AN ASSESSMENT OF GROUND WATER VULNERABILITY IN SELECTED DISTRICTS OF BANGLADESH USING DRASTIC INDEX

A Project Submitted
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The Project titled "**An Assessment of Ground Water Vulnerability in Selected Districts of Bangladesh Using DRASTIC Index**" submitted by Zannatul Ferdausi Sumi, Roll No. 1015162061, Session October 2015, to the Department of Water Resources Engineering, Bangladesh University of Engineering and Technology, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Master of Engineering in Water Resources Engineering and approved as to its style and content on 2 August, 2023.

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This is to certify that this project work entitled "**An Assessment of Ground Water Vulnerability in Selected Districts of Bangladesh Using DRASTIC Index**" has been done by me under the supervision of Dr. Anika Yunus, Professor of the Department of Water Resources Engineering (WRE), Bangladesh University of Engineering and Technology (BUET), Dhaka. I do hereby declare that this project work or any part of it has not been submitted elsewhere for the award of any degree or diploma from any other institution.

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ABSTRACT

Around 75% of population of Bangladesh relies on groundwater for potable supplies and it is also extensively used for irrigation purpose during the dry season. Therefore, pollution of groundwater is a crucial issue. In this study, the pollution potential of three districts of Bangladesh in Pabna, Sirajganj and Natore has been determined using DRASTIC indices. DRASTIC is a methodology that systematically evaluates the pollution potential of groundwater of an area. DRASTIC is acronym of depth to ground water, net recharge, aquifer media, soil media, topography, impact of vadose zone and hydraulic conductivity. It is then combined with weights and ratings to produce drastic index value. As the objective of the study was to determine the temporal variation of vulnerability of groundwater pollution of Pabna, Sirajganj and Natore district by DRASTIC index. Vulnerability of groundwater was determined for three seasons that is pre-monsoon, monsoon and post-monsoon periods consist of March to May, June to October, November to February respectively. For pre-monsoon period The DRASTIC index value range for Pabna, Sirajganj and Natore districts are 83-109, 83-105 and 105-141 respectively which indicates that Pabna has very low to low vulnerability, Sirajganj falls under the same category and Natore district shows low to moderate vulnerability. For monsoon period The DRASTIC index value range for Pabna, Sirajganj and Natore districts are 113-147, 121-146 and 123-141 respectively which indicates that Pabna and Sirajganj falls under the same category low to moderate vulnerability and Natore district also shows the same results. For post-monsoon period The DRASTIC index value range for Pabna, Sirajganj and Natore districts are 113-135, 113-135 and 93-113 respectively which indicates that Pabna and Sirajganj falls under low to moderate vulnerability and Natore district falls under very low to low vulnerable areas. The objective was also to determine which parts of the areas are more vulnerable than other. From the study it is also found that in these three districts there is urban area where pollution potential is very low due to covered soil surface as waste materials cannot seep through it. It is hoped that this study will be helpful in future development and land use planning of this area and also assist in prioritizing protection, monitoring and cleanup efforts.

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LIST OF ABBREVIATIONS

ACRONYM	ELABORATION
BARC	Bangladesh Agricultural Research Council
BMD	Bangladesh Meteorological Department
BWDB	Bangladesh Water Development Board
DEM	Digital Elevation Model
DPHE	Department of Public Health Engineering
EPA	Environmental Protection Engineering
GIS	Geographic Information System
GW	Ground Water
GWT	Ground Water Table
IWM	Institute of Water Modeling
SW	Surface Water
USGS	United States Geological Survey

CHAPTER 1

INTRODUCTION

1.1 General

In recent decades, water scarcity and its pollution became a major issue all over the world. Preserving the groundwater quality is very important for assuring the drinking water resources, given that billions of people all over the world do not have access to water or suffer from water scarcity. In Bangladesh abundance of water during monsoon causes flood. On the other side during dry season water is too scarce to meet the requirement. This makes it imperative for us to maintain a well-planned water management. Bangladesh has gained notable success in groundwater development for its irrigated agriculture, industrial development and domestic water supply system and thus gained food security for its people. Currently, about 98% of drinking water and 80% of irrigation water supply is being provided by ground sources which necessitate the sources to be pollution free (BGS, 2001; (Rahman and Ahmed, 2008). An according to the target 6.3 of Sustainable Development Goal (SDG): By2030, water quality should be improved by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials; which also strengthens the need of groundwater to be free of contamination (The Sustainable Development Goals for Water and Sanitation Services, 2018).

For this reason, pollution potential of groundwater has been selected considering huge importance on local agriculture and drinking water supply system.

1.2 Study Area

Three districts have been for this study (Figure 1.1). These are Pabna, Sirajganj and Natore District. Pabna forms the south-east boundary of Rajshahi Division. Sirajganj District is on the north-east, while the Padma River, main stream of the holy river Ganges, in the south separates it from Rajbari District and Kushtia District. The Jamuna River runs along its eastern border separating it from Manikgonj District; and on the north-west, it has a common boundary with the Natore District. It is located in between 23°48' and 24°21' north latitudes and in between 89°00' and 89°44' east longitudes with having an area of 2371.50 sq km. Characteristically, the soil of the district is divided into four, due to the flood plains of the Ganges, Karatoya, Jamuna, and Barind Tracts. Sirajganj District is also in Rajshahi Division. It is bordered on the north by Bogra District and Natore District; on the west by Natore District and Pabna District; on the south by Pabna District and Manikganj District; on the east Manikganj District, Tangail District and Jamalpur District. It has an area of 2497.92 sq km and located in between 24°01' and 24°47' north latitudes and in between 89°15' and 89°59' east longitudes. About 10% of the total area of Chalan Beel belongs to the Tarash upazila of the district. While Natore is also in Rajshahi Division. It is located in between 24°25' and 24°58' north latitudes and in between 88°01' and 88°30' east longitudes. It has an area of 1896.05 sq km. It is bounded by Naogaon and Bogra districts on the north, Pabna and kushtia districts on the south, Pabna and Sirajganj districts on the east, Rajshahi district on the west.

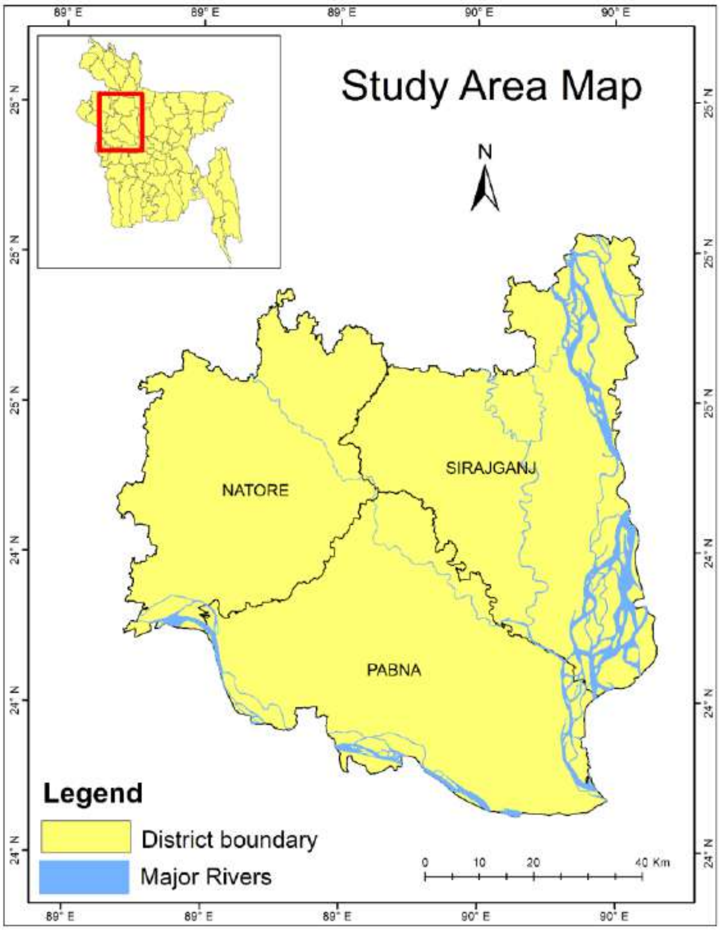


Figure 1.1: Location map of the study area

1.3 Ground Water Quality of the Study Area

Water quality varies from place to place with the season of the year, climate, structure and position of rocks and soils and biochemical effects associated with life cycles of plants and animals. Safe water is a precondition for health and development. For the betterment of life and society the quality of water should be maintained. For this reason, we need to assess the quality of it first. Table 1.1 shows water quality parameters of Pabna, Sirajgonj and Natore districts (Md. Zasim Uddin et. Al., (2019).

Table 1.1: Water quality parameters of the study area (BWDB)

Parameters	**Units**	**Bangladesh Standards**		**WHO standards**	**Pabna**	**Sirajganj**	**Natore**
		Drinking limit	**Irrigation limit**	**Drinking limit**			
pH	µs/cm	6.5-8.5	6.0-9.0	6.5-8.5	7.07-7.30	6.71-7.34	6.99-7.26
EC	mg/l	600-1000	1200	-	208-292	218-754	639-801
TDS	mg/l	1000	2100	500-1000	150.9-190	123-307	499-626
Calcium (Ca)	mg/l	75	-	75-200	2.40-3.70	1.36-6.88	38.07-122.24
Magnesium(Mg)	mg/l	30-50	-	50	0.20-2.40	0.08-3.84	10.93-37.67
Sodium(Na)	mg/l	200	-	200	0.01-0.20	0.13-1.11	55.14-94.22
Potassium(K)	mg/l	12	-	-	0.01-0.09	0.02-0.17	1.15-3.99
Bicarbonate(HCO$_3$)	mg/l	-	200	-	0.67-1.14	0.6-1.2	366-695.4
Carbonate(CO$_3$)	mg/l	100		-		Trace	
Chloride(CL)	mg/l	150-600	600	200-600	5-18	0.28-1.06	14.18-49.63
Nitrate (NO$_3$)	mg/l	10	-	50			0.031-0.370

Phosphate(PO_4)	mg/l	6	10	-	Trace-0.11	0.00-0.15	0.084-0.174
Sulphate(SO_4)	mg/l	400	-	250	0.12-0.95	0.79-12.67	2.25-10.28
Iron(Fe)	mg/l	0.3-1.00	1-2	0.3	1.3-0.09	0.23-21.75	0.23-3.9
Manganese(Mn)	mg/l	0.1	5	0.1	0.53-0.14	0.04-4.68	0.19-0.95
Arsenic(As)	mg/l	0.05	1	0.01	0.003-0.0034	0.0007-0.061	0.0005-0.006

These water quality data, collected from BWDB, (2013) and Zasim Uddin et.Al., (2019) (table 1.1) show that water quality of (Pabna/Sirajgonj/Natore) districts are not safe and satisfactory in terms of salinity and iron contamination. Among three districts Iron content exceeds more in the sirajganj district. But according to the BWDB officials, except the area of arsenic contamination, aquifer water is being used for the different purposes of daily consumptions in these areas although few parameters don't fulfill the all requirements.

1.4 Motivation behind the Study

Being the main source of potable supply Ground water possess a huge importance in Pabna, Sirajgonj and Natore districts. Due to arsenic contamination ground water use has been decreased to some extent in these areas. Yet the demand of it requires the groundwater source to be free of contamination. Therefore, it is important to determine the vulnerability of groundwater.

Vulnerability is not an absolute property, but a relative indication of where contamination is likely to occur; Ground water vulnerability is an amorphous concept, not a measurable property. It is a probability of contamination occurring in the future. In this sense, a ground water vulnerability assessment is a predictive statement.

A lot of approaches for predicting ground water vulnerability has been developed from an understanding of the factors that affect the transport of contaminants introduced at or near the land surface. These methods fall into three major classes:

(1) **Overlay and index methods:** It combines specific physical characteristics that affect vulnerability, often giving a numerical score.

(2) **Process-based methods:** Consisting of mathematical models that approximate the behavior of substances in the subsurface environment, and

(3) **Statistical methods:** Draw associations with areas where contamination is known to have occurred.

Some examples of index and overlay Methods are: The DRASTIC index model (Aller et. Al., 1987), GOD model (Foster, 1987), EPIK model (Doerfliger, 1999), PI model (Goldscheider, 2000) and COP model (Vias et. Al., 2005) Among them DRASTIC model is being used throughout the world such as Ahmed (2007), Jasrotia and Singh (2005), Al-Adamat et. Al., (2003), Castillejos (2010), Dikerson (2007) etc. For this study DRASTIC model was chosen because of its simplicity, applicability at all scale and dependence on existing data.

1.5 Scope of the Study

The scope of this project includes not only the development of a standardized system for evaluating pollution potential, but also the creation of a system which can be readily displayed on maps. For purpose of relative evaluation, a system has been designed which produce a numerical rating. For purpose of mapping, the study areas have been divided into hydrogeologic settings. These setting incorporate the many hydrogeologic factors which will influence the vulnerability of that setting to ground-water pollution.

1.6 Specific Objectives of the Study:

This research work is being conducted with a view to attaining some specific objectives. Based on above discussion the objectives are the following:

1. To prepare the temporal variation of vulnerability of groundwater pollution of Sirajganj, Pabna and Natore districts by DRASTIC index.
2. To compare the spatial vulnerability of groundwater pollution among three districts.

Possible outcome of the research work:

The expected outcomes of this research work are as follows:

(i) A distinct map of seven DRASTIC parameters.

(ii) From DRASTIC index which parameter is more responsible for ground water vulnerability.
(iii) Identified the most contaminated areas between three districts.
(iv) Comparative analysis of vulnerability potential of these three selected areas will be shown which can be used in future planning related to local groundwater resources by prioritizing the areas where groundwater protection is critical.

1.7 Organization of the Thesis:

Considering the literature review, location of the study area, theory and methodology, data analysis, results and discussions, the thesis has been organized under five chapters which are described below:
Chapter 1 is the Introduction of the project. This chapter describes the background, highlights the objectives of the study and contains the organization of the thesis.

Chapter 2 is the Literature Review. In this chapter detail literature review have been conducted. In addition, the possible research gap has also been identified.

Chapter 3 is the Theory and Methodology, where descriptions about the study area have been incorporated. The basic theory of the DRASTIC index method and relevant equations have also been discussed in detail.

Chapter 4 is the Results and Discussions. This chapter presents the results of the groundwater vulnerability assessment of Pabna, Sirajganj and Natore districts selected as study area in the period of pre-monsoon, monsoon, post-monsoon with the help of DRASTIC method. Resulting vulnerability map was then compared the spatial vulnerability of groundwater pollution among three districts.

Chapter 5 Conclusions and Recommendations. This Chapter provides the overall conclusions of the study and some recommendations for further study.

CHAPTER 2
LITERATURE REVIEW

2.1 General

This chapter comes up with the basic information of the groundwater vulnerability and its definition, different methods for determining the groundwater vulnerability and assessment process of vulnerability for groundwater and introduction of DRASTIC index method for groundwater vulnerability assessment. Numerous studies and research have been conducted for groundwater vulnerability assessment. This chapter also focuses on the literature review of a few related studies conducted by previous researchers on the assessment of groundwater vulnerability by DRASTIC index. This chapter also reviewed the literature related to assess the groundwater vulnerability by DRASTIC index in Bangladesh.

2.2 General Concept of Groundwater Vulnerability

The original concept of groundwater vulnerability was based on the assumption that the physical environment may provide some degree of protection with regard to contaminants entering the subsurface water. The surface and subsurface materials may act as natural filters to screen out some contaminants. Water infiltrating at the land surface may be contaminated but is naturally purified to some degree as it percolates through the soil and other fine-grained materials in the unsaturated zone (Vrba and Zaporozec, 1994).

Groundwater vulnerability is a function of the geologic setting of an area. Geologic settings largely control the residence time of the subsurface water that has passed since the water fell as rain, infiltrated through the soil, reached the water table, and began flowing to its present location. In any given area, the GW within an aquifer, or the GW produced by a well, has some degree of vulnerability to contamination from human activities. This concept exists since the 1960s when it was first introduced in France by Margat. The idea was conceived in order to create awareness about the danger of groundwater contamination (Albinet and Margat in Zaporozec, 1994), variability of natural protection and identification of areas where protections are needed. The most common definition comes from Vrba et al., (1994), who described aquifer vulnerability as concept representing the intrinsic properties of aquifer vulnerability as concept representing the intrinsic properties of aquifer systems as a function of their sensitivity to human and natural activities.

Vulnerability mapping is defined as a technique for quantifying the sensitivity of the resource to its environment, and as a practical visualization tool for decision-making. GW vulnerability is also defined as "the tendency and likelihood for general contaminants to reach the water table water table after introduction at some location above the uppermost aquifer."

Vulnerability is distinct from pollution risk; pollution risk depends not only on vulnerability but also on the existence of significant pollutant loading entering the sub-surface environment (Margane, 2003). It is possible to have high aquifer vulnerability but no risk of pollution, if there is no significant pollutant loading. It can have high pollution risk in spite of low vulnerability, if the pollutant loading is exceptional. A vulnerability assessment defines the risk to an aquifer based on the physical characteristics of the vadose zone and aquifer and the presence of potential contaminant sources. According to Foster (1987), aquifer pollution vulnerability is "the intrinsic characteristics which determine the sensitivity of various parts of an aquifer to being adversely affected by an imposed contaminant load".

2.2 Approaches to Vulnerability Assessment

Methods of assessing groundwater vulnerability to contamination are numerous. However, there are three traditional methods of assessing groundwater vulnerability to pollution

1. Index and overlay methods
2. Methods employing process-based simulation models and
3. Statistical models.

Index and overlay methods: These methods are based on the assumption that a few major parameters largely control groundwater vulnerability and they are based on limited basic data, used in regional studies, and usually cover extensive areas. The groundwater vulnerability evaluated is qualitative and relative. Scoring, integrating or classifying to produce an index of vulnerability, interprets the information. The simplest parametric systems identify areas whereas parameters indicating high vulnerability coincide e.g. shallow groundwater and sandy soil. More sophisticated systems assign numerical scores based on several parameters. Some parameters system models are the DRASTIC index model (Aller et al., 1987), GOD model (Foster, 1987), PI model (Goldscheider, 2000) and COP model (Vias et al., 2005). The most commonly used of these methods, DRASTIC (Aller et al., 1987), uses a scoring system based on seven hydrogeological characteristics of a region. In general, parametric system models rely on simple mathematical representation of expert opinion and not on process representation. The advantage of spatial information's into maps of vulnerability classes. The method is particularly suitable for use with GIS. However, the lack of a physically-based, precise definition also has some drawbacks. The result tends to be subjective.

Process-based simulation models: are used for examining vulnerability from a quantitative point of view and to establish clearly identified reference criteria for quantification, comparison and validation purposes. These models use current scientific understanding to incorporate the most important and relevant processes, using the governing equations for water flow and solute transport. The focus is on computing travel times or concentrations of a contaminant in the unsaturated and groundwater zones. These models can be used to analyze flow in hypothetical hydrogeological systems and they may be useful to define regulatory guidelines for a specific region (Anderson et al., 1992). They are also useful for different prediction involving contamination hazards at specific sites. However, their need for extensive data input and the expertise required to implement them may, in some cases, limit their use over large areas.

Statistical models: Statical models are the least common category of vulnerability assessment methods found in the literature. Although Statical studies are used as tests for other methods and geostatistical methods, very few vulnerability assessment methods are directly based on statistical methods. These methods are used to quantify the vulnerability of groundwater contamination by determining the statistical dependence or relationship between observed contamination or observed environmental conditions that may or may not characterize vulnerability and observed land uses that are potential sources of contamination. Once a model has been developed with statistical analysis, the probability of contamination can be evaluated. Knowledge of significant environmental conditions is required for the study area. In statistical methods the vulnerability is expressed as contamination probability. The higher the contamination probability, the higher the vulnerability. Furthermore, the statistical significance of the results can be explicitly calculated. This provides a measure of uncertainty in the model. The disadvantage is that statistical methods are difficult to develop and once established, can only be applied to regions that have similar environmental conditions to the region for which the statistical model was developed. Teso et al. (1996) used a logistic regression model and GIS to predict ground water vulnerability to pesticides. A statistical method, CALVUL (Troiano et al., 1999), is used to determine the groundwater vulnerability due to pesticide leaching in California. In Texas, Evans et al. (1995) developed a similar statistical analysis using nitrate in groundwater as the basis for delineating vulnerable groundwater areas.

2.3 DRASTIC Method for Vulnerability Assessment

It was developed by US EPA (Environmental Protection Agency) (1994). It provides a basis for evaluating the vulnerability to pollution of groundwater resources based on hydraulic parameters: depth to water table, net recharge, aquifer media, soil media, topography, impact of vadose zone and hydraulic conductivity of the aquifer. It also provides an approach to evaluate an area based on known conditions without the need for extensive, site-specific pollution data. It is an inexpensive method to identify areas that need more investigation. It is based on four major assumptions:

1. The contaminant is introduced at the ground surface.
2. The contaminant is flushed into the ground water by precipitation.
3. The contaminant has the mobility of water; and
4. The area evaluated is 100 acres or larger.

DRASTIC model is being used throughout the world such as Ahmed (2007), Jasrotia and Singh (2005), Al-Adamat et al., (2003), Castillejos (2010), Dikerson (2007) etc. Because of its simplicity, applicability at all scale and dependence on existing data.

Vrba and Civita (1994) in their study named "Assessing and mapping groundwater vulnerability to contamination: The Italian "combind" approach" classified the vulnerability assessment methods into three basic groups. According to them aquifer vulnerability map is an environmental planning document and they also focused on the data reliability, distribution and amount of data for choosing a suitable model.

Aller et al., (1987) in their study "DRASTIC: A Standardized system for evaluating Groundwater pollution potential using Hydrogeologic settings "Developed DRASTIC model to produce meaningful aquifer vulnerability map using readily available data within a minimum of time and at minimum of cost. The methodology was described that will allow the pollution potential of any hydrogeologic setting to be systematically evaluated anywhere in the United States. The system has two major portions: the designation of mappable units, termed hydro-geologic settings, and the superposition of a relative rating system called DRASTIC. Hydro-geologic settings form the basis of the system and incorporate the major hydro-geologic factors which affect and control ground-water movement including depth to water, net recharge, aquifer media, soil media, topography, impact of the vadose zone media and hydraulic conductivity of the aquifer.

Jasrotia and Singh, (2005) conducted their study on DEVAK-RUI watershed, India in a GIS based DRASTIC environment and estimated DRASTIC indices for both normal and agriculture pollutants. DRASTIC index model was employed in the assessment of the intrinsic groundwater vulnerability to contamination in Kaduna metropolis, Nigeria. The model evaluates the contribution of seven environmental parameters (Depth to water level, Net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone, and Hydraulic Conductivity) in the protection of groundwater against contamination. The mapping was conducted within the framework of Geographical Information System. The study area has very low, low to slightly moderate vulnerability with highest and lowest DRASTIC values of 131 and 77 respectively. To have better understanding of the spatial vulnerability of groundwater in the area, the DRASTIC map was reclassified into five (very high, high, moderate, low and very low) vulnerability zones. Generally, the distribution of the vulnerability classes indicated the low to moderate vulnerability status of the majority parts of the study area, with high vulnerability at the center. Strict control measures should be put in place when locating land uses with high potential hazards in the high and very high vulnerability areas.

Al-Adamat et al., (2003) conducted her study on "Groundwater vulnerability and risk mapping for the Basaltic aquifer of the Azraq basin of Jordan using GIS, Remote sensing and DRASTIC" This paper focuses on a small part of the northern Badia region of Jordan that is underlain by the Azraq groundwater basin where it has been estimated that annual abstraction stands at over 100% of the projected safe yield. While water supply is a crucial issue, there is also evidence to suggest that the quality of groundwater supplies is also under threat as a result of Stalinization and an increase in the use of agrochemicals. Focusing on this area, this paper attempts to produce groundwater vulnerability and risk maps. These maps are designed to show areas of greatest potential for groundwater contamination on the basis of hydro-geological conditions and human impacts. All of the major geological and hydro-geological factors that affect and control groundwater movement into, though, and out of the study area were incorporated into the DRASTIC model. Parameters included; depth to groundwater, recharge, aquifer media, soil media, topography, and impact of the vadose zone. The hydraulic conductivity of the aquifer was not included in calculating the final DRASTIC index for potential contamination due to a lack of sufficient quantitative data. A Geographical Information System (GIS) was used to create a groundwater vulnerability map by overlaying the available hydro-geological data. The resulting vulnerability map was then integrated with a land use map as an additional parameter in the DRASTIC model to assess the potential risk of groundwater to pollution in the study area. The final DRASTIC model was tested using hydro-chemical data from the aquifer. Around 84% of the study area was classified as being at moderate risk while the re mainder was classified as low risk. While the analysis of groundwater chemistry was not conclusive, it was encouraging to find that no well with high nitrate levels was found in the areas classified as being of low risk suggesting that the DRASTIC model for this area provided a conservative estimate of low risk areas. It is recognized that the approach adopted to produce the DRASTIC index was limited by the availability of data. However, in areas with limited secondary data, this index provides important objective information.

Khodabakhshi et al., (2015) in their study on ‘Application of a GIS-based DRASTIC model and groundwater quality index method for evaluation of groundwater vulnerability: a case study, Sefid-Dasht’. The aim of this paper was to determine the aquifer vulnerability of Sefid-Dasht, in Chaharmahal and Bakhtiari province, Iran, using the DRASTIC model. In addition, the groundwater quality index (GQI) technique was applied to assess the groundwater quality and study the spatial variability of major ion concentration using a geographic information system (GIS). The vulnerability index ranged from 65 to 132, classified into two classes: low and moderate vulnerability. Furthermore, the results indicate that the magnitude of the GQI index varies from 92% to 95%. This means the water has a suitable quality. A comparison of the vulnerability maps with the GQI index map indicated a poor relation between them. In DRASTIC method, movement of groundwater is not considered and may be the reason for such inconsistency.

Alina Barbulescu (2020) conducted her study on ‘Assessing Groundwater Vulnerability: DRASTIC and DRASTIC-Like Methods: A Review’. She reviewed DRASTIC and the main DRASTIC-like approaches proposed by scientists for improving the initial algorithm. The methods for assessment of the groundwater vulnerability in karstic regions were not discussed here. DRASTIC uses readily available geo-data with no experimental data. DRASTIC employs numerous parameters, and its outputs are only sometimes compared with field collected data. DRASTIC based forecast should be rigorously checked before making management decisions.

This model was also criticized by some scholars for its non-flexibility to customize specific need (Vrba and Civita, 1994), under estimation of the vulnerability of fractured aquifer compared to unconsolidated aquifer (Rosen in Foster and Skinner, 1995).

According to Foster and Skinner (1995), this method generates vulnerability index whose meaning is rather obscure and significance is unclear. They think that this is because of interaction of too many parameters some of which are not independent rather strongly correlated. In spite of these facts, the advantage of this method was adjudged to have outweighed its shortcomings (Wang et al., 2012). Keeping these things in mind and considering its simplicity and incorporation of available data this method was chosen for this study.

2.4 Reviews on Previous Study with DRASTIC Method in Bangladesh

In 2006, IWM prepared aquifer vulnerability map for Dhaka watershed area using DRASTIC. It is observed that the Normal DI values ranges from 86 to 135. The vulnerability map exhibits that some locations in northwestern part and southeastern part (Kalikoir and Narayanganj) of the study area have the higher magnitude of aquifer vulnerability and therefore possess more pollution potential than other area. Aquifer of Tejgaon and Mirpur area show DI below 100. In 2008, IWM prepared a vulnerability map for Singair upazila of Manikganj district.It is observed that or values range from 70 to 100. The maximum part of the target area in the Singair upazila has lower DI value.

Uddin, M. S. (2009) made an effort to determine aquifer vulnerability of Dinajpur,Thakurgaon, Panchagarh and Joypurhat districts in his thesis: “Groundwater Quality and Aquifer Vulnerability Assessment of several Northern Districts of Bangladesh”.He found that the impact of the vadose zone and soil type are the main parameters acting behind the distribution of vulnerability potential. He also observed that a positive correlation exists between DI and concentration of ammonium, potassium and nitrate of STW samples and no positive correlation between DI and Iron, boron and manganese concentration. He said that the high concentration of these parameters for STW sample was due to the soil chemical properties, which was not considered in DRASTIC analysis.

Giri, et al., (2012) conducted a study on the North-Eastern region of Bangladesh using DRASTIC Index. The pollution vulnerability maps were validated with existing groundwater quality data. It showed that majority of the area was highly vulnerable to agricultural pollutants. 200 public's views were taken to calculate gross weightage of all parameters. Therefore in this study DRASTIC has been chosen to evaluate the GW potential.

Sajal, et al., (2013) conducted a study on "DRASTIC-based Vulnerability Assessment of Barind Tract Aquifer in Northwestern Bangladesh". The Barind Tract aquifer located in three northwestern districts (Rajshahi, Naogaon, Chapai Nawabganj) of Bangladesh have been considered in this study. Based on estimated DRASTIC index values, a GW vulnerability map is established in the framework of ArcGIS platform. The higher index values symbolize greater potential for GW pollution, or greater aquifer vulnerability. The results provide valuable information and the pollution risk map can be useful to local authorities and decision makers for successful GW resource management and protection zoning. The result demonstrates that 63% of the total study area (4700 sq. km.) is highly vulnerable and only 8% of the study area (579 sq. km.) is located within the low vulnerable domain. The study conclusively proves that the Barind Tract aquifer in the northwest region of Bangladesh is highly vulnerable to potential GW pollution due to unplanned activities practiced in the study area.

Chandni, A. A. (2018) made an effort to determine Groundwater vulnerability of Magura and Narail districts in his B.Sc. Engineering thesis: "A GIS based DRASTIC Model for Assessing Groundwater Vulnerability in Magura and Narail Districts of Bangladesh". It showed that in both the districts there is small urban areas where pollution potential is very low due to covered soil surface as waste materials cannot seep through it. It is hoped that this study will be helpful in future development and land use planning of this area and also assist in prioritizing protection, monitoring and cleanup efforts. Therefore in this study DRASTIC has been chosen to evaluate the GW potential.

2.5 Study Gap

Several studies have been carried out on assessing groundwater vulnerability using DRASTIC index method. Those studies reported that, DRASTIC is the most commonly used method throughout the world for assessing groundwater vulnerability (Aller et al., 1987), this method provides relatively simple algorithms to integrate a large amount of spatial information into maps of vulnerability classes. The methods are particularly suitable for use with GIS. From the literature it has been showed that some advantage and disadvantage of DRASTIC method but this method was used worldwide for assessing groundwater vulnerability. It was also showed that Resultant DRASTIC indices do not give any absolute value of pollution of the study area. Rather it provides a basis for comparative evaluation of pollution potential. From the literature, it is also been identified that some previous studies were conducted in the northern, north-eastern, south-western parts of Bangladesh using DRASTIC method (Mahmudul et. al., 2019). In their studies they only focus on specific zone with specific time to determine groundwater vulnerability. In my study I have determined the groundwater vulnerability using DRASTIC index for north western region of Bangladesh (Pabna, Natore, Sirajganj) with temporal analysis such as pre-monsoon, monsoon and post-monsoon periods. It has been identified that the study of groundwater vulnerability assessment using DRASTIC index with temporal analysis such as pre-monsoon, monsoon and post-monsoon periods has not been conducted yet for north western parts of Bangladesh.

CHAPTER 3

METHODOLOGY

3.1 General

Groundwater pollution occurs as a result of the release of pollutants into the ground to aquifers. The protection and preservation of groundwater resources are compulsory. In this study the pollution potential of groundwater has been determined using DRASTIC indices. DRASTIC is a methodology that systematically evaluates the pollution potential of groundwater of an area. It provides a basis for evaluating the vulnerability to pollution of groundwater resources.

3.2 Study Area selection

In this study three districts have been selected (Sirajganj, Pabna and Natore) because of most of the people of these areas are fully depends on agriculture and for irrigation they depend on groundwater in dry season as well as other seasons also (Figure 1.1). Based on DRASTIC index value, it could be possible to identify the area which are more vulnerable and which factors are most responsible for this groundwater vulnerability among these three districts. This study will help in future planning related to local groundwater resources by prioritizing the areas where groundwater protection is critical.

3.3 Data Collection

Data on seven distinct parameters were collected from various sources. Data type include groundwater table data collected from BWDB, Rainfall data information on Aquifer media and Vadose zone collected from BWDB and data on aquifer recharge and soil media collected from BARC. Topography data has been collected from USGS and the information on Conductivity of Aquifer has been obtained from secondary data source and existing literature. Table 3.1 summarizes the data sources.

Table 3.1: List of data collected from different sources

Parameters	Data sources	Period
Depth to water level (as Static water level)	GIS shape file of well stations from BWDB	2018 to 2019 (March to February)
Slope	Digital Elevation Model (DEM) from USGS	2016
Soil Permeability	GIS shape file of Soil Texture Map from BARC	2005
Rainfall	Rainfall data from BWDB	2018 to 2019 (March to February)
Aquifer media	Bore -Log data from BWDB, Literature	2013 to 2018
Soil media	GIS shape file of Soil Texture Map from BARC	2013 to 2018
Topography	DEM from USGS	2017
Vadose zone	Bore -Log data from BWDB, Literature	2013 to 2018
Conductivity of Aquifer	Literature	------

3.4 Drastic Index Model

DRASTIC is a model that considers the main hydrological and geological factors with a potential impact on aquifer pollution. It is a methodology through which pollution of an area can be evaluated systematically.

The factors considered to determine the pollution potential are

D = Depth to water table.

The depth to water table (D) [m] is the thickness of the layer crossed by the pollutant before reaching the aquifer. The aquifer vulnerability is inverse proportional to the depth to the water table.

R = Net recharge.

The net recharge (R) [mm/year] represents the volume of infiltrated water that reaches the aquifer. The contamination possibility increases if the net recharge increases. Three types of recharges can be distinguished: direct, indirect, and localized

A = Aquifer media

The aquifer media (A) consists of different types of rocks serving as an aquifer.

S = Soil media

The upper part of the vadose zone, with intense biological activity, is defined to be the soil media (S).

T = Topography

The topography (T) (%) is defined by the terrain slope, together with its variation. A low slope will determine a small surface flow and a high pollution risk.

I = Impact of vadose zone and

The vadose zone’s impact (I) — The unsaturated or discontinuously saturated layer situated above the water table is called vadose. The pollutant’s transfer is influenced by the vadose zone’s lithology.

C = Hydraulic conductivity of the aquifer.

The aquifer hydraulic conductivity (C) is the aquifer materials’ capacity to leave the water to pass through it. The aquifer vulnerability is low for reduced hydraulic conductivities

Though these parameters do not include all the factors that affect the pollution potential, they are selected considering different technical perspectives. In times of formulating this method factors like aquifer chemistry, temperature, transmissivity, tortuosity, gaseous phase etc. were evaluated and at the same time the availability of mappable data has been considered. As a result of this evaluation, these parameters were determined to include the basic requirements to access the pollution potential of any hydro-geologic setting.

The DRASTIC index is determined solving the following equation:

The DRASTIC index (DI) is determined by solving the following equation:

$$DI = D_R \times D_w + R_R \times R_w + A_R \times A_w + S_R \times S_w + T_R \times T_w + I_R \times I_w + C_R \times C_w$$

Where, the subscript R indicates rating and W is the weightage given to each parameter. So, this model also has three significant parts: weights, ranges, ratings.

Weights: Each DRASTIC factor is given relative weightage to reflect the relative importance of different parameters. Weightage value ranges from 1 to 5. The most significant factors have weights of 5; the least significant, a weight of 1. This exercise was accomplished by the committee using a Delphi (consensus) approach. Table 3.2 shows the assigned weights for DRASTIC features.

Table 3.2: Assigned weights for DRASTIC parameters (Aller et al., 1987).

Parameters	Weight
Depth to water	5
Net recharge	4
Aquifer media	3
Soil media	2
Topography	1
Impact of vadose zone media	5
Hydraulic conductivity of the aquifer	3

Ranges: Each DRASTIC parameter has been divided into either ranges or media types. Aquifer, soil and vadose zone media have been divided into different types while others are divided into different ranges (Aller et al., 1987).

Ratings: Each DRASTIC range is then assigned different ratings ranging from 1 to 10 to assess the relative pollution potential of the parameters. The factors of D, R, S, T and

C have been assigned one value per range. A and I have been assigned a "typical" rating and a variable rating. The variable ratings leave the opportunity to use specific knowledge. Table 3.3 to 3.9 illustrates different ranges and ratings for DRASTIC parameters (Aller et al., 1987).

According to National Research Council, "all groundwater is vulnerable'' and it is not an absolute property, rather is a probability. That is why GW vulnerability is a predictive statement. This is a general shortcoming of all the vulnerability assessment method and so is of DRASTIC method. However, site specific weights and ratings can be applied for different hydrogeologic settings using Delphi approach for that specific area. Table 3.3 to 3.9 shows the ranges and ratings of each parameter (Aller et al., 1987).

Table 3.3: Ranges and Ratings for Depth to water (Aller et al., 1987).

Depth to Water (feet)	
Ranges	**Ratings**
0-5	10
5-15	9
15-30	7
30-50	5
50-75	3
75-100	2
100+	1

Table 3.4: Ranges and ratings for net recharge.

Net recharge (Inches/Year)	
Ranges	Ratings
0-2	1
2-4	3
4-7	6
7-10	8
100+	9

Table 3.5: Ranges and Ratings for Aquifer Media

Aquifer Media		
Ranges	**Ratings**	**Typical Rating**
Massive Shale	1-3	2

Metamorphic/Igneous	2-5	3
Weathered Metamorphic/Igneous	3-5	4
Glacial Till	4-6	5
Bedded Sandstone, Limestone, Shale sequence	5-9	6
Massive Sandstone	4-9	6
Massive Limestone	4-9	6
Sand and Gravel	4-9	8
Basalt	2-10	9
Karst Limestone	9-10	10

Table 3.6: Ranges and Ratings for Soil Media

Ranges	**Ratings**
Thin or absent	10
Gravel	10
Sand	9
Peat	8
Shrinking and/or Aggregated clay	7
Sandy Loam	6
Loam	5
Silty Loam	4
Clay Loam	3
Muck	2
Non shrinking and Non-aggregated clay	1

Table 3.7: Ranges and Ratings for Topography.

Topography (Percent Slope)	
Ranges	Ratings
0-2	10
2-6	9
6-12	5
12-18	3
18+	1

Table 3.8: Ranges and Ratings for Impact of Vadose Zone media

Impact of Vadose Zone Media		
Ranges	**Ratings**	**Typical Rating**
Confining layer	1	1
Silt/Clay	2-6	3
Shale	2-5	3
Limestone	2-7	6
Sandstone	4-8	6
Bedded Limestone Sandstone, Shale	4-8	6
Sand and Gravel with significant Silt and Clay	4-8	6
Metamorphic/Igneous	2-8	4
Sand and Gravel	6-9	8
Basalt	2-10	9
Karst Limestone	8-10	10

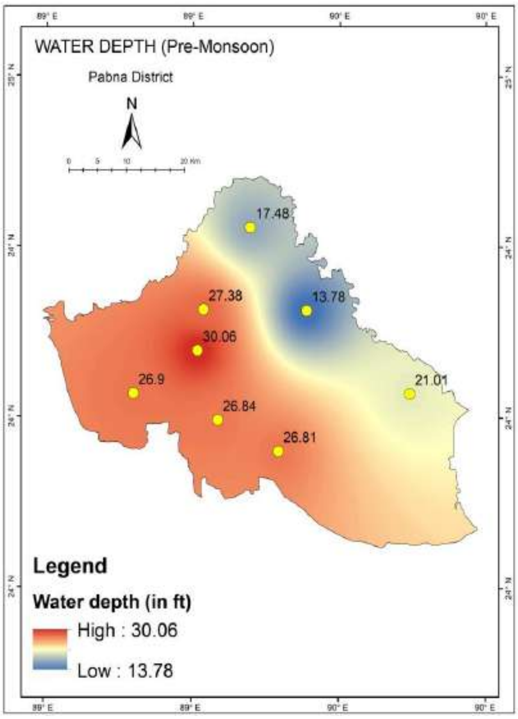
Table 3.9: Ranges and Ratings for Impact of Hydraulic Conductivity

Hydraulic Conductivity (Gpd/Ft^2)	
Ranges	**Ratings**
1-100	1
100-300	2
300-700	4
700-1000	6
1000-2000	8
2000+	10

This Study was conducted following the research paper of Aller et al., (1987). Seven DRASTIC layers were prepared following the method described in the paper except with some modification of the net recharge component which was calculated according to Piscopo (2001).

3.4.1 Depth to Water Level

Depth to water is primarily important because the contaminant particles must pass through this vertical distance before reaching the aquifer. While passing through this space the contaminant also gets oxidized by atmospheric oxygen. That is why there is a greater chance for attenuation to occur as the depth to water increases because deeper water levels imply longer travels times. However, whether the aquifer is confined or unconfined, it is to be determined first. GW occurs in unconfined, confined or semi-confined conditions. The study area falls in the regions of semi confined to confined zone of aquifer. DRASTIC was originally designed for the evaluation of unconfined aquifer. So, special definition must be assumed when evaluating depth to water for a confined aquifer. On the other hands DRASTIC does not permit to choose a semi-confined aquifer. The upper shallow aquifer of the study area is an unconfined aquifer.



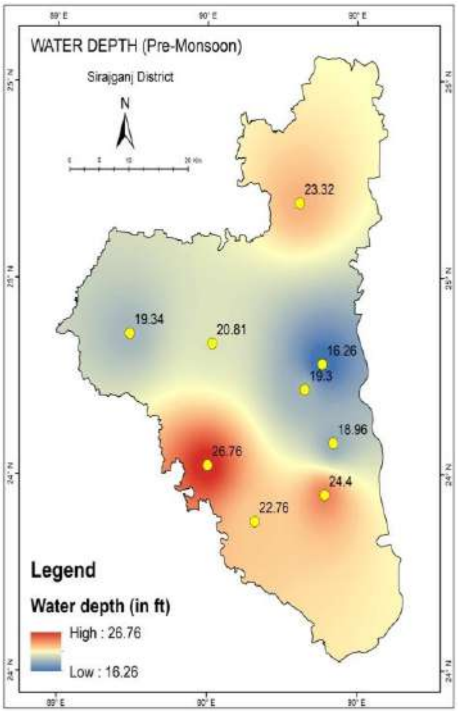


Figure 3.1: Clipped map of GWT of Pabna for Pre-Monsoon period

Figure 3.2: Clipped map of GWT of Sirajganj for Pre-Monsoon period

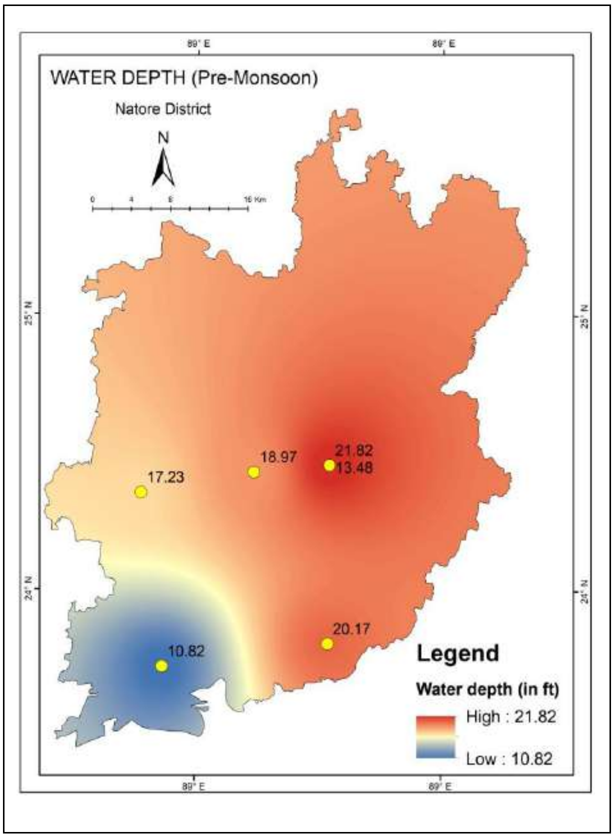


Figure 3.3: Clipped map of GWT of Natore for Pre-Monsoon period

Data of depth to water levels are divided into three periods' pre-monsoon, monsoon and post-monsoon. Pre-monsoon, monsoon and post-monsoon periods consists of March to May, June to October and November to February in 2018 and 2019. In Pre-monsoon period most part of the Pabna, Sirajganj and Natore district have GW level within 10.82-30.06 feet Depth of water level in Pabna districts within 13.78 to 30.06 feet. So, rating 5, 7and 9 were used for Pabna districts as seen in figure 3.4. Depth of water level in Sirajganj districts within 16.26 to 26.76 feet. So, rating 7 was used for Sirajganj districts as seen in figure 3.5. Natore district have GW level within 10.82-21.82 feet. So, rating 7 and 9 was used for Natore district as seen in figure 3.6. Here data on water level of within and nearby station was used. Study area was clipped out of it (as found in figure 3.1, 3.2 and 3.3).

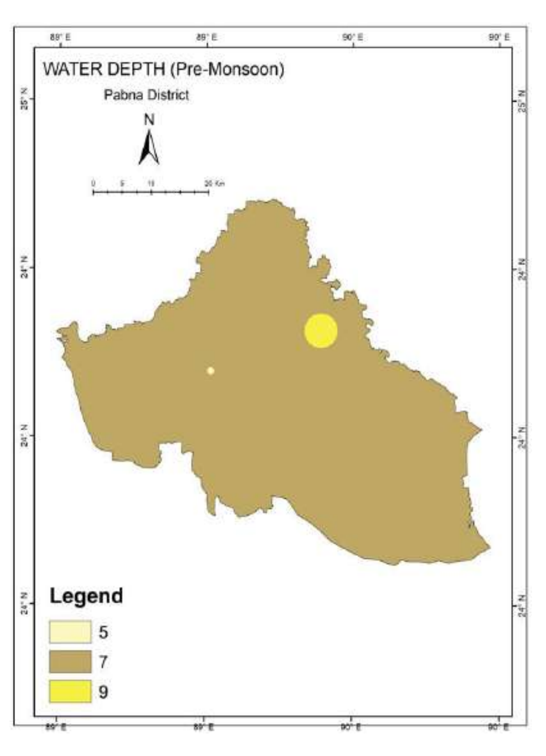


Figure 3.4: Ratings for depth of GWT of Pabna for Pre-Monsoon period

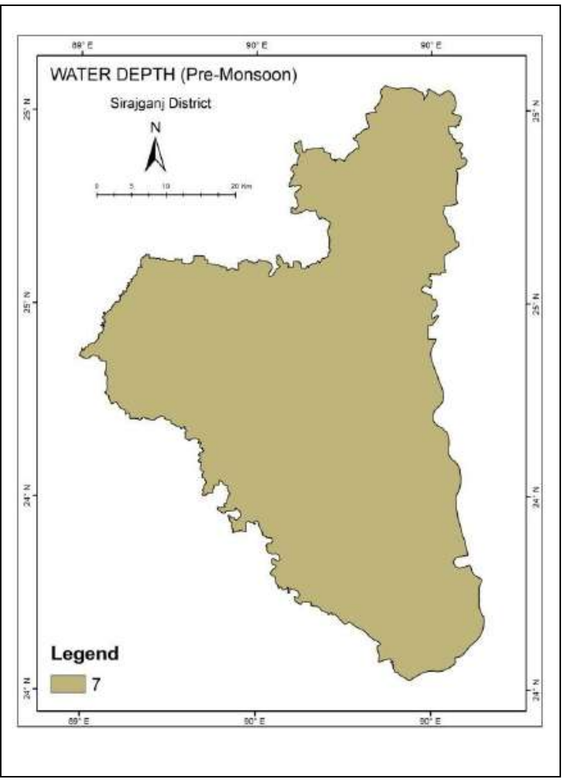


Figure 3.5: Ratings for depth of GWT of Sirajganj for Pre-Monsoon period

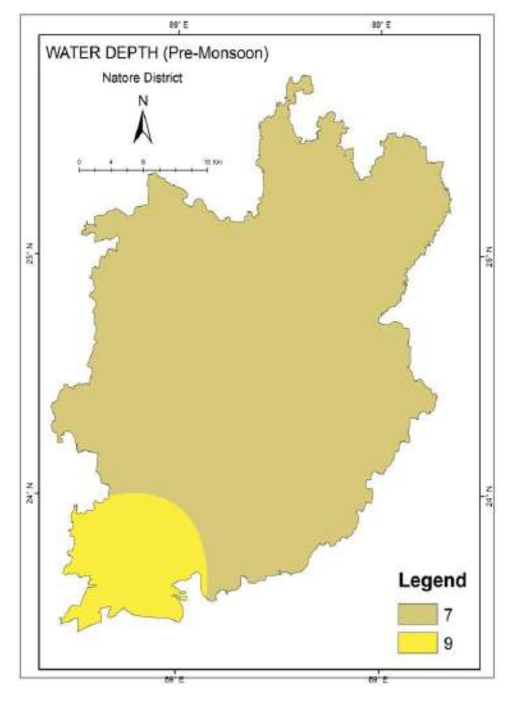
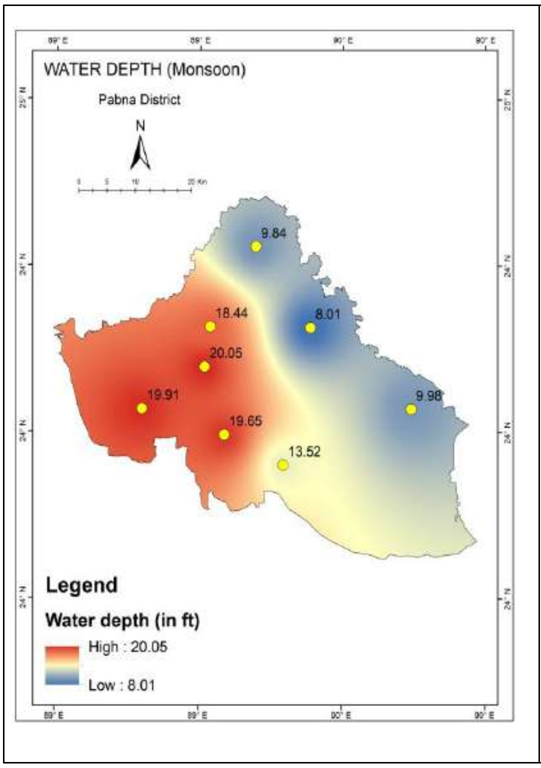


Figure 3.6: Ratings for depth of GWT of Pabna for Pre-Monsoon period



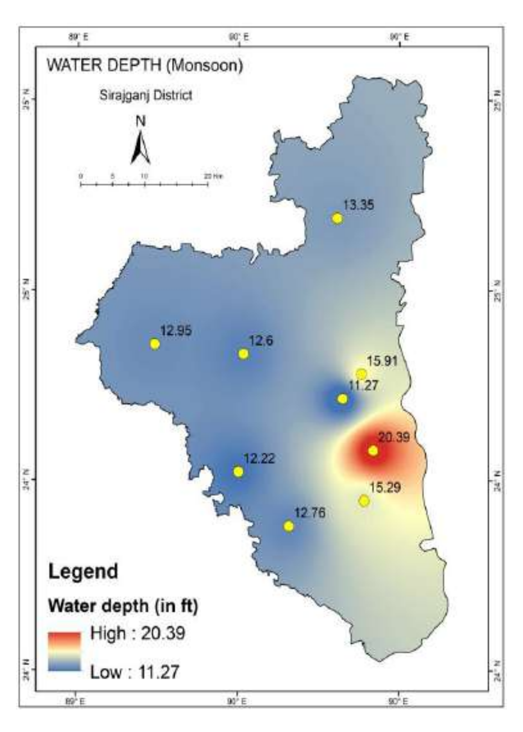


Figure 3.7: Clipped map of GWT of Pabna district for Monsoon period

Figure 3.8: Clipped map of GWT of Sirajganj district for Monsoon period

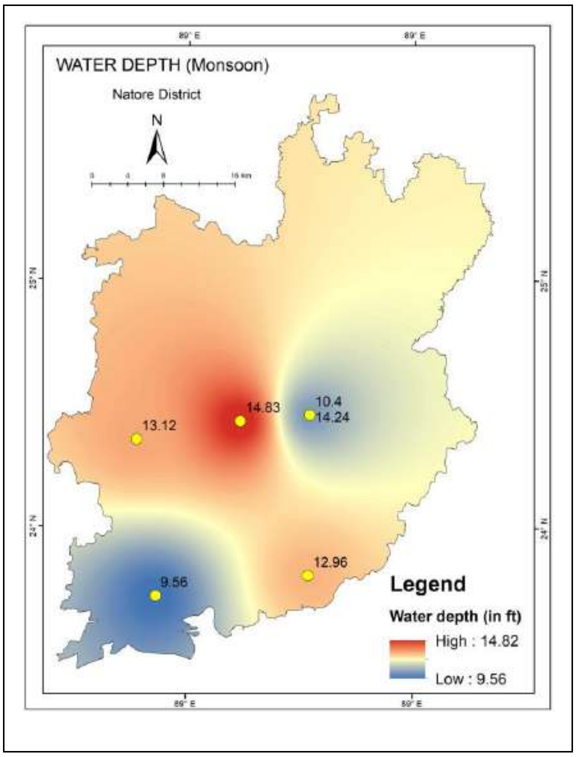


Figure 3.9: Clipped map of GWT of Natore district for Monsoon period

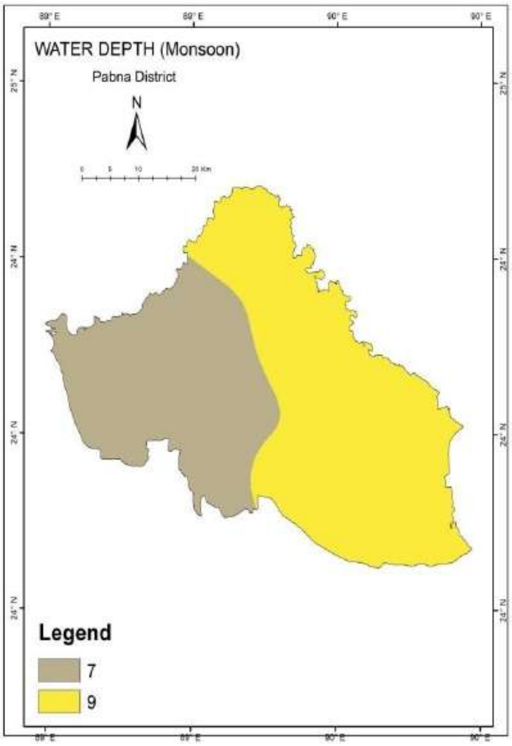


Figure 3.10: Ratings for depth of GWT of Pabna for Monsoon period

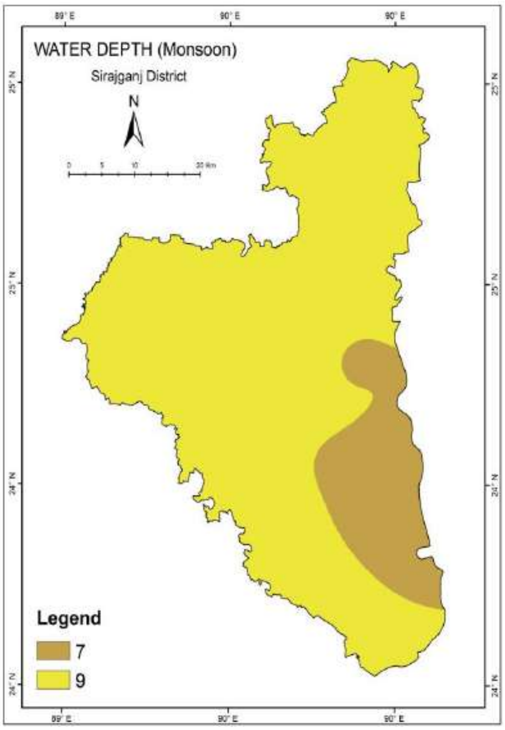


Figure 3.11: Ratings for depth of GWT of Sirajganj for Monsoon period

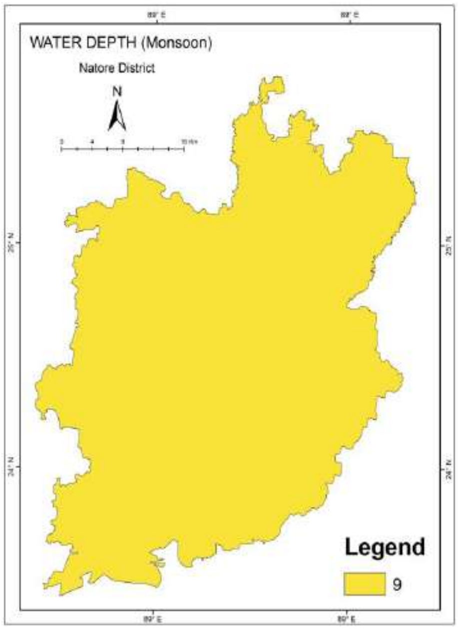
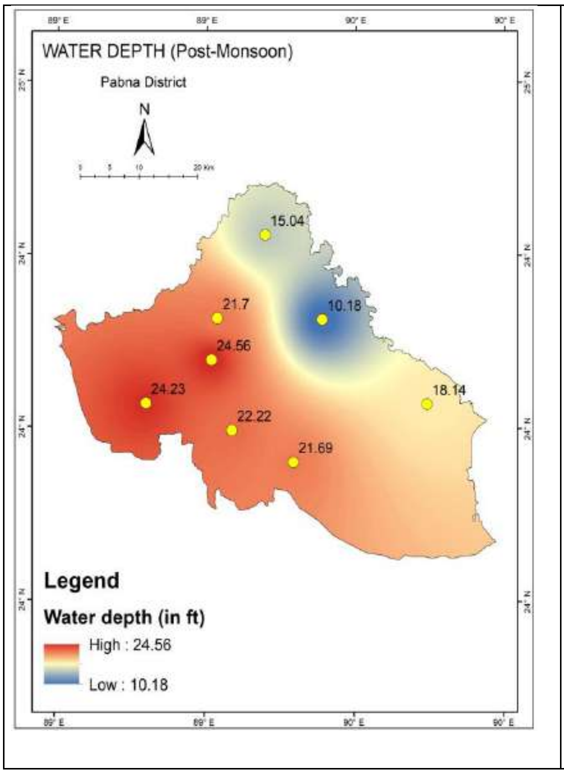


Figure 3.12: Ratings for depth of GWT of Natore for Monsoon period



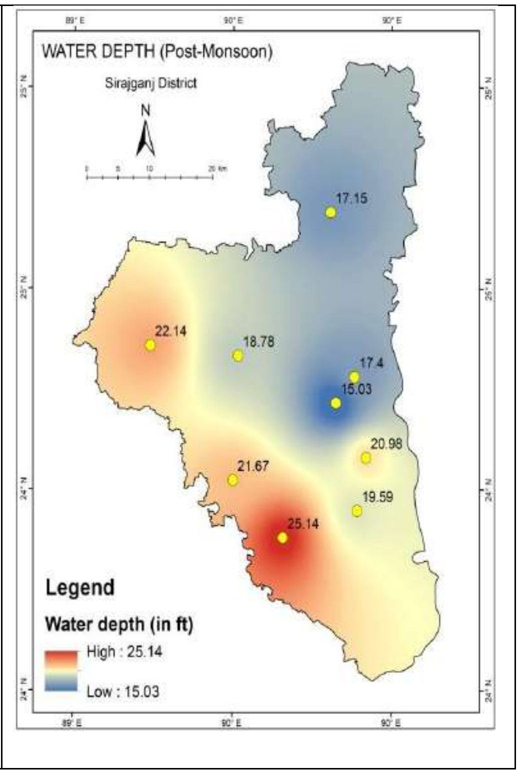


Figure 3.13: Clipped map of GWT of Pabna for Post-Monsoon period

Figure 3.14: Clipped map of GWT of Sirajganj for Post-Monsoon period

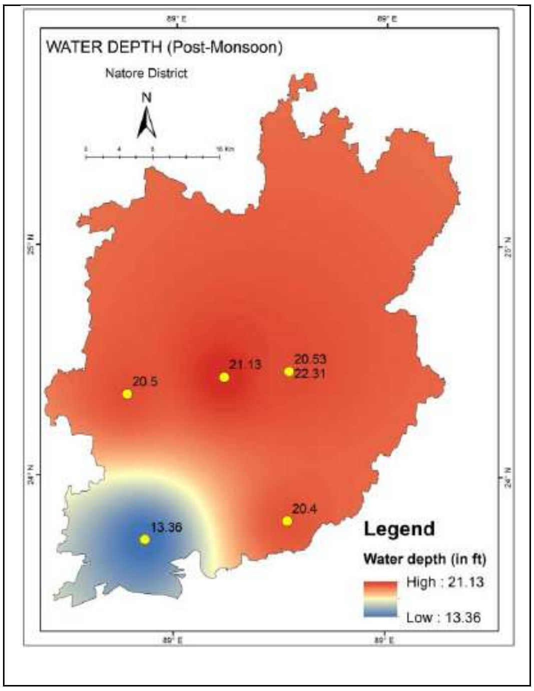
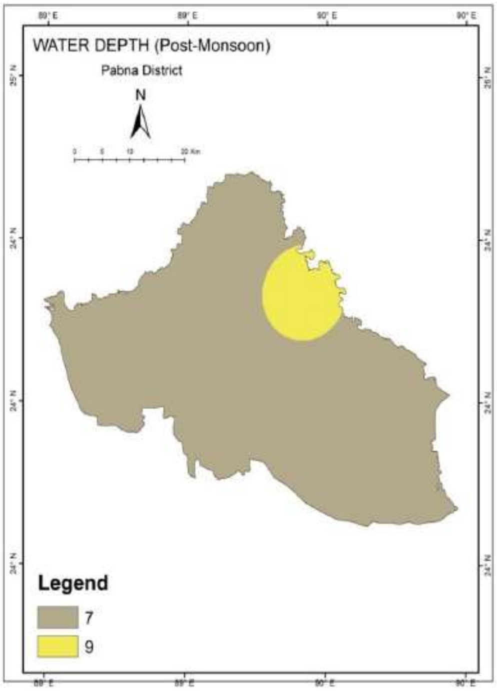


Figure 3.15: Clipped map of GWT of Natore for Post-Monsoon period



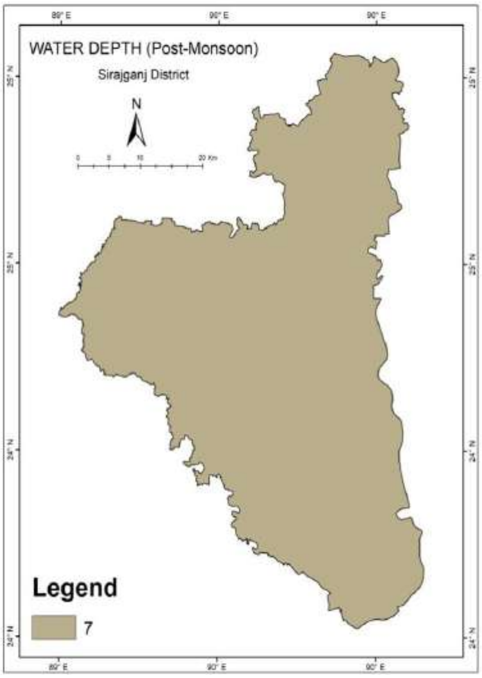


Figure 3.16: Ratings for depth of GWT of Pabna for Post-Monsoon period

Figure 3.17: Ratings for depth of GWT of Sirajganj for Post-Monsoon period

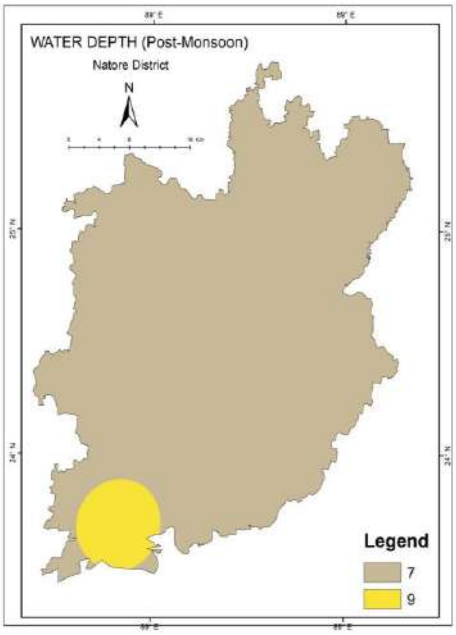


Figure 3.18: Ratings for depth of GWT of Natore for Post-Monsoon period

In monsoon period most part of the Pabna, Sirajganj and Natore district have GW level within 8.01-20.39 feet. Depth of water level in Pabna districts within 8.01 to 20.05 feet. So, rating 7 and 9 was used for Pabna districts as seen in figure 3.10. Depth of water level in Sirajganj districts within 11.27 to 20.39 feet. So, rating 7 and 9 was used for Sirajganj districts as seen in figure 3.11. Natore district have GW level within 9.56-14.82 feet. So, rating 9 was used for Natore district as seen in figure 3.12. Here data on water level of within and nearby station was used. Study area was clipped out of it (as found in figure 3.7, 3.8 and 3.9).

In post-monsoon period most part of the Pabna, Sirajganj and Natore district have GW level within 10.18-25.14 feet. Depth of water level in Pabna districts within 10.18 to 24.58 feet. So, rating 7 and 9 was used for Pabna districts as seen in figure 3.16. Depth of water level in Sirajganj districts within 15.03 to 25.14 feet. So, rating 7 was used for Sirajganj districts as seen in figure 3.17. Natore district have GW level within 13.36-21.13 feet. So, rating 7 and 9 was used for Natore district as seen in figure 3.18. Here data on water level of within and nearby station was used. Study area was clipped out of it (as found in figure 3.13, 3.14 and 3.15).

3.4.2 Net Recharge

Net recharge represents the amount of water per unit area of land which penetrates the ground surface and reaches the water table. In our country huge amount of rainfall in monsoon makes itself significantly important for groundwater recharge in the subsequent period. Rainwater infiltrates through the surface of the ground and percolates to the water table. This recharge water is thus available to transport a contaminant vertically to the water table and horizontally within the aquifer which implies that this recharge water will contribute to dispersing and diluting the contaminant in the vadose zone and at the same time transport it to the water table. Generally, the greater the recharge, the greater the potential for ground water pollution.

Due to lack of availability of direct recharge data of the study area, a simple formula proposed by Piscopo (2001) was used to find out recharge value.

Recharge value =Slope % + Rainfall + Soil permeability………… (1)

Eq 1 expresses Piscopo's method, which was applied to prepare the net recharge map (Piscopo 2001)

Where, the Rates for three parameters are selected from the tables below

Table 3.10: Rates for percentage of slope

Range (%)	**Rate**
<2	4
2-10	3
10-33	2
>33	1

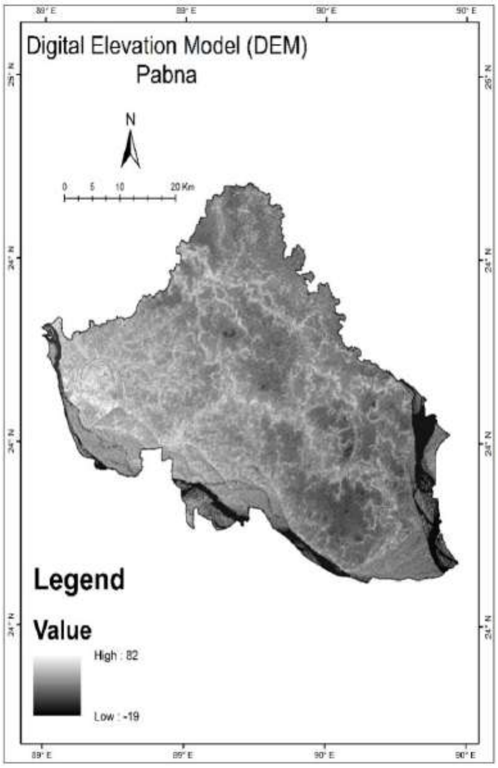
Table 3.11: Rates for Rainfall

Range (mm)	**Rate**
>850	4
700-850	3
500-700	2
<500	1

Table 3.12: Rate for Soil Permeability

Range	**Rate**
High	5
Mod- high	4
Moderate	3
Slow	2
Very slow	1

Percentage slope was generated from Digital Elevation Models (DEM) of the study area which was obtained from the USGS website. Before that study area was clipped from combined DEM then it was reclassified to obtain the factor given by Piscopo (2001) shown in figure 3.22, 3.23 and 3.24. Permeability shape file was secured from the website of BARC where it was already classified, so suitable factor was given on them in figure 3.25, 3.26 and 3.27.



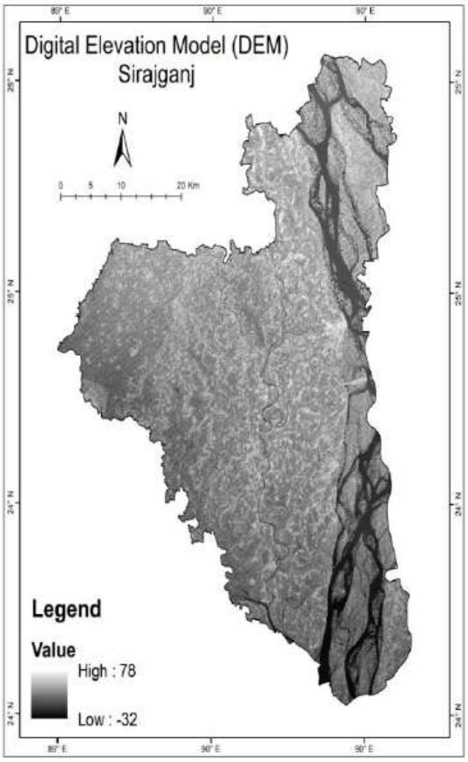


Figure 3.19: DEM of Pabna

Figure 3.20: DEM of Sirajganj

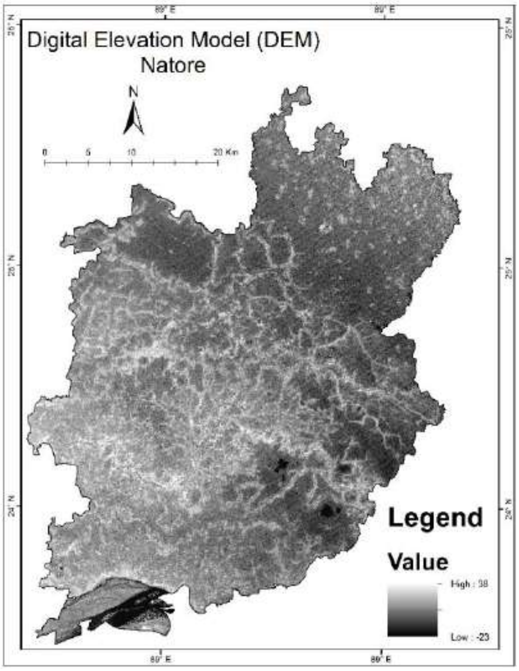


Figure 3.21: DEM of Natore

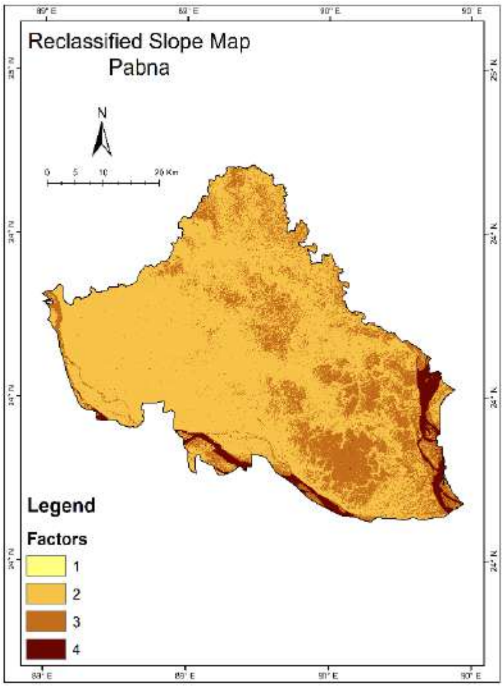


Figure 3.22: Reclassified slope map of Pabna

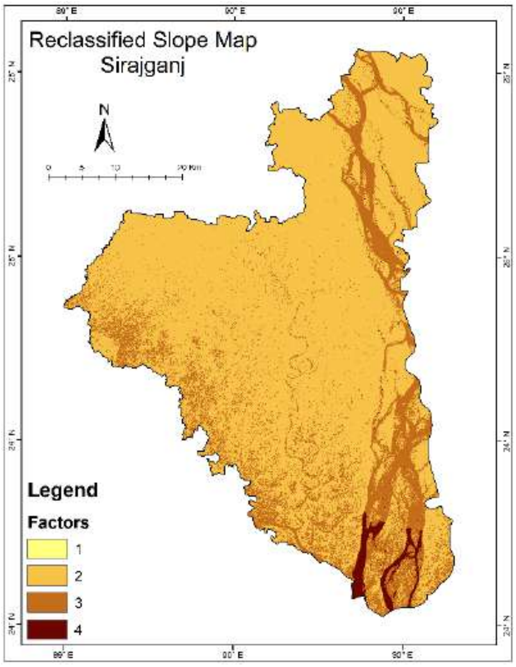


Figure 3.23: Reclassified slope map of Sirajganj

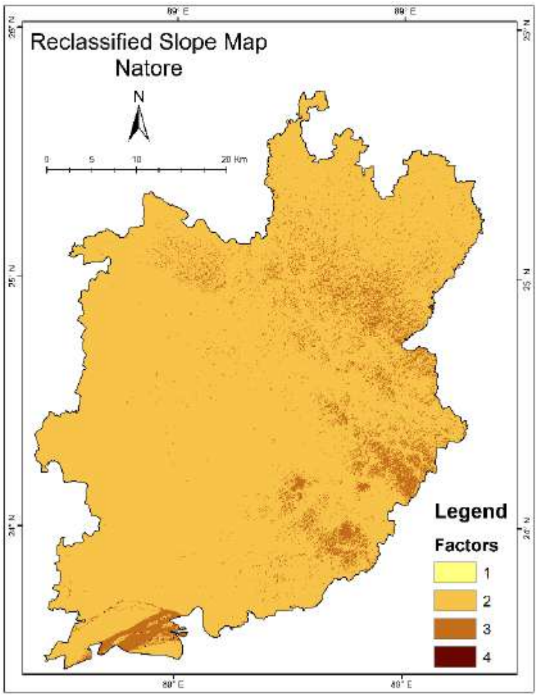


Figure 3.24: Reclassified slope map of Natore

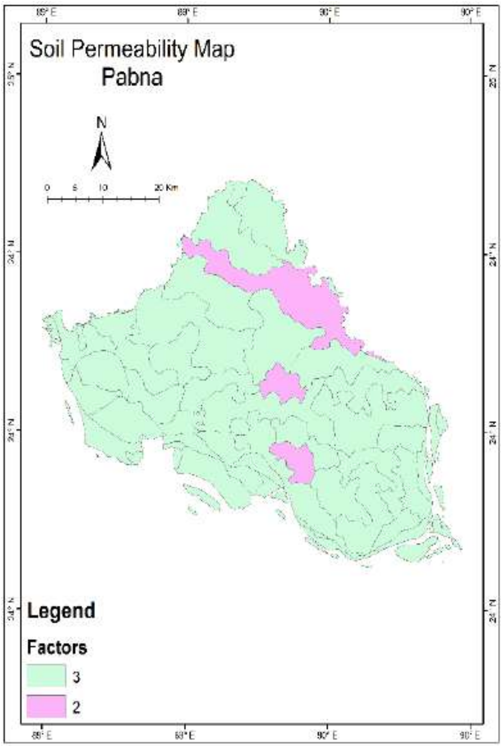


Figure 3.25: Soil permeability of Pabna

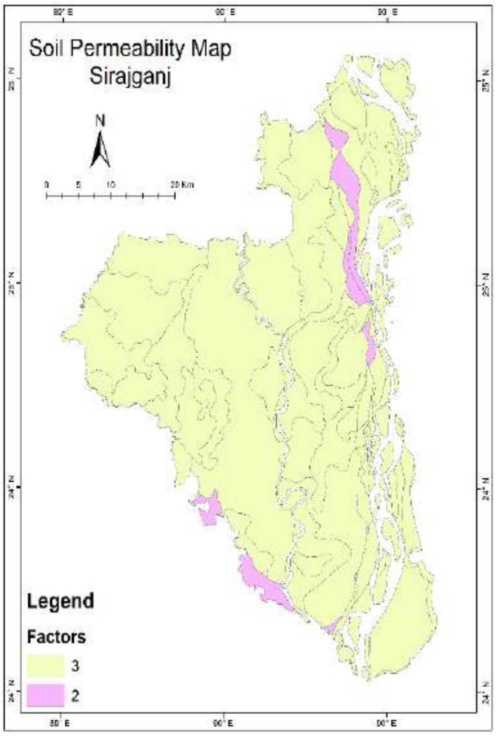


Figure 3.26: Soil permeability of Sirajganj

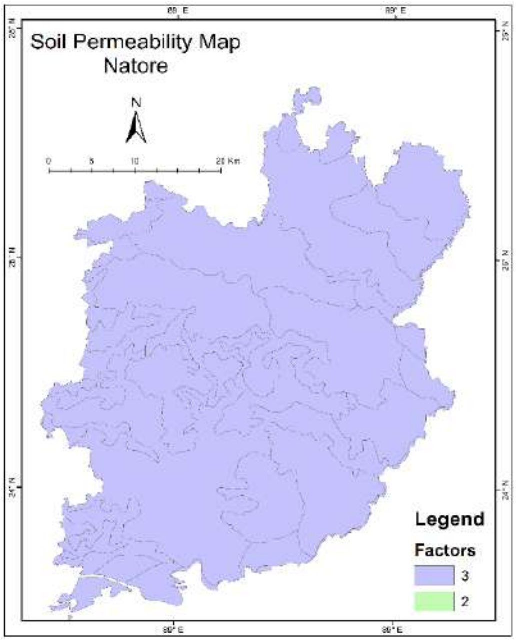


Figure 3.27: Soil permeability of Natore

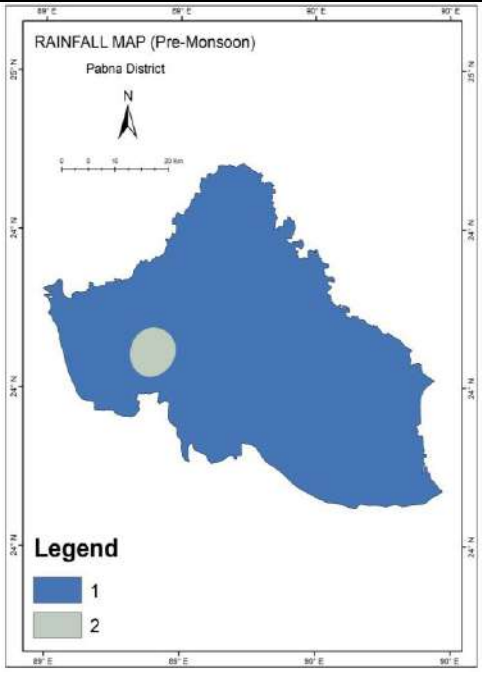


Figure 3.28: Rainfall in Pabna for Pre-Monsoon Period

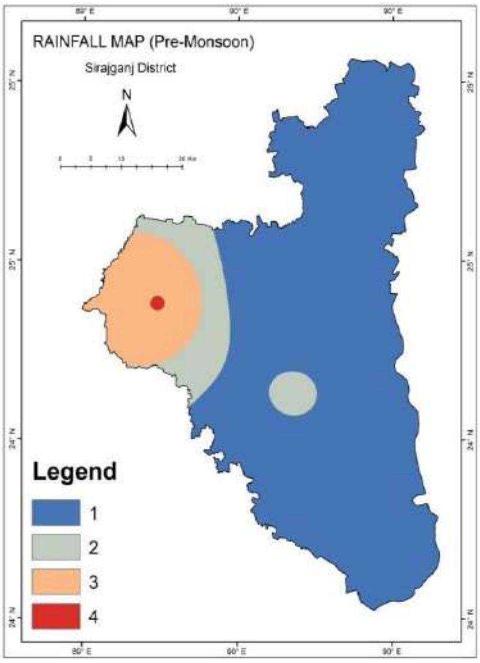


Figure 3.29: Rainfall in Sirajganj for Pre-Monsoon Period

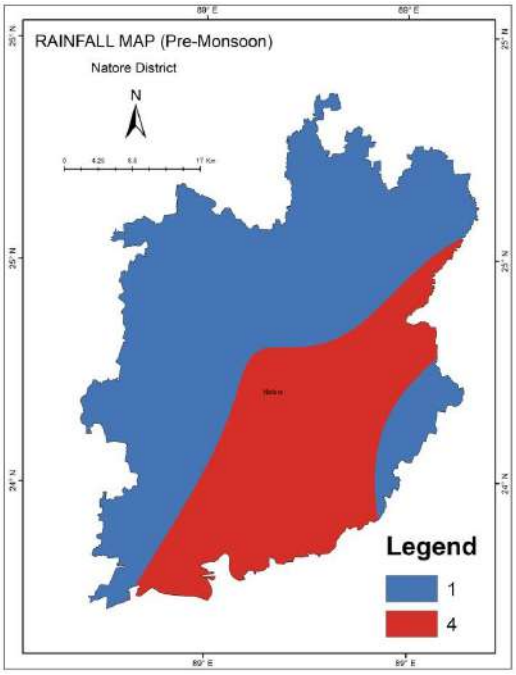
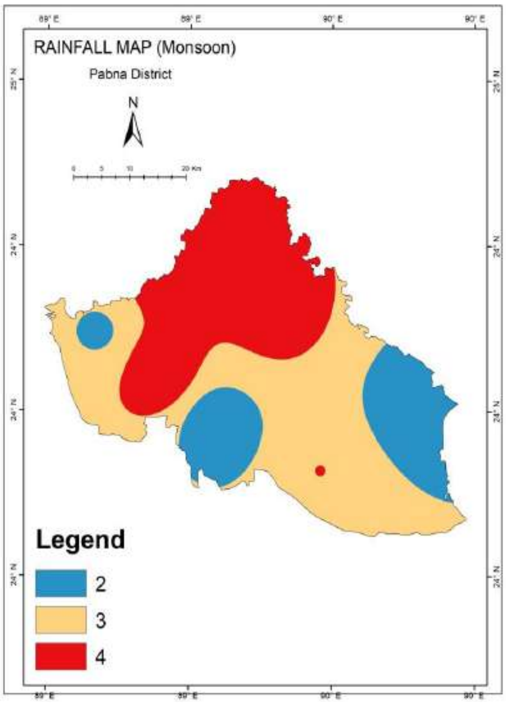


Figure 3.30: Rainfall in Natore for Pre-Monsoon Period



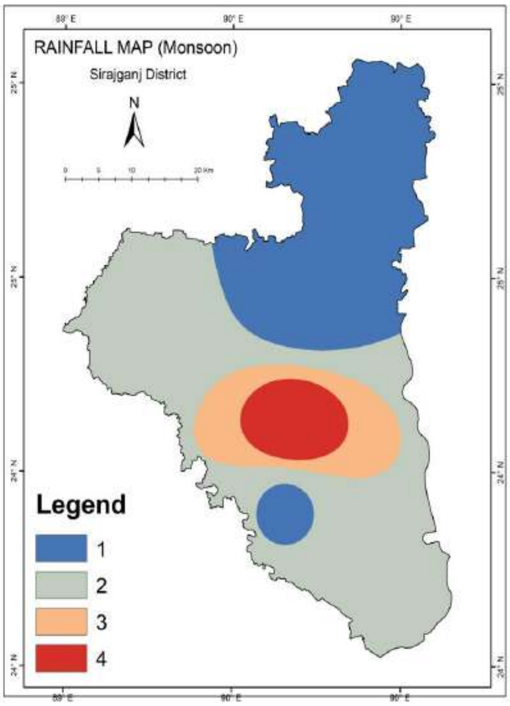


Figure 3.32: Rainfall in Sirajganj for Monsoon Period

Figure 3.32: Rainfall in Sirajganj for Monsoon Period

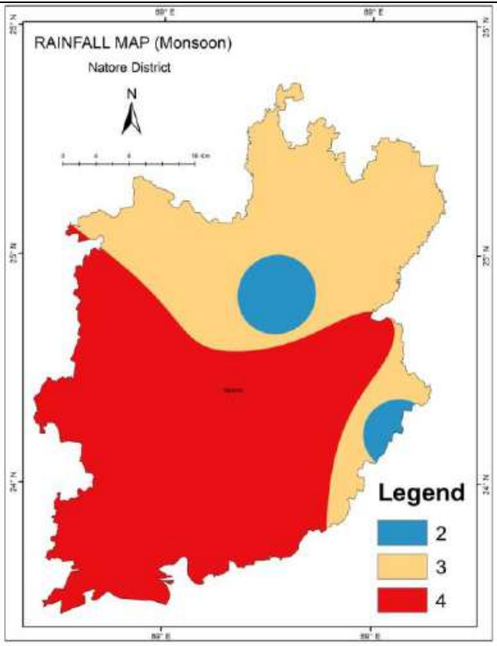
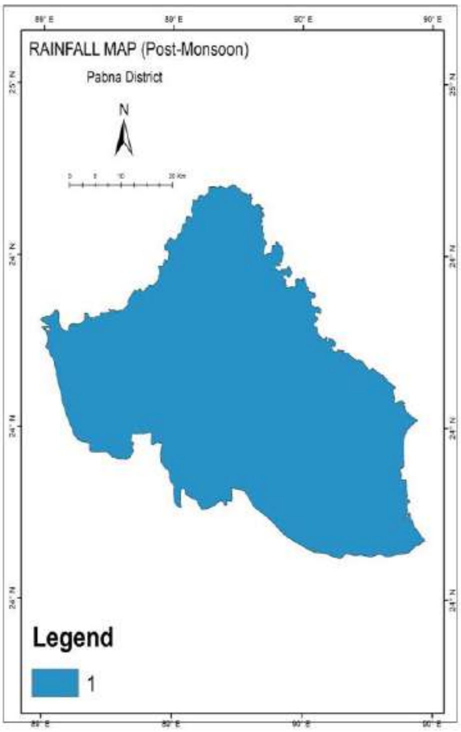


Figure 3.33: Rainfall in Natore for Monsoon Period



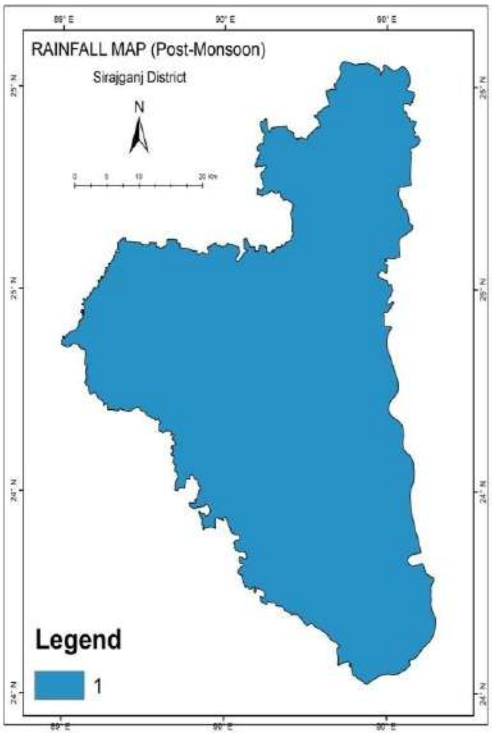


Figure 3.34: Rainfall in Pabna for Post-Monsoon Period

Figure 3.35: Rainfall in Sirajganj for Post-Monsoon Period

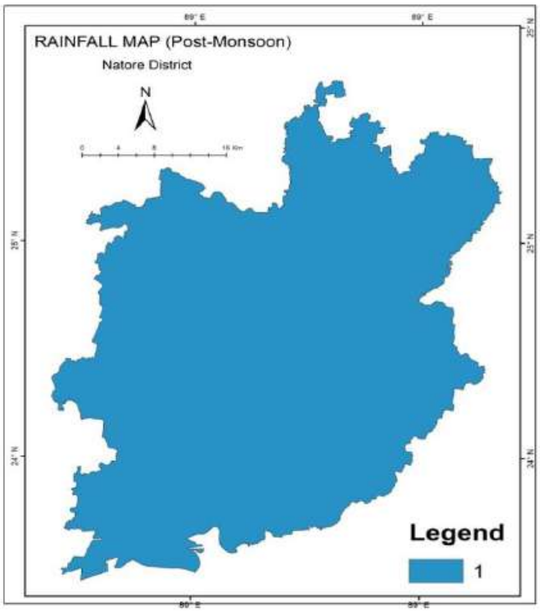


Figure 3.36: Rainfall in Natore for Post-Monsoon Period

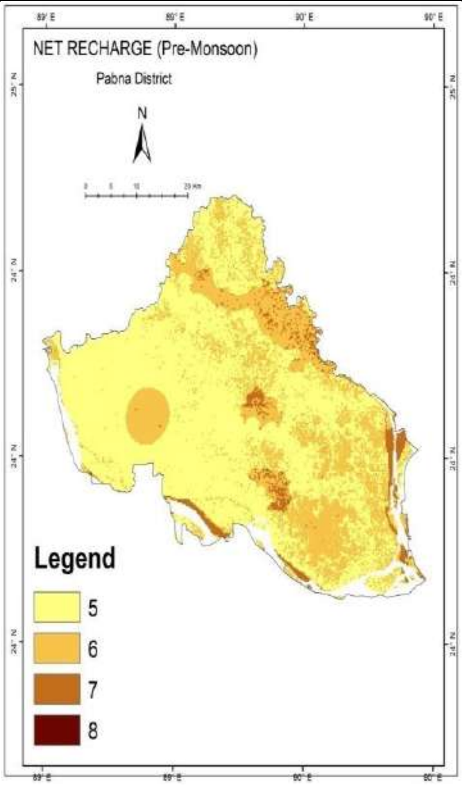


Figure 3.37: Net Recharge in Pabna for Pre-Monsoon period

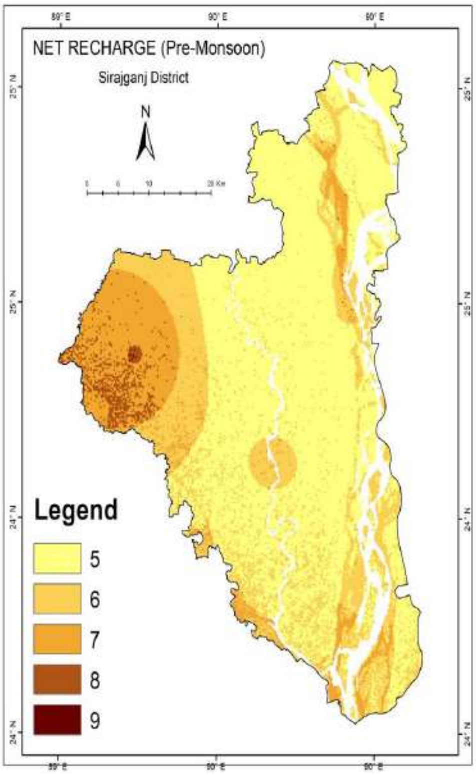


Figure 3.38: Net Recharge in Sirajganj for Pre-Monsoon Period

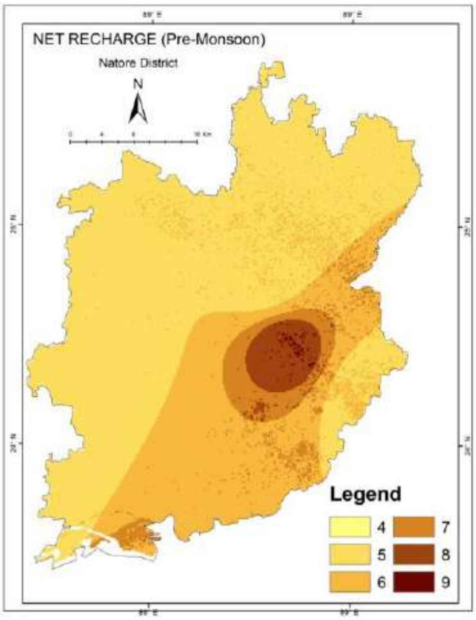


Figure 3.39: Net Recharge in Natore for Pre-Monsoon Period

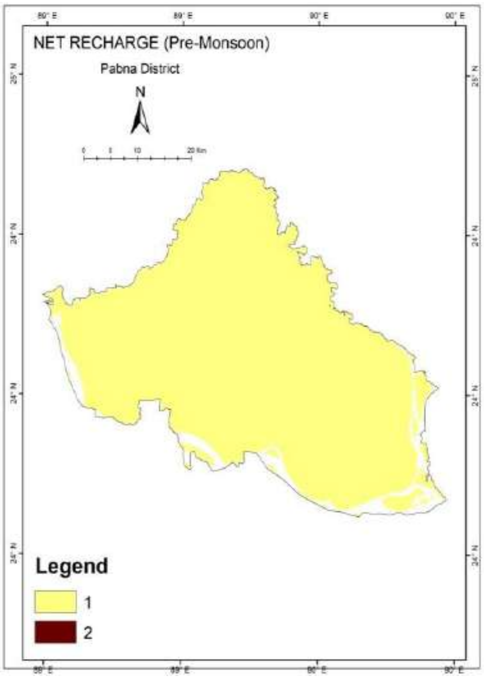


Figure 3.40: Rating for net recharge in Pabna for Pre-Monsoon Period

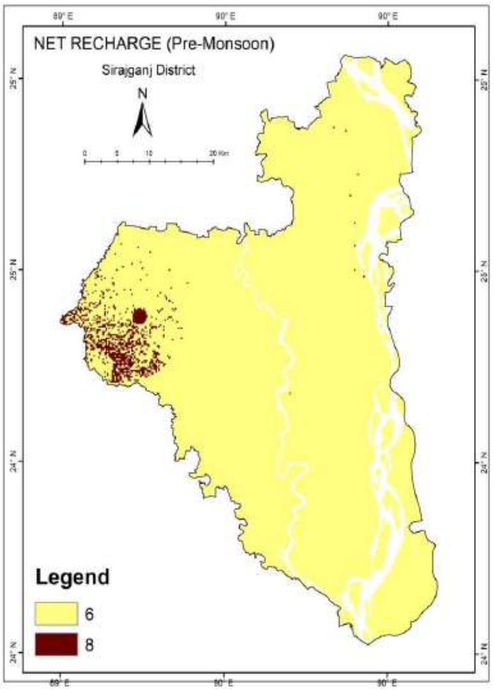


Figure 3.41: Rating for net recharge in Sirajganj for Pre-Monsoon Period

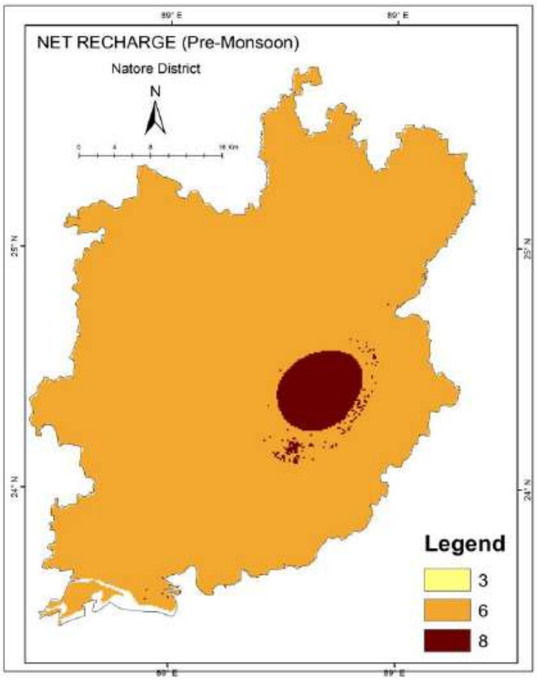


Figure 3.42: Rating for net recharge in Natore for Pre-Monsoon Period

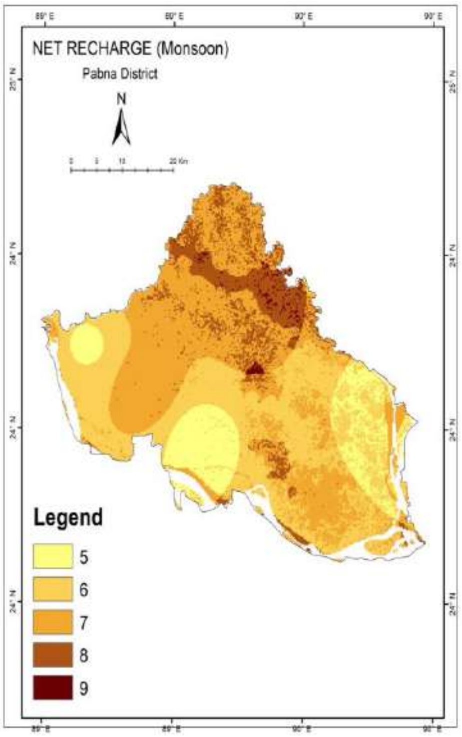


Figure 3.43: Net Recharge in Pabna for Monsoon Period

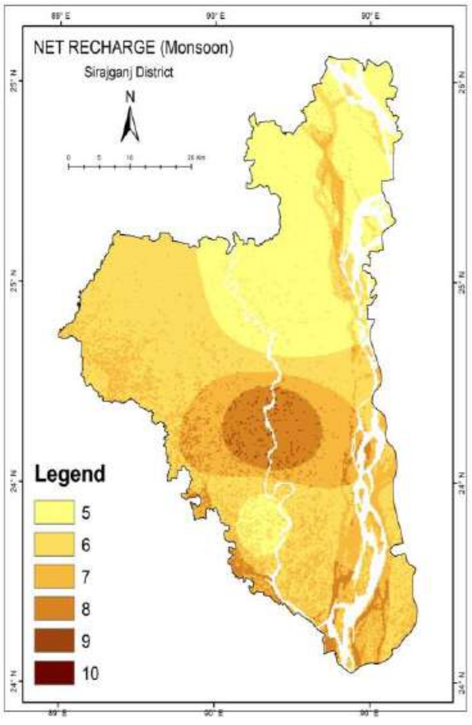


Figure 3.44: Net Recharge in Sirajganj for Monsoon Period

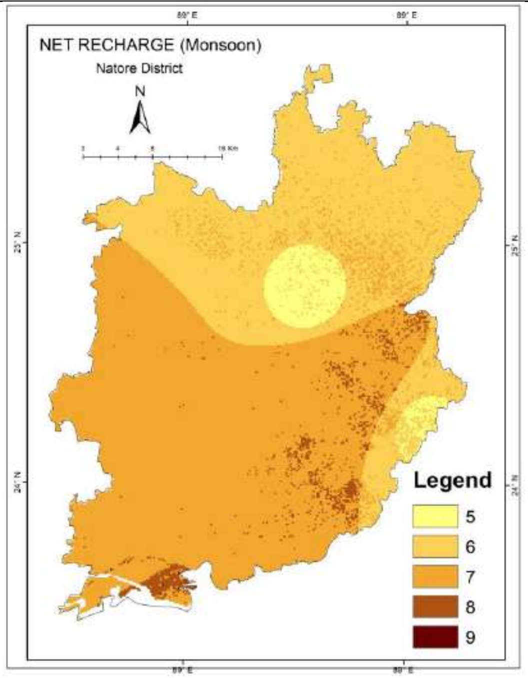
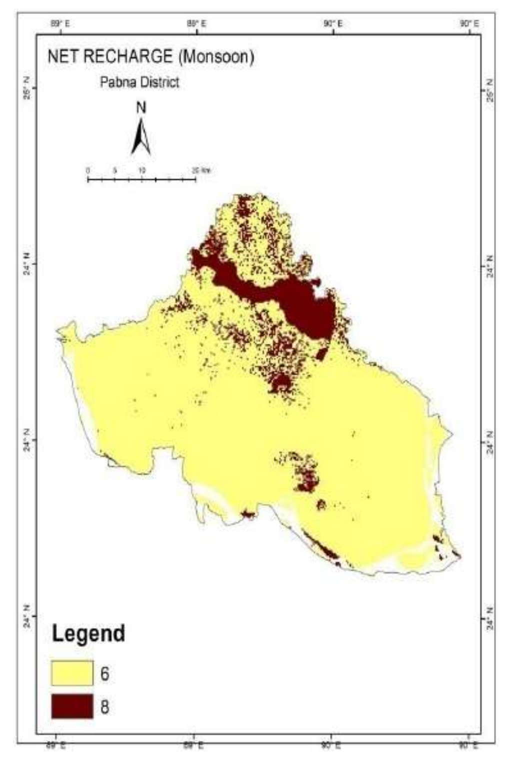


Figure 3.45: Net Recharge in Natore for Monsoon Period



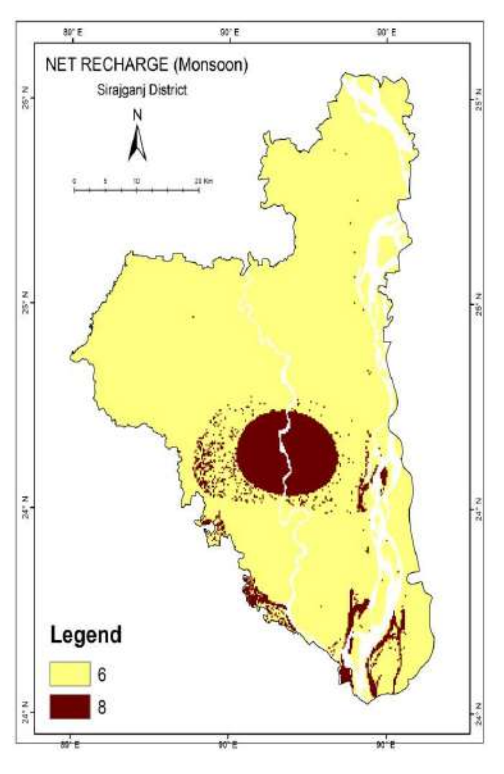


Figure 3.46: Rating for net recharge in Pabna for Monsoon Period

Figure 3.47: Rating for net recharge in Sirajganj for Monsoon Period

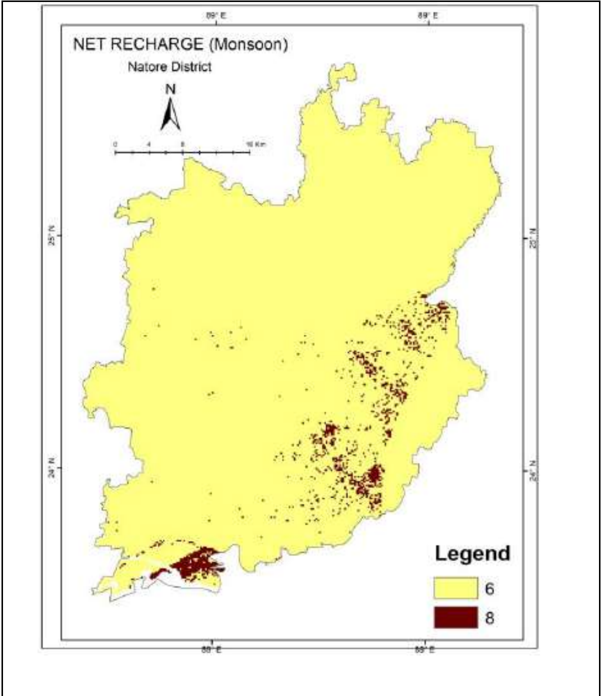
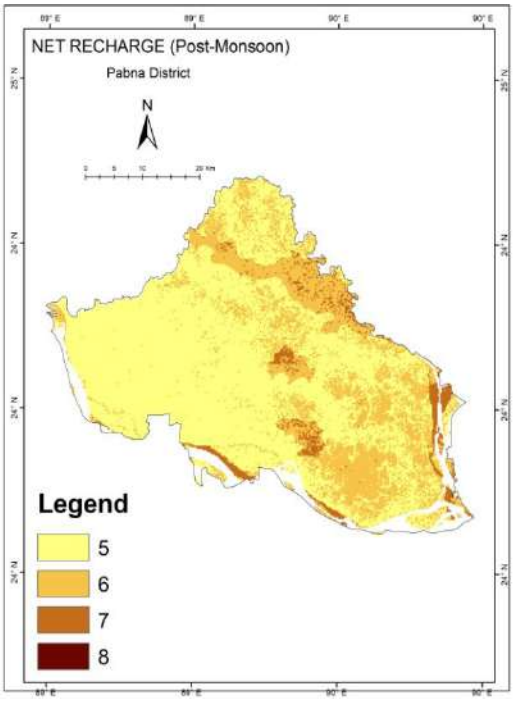


Figure 3.48: Rating for net recharge in Natore for Monsoon Period



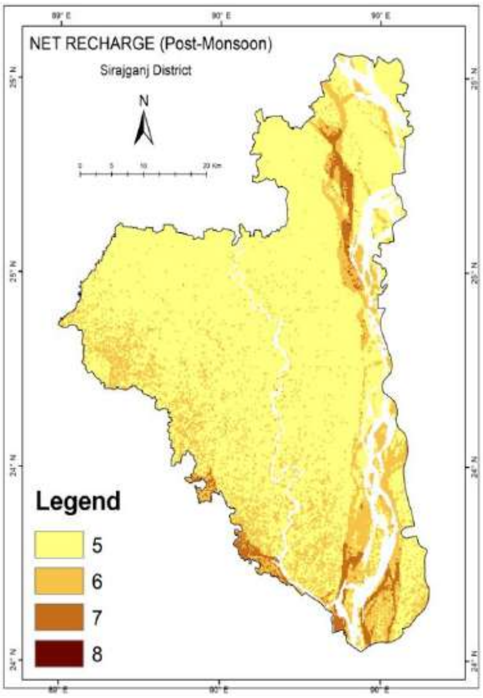


Figure 3.49: Net Recharge in Pabna for Post-Monsoon Period

Figure 3.50: Net Recharge in Sirajganj for Post-Monsoon Period

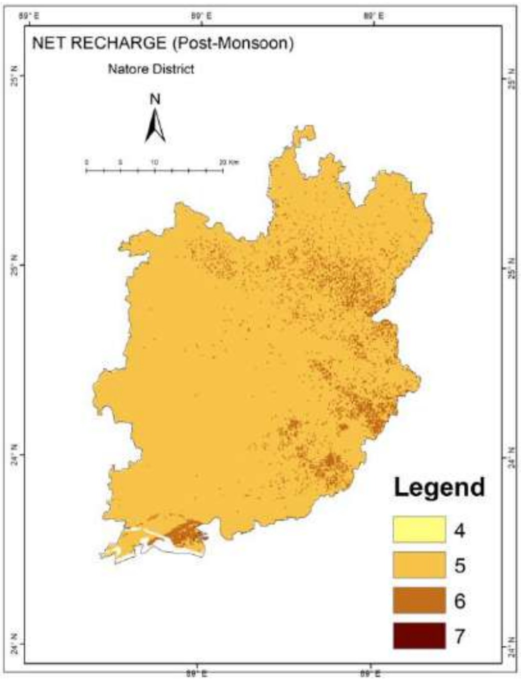


Figure 3.51: Net Recharge in Natore for Post-Monsoon Period

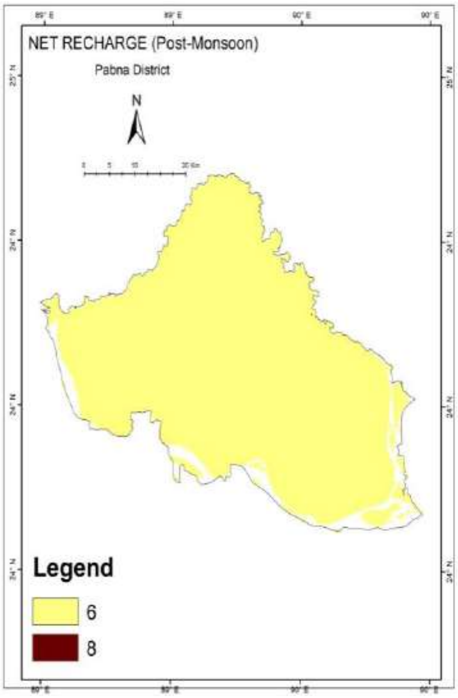


Figure 3.52: Rating for net recharge in Pabna for Post-Monsoon Period

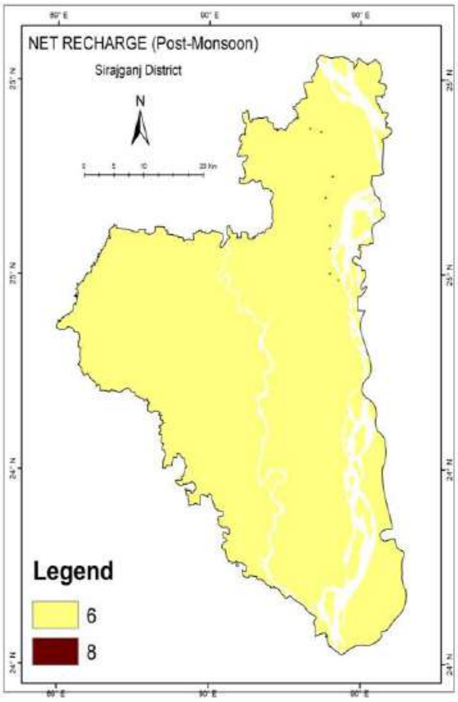


Figure 3.53: Rating for net recharge in Sirajganj for Post-Monsoon Period

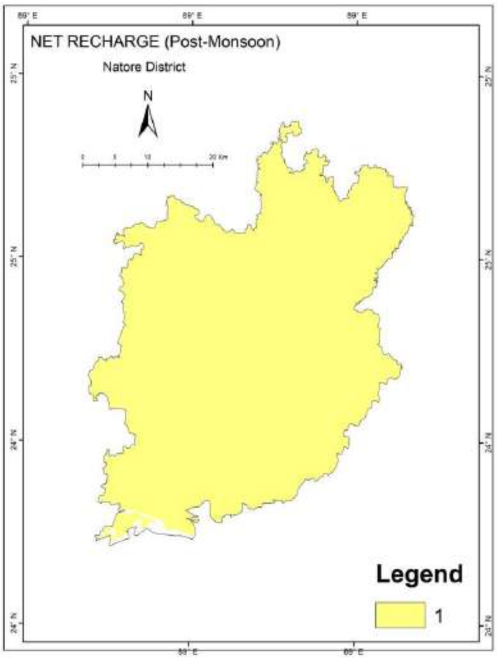


Figure 3.54: Rating for net recharge in Natore for Post-Monsoon Period

Data of Rainfalls are divided into three periods' pre-monsoon, monsoon and post-monsoon. Pre-monsoon, monsoon and post-monsoon periods consists of March to May, June to October and November to February in 2018 and 2019. Firstly, in Pre-monsoon period lowest rainfall was recorded 355mm in Chatmahar upazilla of Pabna district and highest rainfall was recorded 529mm in Atgharia upazilla of Pabna district. So, rating 1 and 2 was used shows in figure 3.28. At Sirajganj district lowest rainfall was found in Raiganj upazilla which is 68mm and maximum rainfall was found in Tarash upazilla which is 853mm. So, rating 1, 2, 3, and 4 was used shows in figure 3.29. For Natore district we have found lowest rainfall 247mm in Singra and maximum rainfall 1129 in Gurudaspur. So, rating 1, 2, 3, and 4 was used shows in figure 3.30.

Secondly, in monsoon period lowest rainfall was recorded 547mm in Pabna sadar and highest rainfall was recorded 957 mm in Atgharia upazilla of Pabna district. So, rating 2, 3 and 4 was used shows in figure 3.31. At Sirajganj district lowest rainfall was found in Raiganj upazilla which is 165mm and maximum rainfall was found in Ullapara which is 1127mm. So, rating 1, 2, 3, and 4 was used shows in figure 3.32. For Natore district we have found lowest rainfall 584mm in Singra and maximum rainfall 1294 in Gurudaspur. So, rating 2, 3, and 4 was used shows in figure 3.33.

Finally, in Post-monsoon period for Pabna district, shwardi upazilla was having the lowest rainfall and Bera upazilla was having the highest rainfall which was 25mm and 110mm respectively. So, rating 1 was used shows in figure 3.34. In the same period no rainfall was recorded most areas of Sirajganj district. In contrast 237mm rainfall was recorded in ullapara of Sirajganj district. For Natore district, Lalpur upazilla was having minimum rainfall which was 27mm and Gurudaspur was having maximum rainfall which was 110. So, rating 1 was used shows in figure 3.36.

Thematic layer of net recharge was them produced using raster calculator and putting equation (1) in it as seen in figure for pre monsoon period 3.37, 3.38 and 3.39, for monsoon period 3.43,3.44,3.45 and for post-monsoon period 3.49,3.50, 3.51 respectively.

In pre-monsoon period rating 1 & 2 was used for Pabna. For Sirajganj district rating 6 & 8 was used and for Natore district 3, 6 and 8 rating was used. In monsoon period similar rating was used for all three districts 6 & 8. In post-monsoon period rating 6 &

8 was used for both Pabna and Sirajganj districts whereas rating 1 was used for Natore district.

3.4.3 Aquifer Media

An aquifer is defined as a subsurface rock unit which will yield sufficient quantities of water for use. Aquifer medium regulates the flow system. The route and path length which a contaminant must follow are governed by the flow system within the aquifer. The path lengths along with the hydraulic gradient which is an important control in determining the time available for attenuation process such as sorption, reactivity and dispersion to occur. The aquifer medium also responsible for the amount of effective surface area of materials with which the contaminant may come in contact within the aquifer. In general, the larger the grain size and the more the fractures or openings within the aquifers, the higher the permeability and the lower the attenuation capacity of the aquifer media. This DRASTIC parameter is less quantifiable than numerical parameters.

According to literature and aquifer database inventory of DPHE, the study area is completely overlain by the Holocene aquifers.

For Pabna district borehole information was collected from the report of DPHE which shows that the topmost formation, composed of clay and silt, is underlain by fine, medium and coarse sand. The aquifer of the study area is unconfined in nature. From data Upper layer (0-18m) shows grey colored clay at Atghoria upazilla. Light brown coarse sand, medium sand to fine sand, trace gravel was identified at the location of the aquifer. At Faridpur upazilla also shows the similar category of soil formation for the aquifer media. In figure 3.55 where a uniform rating of 8 was used for the whole area indicating presence of sand and gravel at 80m from the ground surface.

From borehole information for the Natore district shows that some of the area of this district is overlain by a clay and trace silt. At Gopalpur of Lalpur upazilla shows the existence of black colored plastic clay between first 18m. At the location of the aquifer grayish and light brown colored fine, medium to coarse sand was found up to 93m. The upper shallow aquifer is semi confined to unconfined. But due to frequent recharge location the aquifer also is also assumed to be unconfined to satisfy the DRASTIC requirements. According to the information from BWDB, a typical rating of 8 was used due to the presence of sand and few gravel particle of various size as aquifer forming layer indicated in figure 3.56.

From lithology of PTW and TTW data from DPHE, for the Sirajganj district shows very thin layer of grey colored clay was present (maximum 6.0) at the upper portion. Maximum depth of borehole data was considered for the Raiganj pourashava consists of 168m. At the location of the aquifer formation averagely fine to coarse sand with gravel was found. For that reason, again a typical rating of 8 was used which indicated in figure 3.57.

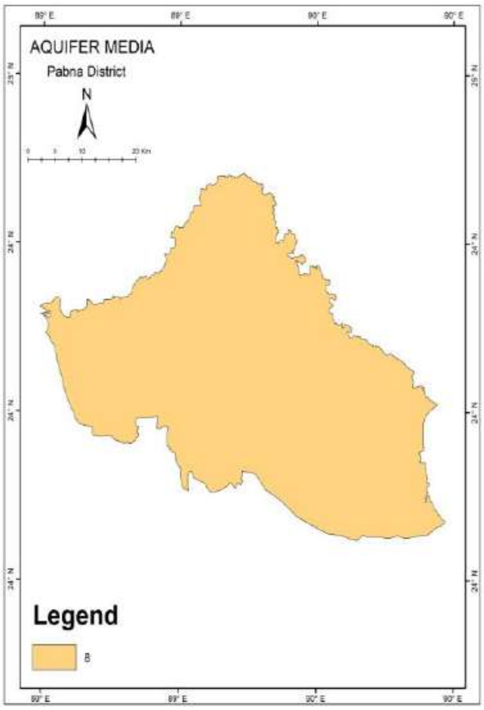


Figure 3.55: Rating for Aquifer media in Pabna

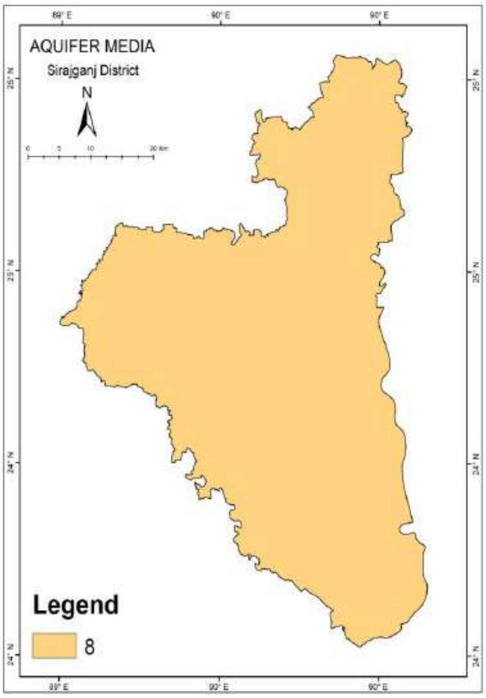


Figure 3.56: Rating for Aquifer media in Sirajganj

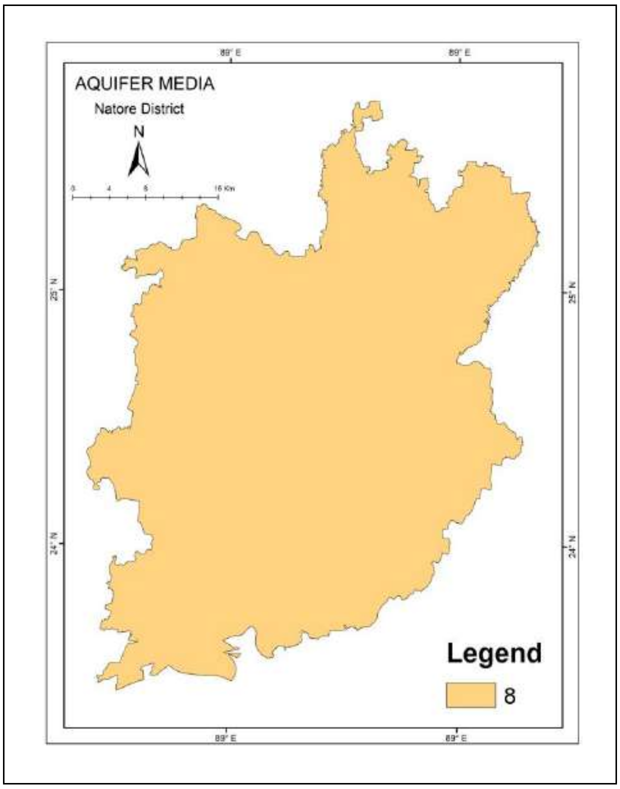


Figure 3.57: Rating for Aquifer media in Natore

3.4.4 Soil Media

Soil media refers to that uppermost portion of the vadose zone where significant biological activity takes place. Here soil is considered the upper weathered zone which extends a depth of six feet on an average or less from the ground surface. Soil has a significant impact on the amount of recharge which can infiltrate into the ground and hence on the ability of a contaminant to move vertically into the vadose zone. The presence of fine-textured materials such as silts and clays can decrease relative soil permeability and restrict contaminant migration. Moreover, where the soil zone is fairly thick, the attenuation processes of filtration, Biodegradation, sorption, and volatilization may be quite significant. In general, the smaller the grain size, the less the pollution potential.

A GIS shape file of the soil texture of Bangladesh was collected from BARC website and it was geo referenced and the study areas were clipped. Five textural classes were identified from the map. Clayey and silty clayey soil was rated 1 because of higher percentage of clay. Mixed muck and clay soil was rated 2. Mixed silty clay and silt loam soil was rated 3 because of greater importance of clayey soil in context of pollution. Mixed silt loam and silty clayey soil was given a rating of 4 where very lower percentage of clay and higher percentage of silt is present. In few locations we identified loam and sandy loam which are rated 5 and 6 accordingly. Figure 3.58 and 3.59 and 3.60 show the thematic layer of soil media.

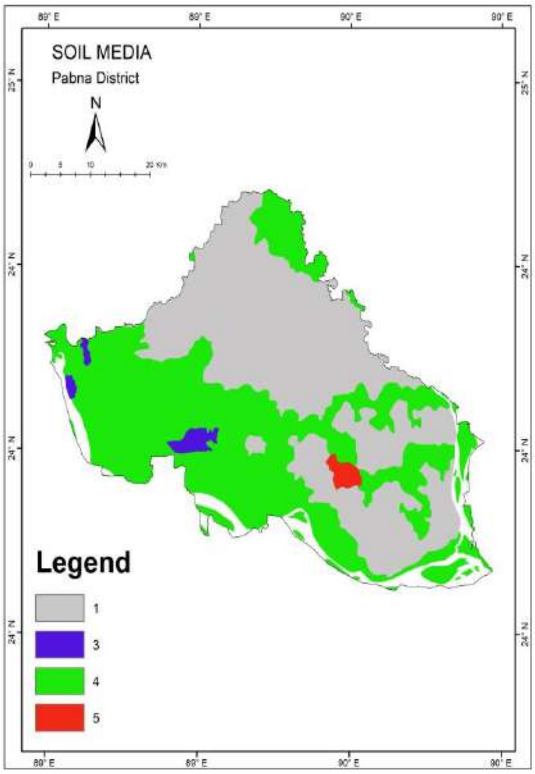


Figure 3.58: Soil media of Pabna district

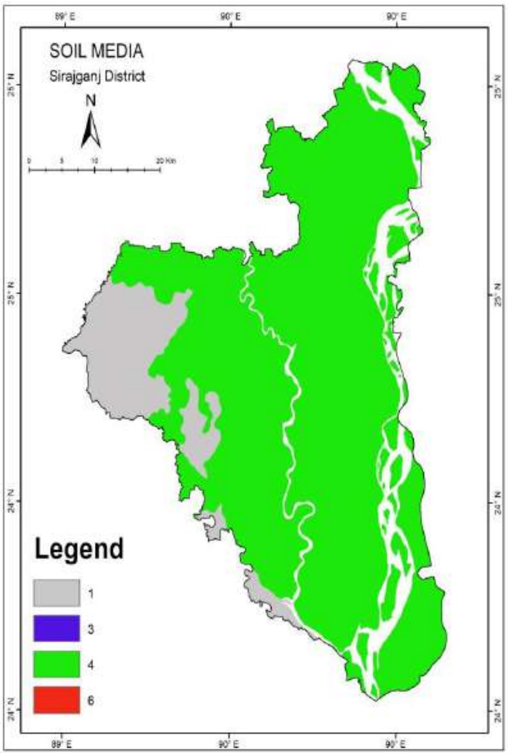


Figure 3.59: Soil media of Sirajganj district

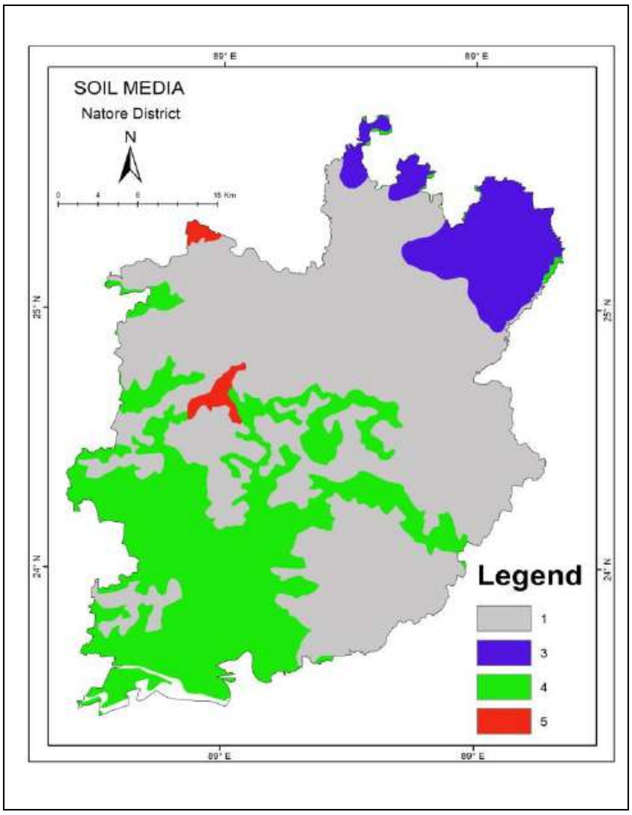


Figure 3.60: Soil media of Natore district

3.4.5 Topography

Topography refers to the slope and slope variability of the land surface. Its helps to understand whether a pollutant will run off or remain on the surface in one area long enough to infiltrate. Flatter slopes provide a greater opportunity for contaminants to infiltrate as contaminant remains on the surface longer than on sleeper slopes and that is why it will be associated with a higher ground-water pollution potential. Topography influences soil development and therefore has an effect on contaminant attenuation. It also regulates flow pattern and direction of flow.

Topography of the study area was generated from DEM using ArcGIS 10.3. Percentage slope was then calculated using the slope function of the same software. It was then classified according to the DRASTIC rating in the figure 3.61 and 3.62 and 3.63.

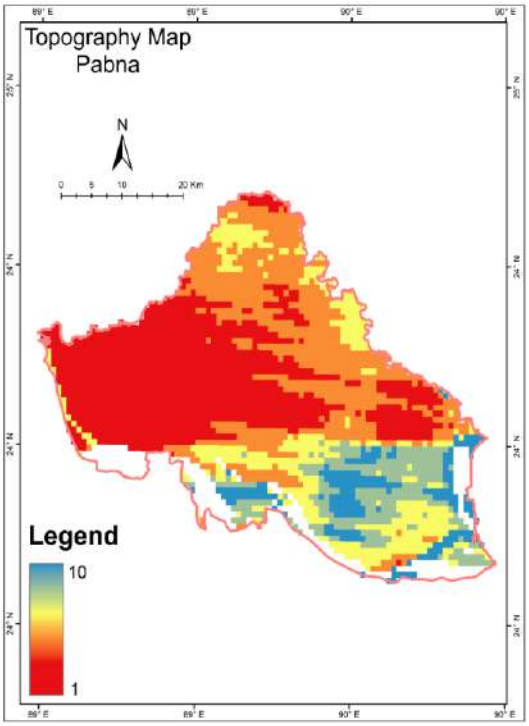


Figure 3.61: Rating for Topography of Pabna district

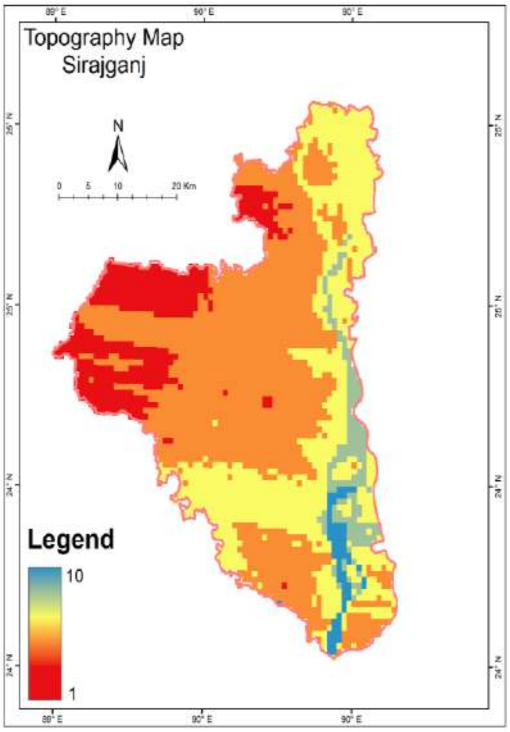


Figure 3.62: Rating for Topography of Sirajganj

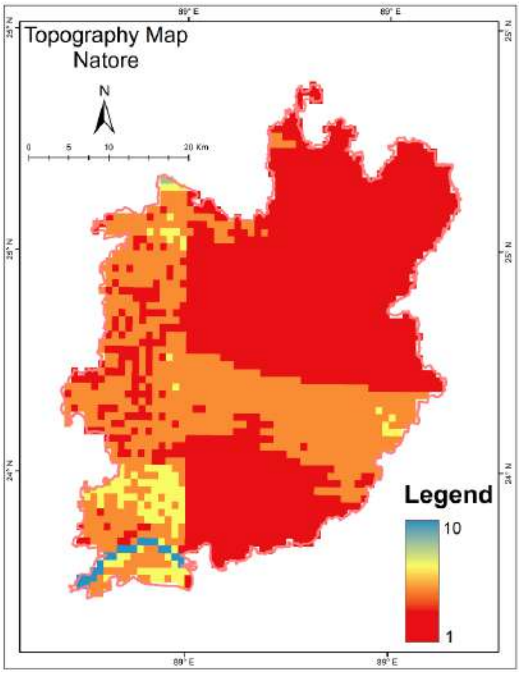


Figure 3.63: Rating for Topography of Natore district

3.4.6 Impact of Vadose Zone

The vadose zone is defined as that zone above the water table which is discontinuously saturated. The type of vadose zone media determines the attenuation characteristics of the material below the typical soil horizon and above the water table. Bio degradation, neutralization, mechanical filtration, chemical reaction, volatilization and dispersion are all processes which may occur within the vadose zone. The amount of biodegradation and volatilization decreases with depth. The media also controls the path length and routing, thus affecting the time available for attenuation. The routing is strongly influenced by any fracturing present. The materials at the top of the vadose zone also exert an influence on soil development.

The selection of the vadose zone media depends on whether the aquifer to be evaluated is unconfined or confined. The vadose zone media of the study area is sedimentary formation consisting of clay and trace silt. So, typical rating of 3 was used for the three study areas according to the DRASTIC rating in figure 3.64, 3.65 and 3.66.

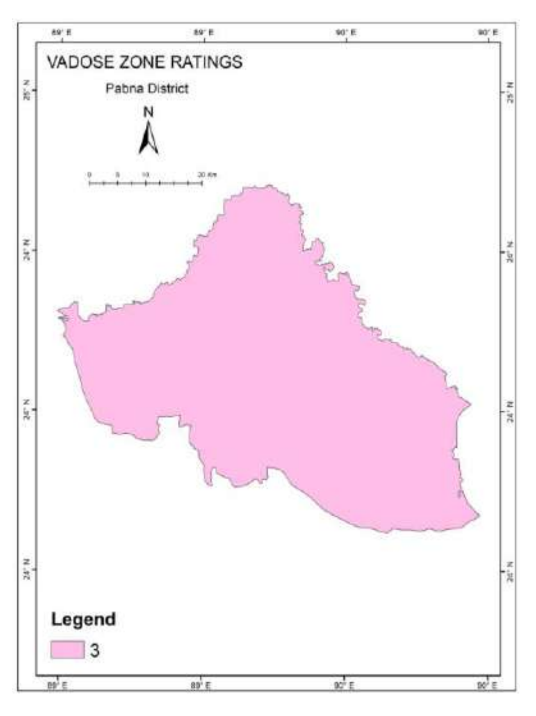


Figure 3.66: Rating for Impact of vadose zone media in Pabna district

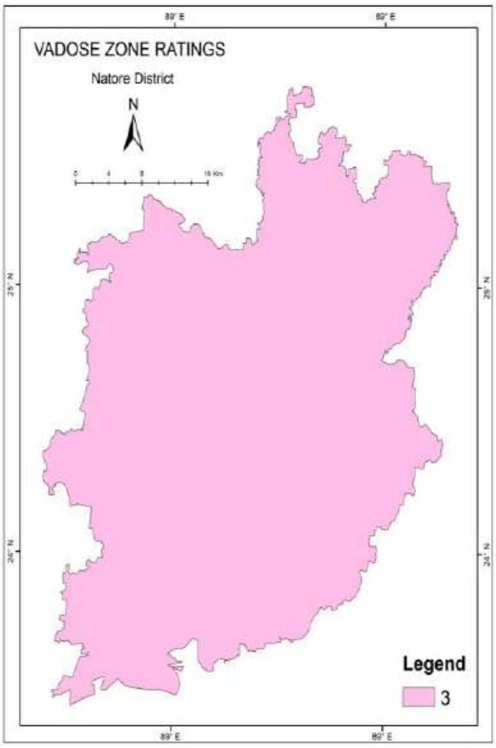


Figure 3.64: Rating for Impact of vadose zone media in Pabna district

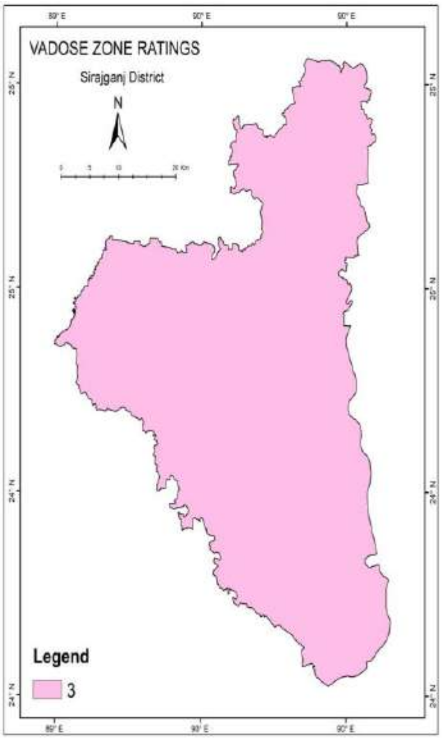


Figure 3.65: Rating for Impact of vadose zone media in Sirajganj district

3.4.7 Hydraulic Conductivity

Hydraulic Conductivity refers to the ability of the aquifer materials to transmit water, which in turn, controls the rate at which ground water will flow under a given hydraulic gradient. It is controlled by the amount and interconnection of void spaces within the aquifer which may occur as a consequence of intergranular porosity, fracturing and bedding planes. The velocity of ground water also controls the rate at which a contaminant moves away from the point at which it enters the aquifer. In DRASTIC index method, hydraulic conductivity is divided into ranges where high hydraulic conductivities are associated with higher pollution potential.

Information on this parameter was very little in this study area. Hydraulic conductivity data was collected from the literature review. Pabna district parameter was found to be 22.8 m/day which falls within the range of 300-700 GPD/ft^2 and a rating of 4 was used for this area in figure 3.67. For Natore, the average value of conductivity was taken

24.6 m/day. This value also falls within the range of 300-700 GPD/ft^2 and a same rating of 4 was used as indicated in the figure 3.68. Furthermore, at Sirajganj district the average value was count 18.5 m/day which falls in the range of 300-700 GPD/ft^2. So, rating of 4 was used for this study area as indicated in figure 3.69.

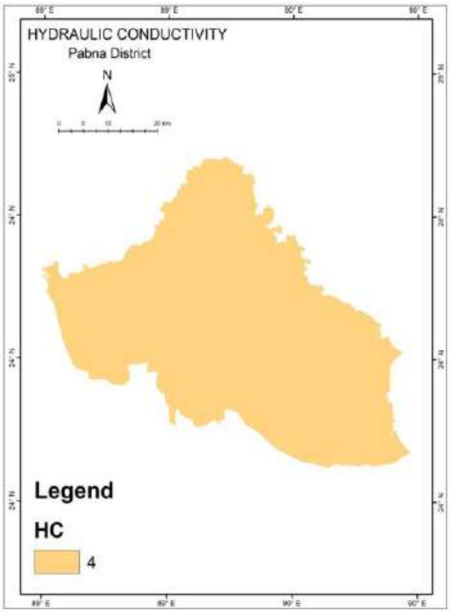


Figure 3.67: Rating for Hydraulic conductivity in Pabna district

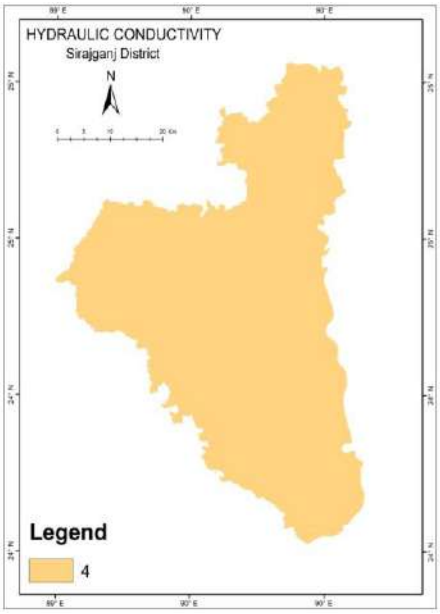


Figure 3.68: Rating for Hydraulic conductivity in Sirajganj district

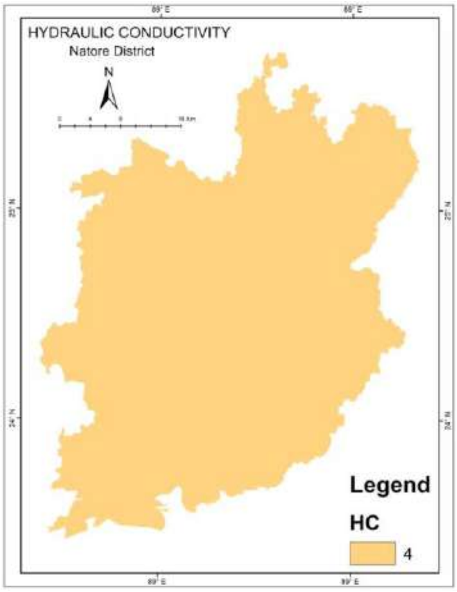


Figure 3.69: Rating for Hydraulic conductivity in Natore district

CHAPTER 4

RESULTS AND ANALYSIS

4.1 General

This Chapter presents the results of the groundwater vulnerability assessment of Sirajganj, Pabna and Natore districts selected as study area in the period of pre-monsoon, monsoon and post-monsoon with the help of DRASTIC method. Resulting vulnerability map was then compared the spatial vulnerability of groundwater pollution among three districts. Quality and reliability of the data and map was also assessed in the preceding section.

4.2 Drastic Index Vulnerability Map

Using the raster calculator of the ArcGIS 10.3 equation (2) was solved and DRASTIC vulnerability maps of Sirajganj, Pabna and Natore were produced.

The DRASTIC index (DI) is determined by solving the following equation:

$$DI = D_R \times D_w + R_R \times R_w + A_R \times A_w + S_R \times S_w + T_R \times T_w + I_R \times I_w + C_R \times C_w \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

DRASTIC Indices obtained for Sirajganj, Pabna and Natore districts in the period of of pre-monsoon, monsoon and post-monsoon. Pre-monsoon, monsoon, post-monsoon periods consist of March to May, June to October, November to February respectively. In the period of pre-monsoon for Pabna, Sirajganj and Natore districts DRASTIC Index values are 83-109 , 83-105 and 105-141 respectively as found in figure 4.1, 4.2 and 4.3. In the period of monsoon DRASTIC Indices obtained for Sirajganj, Pabna and Natore districts are 113-147, 121-146 and 123-141 respectively as found in figure 4.7, 4.8 and 4.9. In the period of post-monsoon DRASTIC Indices obtained for Sirajganj, Pabna and Natore districts are 113-135, 113-135 and 93-113 respectively as found in figure 4.13, 4.14 and 4.15. These three districts are within the range of normal DRASTIC index (65-223) (Aller et al, 1987). Figure 4.4, 4.5, 4.6, 4.10, 4.11, 4.12, 4.16, 4.17 and 4.18 show the classified DRASTIC map as tabulated below.

Table 4.1: Classification and description of the DRASTIC Index value (Aller et al, 1987)

DRASTIC Index Score	Description
65-96	Very Low
96-127	LOW
127-158	Moderate
158-189	High
189-223	Very High

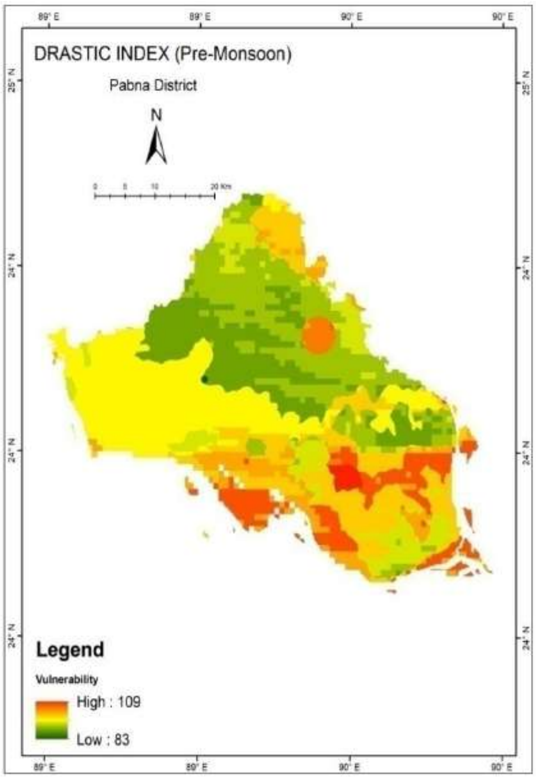


Figure 4.1: Unclassified DRASTIC Vulnerability map of Pabna district for Pre-Monsoon Period

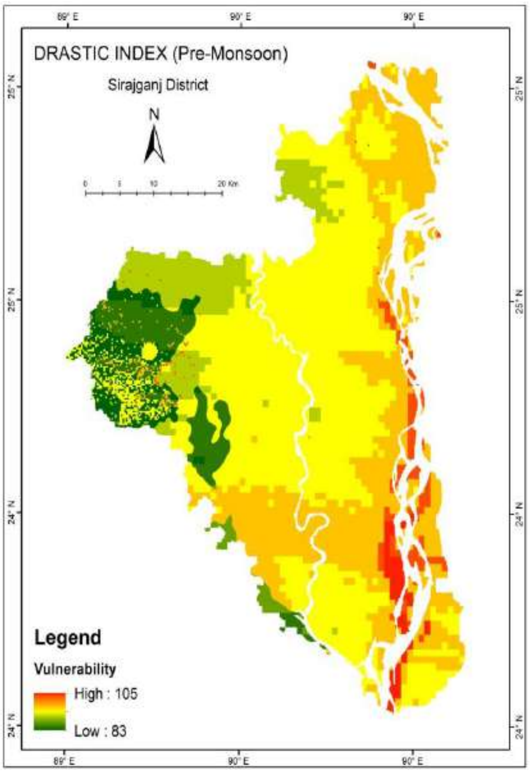


Figure 4.2: Unclassified DRASTIC Vulnerability map of Sirajganj district for Pre-Monsoon Period

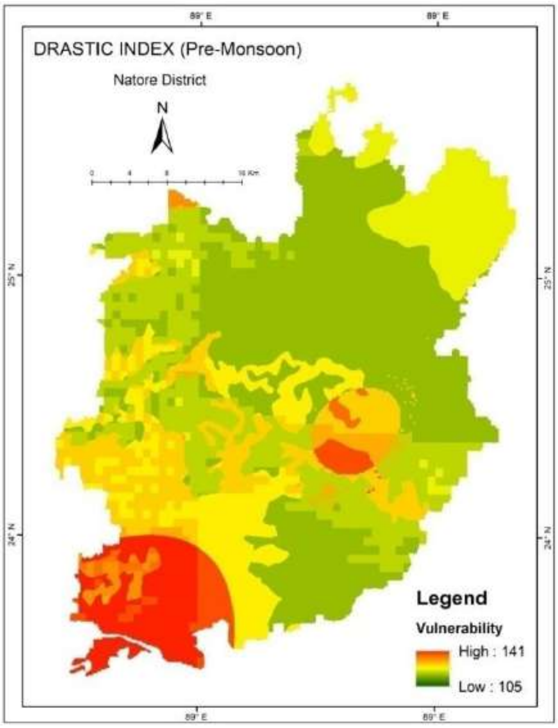


Figure 4.3: Unclassified DRASTIC Vulnerability map of Natore district for Pre-Monsoon Period

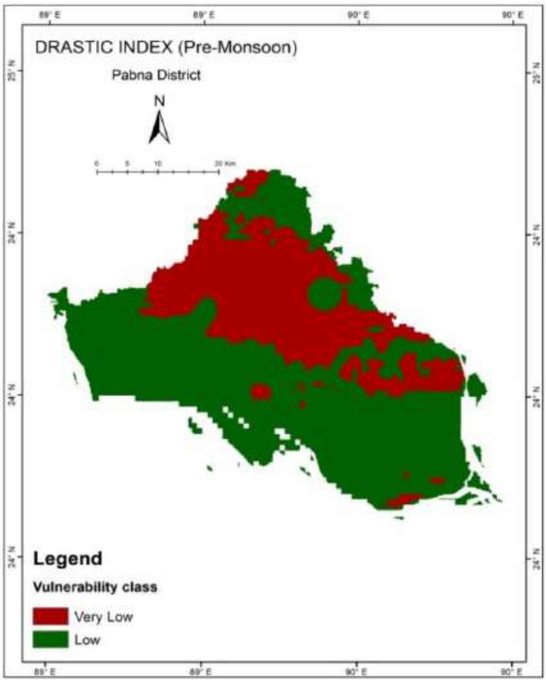


Figure 4.4: Classified DRASTIC Vulnerability map of Pabna district based on Total DRASTIC score for Pre-Monsoon

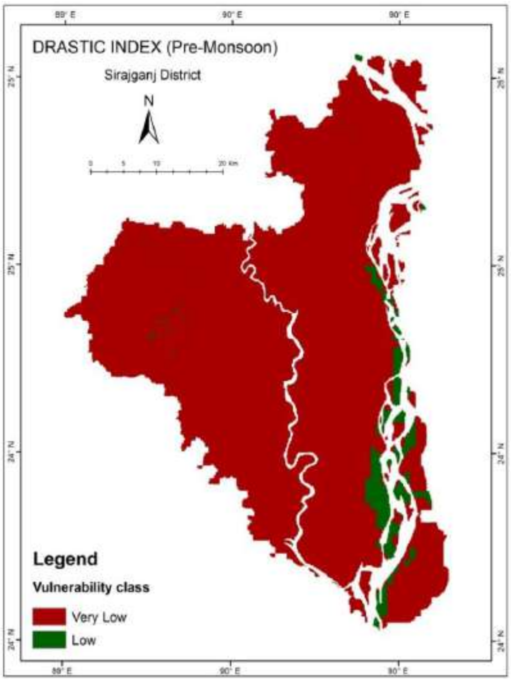


Figure 4.5: Classified DRASTIC Vulnerability map of Sirajganj district based on Total DRASTIC score for Pre-Monsoon

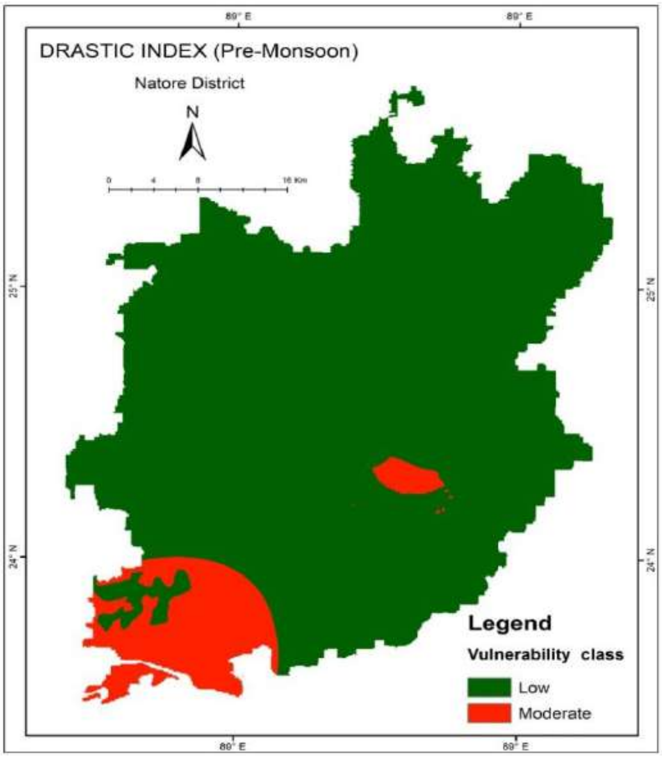


Figure 4.6: Classified DRASTIC Vulnerability map of Natore district based on Total DRASTIC score for Pre-Monsoon Period

According to the classification of Aller et al., (1987), In the pre-monsoon period (march to May) Pabna district falls under very low to low vulnerable zone, Sirajganj district falls under the same category very low to low vulnerable zone and natore district shows low to moderate vulnerable zone.

From the classified DRASTIC vulnerability map of Pabna it is clearly observed that majority of the study area falls within very low vulnerability. Low vulnerable was found in Pabna sadar and Iswardi upazilla with some parts of Ataikula upazilla. For Sirajganj district it is also observed that majority of the study area falls within very low vulnerability and a few parts fall within low vulnerable zone. Sirajganj Sadar of the district is very low with Tarash upazilla. Very low vulnerable area was also found in Shahzadpur Upazila and some parts of the Raiganj upazilla. For Natore districts majority of the study area falls within low vulnerable zone and a few parts fall within moderate vulnerable zone. Most of the areas of the district are under low vulnerability sharing a major portion of Natore Sadar Upazilla, Naldanga Upazilla and Singra Upazilla. Lalpur upazilla falls under moderate vulnerable area.

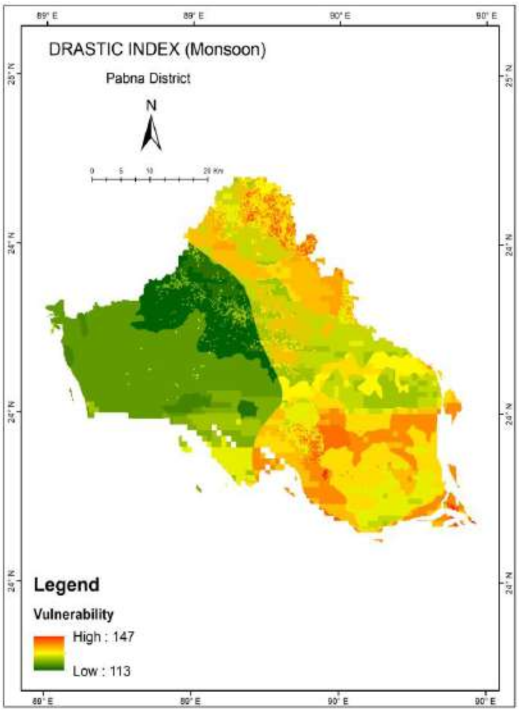


Figure 4.7: Unclassified DRASTIC Vulnerability map of Pabna district for Monsoon Period

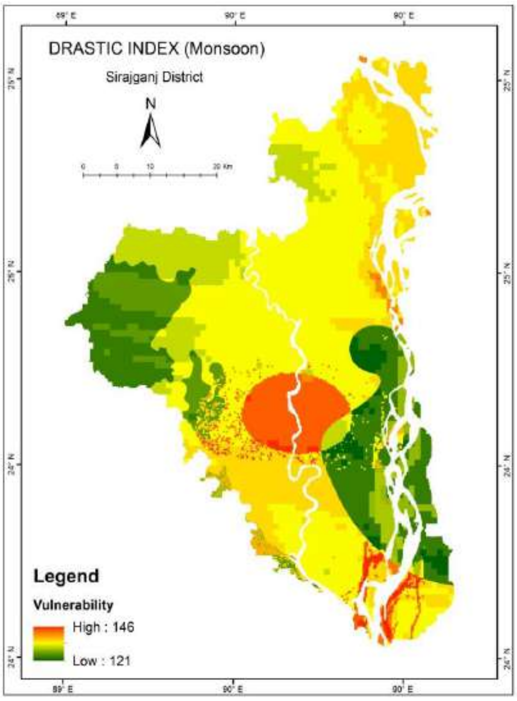


Figure 4.8: Unclassified DRASTIC Vulnerability map of Sirajganj district for Monsoon Period

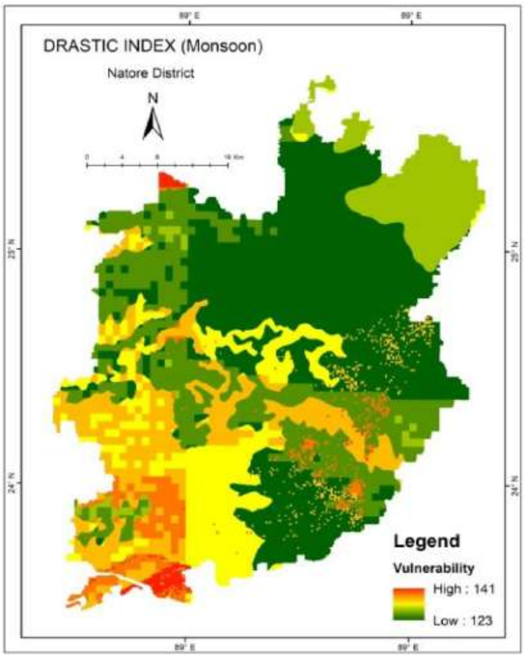
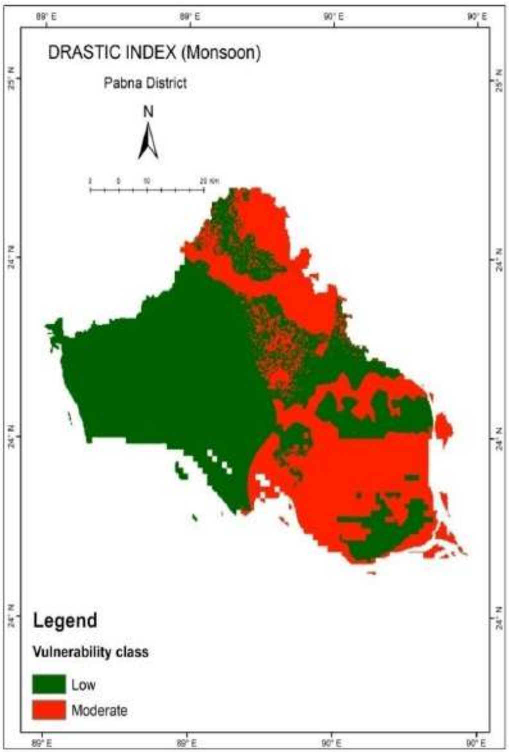


Figure 4.9: Unclassified DRASTIC Vulnerability map of Natore district for Monsoon Period



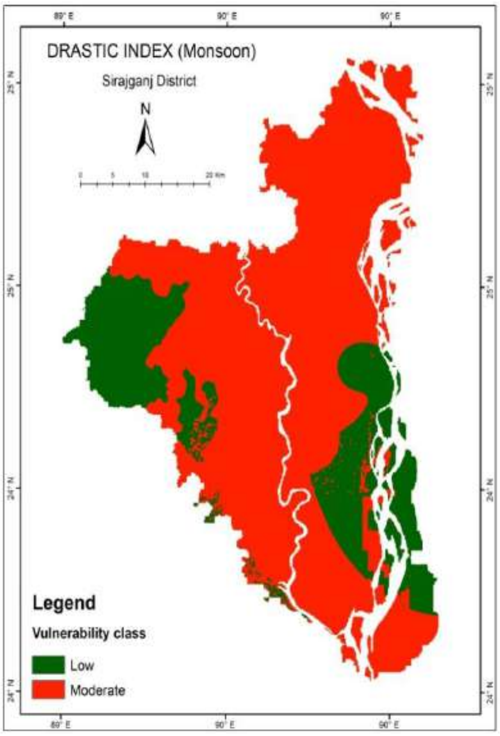


Figure 4.10: Classified DRASTIC Vulnerability map of Pabna district based on Total DRASTIC score for Monsoon Period

Figure 4.11: Classified DRASTIC Vulnerability map of Pabna district based on Total DRASTIC score for Monsoon Period

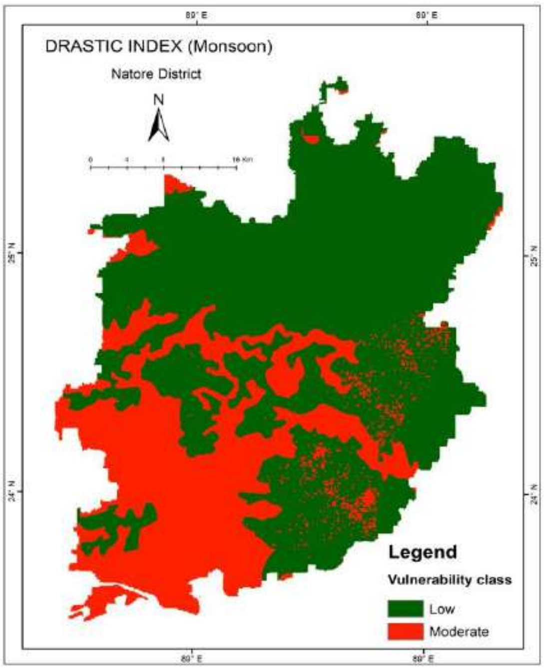


Figure 4.12: Classified DRASTIC Vulnerability map of Natore district based on Total DRASTIC score for Monsoon Period

According to the classification, In the monsoon period (June to October) Pabna district falls under low to moderate vulnerable zone, Sirajganj district falls under the same category low to moderate vulnerable zone and natore district also shows the same results.

From the classified DRASTIC vulnerability map of Pabna it is clearly observed that majority of the study area falls within low vulnerability. Low vulnerable was found in Pabna sadar and Iswardi upazilla. For Sirajganj district it is also observed that majority of the study area falls within moderate vulnerability and a few parts fall within low vulnerable zone. Low vulnerable was found in Sirajganj sadar and Tarash upazilla. For Natore districts majority of the study area falls within low vulnerable zone and other parts fall within moderate vulnerable zone. Low vulnerable was found in Natore sadar and Singra upazilla.

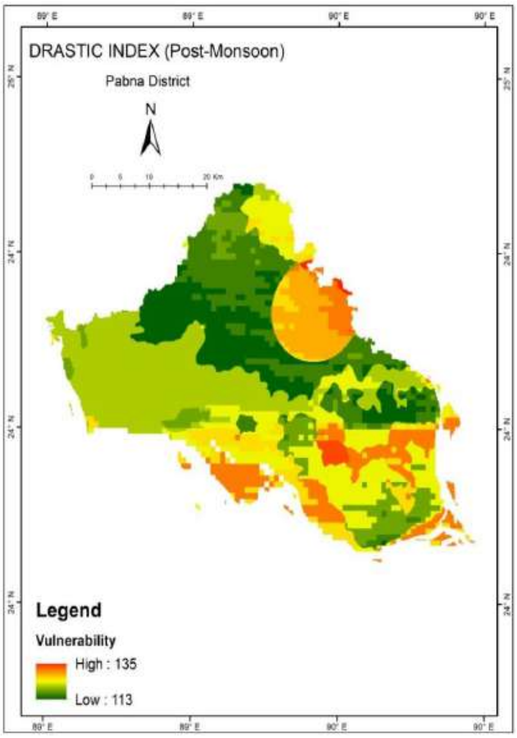


Figure 4.13: Unclassified DRASTIC Vulnerability map of Pabna district for Post-Monsoon Period

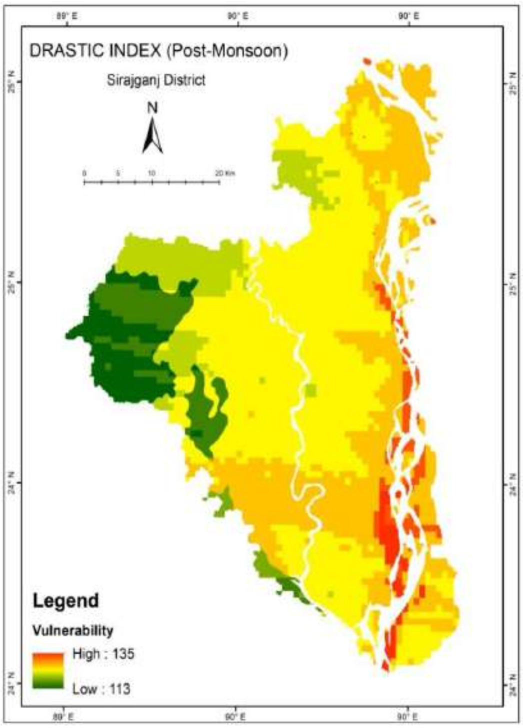


Figure 4.14: Unclassified DRASTIC Vulnerability map of Sirajganj district for Post-Monsoon Period

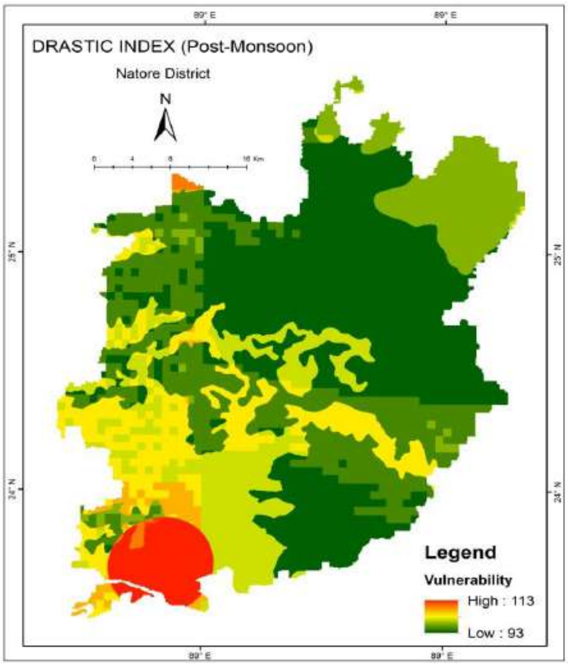
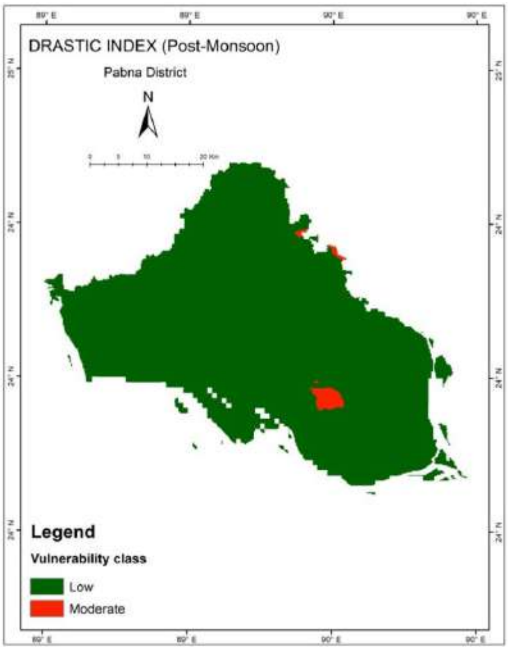


Figure 4.15: Unclassified DRASTIC Vulnerability map of Natore district for Post-Monsoon Period



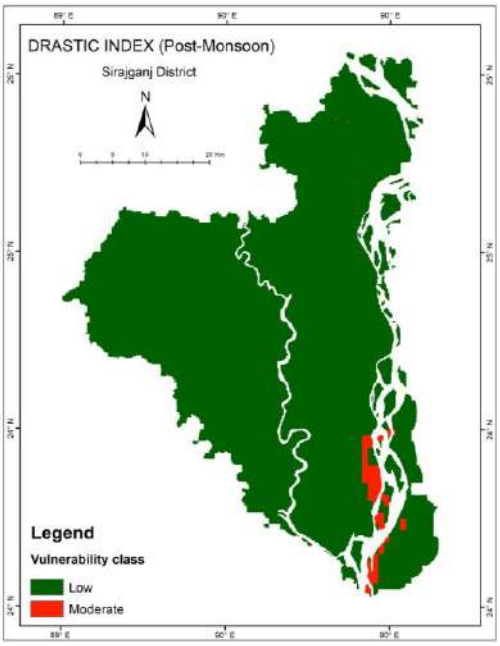


Figure 4.18: Classified DRASTIC Vulnerability map of Pabna district based on Total DRASTIC score for Post-Monsoon Period

Figure 4.17: Classified DRASTIC Vulnerability map of Sirajganj district based on Total DRASTIC score for Post-Monsoon Period

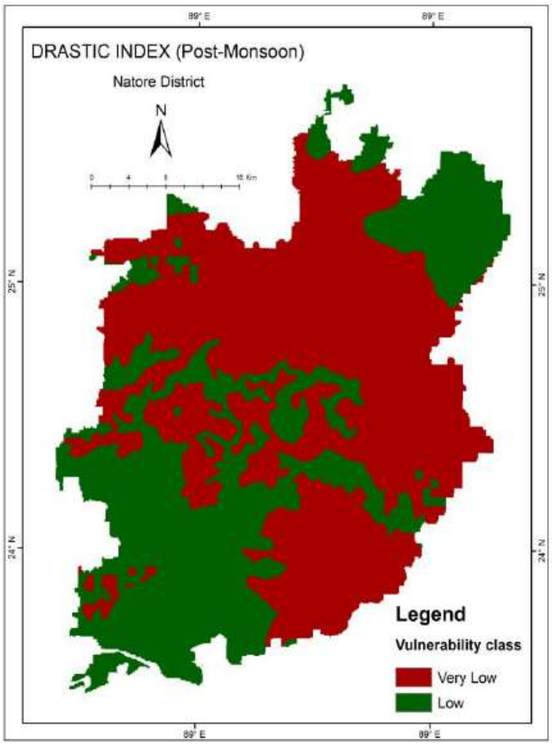


Figure 4.16: Classified DRASTIC Vulnerability map of Natore district based on Total DRASTIC score for Post-Monsoon Period

In the post-monsoon period (November to February) Pabna and Sirajganj both districts fall under low to moderate vulnerable zone and Natore district falls under very low to low vulnerable zone.

From the classified DRASTIC vulnerability map of Pabna in post-monsoon period it is clearly observed that majority of the study area falls within low vulnerability and a few parts fall under moderate vulnerable zone. Low vulnerable was found in Pabna sadar and Iswardi upazilla with Ataikula upazilla. According to the classification, Sirajganj district also falls under low to moderate vulnerability zones. From the classified DRASTIC vulnerability map of Sirajganj it is clearly observed that a major part of the study area falls within low vulnerability and a very few parts falls under moderate vulnerable zone. Natore district falls under very low to low vulnerability zones.

4.3 Comparative Analysis of Result

From the Attribute table of classified DRASTIC map, percentage area under different vulnerability zone was calculated in ArcGis 10.3. To have a better understanding of comparative expansion of different vulnerability zone based on percentage of area, three graphs have been plotted for pre-monsoon, monsoon, post-monsoon period.

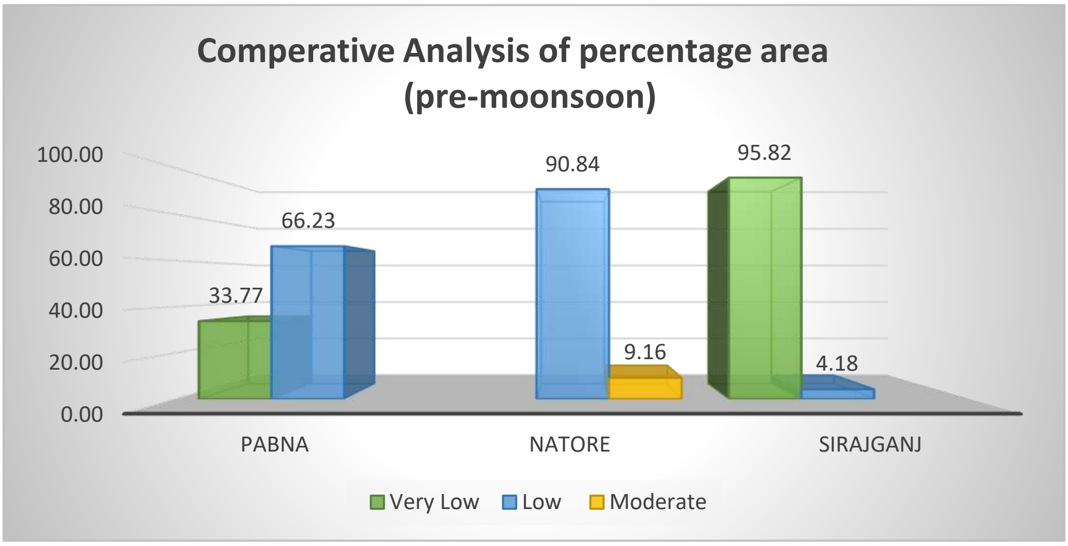


Figure 4.19: Comparative analysis of percentage area based on Aller et al, (1987) Classification for pre-monsoon period

From the Figure 4.19, we can say that Sirajganj district has the least vulnerable area with 95.82% and low vulnerable area with the 4.18%. 90.84% area of Natore district falls under low vulnerability. In addition, 66.23% area of Pabna district belongs to in low vulnerable.

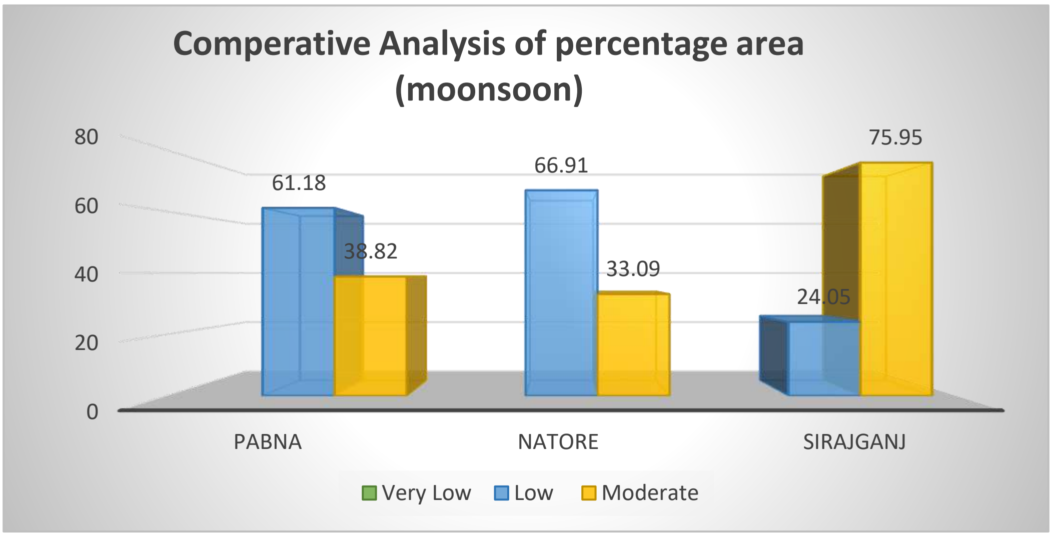


Figure 4.20: Comparative analysis of percentage area based on Aller et al, (1987) Classification for monsoon period

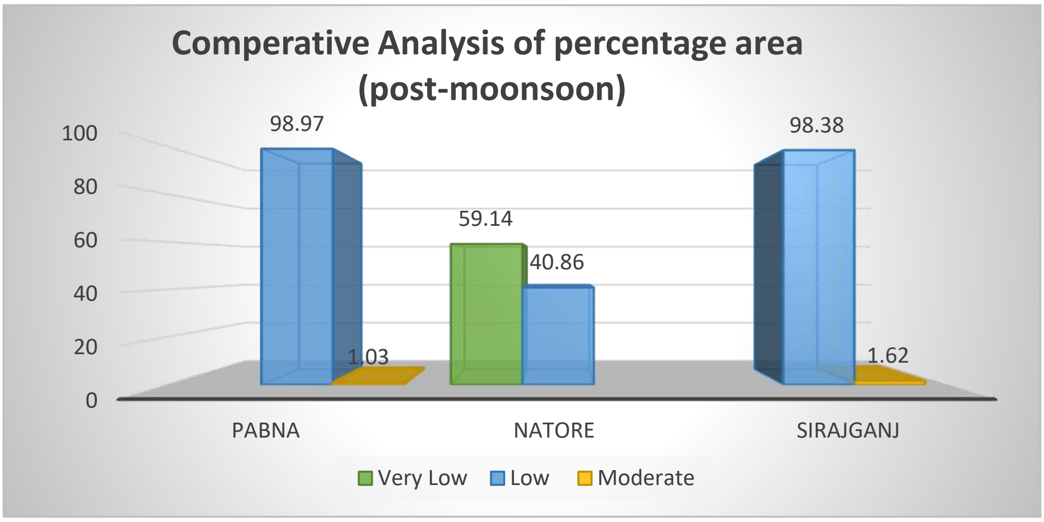


Figure 4.21: Comparative analysis of percentage area based on Aller et al, (1987) Classification for post-monsoon period

From the Figure 4.20 for monsoon period, it is also observed that 61.18% area of Pabna district was found to have low vulnerability which is close to the Natore district. 66.91% area of Natore district falls under low vulnerability. But 75.95% area of Sirajganj district belongs to in Moderate vulnerable whereas 24.05% area falls under low vulnerable zones.

From the Figure 4.21 for monsoon period Pabna district 98.36 % areas are facing low vulnerable and 1.03% area under moderately vulnerable. In Natore district 40.86% area was found to have low vulnerability, 59.14% area under low vulnerability. Sirajganj district has the low vulnerable area with 98.38% and moderate vulnerable area with the 1.62%.

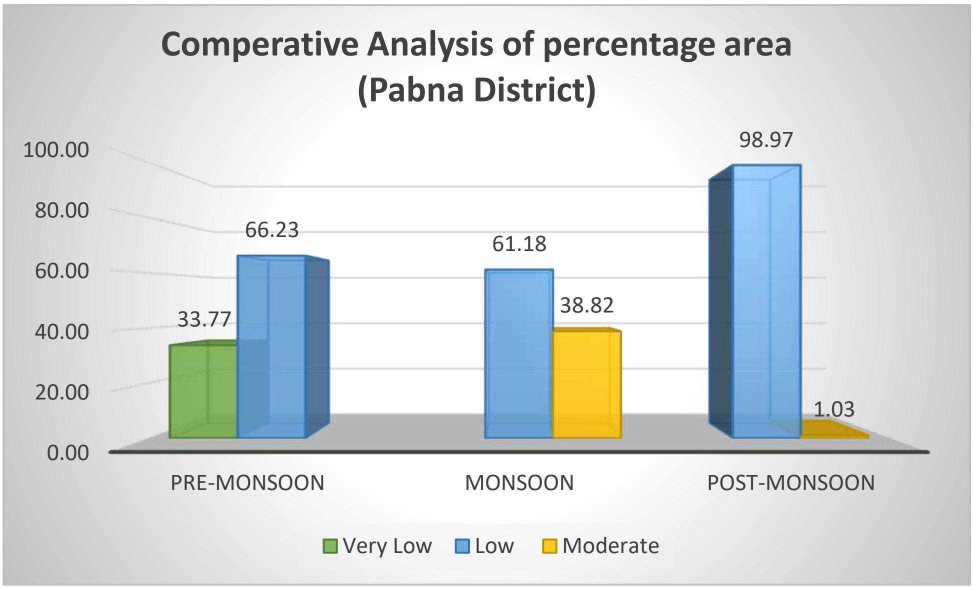


Figure 4.22: Comparative analysis of percentage area based on Aller et al, (1987) Classification for Pabna District

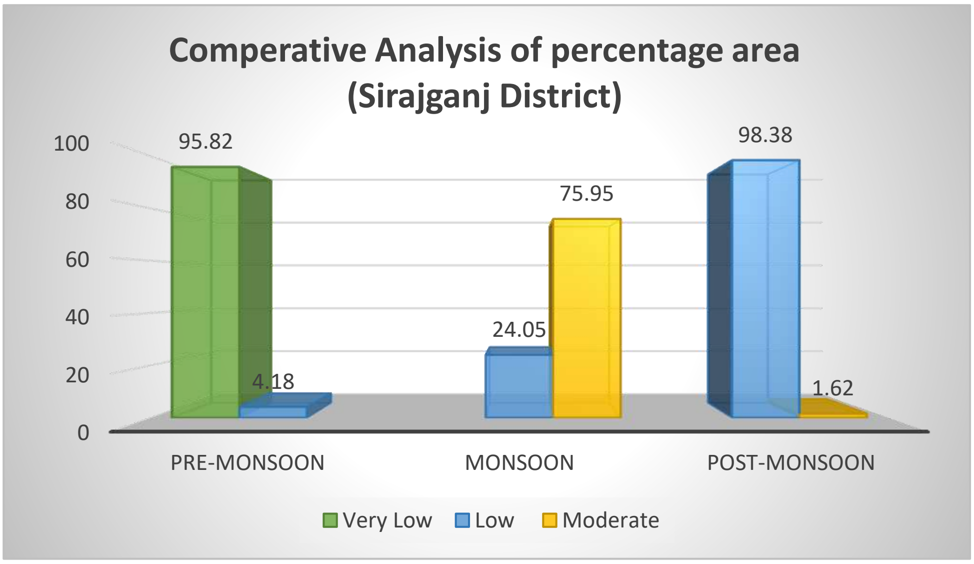


Figure 4.23: Comparative analysis of percentage area based on Aller et al, (1987) Classification for Sirajganj District

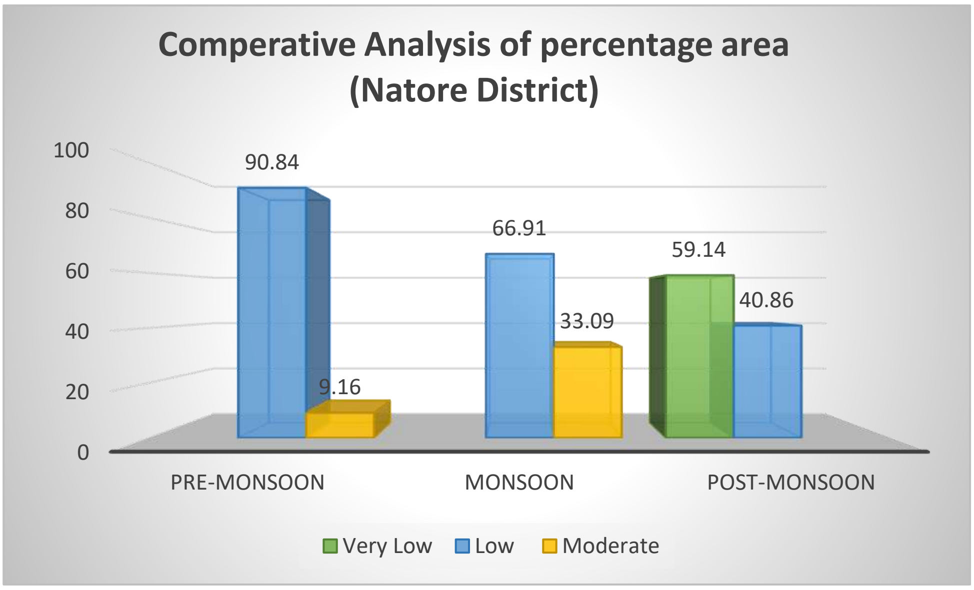


Figure 4.24: Comparative analysis of percentage area based on Aller et al, (1987) Classification for Natore District

Again, From the figure 4.21, 4.22, and 4.23 it is also observed that as per comparative analysis of percentage area for all three districts most vulnerable period is monsoon period. That means due to more rainfall infiltrate to the ground water in monsoon period water level has increased, for instance ground water also become more vulnerable. Again, the ground water vulnerability for pre and post monsoon period are always less than the monsoon period.

From the literature review of the study area, it is also observed that the whole study area is predominantly agricultural land. That is why pollution from soil surface can be a potential source of groundwater contamination for the study area. This image also shows some similarity in between the wetland and comparatively higher vulnerability zone which is mainly due to the easy passage of contaminant particle through this site.

From the analysis of the Arc GIS 10.3, Groundwater table has the most significance impact on the result. Higher ratings for the groundwater table showing highly vulnerable for all places among three districts. As slope protection is almost same for the three districts, and rainfall for Sirajganj districts have only different value and that’s why soil permeability is the major factor for the Net Recharge. Less recharge shows the less vulnerability for the Sirajganj districts.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 General

Bangladesh is likely to be in extreme vulnerable condition under the current scenario of changes in climate condition because of its geographic location and low-lying topographic condition. Almost every sector of socio-economic life is likely to be affected by climate change and water sector is the most vulnerable and sensitive amongst them. In the area of study groundwater is the main source of drinking and irrigation water supply. The vulnerability indices of groundwater of the underlying aquifer of this area have been computed in this study using data of the year 2018 considering individual impact of seven DRASTIC parameters. Comparative analysis of vulnerability potential of the three areas was drawn.

5.2 Conclusion of the Study

The groundwater vulnerability maps are important tools for assessing the groundwater vulnerability and planning future land use. No method developed for creating vulnerability maps is the most reliable, each of them depending on the aquifer characteristics, the land use, the data availability, the parameters involved in the model, the weightings, and rating assigned to each parameter.

The following results have been revealed from the study

1. From the classified vulnerability map of Pabna for the pre-monsoon period, 66.23% area was found to have low vulnerability, 33.77% area under very low vulnerability. In Natore district 90.84 % areas are facing low vulnerable and 9.16% area under moderately vulnerable. In Sirajganj district 95.82% area was found to have very low vulnerability, 4.18% area under low vulnerability.

2. For the monsoon period, 61.18% area of Pabna district was found to have low vulnerability, 38.82% area under moderate threat. In Natore district 66.91 % areas are facing low vulnerable and 33.09% area under moderately vulnerable.

In Sirajganj district 75.95% area was found to have moderate vulnerability, 24.05% area under low vulnerability.

3. For the post-monsoon period, From the classified vulnerability map of Pabna 98.97% area falls under low vulnerability, 1.03% area under moderate threat. In Natore district 59.14 % areas are facing very low vulnerable and 40.86% area under low vulnerable. In Sirajganj district 98.38% area was found to have low vulnerability, 1.62% area under moderate vulnerable areas.

4. Though all the factors that affect groundwater pollution potential are not included in this method, yet they are selected keeping technical considerations in mind and also the availability of map able data was a major influencing factor and this was determined that DRASTIC parameters, in combination are all inclusive to assess the general pollution potential of the hydro geologic settings of the study area.

5. This study will also help in future planning related to local groundwater resources by prioritizing the areas where groundwater protection is critical specially in very highly vulnerable areas of these three districts.

6. Though DRASTIC index of the study area cannot indicate where the pollution has already occurred, it can focus on cleanup efforts with the help of effective monitoring system especially in the range of high to very highly vulnerable areas of both the districts.

7. The vulnerability map produced in this study gives a decision maker a very comprehensive idea of areas that need to be closely monitored, as well as those areas which are less likely to become contaminated and require less intensive monitoring.

5.3 Limitations

1. Chemical reaction of the contaminant with soil and subsoil particles is not considered here. DRASTIC is only concern about the physical characteristics of the study area and its degradation with contaminant particles that are introduced on ground surface and seep through the top soil and sub soil area with recharge water.

2. High vulnerable water zones are usually difficult to monitor, as it requires the drilling of many monitoring wells, which is very expensive.

3. Resultant DRASTIC indices do not give any absolute value of pollution of the study area. Rather it provides a basis for comparative evaluation of pollution potential. This study is very helpful prior to any site specific investigation.

5.4 Recommendations:

The result obtained in the study is by far believed to be the most accurate both in terms of available data and the process followed. Due to limited time span of the study, however, the following recommendations should be considered in the future research.

1. In the present study, data availability of the hydro geologic settings was a big challenge. The study was conducted with the data of the year of 2018 and 2019. Data on each required parameters are not collected and updated regularly by the concerned authority. Incorporation of remote sensing data with DRASTIC model will be able to give the immediate condition of the study area.

2. The study suggests that the DRASTIC model can be used for prioritization of vulnerable areas in order to prevent the further pollution to already more polluted area. There is need to develop a system that can be used to identify areas where attention or protection effort is required. There should be a detailed and frequent monitoring in high and very high vulnerable zones in order to monitor the changing level of pollutants.

3. This method suggests that the more the depth to groundwater table the better it is in terms of pollution potential. But with the lowering of groundwater table salinity intrusion as well as arsenic problem can emerge as a big threat. That’s why a combined study of the DRASTIC parameters with these two potential pollution factors can be more effective for the study area.

4. There are many significant sources of surface water around the study area such as Padma, Jamuna river etc. A comprehensive study considering interaction between these surface water sources with the groundwater aquifer will be of better use for planning authority.

5. As the study area is mainly agricultural land, heavy withdrawal of groundwater for irrigation as well as industrial and domestic purpose needs to be controlled. Groundwater resources that can be safely used both from upper and deeper aquifer needs to be assessed by concerned government agencies before large scale abstraction.

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