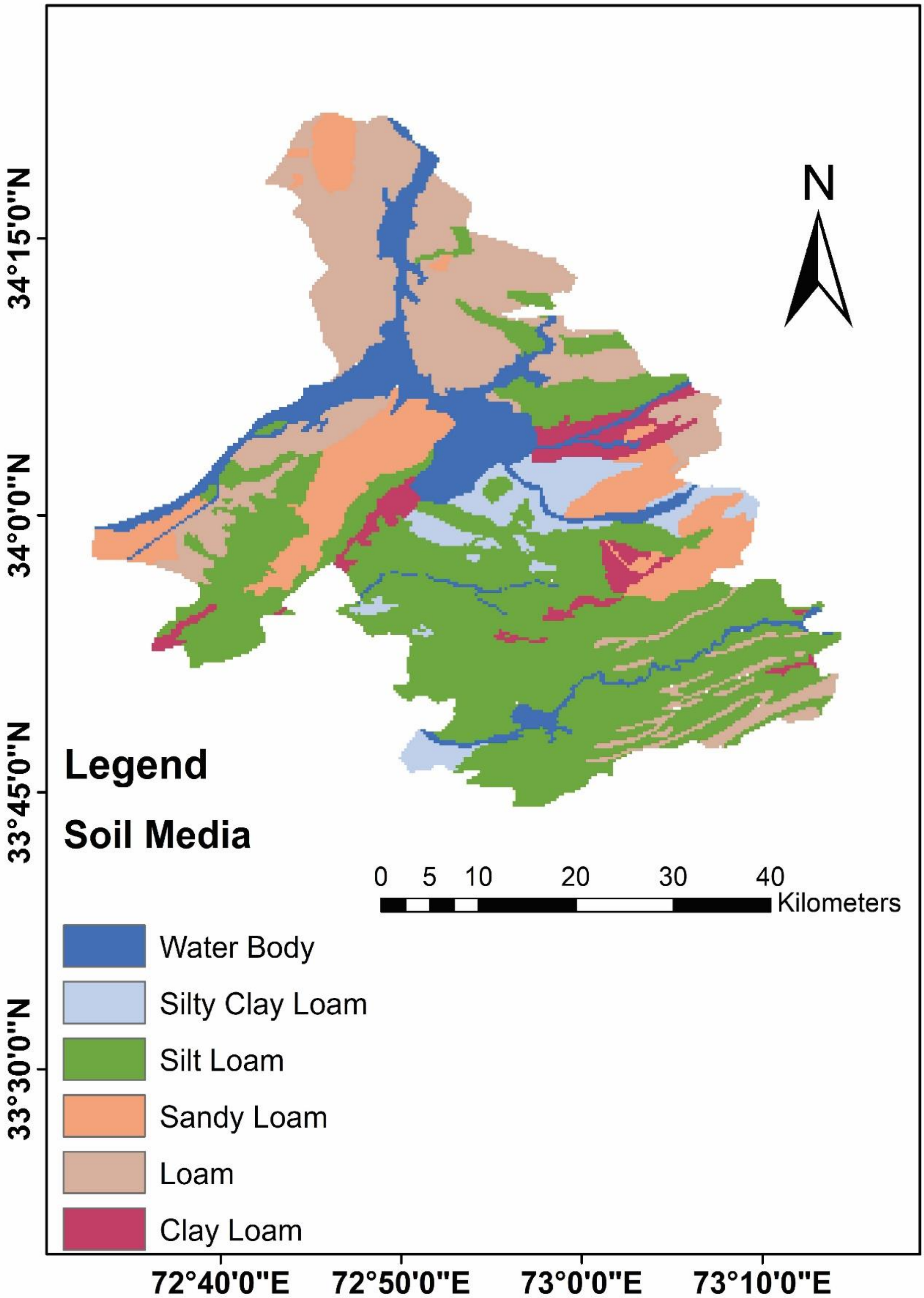

Figure 4.6. Spatial Distribution of Soil Media.

4.5 Topography

The topography of an area denotes the slope. (Rehman,2008). The groundwater susceptibility is affected by the slope of area because the slope governs the water withholding and retaining time. Water is retained for less amount of time for a region having high gradient. So the high or steep slope can decrease the percolation capability for the contaminants thus decreasing the vulnerability of groundwater as less amount of pollutants can be absorbed by the soil and leeched down to the vadose zone and ultimately groundwater. On the other hand, the region with low angle of slope gives more retention time to water, providing more chance to the contaminants to leech down to the aquifer thus increasing the probability of contamination. So the areas having steep angle of slope will be less susceptible to pollution as the water will runoff quickly providing less retention time to contaminants and the area with gentle or no slope will be more prone to pollution.

The district Haripur has a variety of landforms and topography. It has both plains and mountainous areas. The slope of the study area was extracted from Digital Elevation Model obtained from SRTM. The extracted slope was classified into three ranges as <10, 10-35 and 35-70. Appropriate rating was allotted to each range and is mentioned in the table 4.7. The weight allotted to the parameter of topography is ‘1’ due to its less contribution towards groundwater contamination.

The majority portion of the district has slope angle <10 surrounding the major cities of the district and the agricultural lands surrounding them. The steep slope areas are present in the north of district and eastern parts of the tehsil Ghazi and Khanpur.

Table 4.7. Ranges & Ratings of Topography.

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

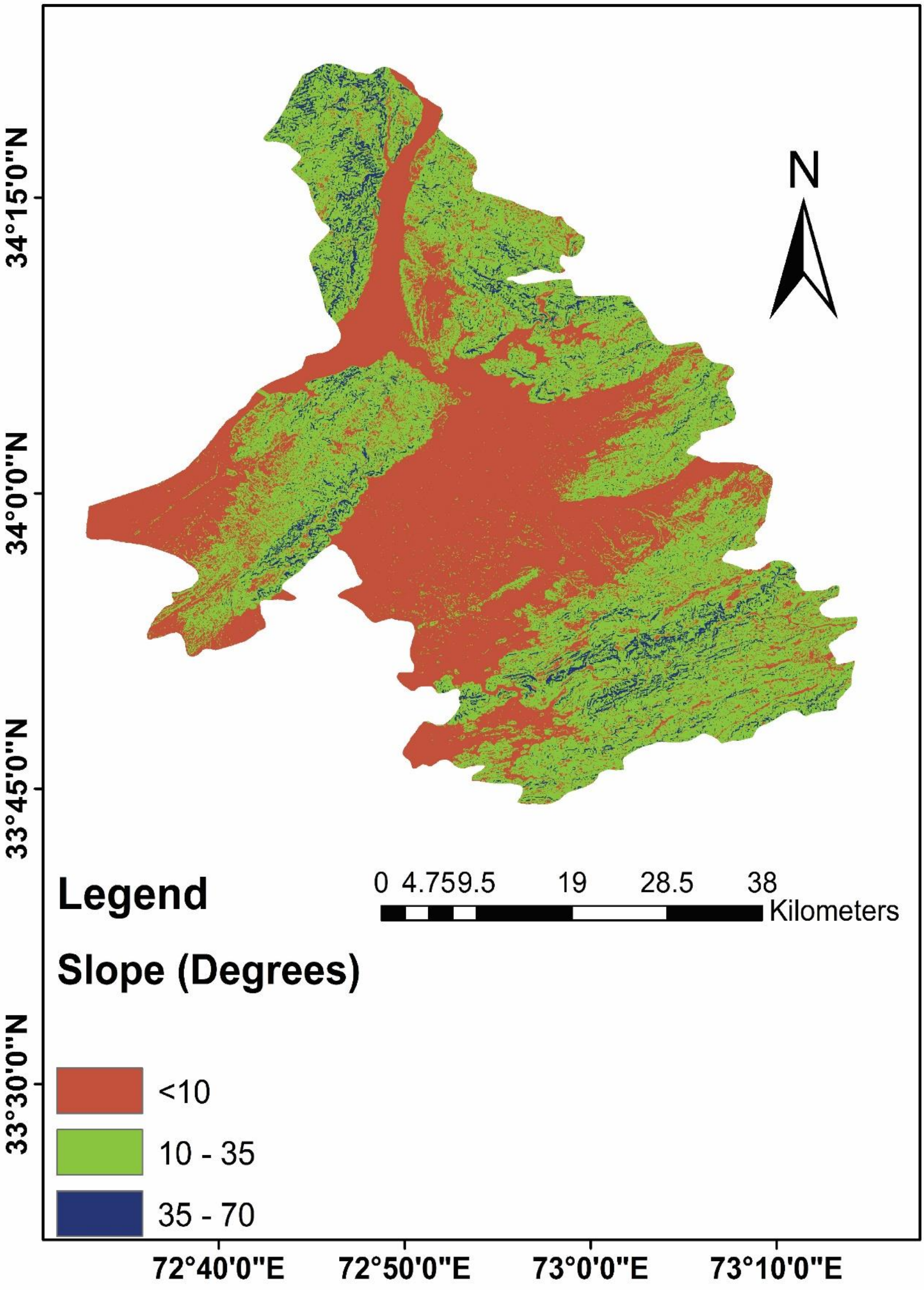

Figure 4.7. Topography (Slope) of study area.

4.6 Impact of vadose zone

The Vadose zone is the part present in between soil media and aquifer. The significance and working of hydrogeological parameters of soil media and vadose zone is almost similar. The Vadose zone seize and restrict the pollutants seeping down to water. Capture of contaminants is determined by type of contaminants and the type of material comprising the vadose zone.

The permeability of the material comprising the vadose plays a significant part in controlling the leaching of contaminants. If the vadose zone is comprised of material with large grain size thus having high permeability, then contaminants can be leached down easily and the vadose cannot capture them and will be an ineffective barrier. On the other hand, if the grain size of vadose zone's material is small, the vadose zone will have less permeability. The vadose zone will capture and restrict contaminants thus preventing underlying groundwater from pollution.

Like soil media, various biological, chemical and physical procedures occur in the vadose zone e.g. volatilization, biodegradation, dispersion, mechanical filtration, neutralization etc. (Aller, 1987). All these procedures together regulate the outcome for the contaminant. The capturing and attenuation properties of the vadose is governed by the size and type of the media which make up this zone existing in between the aquifer and soil media (Aller, 1987).

The ranges were made according to the available data and the type of material in the vadose zone. Ratings to each range was allotted according to the grain size of each range. The ranges with large grain size were given higher ratings due to their high permeability and low capturing potential towards contaminants on the other hand lower ratings were allotted to ranges with smaller grain size having low permeability and high attenuation capability towards contaminants. The impact of vadose zone is quite significant regarding vulnerability assessment of groundwater so a weight of '5' is allotted to this parameter.

The data was gathered, organized, compiled and then interpolated in the GIS setting using Ordinary kriging technique of interpolation and a map was generated illustrating the spatial distribution of vadose zone media. The map generated is given in the figure 4.8.

Six ranges or classes were made for vadose zone parameter i.e. Clay, Clay + Gravel, Sand + Gravel, Clay + Gravel + Boulder, Sand + Gravel + Boulder and Gravel + Boulder. The ratings were allotted to these ranges with respect to their grain size and significance in susceptibility assessment. The rating assigned to each range is given in the table 4.8.

Table 4.8. Ranges & Ratings of Vadose zone.

VADOSE ZONE		
RANGES	**RATINGS**	**WEIGHT**
Clay	5	5
Clay + Gravel	6	5
Sand + Gravel	7	5
Clay + Gravel + Boulder	8	5
Sand + Gravel + Boulder	9	5
Gravel + Boulder	10	5

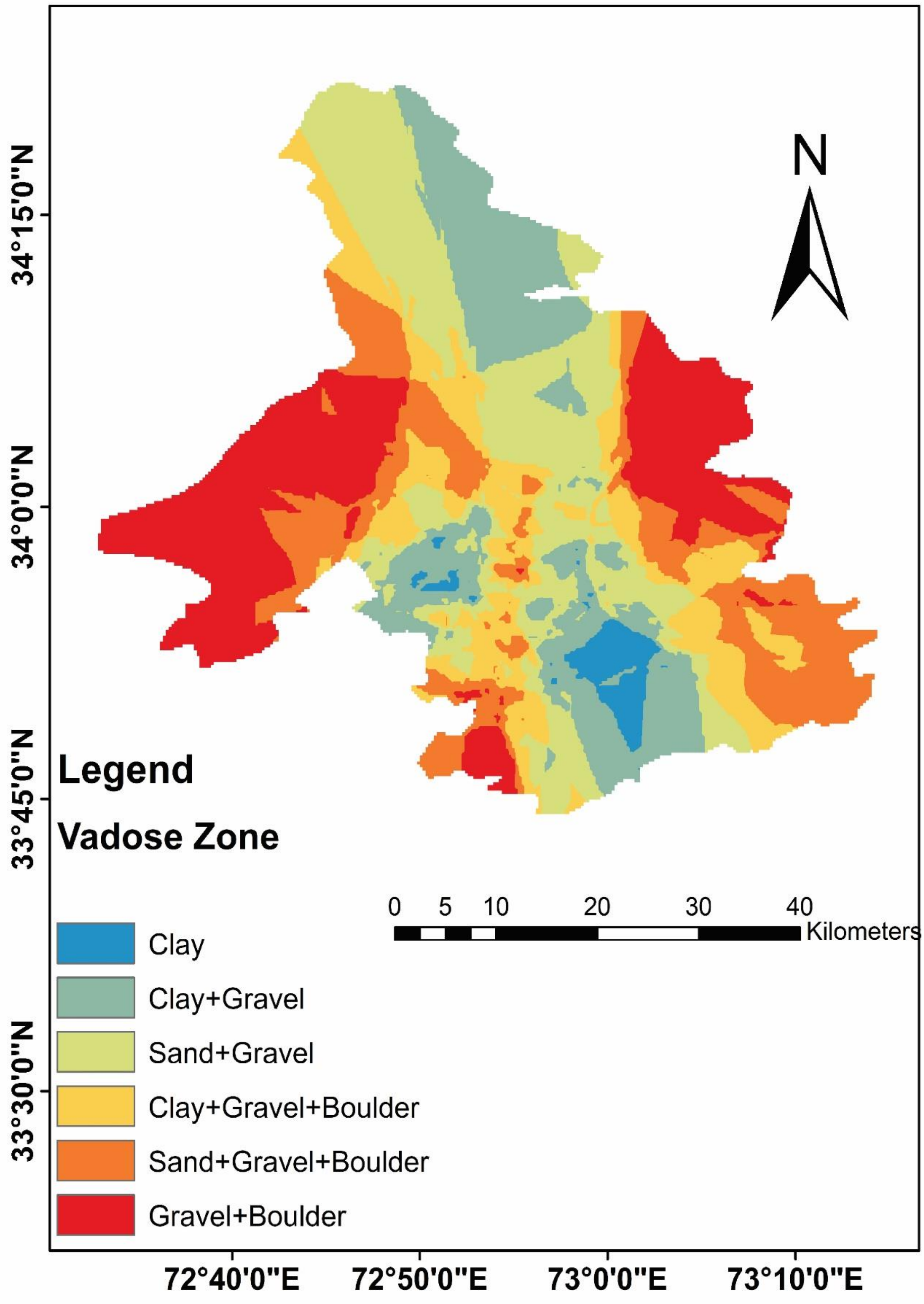

Figure 4.8. Spatial Distribution of Vadose zone.

4.7 Hydraulic conductivity

The conductivity or specifically hydraulic conductivity is the capability of aquifer to transmit or flow water through it (Rahman, 2008). The hydraulic conductivity is the rate at which water flows horizontally within aquifer (Almasri, 2008). The parameter of hydraulic conductivity relies upon permeability or texture of aquifer material and the degree of saturation in aquifer. This parameter is very significant in evaluating the vulnerability because hydraulic conductivity determines motion of contaminant along with water movement underneath a specific hydraulic gradient. Aquifer susceptibility and the hydraulic gradient are directly related to each other. More the hydraulic conductivity of an aquifer more will be its capability to transmit contaminants to aquifer from the place of discharge.

The data was obtained from PHED, and was arranged, organized, complied and interpolated using ordinary kriging technique. A map was generated which is given in the figure 4.9.

The ranges and ratings are assigned by following Aller's (1987) method. Aller et al (1987) has allotted a weight of '3' to this parameter as it is more vital in assessment as compared to soil media and topography. For this parameter four classes are established. The ranges of lower hydraulic conductivity are given smaller rating where as high rating is allotted to higher ranges of hydraulic conductivity. The allotted ratings and ranges are given in table 4.9.

The conductivity values vary from 1730 meters/day to 2600 meters/day. A major portion of the study area has a hydraulic conductivity between 1731-2310. However, the Haripur city area and south eastern part of Khanpur tehsil have the highest hydraulic conductivity, ranging from 2311-2600 meters/day.

Table 4.9. Ranges & Ratings of Hydraulic Conductivity.

HYDRAULIC CONDUCTIVITY		
RANGES	**RATINGS**	**WEIGHT**
<1730 M/Day	4	3
1731 – 2020 M/Day	6	3
2021 – 2310 M/Day	8	3
2311 – 2600 M/Day	10	3

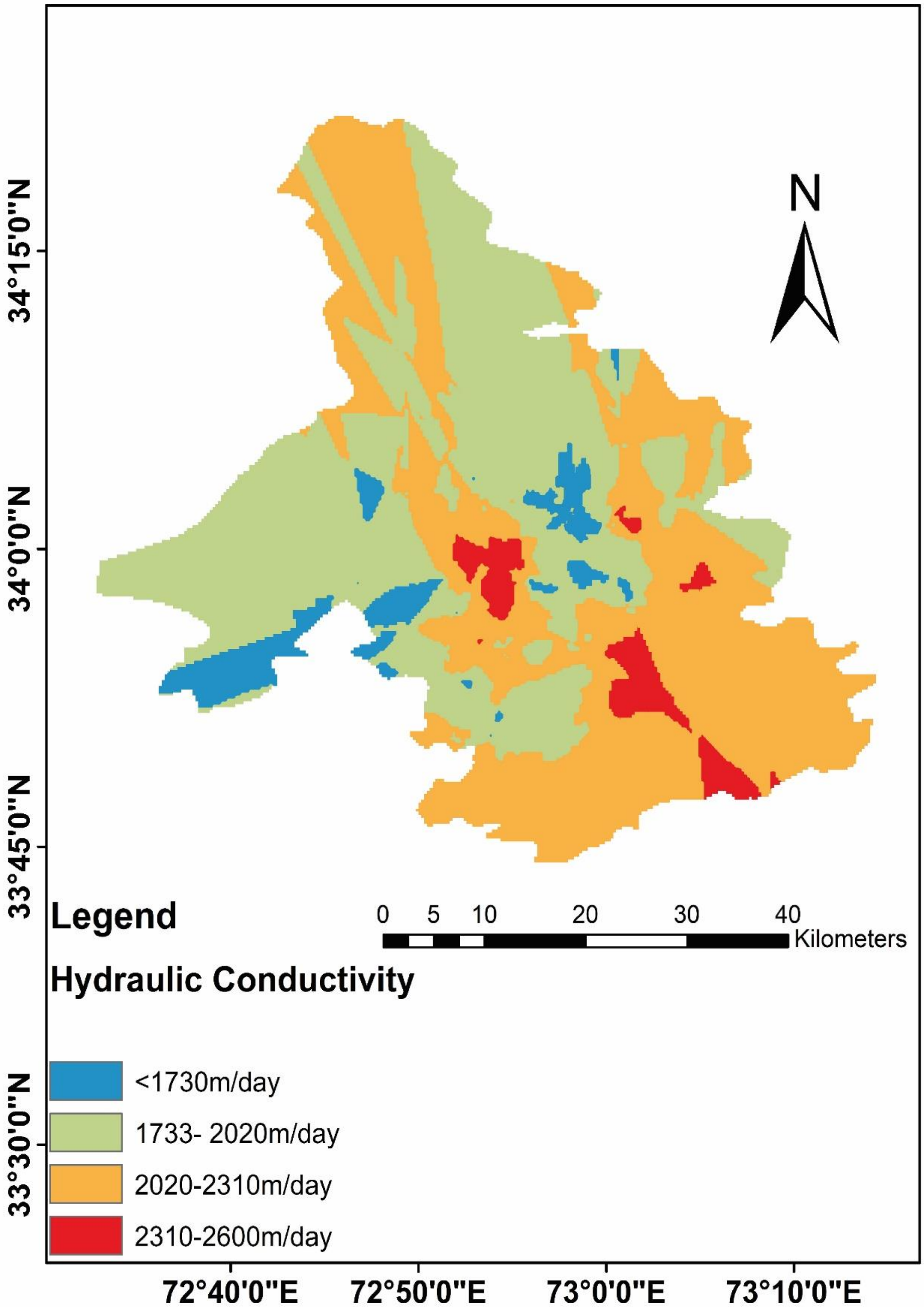

Figure 4.9. Spatial Distribution of Hydraulic Conductivity.

4.8 DRASTIC based intrinsic vulnerability assessment

After categorizing the data into specific ranges for each parameter and assigning them respective ratings and weights, weighted overlay analysis was executed in order to generate a DRASTIC based susceptibility map. Equation 1 was used in GIS environment and the thematic map layers of all seven hydrogeological parameters were overlaid in order to generate DRASTIC indices and a thorough Groundwater susceptibility map of the study area.

After executing the overlay analysis, the values attained were in between 88-190. These values of the DRASTIC indices show the grade of susceptibility. Higher the DRASTIC index more will be the aquifer's vulnerability towards pollution on the other the aquifer's vulnerability will be less if the value of DRASTIC index is smaller. The DRASTIC indices were classified into five ranges or classes to effectively separate fluctuating vulnerability of areas. The classes in which DRASTIC indices were divided are very high, high, moderate, medium and low. Each class was assigned a specific color on the map to easily demarcate it as shown in the figure 4.10.

Table 4.10. DRASTIC indices, Zoning, Ranges & Color Coding.

DRASTIC RANGES & ZONING		
ZONE	**RANGES**	**COLOR CODE**
Low	88 – 109	Dark Green
Medium	110 – 129	Light Green
Moderate	130 – 149	Yellow
High	150 – 169	Orange
Very High	170 - 190	Red

The main causes to divide the area in to five classes are:

1. To enable various private and government sector organizations to make decisions easily concerning land use actions.
2. Another reason for this classification is different domestic, agricultural and industrial activities in the area.

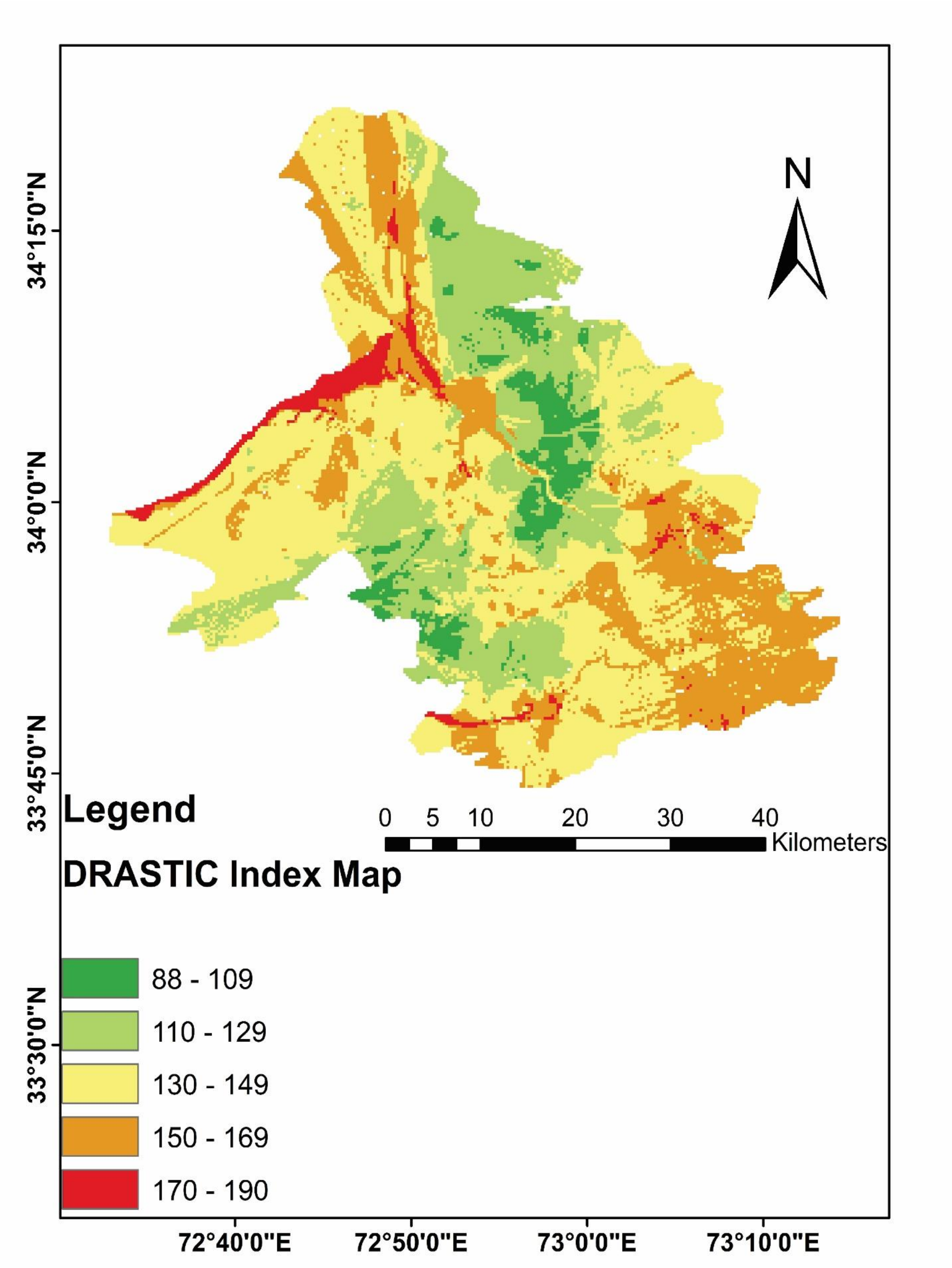

Figure 4.10. Spatial Distribution of DRASTIC index.

It is clearly visible in the figure 4.10 that major portion of the study area is in the moderate susceptible zones trailed by medium and high vulnerable zone which encompass the same area in the district. The low vulnerable and very high susceptible zone is on the 4 and 5 marks in terms of covered area. It should be noted that all zones are very critical except low vulnerable zone in susceptibility assessment due to the reservations and possibilities regarding the pollution process, nature of subsurface water pollution procedure and the complexities regarding the remediation of groundwater if it gets contaminated. For each zone of the DRASTIC index, area was calculated using raster area calculator in ARCGIS and is given in table 4.11.

Table 4.11. Vulnerable zones, ranges and area covered.

Vulnerable Zones, Area Covered and Ranges		
RANGES	**ZONE**	**AREA COVERED (KM^2)**
88 – 109	Low	119
110 – 129	Medium	506
130 – 149	Moderate	966
150 – 169	High	506
170 - 190	Very High	66

4.8.1 Low vulnerable zone

Almost 118 kilometers square of area is encompassed by the low vulnerable zone. The low vulnerable zone is present only in the tehsil Haripur of the area and is scattered in the form of patches. Various factors play an important part in low vulnerability index of this area. Quite a few reasons cause lesser susceptibility in this region among them most important one is deeper water level which is 45-55 meters, this particular range was assigned the minimum rating during weighted overlay analysis. Relatively more depth of the water table has made this area less susceptible to the pollutants leaching down. Another key reason for this area to be less prone to surface pollution is that this area receives very small amount of recharge. The aquifer media is also quite impermeable which plays its part in making this area low vulnerable. The area has fine sized soil particles covering it which restrict the seepage of contaminants. In the same way small grain size of vadose zone restrict the downward movement of pollutants and filters the water leaching down. The hydraulic conductivity in this area is between 1730-2020 meters/day which is very low as compared to the other parts of the district.

Villages like Hattar, Pannian, Dehdeen, Kalitrat Gullubandi, Talokar, Pandak, Sikandarpur, Jattipind, Alluli and TIP housing society lies in the low vulnerable zone. A major portion of the Hattar Industrial State is present in the Low vulnerable zone and groundwater of the nearby areas is quite safe for everyday use.

4.8.2 Medium vulnerable zone

In the DRASTIC index map, the medium vulnerable zone covers an area of almost 506 square kilometers. The medium vulnerable zone encompasses the tehsil Haripur and south eastern region of tehsil Ghazi. A small part of medium vulnerable zone is present in southwestern region of tehsil Khanpur. A major portion of the population lives upon the medium vulnerable zone

The northern part of this zone is relatively less populated as compared to the southern region. Some portion of Hattar Industrial State is in this zone which is a noteworthy point. As the industrial activities on the surface increases the amount of contaminants. In Tehsil Ghazi, Jhamra village is in this zone having shallow water table of 25-35 meters. This area lies in 2^{nd} range allotted to the recharge parameter, thus allowing less contaminants to enter. Silt Loam soil is present on this region which is the very fine grain size of soil. The Aquifer media is also of the smallest size i.e. sand + gravel. On the contrary, vadose zone is made up of the largest grain size i.e. gravel + boulder thus having maximum permeability in the area and make this region more prone to pollution as compared to the low vulnerability index region. The hydraulic conductivity in this region is minimum i.e. <1730 meters/day.

The southern part of the tehsil Haripur and a smaller portion of tehsil Khanpur is also inside the medium vulnerable zone. Kot Najibullah, Gudwalian, Bhera, Raniwah, Pind Munim, Suraj gali and Demakeh are the major villages of this region. This segment of this zone has quite shallow water table i.e. 25-45 contributing towards the chances of vulnerability. The aquifers of this region does not get much recharge. This area is covered with Silt loam soil. The aquifers are made up of Gravel and sand + boulder which have considerable permeability. The Vadose zone also has medium permeability similar to hydraulic conductivity. This region has the lowest slope in the area. These parameters collectively make the area medium vulnerable zone. Importantly the shallow water table contributes the most in making this area medium vulnerable zone, whereas other factors restrict the contamination process.

Last segment of this zone is comprised of the northern part of tehsil Haripur which is comparatively less populated however it has some major villages like Padhana, Qazian, Roshanabad, Mohrinoz, Kag and Dheri Sikandarpur. This segment has shallow water table but deeper than other segments of the medium vulnerable zone. It has different sized soil patches and low permeable aquifer media and vadose zone. The factors which contributes towards its vulnerability index are shallow water table, courser soil media and relatively more hydraulic conductivity.

4.8.3 Moderate vulnerable zone

The next zone on the vulnerability index is the moderate vulnerable zone. This zone covers almost 965 kilometers square hence it is the largest amongst. It encompasses all three tehsils i.e. Ghazi, Haripur and Khanpur. However, it has comparatively smaller segment in tehsil Haripur. all zones in the vulnerability index. The city of Ghazi is in this zone other major villages in this zone include Serikot, Bandi Mian Pirdad, Kundi Umer Khan, Pind Gakhar, Nartopa, Choi, Dobandi and Paswal Shingri.

The significance of this zone is more as it as the hydrogeological setting which makes it more prone to groundwater contamination. The hydrogeological factors of this zone does not screen out the contaminants effectively. This zone has comparatively shallow depth to water table i.e. between 25-45 meters. As this zone is quite large, it receives an adequate amount of recharge. However mainly it has finer soil i.e. silt loam which filtrates the contaminants effectively. Gravel and Sand + Boulder are the aquifer media which are permeable and makes the zone more vulnerable to the pollution. Similarly, the vadose zone is also very permeable, it is made up of Clay + Gravel + Boulder, Sand + Gravel + Boulder and Gravel + Boulder. These material in the vadose zone helps in the leaching of contaminants downward. The hydraulic conductivity also makes the zone more vulnerable as its value is between 1733 and 2310 meters/day. The topography varies in this zone however since topography parameter has less weight, its significance is reduced since other parameters chiefly contributes towards susceptibility.

4.8.4 High vulnerable zone

An area of almost 506 square kilometers is covered by high vulnerable zone and is very significant as its DRASTIC index ranges between 150 to 169. The area in this zone is highly susceptible to contamination. This zone covers a significant portion of Tehsil Ghazi and Khanpur. The major villages in this zone include Tarnawa, Dobandi, Purj Katha, Saradhana, Ferozpura and Khal Bala.

One of the main reason for this area to be highly vulnerable is that it receives huge recharge and has quite permeable aquifer media, vadose zone and high hydraulic conductivity. These parameters play their pat in increasing the vulnerability of the area according to their respective weight and ratings assigned to each range. The slope in this zone is quite steep, however it is not sufficient to reduce susceptibility as Aller (1987) has assigned the minimum weight of “1” to this parameter.

4.8.5 Very high vulnerable zone

The very high vulnerable zone is the most vulnerable zone to contamination the study area, it covers an area of 66 kilometers square. The chief factor contributing towards its vulnerability is the maximum recharge which this zone receives, as parameter of Recharge is given a weight of ‘4’. The aquifer media and vadose zone in the area also makes it very high vulnerable zone as they are very permeable and helps contaminant to leach down easily. A thin strip of this zone is adjacent to the city of Ghazi and present on the western border of the study area. Sultanpur is the major village in this zone in tehsil Khanpur.

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-Two samples were gathered from the assessable areas of the district and analyzed for Nitrate parameter. The whole region had an average concentration of 7.8 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 0.5 ppm and the highest concentration recorded was 15 ppm. Around 10 % of the samples surpassed the approved limit of PSQCA and NSQWQ standards. Figure 4.11 shows the concentration of Nitrate in Haripur district. It can be seen that highest concentrations of nitrate are present in South western section of the district.

The Concentration of Nitrate >10 ppm represents that some human action has contributed towards this high concentration. (Spalding and Exner 1993). It is identified that 7% of high nitrate samples are present in the very high vulnerable zone. Whereas the nitrate values between 5 – 10 ppm lies in moderate and high vulnerable zone. This outcome demonstrates a very accurate match among the DRATIC index map and the Nitrate concentration map. The nitrate values are also correlated with the Depth to water and impact of vadose zone parameters as they have the highest weight in the model. The south western region of the district has high concentration of nitrate, where depth is 25 – 45 meters which is quite shallow as compared to the data available. The vadose zone of this region has sand + gravel + boulder and gravel + boulder in vadose which make this area very vulnerable. Reliable correlation exists among the net recharge, aquifer media, hydraulic conductivity and nitrate concentration showing the reliability of generated Vulnerability map.

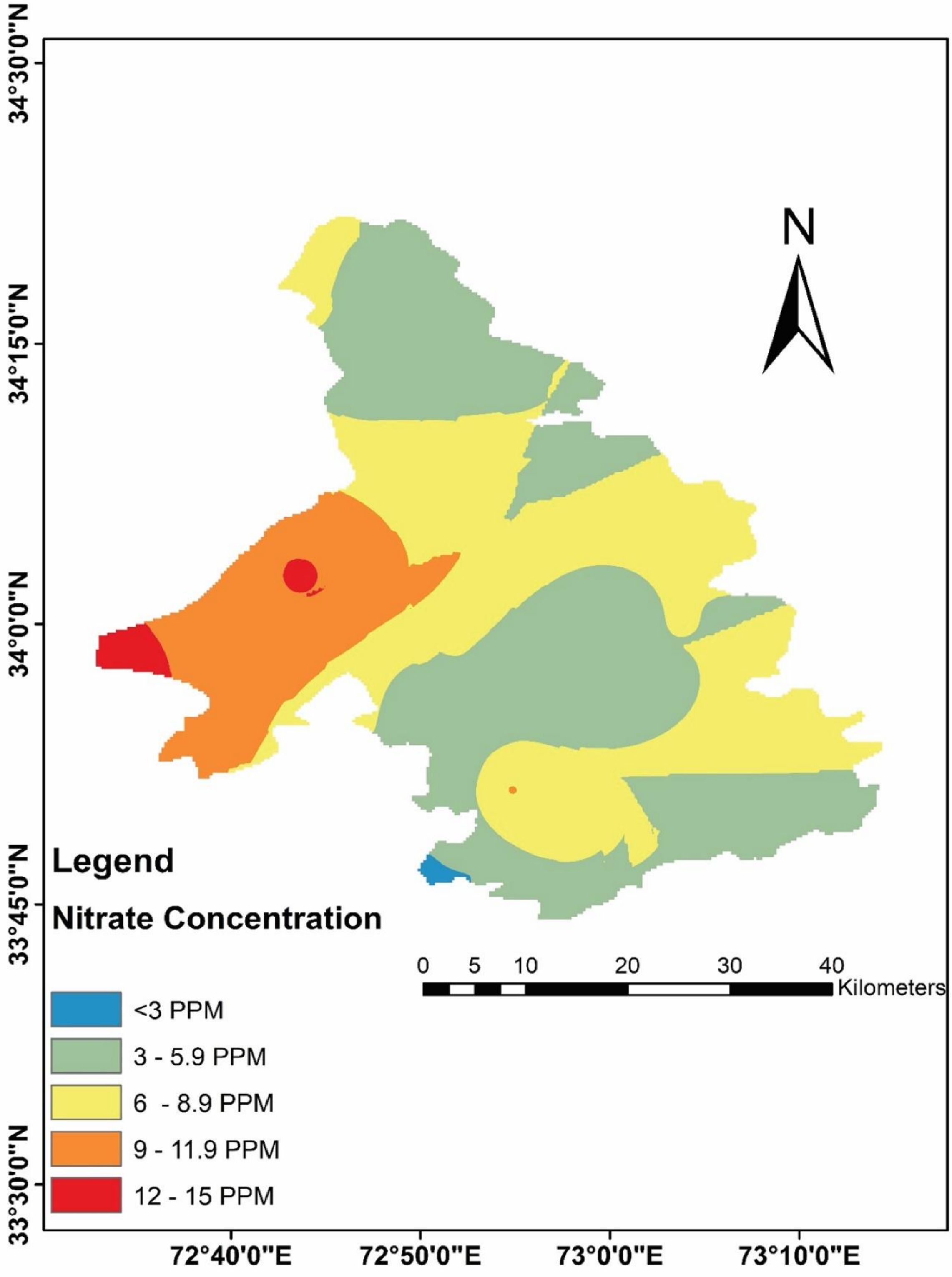

Figure 4.11. Spatial Distribution of nitrate concentration.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

In this study, efforts, were made to assess the intrinsic susceptibility of the groundwater system of District Haripur and its all Tehsils by effectively employing a weighted overlay – index approach called the GIS based DRASTIC model in GIS setting. Haripur is a major district of Pakistan's Hazara division, it is famous for its agriculture. The district Haripur has a major industrial state i.e. Hattar Industrial State which contributes to needs of whole country. Due to the increasing population, advancing industrial sector and other human activities the groundwater of the district is under risk of contamination. As the purification and remediation of the polluted groundwater is a costly and difficult task, a primary step was taken to avoid the chances of groundwater by identifying areas which are vulnerable to groundwater pollution. For this purpose, GIS based DRASTIC model was adopted because of its efficiency, accuracy and easy execution. The data and information needed for assessing the vulnerability of the area was gathered from numerous organizations and from literature survey. Seven thematic map layers were generated from the data gathered which are Depth to water, Net Aquifer Recharge, Aquifer Media, Soil Media, Slope/Topography, Vadose zone and Conductivity (Hydraulic). These maps were generated in GIS environment. A weighted overlay- index analysis was executed using these seven layer to obtain a resultant susceptibility map of the study area.

After executing the Weighted overlay analysis, a range of DRASTIC Indices was developed which was between 88 – 190. This was classified into five smaller classes so that the study area is distributed in five sectors i.e. Low vulnerable zone, Medium vulnerable zone, Moderate vulnerable zone, high vulnerable zone and very high vulnerable zone. Each zone was allotted a distinctive color on the map for easy identification. The salient points of the analysis are given below:

1. The DRASTIC index of 88-109 was termed as low vulnerable zone and it encompass an area of 118 kilometers square.
2. The DRASTIC index of 110 – 129 was named medium vulnerable zone, covering 506 kilometers square.

3. The moderate vulnerable zone is the largest zone having an area of 965 kilometers square in the district and had the DRASTIC index of 130-149.
4. The high vulnerable zone covers the same area as that of medium vulnerable zone i.e. 506 kilometers square and its DRASTIC index is 150 – 169. This region was considered significant due to the fragile natural obstacles against pollution.
5. The most dangerous and vulnerable zone defined in the study area is the very high vulnerable zone and it covers an area of 66 kilometers square.
6. The GIS based DRASTIC model has been valued among the most vital and practicable method to evaluate the susceptibility of groundwater towards pollution.

Recommendations

After working on the DRASTIC model and generating vulnerability map. Taking all the important aspects of the DRASTIC model some recommendations are advised which are given below:

1. The evaluation of groundwater susceptibility can be a primary instrument for water resource management. As this evaluation will aid in threat analysis and classification of groundwater systems. This assessment will also aid in proposing the remedies and preventive steps in this regard.
2. The resultant map generated can be very useful for the decision and policy making authorities and can help them with establishing monitoring and safety approaches according to the vulnerability index for each zone which are low, medium, moderate, high and very high vulnerable zone. The DRASTIC index map can be employed as a screening mechanism in source distribution and water management tasks.
3. The susceptibility map and assessment should be incorporated while making policies regarding land use. The map can act as an instrument to raise awareness and educate general public to play their part in protecting the groundwater of their respective zone.

4. A vulnerability map of whole country specially the industrial zones should be developed in order to lessen the chances of groundwater pollution and to propose respective preventive measures.

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APPENDICES

Appendix-I. Depth to Water Table

Latitude	Longitude	Depth(Feet)	Depth (Meters)
34.07161	72.98528	212	64.61
34.07119	72.96861	250	76.19
33.975	73.098	70	21.33
33.79	73.045	180	54.86
34.053	73.072	92	28.04
33.966	72.732	50	15.23
33.92	72.951	58	17.67
33.92069	72.9575	53	16.15
34.02333	72.84139	136	41.45
34.02347	72.83583	136	41.45
33.95	72.914	280	85.33
34.067	73.082	196	59.73
33.99061	72.84472	121	36.87
34.00078	72.84361	121	36.87
33.787	72.884	140	42.66
34.002	72.832	165	50.28
33.95853	72.77778	210	64
34.073	72.957	125	38.09
34.035	73.048	148	45.1
33.874	72.885	178	54.25
34.00356	72.915	128	39.01
33.783	72.982	60	18.28
33.884	73.085	184	56.08
33.991	72.639	80	24.38
33.976	72.896	147	44.8
33.93	72.812	90	27.43
34.051	72.953	160	48.76
33.837	72.957	82	24.99
34.06	72.976	120	36.57
33.89733	72.91333	8	2.43
34.106	73.097	220	67.05
34.018	73.14	132	40.23
34.00789	72.895	58	17.67
34.218	72.876	132	40.23
33.79	72.905	91	27.73
33.93303	72.92444	44	13.41
33.848	73.13	166	50.59
34.045	72.711	10	3.04
34.00072	72.81194	162	49.37
34.00211	72.80667	162	49.37
33.929	72.865	190	57.9
33.872	72.857	209	63.7
33.893	72.885	100	30.47

34.03883	72.92833	99	30.17
34.04844	72.95611	104	31.69
33.881	72.612	180	54.86
33.979	73.036	125	38.09
34.148	72.979	90	27.43
34.06756	72.94806	20	6.09
33.982	73.147	104	31.69
33.98	73.037	140	42.66
33.89625	72.86889	245	74.67
33.89592	72.86917	245	74.67
33.836	72.899	180	54.86
33.95886	72.88694	62	18.89
33.95764	72.87944	87	26.51
33.979	72.882	40	12.19
33.88	73.209	110	33.52
33.845	73.039	90	27.43
33.857	72.937	14	4.26
33.9	72.921	109	33.22
33.964	73.027	10	3.04
33.93792	72.86306	75	22.85
33.92817	72.8575	75	22.85
33.93219	72.84889	75	22.85
33.94056	72.85222	75	22.85
34.043	72.72	44	13.41
34.027	72.73	45	13.71
34.13	72.869	170	51.81
34.01	72.951	177	53.94
34.02781	72.94194	145	44.19
33.816	72.897	50	15.23
34.02	72.995	213	64.91
33.915	72.904	125	38.09
33.985	73.039	140	42.66
34.009	72.965	125	38.09
33.82	73.005	37	11.27
33.779	73.021	44	13.41
33.84	72.854	108	32.91
34.005	72.931	100	30.47
33.804	72.9055	12	3.65
33.972	72.915	180	54.86
33.896	72.999	86	26.21
34.03636	72.91667	126	38.4
33.88189	72.91583	191	58.21
33.984	72.957	200	60.95
33.97458	72.86	100	30.47
33.97511	72.85389	100	30.47
34.091	73.105	32	9.75
34.039	73.046	111	33.83
33.791	72.845	83	25.29

34.047	73.028	120	36.57
33.911	72.986	190	57.9
33.90894	72.955	135	41.14
33.86808	72.91167	132	40.23
33.774	72.901	86	26.21
34.02531	72.92917	114	34.74
33.846	72.91	225	68.57
33.92228	72.95667	10	3.04
33.979	72.926	130	39.62
33.93081	72.91889	18	5.48
33.94083	72.81944	60	18.28
34.02378	72.83	180	54.86
34.072	73.051	212	64.61
33.892	73.05	139	42.36
33.938	72.896	195	59.43
33.973	73.085	180	54.86
34.03	72.796	65	19.81
34.078	72.775	88	26.82
33.841	72.863	185	56.38
33.988	73.041	88	26.82
33.994	73.028	45	13.71
34.00456	72.94	134	40.84
34.00694	72.93778	134	40.84
34.01075	72.94333	134	40.84
33.93819	72.89306	130	39.62
33.802	72.854	60	18.28
33.847	72.947	206	62.78
33.919	72.924	90	27.43
33.783	72.906	140	42.66
33.972	72.932	140	42.66
34.026	72.915	92	28.04
33.993	72.857	130	39.62
34.003	73.128	98	29.86
33.99	72.961	200	60.95
33.817	72.977	33	10.05

Appendix-II Mean Annual Precipitation

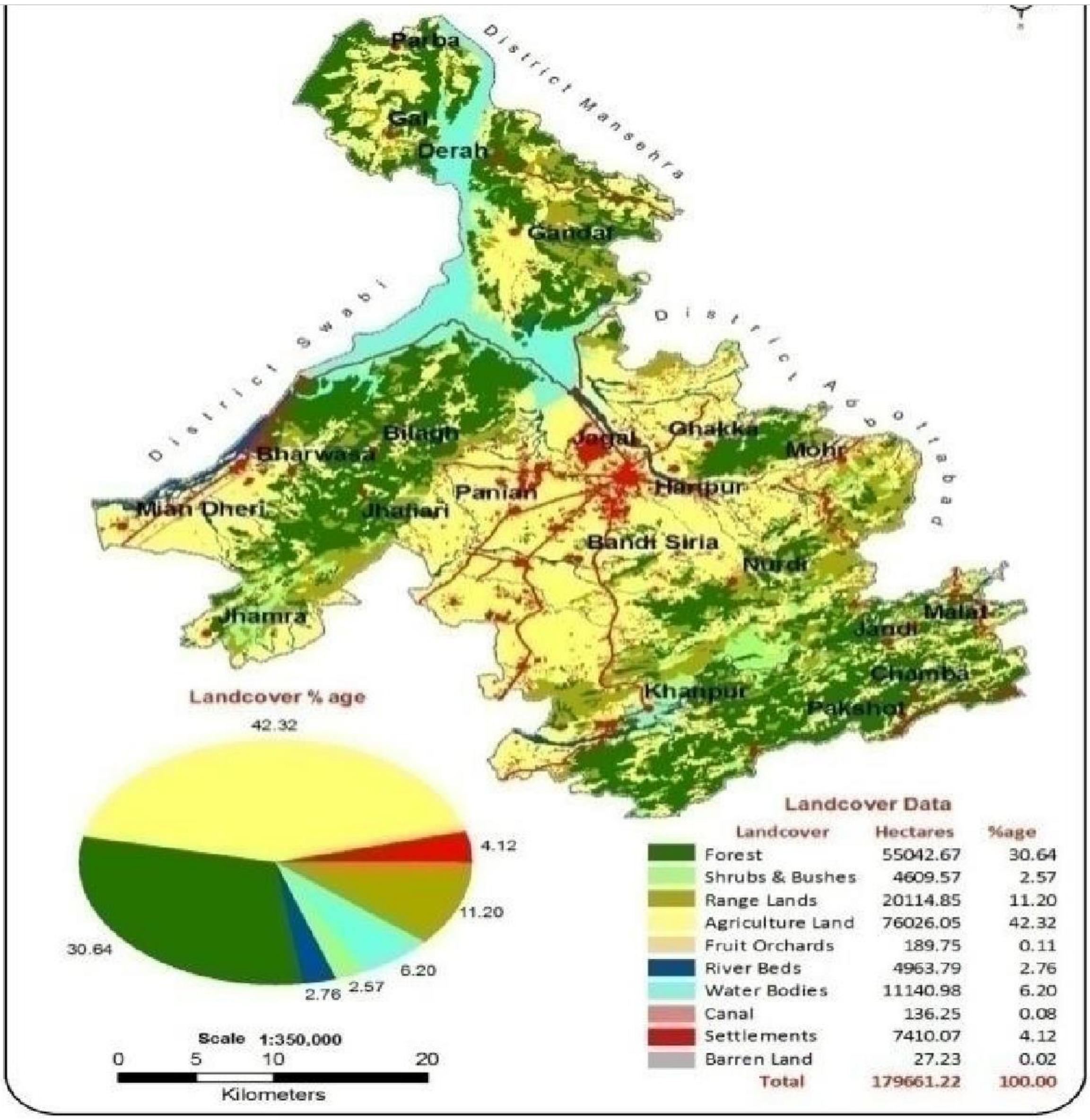
Latitude	Longitude	Annual Precipitation(mm)
34.3338	72.7501	2763
34.33238	72.786244	2936
34.33167	72.821679	2600
34.32671	72.848964	1950
34.30226	72.740178	2835
34.29836	72.779157	2789
34.29907	72.819198	2396
34.2973	72.856406	1898
34.28525	72.888297	2122
34.26505	72.750808	2755
34.25726	72.78022	2940
34.25619	72.822033	1910
34.25726	72.862075	1775
34.25548	72.889006	2321
34.20623	72.756124	2637
34.21686	72.78022	2310
34.21721	72.820262	1892
34.2197	72.859949	1738
34.2197	72.9007	2337
34.21863	72.93897	2340
34.21403	72.974051	1775
34.18958	72.755769	1510
34.17859	72.778802	1658
34.17717	72.822033	1849
34.17824	72.860658	1848
34.17788	72.901763	1854
34.17257	72.933655	1588
34.16831	72.972279	1788
34.14032	72.785535	1691
34.14032	72.82097	2309
34.13855	72.857114	2202
34.13607	72.897511	1530
34.13713	72.93897	1461
34.13784	72.983264	1670
34.13926	73.020117	2146
34.1304	73.052009	1943
34.08646	72.712892	1451
34.09319	72.745847	1872
34.0978	72.782346	2020
34.09992	72.818135	2322
34.09815	72.857114	2148
34.09921	72.899991	1628
34.10205	72.940033	1468

34.09886	72.980075	1801
34.09886	73.019763	2046
34.09886	73.059096	2388
34.09957	73.100555	2246
34.0472	72.673559	1248
34.05747	72.701907	1382
34.05676	72.73876	1799
34.05712	72.780928	2529
34.05464	72.819907	2076
34.05676	72.860304	1767
34.0557	72.899991	1435
34.05995	72.939679	1443
34.05854	72.980784	1265
34.05854	73.0187	1495
34.05924	73.058033	1585
34.06314	73.101406	1490
34.00574	72.629194	1455
34.01708	72.66144	1686
34.01743	72.702545	2096
34.01672	72.74117	2463
34.01778	72.782629	2466
34.01885	72.820191	2037
34.01708	72.86165	1846
34.01778	72.899566	1633
34.01885	72.941025	1559
34.01601	72.981067	1320
34.01956	73.0204	1360
34.01778	73.059379	1513
34.01353	73.098358	1935
34.01034	73.141235	2281
33.97377	72.554355	831
33.97909	72.582703	1053
33.9798	72.620619	1521
33.97803	72.657826	2114
33.97625	72.700348	2692
33.97838	72.739682	2645
33.97944	72.781141	1969
33.97873	72.820829	2079
33.97873	72.855555	1745
33.9759	72.899141	1703
33.97838	72.9406	1661
33.97767	72.981067	1807
33.97661	73.020046	1758
33.97767	73.058316	2210
33.97803	73.096587	2356
33.97838	73.136628	2538
33.95322	72.627918	1443
33.94153	72.660873	1907

33.94011	72.699143	1517
33.94294	72.73387	1379
33.94684	72.788795	1670
33.94046	72.819978	1808
33.93976	72.85839	1774
33.94046	72.900912	1737
33.93905	72.938474	1772
33.9433	72.979933	2308
33.9394	73.018558	2331
33.93905	73.0586	2409
33.93905	73.098642	2387
33.93161	73.133723	2582
33.89759	72.63047	1228
33.90007	72.668031	1386
33.90042	72.696025	1287
33.91141	72.793472	1435
33.90397	72.819695	1251
33.89865	72.859028	1418
33.90007	72.900558	1622
33.89759	72.941309	1866
33.8983	72.973909	2079
33.89688	73.025291	2168
33.89582	73.061789	2506
33.89723	73.10254	3223
33.89723	73.137621	3233
33.89723	73.175537	2593
33.89015	73.212035	2752
33.87548	72.655558	1358
33.85953	72.859666	1606
33.85705	72.898645	1657
33.85634	72.939395	1726
33.85882	72.976248	1837
33.85882	73.020188	2226
33.85776	73.060584	3047
33.85599	73.099917	3355
33.8567	73.139605	3485
33.85776	73.178584	3398
33.85811	73.209058	2744
33.8348	72.866328	1351
33.81956	72.902826	1550
33.82027	72.93897	2018
33.81956	72.979012	2666
33.81708	73.022597	2867
33.8185	73.055552	2686
33.8185	73.096657	2698
33.82098	73.142369	2804
33.82629	73.178159	2672
33.82665	73.212177	2174

33.78377	72.861367	1560
33.78377	72.899637	1821
33.77916	72.939324	1813
33.77881	72.980429	1985
33.78519	73.020117	2083
33.7944	73.059805	1958
33.79492	73.097046	2135
33.7944	73.127486	1945
33.74975	72.946766	1700
33.75046	72.976886	1428

Appendix-III. Land Cover Data



Appendix-IV. Aquifer Media Type

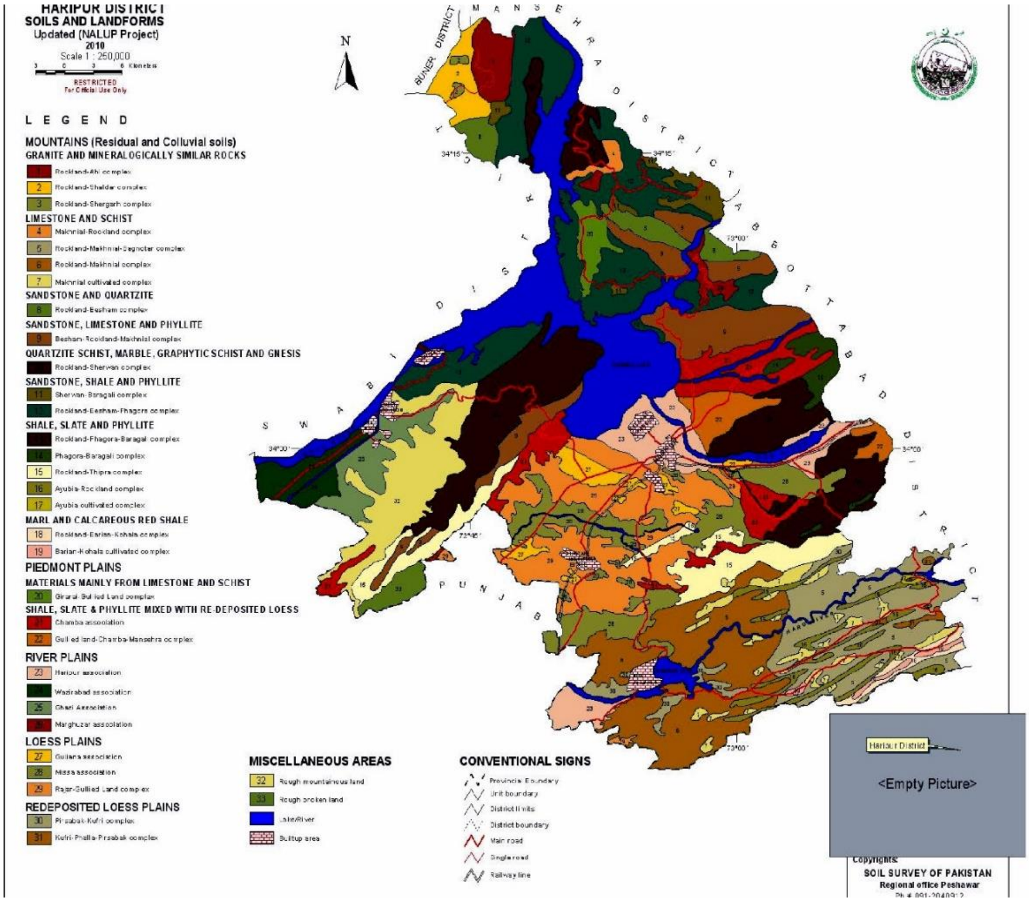
Village	Aquifer Media	Latitude	Longitude
Afzalabad	Clay	33.983	72.921
Alloli 2	Boulder	34.07161	72.98528
Alluli 4	Clay+boulder	34.07119	72.96861
Bagra mohri te/ bagra	Sand+boulder	33.975	73.098
Bakka jabbi/bakka	Gravel+clay	33.79	73.045
Banda munir khan	Shale	34.053	73.072
Bandi mian pirdad	Gravel+sand	33.966	72.732
Bandi munim		33.865	72.928
Bandi siran / bandi serian	Clay	33.92069	72.9575
Basso miara/ basso maira 1	Boulder+gravel	34.02333	72.84139
Batrasi	Gravel+sand	33.95	72.914
Bayan ahmed ali	Sandy gravel	34.067	73.082
Behra	Sandy gravel	33.993	72.857
Bhera 1	Gravel+boulder	33.99061	72.84472
Bhera dobandi	Clay	33.787	72.884
Bugnian (gudwalian)	Sandy gravel	34.002	72.832
Chamba pind	Clay	33.95853	72.77778
Chappra/ chappar	Clay	34.073	72.957
Chapri maira (alloli)	Gravel+boulder	34.035	73.048
Check muneem (pind muneem)	Gravel+boulder	33.874	72.885
Chohar sharif	Gravel+boulder	34.00356	72.915
Choi	Boulder	33.783	72.982
Danna te	Sand+boulder	33.884	73.085
Darra	Gravel+boulder+course sand	33.793	72.897
Darra dade	Gravel+boulder	33.991	72.639
Darwesh	Gravel+boulder+clay	33.976	72.896
Dehdeen/ dehdan	Gravel+boulder	33.93	72.812
Dehri sikandarpur	Clay	34.051	72.953
Demakeh	Clay	33.837	72.957
Dena colony (kag)	Gravel+boulder+clay	34.06	72.976
Dhak qutba	Clay	33.89733	72.91333
Dharam pani	Gravel	34.106	73.097
Dheki/ chitti dhaki	Clay	34.018	73.14
Dhenda/ dheenda jagal	Clay	34.00789	72.895
Dheri	Clay	34.218	72.876
District council	Clay	33.789	72.852
Dobandi	Clay	33.79	72.905
Dobandi	Gravel+boulder	34.003	73.128

Dohrian hattar	Gravel+boulder	33.881	72.859
Doyan khushki	Clay	33.93303	72.92444
Ferozpura	Gravel+boulder	33.848	73.13
Gehba		33.961	73.019
Gheri miara	Sandy gravel	34.045	72.711
Gudwalian 1	Clay	34.00072	72.81194
Gunjian kamala	Clay	33.929	72.865
Hattar	Gravel	33.872	72.857
Ibrar colony	Gravel+boulder	33.98	72.911
Islampur (khidu)	Clay	33.893	72.885
Jamia	Clay	34.03883	72.92833
Jatti pind	Clay	34.04844	72.95611
Jhamra vilage	Gravel+boulder	33.881	72.612
Jogi mohra	Gravel+boulder	33.979	73.036
Kachi	Boulder+clay	34.148	72.979
Kag	Clay	34.06756	72.94806
Kaileg te	Clay	33.982	73.147
Kalewan mohra/ kalawan	Gravel+boulder	33.98	73.037
Kali trar gullo bandi 1	Clay	33.89625	72.86889
Kamal pur	Clay	33.836	72.899
Kangra colony 1	Clay	33.95886	72.88694
Kangra colony 2	Gravel+boulder	33.95764	72.87944
Kangra village	40'	33.979	72.882
Khal bala/ kohala bala	Gravel+boulder	33.88	73.209
Khoi kamah	Clay	33.845	73.039
Khoi maira	Gravel+boulder	33.857	72.937
Kidho pinju	Clay	33.9	72.921
Koka jabbi	Clay	33.964	73.027
Kot najibullah 1	Clay	33.93792	72.86306
Kotnajibullah 2	Clay	33.94056	72.85222
Kundi umar khana	Gravel+boulder	34.043	72.72
Kundi umer khan	Gravel+boulder	34.027	72.73
Maira ali khan	Gravel+boulder	34.13	72.869
Makhan colony	Gravel	34.01	72.951
Makhan village	Gravel+boulder	34.02781	72.94194
Mamrial	50'	33.816	72.897
Manakarai & mohra mondi	Clay+sand	34.02	72.995
Mang	Clay	33.915	72.904
Mirpur	Clay	33.946	72.949
Mohallian sessin musa	Gravel+boulder	33.995	72.938
Mohrinoz (shah maqsood)	Fractured rock	33.985	73.039
Mumbrial	Boulder	33.794	72.899

Najafpur khoi kamah saradhna	Gravel	33.82	73.005
Nartopa	Gravel+boulder	33.779	73.021
Nazerabad	Clay	33.84	72.854
New abadi malikyar	Gravel+boulder	34.005	72.931
New khanpur township	Gravel+boulder	33.804	72.9055
Noor colony	Clay	33.972	72.915
Nordi	Gravel+boulder	33.896	72.999
Padhana	Clay	34.03636	72.91667
Padni (bareela)	Gravel+clay	33.88189	72.91583
Pandak	Boulder	33.984	72.957
Pandak village	Clay	33.99	72.961
Pannian	Clay	33.97458	72.86
Paswal shingri	Gravel+boulder	34.091	73.105
Pharari	Gravel+boulder	34.039	73.046
Pind ghakhar	Gravel+boulder	33.791	72.845
Pind hashim khan 2nd trail	Sandy gravel	34.047	73.028
Pind jamal khan	190'	33.911	72.986
Pind kamal khan	Clay	33.90894	72.955
Pind munim	Sandy gravel	33.86808	72.91167
Purj katha(julian)	Clayey gravel	33.774	72.901
Qazian	Gravel	34.02531	72.92917
Raniwah	Sandy gravel	33.846	72.91
Rara & thala	Clayey gravel	33.92228	72.95667
Roshanabad	Gravel+boulder	33.979	72.926
Sangiyan	Clay	33.93081	72.91889
Saradana	Clay	33.817	72.977
Sarai gadai	Clay	33.94083	72.81944
Sarri	Gravel+boulder	34.02378	72.83
Serai naimat khan te	Clay+boulder	34.072	73.051
Serai selah/ seri	Clayey gravel	33.892	73.05
Seria n khan	Gravel+boulder	33.938	72.896
Serian mohra	Sandy gravel	33.973	73.085
Serikot	Clay	34.03	72.796
Serikot 2	Gravel+boulder	34.078	72.775
Shadi hattar	Clay	33.841	72.863
Shah maqsood	Clay+boulder	33.988	73.041
Shaki laban bandi	Gravel+boulder	33.994	73.028
Sikandar pur 1	Sandy gravel	34.00456	72.94
Sikandar pur 2	Clayey gravel	34.00694	72.93778
Sikandar pur 3	Clay	34.01075	72.94333
Sirya	Gravel+boulder	33.93819	72.89306
Sultanpur	Gravel+boulder	33.802	72.854
Suraj galli	Sandy clay	33.847	72.947
Talokar		33.967	72.944
Tappre/ thipra	Gravel+boulder	33.919	72.924

Tarnawa	Clay	33.783	72.906
TIP housing society	Gravel+boulder	33.972	72.932
Utman aloed	Gravel+boulder	34.026	72.915

Appendix-V. Soil Map of Study Area



Appendix-VI. Vadose zone Data

Village	Vadose zone	Latitude	Longitude
Afzalabad	Clay	33.983	72.921
Alloli 2	Sand+gravel	34.07161	72.98528
Alluli 4	Clay+gravel+boulder	34.07119	72.96861
Bagra mohri te/ bagra	Clay+gravel+boulder	33.975	73.098
Bakka jabbi/bakka	Clay+gravel+boulder	33.79	73.045
Banda munir khan	Gravel+boulder	34.053	73.072
Bandi mian pirdad	Sand+gravel	33.966	72.732
Bandi siran / bandi serian	Clay	33.92069	72.9575
Basso miara/ basso maira 1	Gravel+boulder	34.02333	72.84139
Batrasi	Clay+gravel+boulder	33.95	72.914
Bayan ahmed ali	Sand+gravel+boulder	34.067	73.082
Behra	Sand+gravel	33.993	72.857
Bhera 1	Gravel+boulder	33.99061	72.84472
Bhera dobandi	Clay	33.787	72.884
Bugnian (gudwalian)	Clay+gravel+boulder	34.002	72.832
Chamba pind	Clay+gravel+boulder	33.95853	72.77778
Chappra/ chappar	Clay+gravel+boulder	34.073	72.957
Chapri maira (alloli)	Gravel+boulder	34.035	73.048
Check muneem (pind muneem)	Gravel+boulder	33.874	72.885
Chohar sharif	Clay+gravel+boulder	34.00356	72.915
Choi	Sand+gravel	33.783	72.982
Danna te	Sand+gravel	33.884	73.085
Darra	Sand+gravel	33.793	72.897
Darra dade	Gravel+boulder	33.991	72.639
Darwesh	Clay+gravel+boulder	33.976	72.896
Dehdeen/ dehdan	Gravel+boulder	33.93	72.812
Dehri sikandarpur	Clay+gravel	34.051	72.953
Demakeh	Clay	33.837	72.957
Dena colony (kag)	Clay+gravel+boulder	34.06	72.976
Dhak qutba	Clay	33.89733	72.91333
Dharam pani	Gravel+boulder	34.106	73.097
Dheki/ chitti dhaki	Clay	34.018	73.14
Dhenda/ dheenda jagal	Clay	34.00789	72.895
Dheri	Clay	34.218	72.876
District council	Gravel+boulder	33.789	72.852
Dobandi	Clay+gravel+boulder	33.79	72.905
Dobandi	Gravel+boulder	34.003	73.128
Dohrian hattar	Clay+gravel+boulder	33.881	72.859
Doyan khushki	Clay+gravel+boulder	33.93303	72.92444
Ferozpura	Gravel+boulder	33.848	73.13

Gheri miara	Sand+gravel	34.045	72.711
Gudwalian 1	Clay+gravel+boulder	34.00072	72.81194
Gunjian kamala	Clay+gravel	33.929	72.865
Hattar	Clay+gravel+boulder	33.872	72.857
Ibrar colony	Gravel+boulder	33.98	72.911
Islampur (khidu)	Clay+gravel+boulder	33.893	72.885
Jamia	Clay+gravel+boulder	34.03883	72.92833
Jatti pind	Clay	34.04844	72.95611
Jhamra vilage	Gravel+boulder	33.881	72.612
Jogi mohra	Gravel+boulder	33.979	73.036
Kachi	Clay+gravel	34.148	72.979
Kag	Clay	34.06756	72.94806
Kaileg te	Clay+gravel+boulder	33.982	73.147
Kalewan mohra/ kalawan	Gravel+boulder	33.98	73.037
Kali trar gullo bandi 1	Clay	33.89625	72.86889
Kamal pur	Clay+gravel+boulder	33.836	72.899
Kangra colony 1	Clay	33.95886	72.88694
Kangra colony 2	Clay	33.95764	72.87944
Khal bala/ kohala bala	Gravel+boulder	33.88	73.209
Khoi kamah	Clay	33.845	73.039
Khoi maira	Sand+gravel+boulder	33.857	72.937
Kidho pinju	Clay+gravel	33.9	72.921
Koka jabbi	Clay	33.964	73.027
Kot najibullah 1	Clay	33.93792	72.86306
Kotnajibullah 2	Clay+gravel	33.94056	72.85222
Kundi umar khana	Gravel+boulder	34.043	72.72
Kundi umer khan	Gravel+boulder	34.027	72.73
Maira ali khan	Clay+gravel+boulder	34.13	72.869
Makhan colony	Clay+gravel+boulder	34.01	72.951
Makhan village	Clay+gravel+boulder	34.02781	72.94194
Manakarai & mohra mondi	Clay+gravel+boulder	34.02	72.995
Mang	Gravel+boulder	33.915	72.904
Mirpur	Clay+gravel	33.946	72.949
Mohallian sessin musa	Clay+gravel+boulder	33.995	72.938
Mohrinoz (shah maqsood)	Clay+gravel+boulder	33.985	73.039
Mumbrial	Gravel+boulder	33.794	72.899
Najafpur khoi kamah saradhna	Clay	33.82	73.005
Nartopa	Clay+gravel+boulder	33.779	73.021
Nazerabad	Clay	33.84	72.854
New abadi malikyar	Clay+gravel+boulder	34.005	72.931
New khanpur township	Gravel+boulder	33.804	72.9055

Noor colony	Clay+gravel+boulder	33.972	72.915
Nordi	Sand+gravel+boulder	33.896	72.999
Padhana	Sand+gravel+boulder	34.03636	72.91667
Padni (bareela)	Sand+gravel	33.88189	72.91583
Pandak	Clay+gravel	33.984	72.957
Pandak village	Clay	33.99	72.961
Pannian	Clay	33.97458	72.86
Paswal shingri	Clay+gravel+boulder	34.091	73.105
Pharari	Sand+gravel+boulder	34.039	73.046
Pind ghakhar	Clay+gravel+boulder	33.791	72.845
Pind hashim khan 2nd trail	Sand+gravel	34.047	73.028
Pind kamal khan	Clay+gravel+boulder	33.90894	72.955
Pind munim	Clay+gravel+boulder	33.86808	72.91167
Purj katha(julian)	Sand+gravel+boulder	33.774	72.901
Qazian	Sand+gravel	34.02531	72.92917
Raniwah	Sand+gravel+boulder	33.846	72.91
Rara & thala	Clay+gravel	33.92228	72.95667
Roshanabad	Clay+gravel+boulder	33.979	72.926
Sangiyan	Clay	33.93081	72.91889
Saradana	Clay	33.817	72.977
Sarai gadai	Clay	33.94083	72.81944
Sarri	Gravel+boulder	34.02378	72.83
Serai naimat khan te	Gravel+boulder	34.072	73.051
Serai selah/ seri	Clay+gravel	33.892	73.05
Seria n khan	Sand+gravel+boulder	33.938	72.896
Serian mohra	Clay+gravel+boulder	33.973	73.085
Serikot	Clay	34.03	72.796
Serikot 2	Clay+gravel+boulder	34.078	72.775
Shadi hattar	Clay+gravel+boulder	33.841	72.863
Shah maqsood	Clay+gravel	33.988	73.041
Shaki laban bandi	Clay+gravel+boulder	33.994	73.028
Sikandar pur 1	Sand+gravel	34.00456	72.94
Sikandar pur 2	Clay+gravel+boulder	34.00694	72.93778
Sikandar pur 3	Clay+gravel+boulder	34.01075	72.94333
Sirya	Gravel+boulder	33.93819	72.89306
Sultanpur	Gravel+boulder	33.802	72.854
Suraj galli	Clay	33.847	72.947
Tappre/ thipra	Gravel+boulder	33.919	72.924
Tarnawa	Clay+gravel+boulder	33.783	72.906
TIP housing society	Gravel+boulder	33.972	72.932
Utman aloed	Clay+gravel+boulder	34.026	72.915

Appendix-VII. Hydraulic Conductivity Data

Latitude	**Longitude**	**Hydraulic Conductivity (m/day)**
33.983	72.921	2600
34.07161	72.98528	1720
34.07119	72.96861	2600
33.975	73.098	1720
33.79	73.045	2600
34.053	73.072	1720
33.966	72.732	2600
33.92069	72.9575	2600
34.02333	72.84139	2600
33.95	72.914	26
34.067	73.082	26
33.993	72.857	26
33.99061	72.84472	2600
33.787	72.884	2600
34.002	72.832	2600
33.95853	72.77778	860
34.073	72.957	2600
34.035	73.048	2600
33.874	72.885	2600
34.00356	72.915	2600
33.783	72.982	860
33.884	73.085	1720
33.793	72.897	2600
33.991	72.639	2600
33.976	72.896	2600
33.93	72.812	2600
34.051	72.953	26
33.837	72.957	2600
34.06	72.976	2600
33.89733	72.91333	2600
34.106	73.097	2600
34.018	73.14	2600
34.00789	72.895	2600
34.218	72.876	2600
33.789	72.852	26
33.79	72.905	2600
34.003	73.128	2600
33.881	72.859	2600
33.93303	72.92444	2600
33.848	73.13	2600
34.045	72.711	26
34.00072	72.81194	26

33.929	72.865	26
33.872	72.857	860
33.98	72.911	2600
33.893	72.885	2600
34.03883	72.92833	26
34.04844	72.95611	2600
33.881	72.612	2600
33.979	73.036	2600
34.148	72.979	2600
34.06756	72.94806	26
33.982	73.147	2600
33.98	73.037	2600
33.89625	72.86889	2600
33.836	72.899	2600
33.95886	72.88694	2600
33.95764	72.87944	2600
33.88	73.209	2600
33.845	73.039	2600
33.857	72.937	2600
33.9	72.921	860
33.964	73.027	2600
33.93792	72.86306	2600
33.94056	72.85222	860
34.043	72.72	1720
34.027	72.73	1720
34.13	72.869	2600
34.01	72.951	860
34.02781	72.94194	2600
34.02	72.995	860
33.915	72.904	2600
33.946	72.949	26
33.995	72.938	2600
33.794	72.899	860
33.82	73.005	2600
33.779	73.021	2600
33.84	72.854	2600
34.005	72.931	2600
33.804	72.9055	2600
33.972	72.915	2600
33.896	72.999	2600
34.03636	72.91667	860
33.88189	72.91583	860
33.984	72.957	860
33.99	72.961	26
33.97458	72.86	2600
34.091	73.105	26
34.039	73.046	2600
33.791	72.845	2600

34.047	73.028	2600
33.90894	72.955	2600
33.86808	72.91167	860
33.774	72.901	2600
34.02531	72.92917	2600
33.846	72.91	2600
33.92228	72.95667	2600
33.979	72.926	2600
33.93081	72.91889	2600
33.817	72.977	2600
33.94083	72.81944	860
34.02378	72.83	2600
34.072	73.051	2600
33.892	73.05	2600
33.938	72.896	2600
33.973	73.085	26
34.03	72.796	2600
34.078	72.775	2600
33.841	72.863	860
33.988	73.041	2600
33.994	73.028	2600
34.00456	72.94	860
34.00694	72.93778	2600
34.01075	72.94333	2600
33.93819	72.89306	2600
33.802	72.854	2600
33.847	72.947	26
33.919	72.924	2600
33.783	72.906	2600
33.972	72.932	2600
34.026	72.915	2600