2014

Impact of Open Pit Coal Mining on Groundwater in and Around Phulbari Area, Bangladesh

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IMPACT OF OPEN PIT COAL MINING ON GROUNDWATER IN AND AROUND PHULBARI AREA, BANGLADESH

Ph.D. Thesis

A Thesis Submitted to
The Institute of Environmental Science (IES)
University of Rajshahi
In Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy
in
Environmental Science

Submitted by
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Institute of Environmental Science (IES)
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December, 2014

IMPACT OF OPEN PIT COAL MINING ON GROUNDWATER IN AND AROUND PHULBARI AREA, BANGLADESH

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December, 2014

Dedicated

To

My Respective Parents and My Beloved Wife Who Inspired all-time

DECLARATION

I do hereby declare that this research work is submitted as a thesis titled **"IMPACT OF OPEN PIT COAL MINING ON GROUNDWATER IN AND AROUND PHULBARI AREA, BANGLADESH"** to the IES, University of Rajshahi, Rajshahi, Bangladesh for the degree of Doctor of Philosophy. This study was carried out by myself and has not been concurrently submitted for any other degree.

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CERTIFICATE

This is to certify that this thesis entitled **"IMPACT OF OPEN PIT COAL MINING ON GROUNDWATER IN AND AROUND PHULBARI AREA, BANGLADESH"** submitted by Md. Emdadul Haque has been carried out under our joint supervision. This is further to certify that it is an original work and suitable for the degree of Doctorate of Philosophy at the Institute of Environmental Science (IES), University of Rajshahi. The work has not previously been published elsewhere for any other degree.

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Acknowledgement

First of all, I owe all my gratitude and special thanks to Almighty Allah- the most merciful and the creator of the universe, that by his endless grace. Who gives me ability to research and also gives ability to study about the mystery of the environment.

I express my deepest sense of gratitude and indebtedness to my respected supervisor, Dr. Raquib Ahmed, Professor, Department of Geography & Environmental Studies, University of Rajshahi, who took a lot of trouble during my research work and gave continuous inspiration in conducting the thesis work. His sincere guidance, generous support, valuable suggestions, helpful ideas, whole-hearted co-operation and scholastic scrutinization made possible to complete this research work. Without his affectionate cooperation, this painstaking investigation would not have been realized.

I feel happy to express my deep gratitude and sincere indebtedness to my respected teacher and my thesis co-supervisor, Professor Dr. A.H.M Selim Reza, Department of Geology and Mining, University of Rajshahi, for his help in topic selection, instant guidance, scrutinization, affectionate encouragement and charming behavior for which I will remain ever grateful to him. Without his constant help inspiration and constructive suggestions it would not be possible to complete this research work.

I am deeply indebted to various organizations like CEGIS, BWDB, BMDA, SPRRSO, Central Chemistry Laboratory, RU, they help and cooperate me in research work and library work during the whole period of research work. It is with great admiration that I offer my sincere thanks to all the teachers of IES, RU, the secretary and all of the stuff of the institute, for their cooperation friendly behavior and sincere support at all stages of my work.

Finally, I would express my gratitude to my beloved wife Dr. Nur-E-Mina Mst. Rabeya Siddiqua for her full cooperation, patience, courageous inspiration and continuous support during entire course of my study period. I also would like to convey thanks to all of my friends and colleagues who helped me directly or indirectly at different stages of my thesis period.

Md. Emdadul Haque

Abstract

This study attempts to evaluate current state of the groundwater environment considering natural and artificial system together, to better understand origin of stresses, their state, expected impact and responses made to restore healthy groundwater environment in Phulbari coal mine area. Impacts on groundwater were carried out for an open pit coal mining area located in Phulbari under Dinajpur District in Bangladesh. The exploration of coal following the open pit method will influence the ground water resources in and around the mine due to pumping of groundwater as well as precipitated water which will be accumulated in the floor of the open pit mine. Groundwater is the main source for agriculture and domestic use of that region. In this area the average groundwater level is declining 0.166m each year. During the drought season groundwater depletion rate is 0.209 m/year and during monsoon period this rate is 0.112 m/year. During the twenty five years period (1985–2010) total depletion of groundwater is 4.15 m in Phulbari. On the other hand, during the summer season temperature ranges from 22^0C to 38^0C and during the winter season it varies from 5.4^0C to 16^0C during the 41 years period (1970–2010). The analysis reveals that due to dry up of rivers and discharge of groundwater level for irrigation, temperature increased and groundwater level decreased. Hydrographically it is also seen the close relationship between groundwater level and rainfall from the time series analysis. It is observed that temperature is increasing with time and groundwater level is decreasing with time. Here it is found a reverse relationship between groundwater level and temperature. But if open pit coal mine will be done in that area, this will abruptly change the water table, because total water of mine area has to be pumped out. As a result drying up of wells, reduction of water in streams and lakes, deterioration of water quality, increased pumping costs and land subsidence will occur around the mine. For qualitative analysis four water samples out of eight showed high contamination level ($C_d > 3$) ranging between 4.613- 8.619 (6.6), two samples showed medium contamination level (C_d 1-3) ranging between 2.171-2.785 and two samples showed the low contamination level (C_d <1) ranging between 0.506-0.952 value before mining activities. After mining activities the predicted concentration index for groundwater samples will show the very high contamination level ($C_d > 3$) ranging between 155.868– 1627.256. Before mining activities C_d ranged between 0.51 -8.62 and HPI ranged between 2.04-4.42, but after mining activities C_d values are expected to be 155.86 – 1649.7 and HPI ranges between 22.53-204.58. The DRASTIC vulnerability index is computed for evaluation of three conditions (conventional DRASTIC, Modified DRASTIC-C_dHPI for before and after mining activities). For conventional DRASTIC the vulnerability index is found ranging from 81-167 of which 31% area is high vulnerable. Before mining activities the vulnerability index was found ranging from 87 -182 of which 30% area was high vulnerable but after mining activities the vulnerability index will be found ranging from 185 – 375 of which 24% area will be high vulnerable, 35% will be very high vulnerable and 41% will be extreme vulnerable. Groundwater, temperature and rainfall were analyzed by following fitting of straight line by least square method. Selected eight heavy metals were analyzed using AAS. The prediction is done by following the data of Raniganj coal field, Maharashtra coal fired power plant in India and Poltegor coalmine, Poland. Two methods such as contamination index (C_d) and heavy metal pollution index (HPI) were used to evaluate the contamination levels. The software used for this study are Arcview 3.3 for the preparation of location map and DRASTIC vulnerability maps. Surfer software were used for 3D groundwater level map and Rockware were used for analysis of lithology and stratigraphy of the study area. The groundwater vulnerability assessment was done using DRASTIC model in GIS environment.

LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrophotometer
AEC	Asian Energy Corporation
AMD	Acid Mine Drainage
BADC	Bangladesh Agricultural Development Corporation
BLA	Base Line Average
BMDA	Briand Multipurpose Development Authority
BWDB	Bangladesh Water Development Board
CWR	Consumptive Water Requirement
CEGIS	Center for Environmental and Geographic Information Services
DRASTIC	Depth, Recharge, Aquifer, Soil, Topography, Impact and Conductivity
DVI	DRASTIC Vulnerability Index
ECL	Eastern Coalfield Ltd
EU	European Union
GIS	Geographical Information System
GSRBPL	Golden Star Resources Bogoso Prestea Limited
GWL	Ground Water Level
HPI	Heavy Metal pollution index
IPCC	Inter Governmental Panel of Climate Change
MAC	Maximum Admissible Concentration
MSL	Mean Sea Level
PET	Potential Evapotranspiration
RPM	Respiratory Particulate Matter
SAIL	Steel Authority of India
SAIL	Steel Authority of India
SPARSO	Bangladesh Space Research and Remote Sensing Organization
SPM	Suspended Particulate Matter
SPSS	Statistical Package for Social Science
TM	Thematic Mapper
USEPA	United States Environment Protection Agency
VOC	Volatile Organic Compounds

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CHAPTER ONE

GENERAL INTRODUCTION

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GENERAL INTRODUCTION

1.1 INTRODUCTION

Coal forms from compaction and indurations of variously altered plant remains similar to those of peat deposits. The plant remains that turn into coal over millions of years were deposited in various parts of environment: floodplain, coastal plain, delta, estuary, etc. as sedimentary rocks similar to the Sundarban or land forests. The northwestern part of Bangladesh is found to have rich in coal resources. Seven coal fields have so far been discovered in this region with proven reserve of 2335 million tons from 1962 to 2006. Among Jamalgonj, Barapukuria, Khalashpir, Deghaepara Phulbari, Hakimpur and Buzruk Horina, Nobabganj-the Phulbari Coalmine contain 572 million tons of which 532 million ton is explorable. The monetary value of this is equal to the 70 trillion cubic meters of natural gases (AEC, 2005).

Asian Energy Corporation (AEC) has obtained lease for exploring the Phulbari deposit. They have undertaken seismic and geo-technical study to know the extent of deposit as well as to see the feasibility of the deposit. Specially, they are examining the possibility of mining. They have chosen open pit mining method instead of underground method adapted for Barapukuria deposit. But suitability of opencast mining for Phulbari deposit needs to be examined very carefully. Open pit coalmining activity is the first time in Bangladesh. So, its environmental impacts are unknown to people.

Most of the people in the study area are ignorant about the effects of open pit coalmining activities. So, a study regarding the environmental impacts such as impacts on groundwater should be required. In order to make people aware of the potential environmental impacts resulting from open pit coal mining activities a study is necessary. This study will show the groundwater pollution and vulnerability assessment in the alluvial aquifer of Phulbari basin of northern Bangladesh. Firstly, results from previous hydro-geological studies, including the hydraulic parameters and groundwater quality are discussed and are compared with the groundwater quality of India and Poland. A calculation of contamination index and heavy metal pollution index was carried out and then a vulnerability map is presented, using the DRASTIC method in a GIS context.

1.2 NATURE OF GROUNDWATER POLLUTION BY SURFACE MINING

Ground water is becoming a major concern with respect to surface mining in most of the countries of the world. Two major concerns are ground-water quality and ground-water quantity, but only the aspects of quality will be addressed in this study.

The effects of open pit coal mining on ground water are still poorly understood. It is my intention to elaborate on general aspects of ground water, and to share the results of research done in Phulbari and its adjacent area. Ground water is produced in a variety of ways, depending upon depth below land surface, rock type, and topography.

Three important aspects of ground water related to the "hydrologic balance" are the storage capacity of rocks for ground water, the rate of movement of ground water and chemical quality. Rock units that have relatively high storage capacities and that allow relatively rapid movement of ground water are termed aquifers. A simple practical definition of an aquifer is a rock unit of other underground layer or zone that yields a sufficient quantity of water to a well or spring being used as a water supply source. This is generally at least one gallon per minute for domestic supplies for single families. Rock types that are usually considered aquifers, where they occur in thick enough units, are sandstone, limestone, and coal. Thick coal seams sometimes are the best yielding aquifers in certain localities, because of the coal cleats or fractures. Shale, mudstones, and clays are usually not aquifer units. Ground water can be classified by depth. Shallow ground water usually supplies springs and dug wells, whereas deeper ground water supplies mostly drilled wells. Shallow ground water is intersected beneath the water table, and deeper ground water (in drilled wells) commonly is artesian water under significant pressure. Deeper ground water is usually at least 30 feet deep, and has typically been in the ground longer and is flowing slower than shallow ground water. Ground water typically moves at rates ranging from a few feet per year to a few feet per day, which is much slower than stream flow.

Groundwater pollution can occur both directly and indirectly as a result of surface mining. Direct degradation can occur to ground water situated downhill or down gradient from a surface mine, by flow of contaminated drainage from the mine. This mine drainage can come from pits, ponds, or from rainfall infiltration and groundwater flow during mining and after reclamation. Groundwater pollution would result from the same toxic overburden and coal materials that cause surface water contamination. Indirect degradation of ground water could result from blasting, which causes a temporary shaking of the rock and results in new rock fractures near working areas of the mine. Blasting can also cause old preexisting rock fractures to become more open or permeable, by loosening mineral debris or cement in these fractures; this could affect nearly vertical fractures located up to several hundred feet away from the surface mine, causing vertical leakage of ponded mine drainage from nearby abandoned deep mines to underlying aquifers. These deep mines could be situated in the same coal seam being surface mined or in a lower coal seam (Rauch, 2014).

1.3 ENVIRONMENTAL FUNCTION OF GROUNDWATER

Groundwater has storing, filtering and transforming capacities and regulates atmospheric, hydrologic and nutrient cycles. Groundwater stores and partly transforms CO_2, energy, plant nutrients and other chemical substances. Groundwater can act as sink in carbon cycle. It can immobilize or breakdown a multitude of pollutants, for example from waste disposal. Groundwater maintains wetlands and their ecosystems. It makes part of base flows of rivers and support river in ecosystem. Groundwater is principal pathway through which solute (such as nitrate, silica and cations) enters into lake. It sustains aquatic ecological functions in rivers, lakes, riparian zones and estuaries which require huge volume of water. Groundwater is principal pathways of essential and nonessential exotic trace elements in nature to get to human metabolism (Kebede, 2013).

1.4 PROBLEMS ASSOCIATED WITH OPEN PIT COAL MINING

Surface mining may often cause lowering of the groundwater table and in consequence could form a widely developed depression cone. It can also change hydrological balance of the region and result in a need to change the crop structure and to build substitute water intakes. Storage of coal refuse and ashes in open pits substantially affects the ground water quality (Libicki, 2006). Sources of mine water in surface mining are described together with the operational problems created by adverse groundwater conditions. This includes a) inflow from atmospheric precipitation and percolation through the backfill which forms its own water table; b) inflow through geological/ structural features; c) inflow from mineral beds and underground aquifers; d) transformation via disused/abandoned mine working; and e) inflow via pit floor heave and/ or "piping" (Ngah *et al*., 2006).

This was very important as the disposal was being washed by the rain water, so leaching and carrying pollutants down to the aquifer. First small symptoms of pollution were found in the immediate subsoil of the disposal site after one month of storage. The large amount of pollutants found downstream of the ground was about 7 months after storage, after a period of heavy rains. This content of particular components rose in groundwater as follows (max. value): Sodium from 3.0 to 500 mg/l, Chloride from 10 to 400 mg/l, Potassium from 2.0 to 40 mg/l, Magnesium from 10 to 30 mg/l, Sulphate from 100 to 900 mg/l, Phosphate from 0.05 to 0.3 mg/l, Boron from 0.2 to 2.0 mg/l, Molybdenum from 0.005 to 1.0 mg/l, Copper from 0.003 to .02 mg/l, Strontium from 0.07 to 0.4 mg/l, Cadmium from 0.002 to 0.005 mg/l and Cyanides from .002 to 0.008 mg/l ((Libicki, 2006).

Coal is a very important but dirty fossil fuel. Coal mining has severe environmental, ecological, human-health consequences. If not done properly, coal mining has potential to damage landscape, soils, surface water, groundwater, air during all phases of exploration and use. Coal mining has some unavoidable negative impacts on humans and the environment (Khalequzzaman, 2010).

Water quality in Pensilvenia following coal mining- no fish in rivers & stream, more than 1,000 miles of main stem and tributaries have significant AMD (Acid Mine Drainage). AMD treatment (active and passive) is very expensive and time consuming and some will never get done (Khalequzzaman, 2010).

When an open pit intersects the water table, groundwater flows into the open pit. For mining to proceed, mining companies must pump and discharge this water to another location. Pumping and discharging mine water causes a unique set of environmental impacts that are well described in a study commissioned by European Union (EU). Figure 1.1 shows the rivers of study area by which contaminants will transport from one location to another location in the study area.

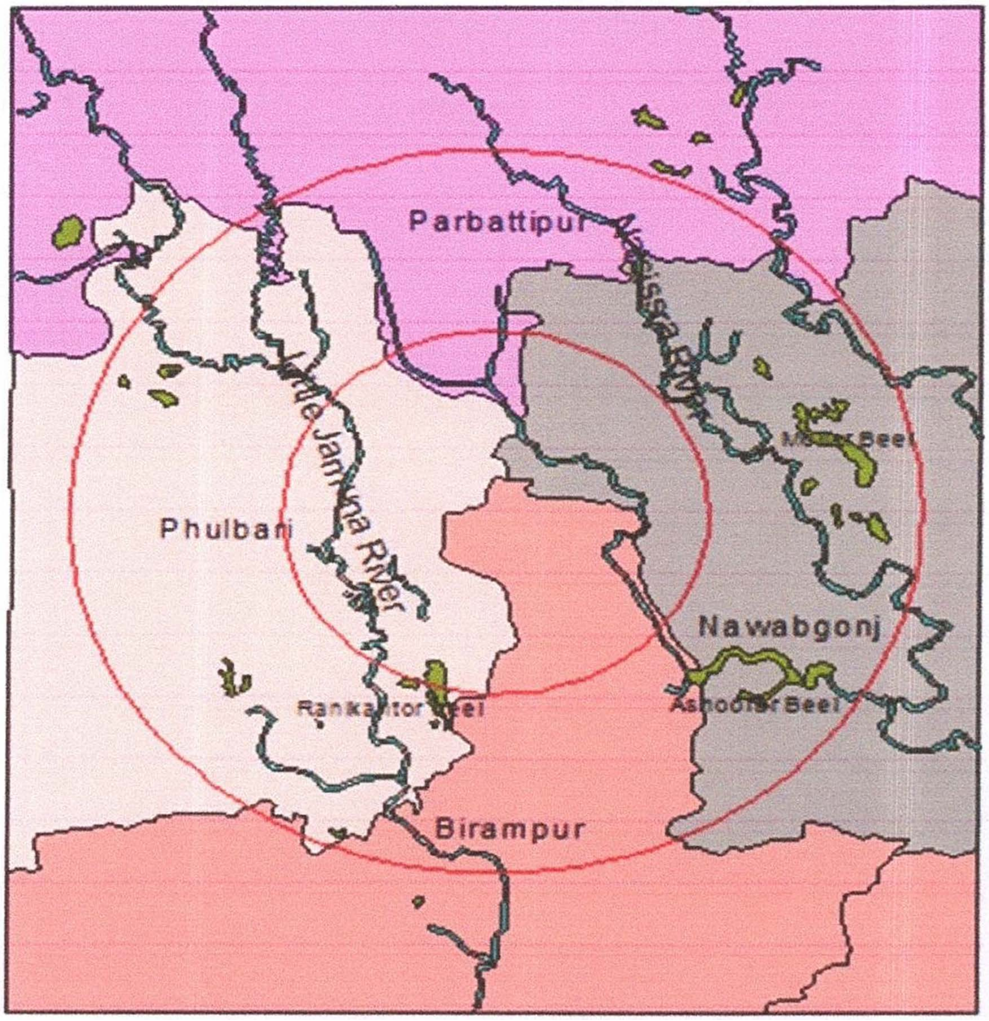

Figure 1.1: Rivers in the mine area (Data Source: AEC, 2005)

Opencast mining can be referred to as an activity with substantial impact on the environment. The consequences can be very detrimental to the environment, especially through the exploration of coal, alteration of the rock structure and groundwater regimen, pollution of the air, the effects of noise and dust, pollution of surface water and alteration and disruption of the landscape. With the exception of leftover rubbish dumps, the area in question is only needed for as long as the deep mine remains in operation.

A serious concern relating to open pit mining is its environmental impact. The open pit method requires the mine area to be completely dewatered so that the hollow of the mine does not get immersed in water. The average thickness of the coal layer in Phulbari is 38m. In order to reach the layer of coal, overburden between 150 and 250m needs to be removed, leaving a thousand-feet deep hollow. The area filled up will not become useful in many years. Topsoil will be brought back and spread on the top of the area filled in. After 30 years of digging and other activities, it will contain toxic substances. It may not be realistic to imagine this polluted lake becoming a source of fresh water. Figure 1.2 shows that coal resources in Bangladesh are overlain by a regionally extensive aquifer (Upper Dupi Tila) and efficient water management is an integral part of mine development (Khalequzzaman, 2010).

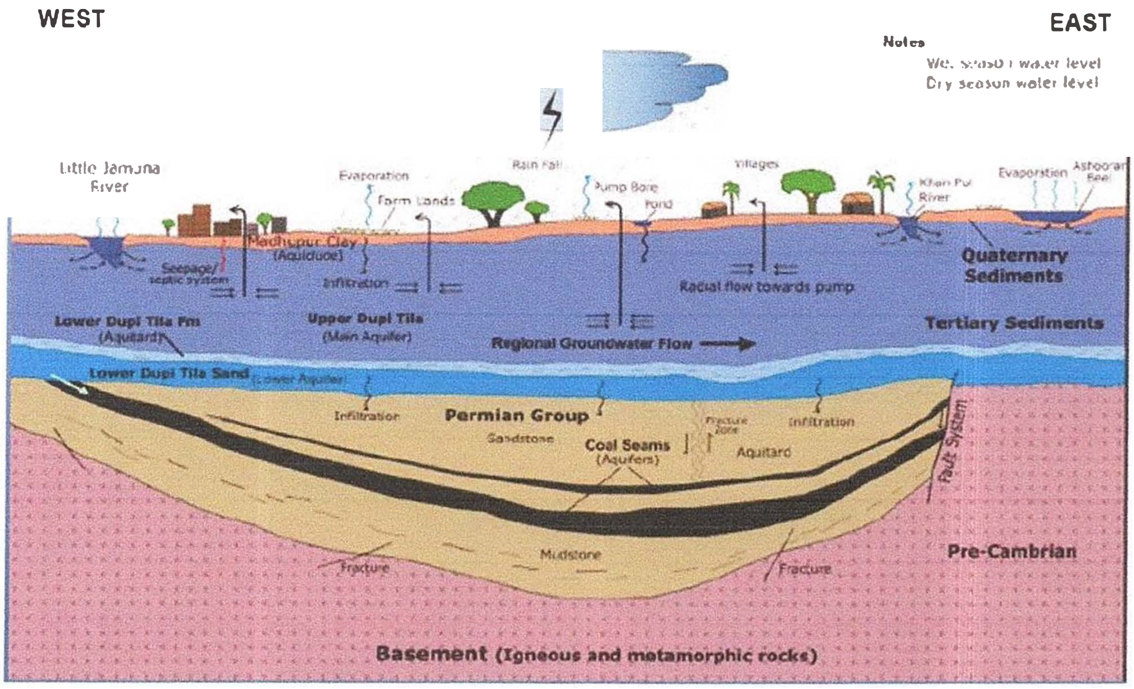

Figure1.2: Conceptual model showing aquifer conditions in coal bearing Gondwana basin (Khalequzzaman, 2010).

1.5 CONCEPTUAL FRAMEWORK

The conceptual framework (Figure 1.3) used for the study shows the impacts of mining activities.

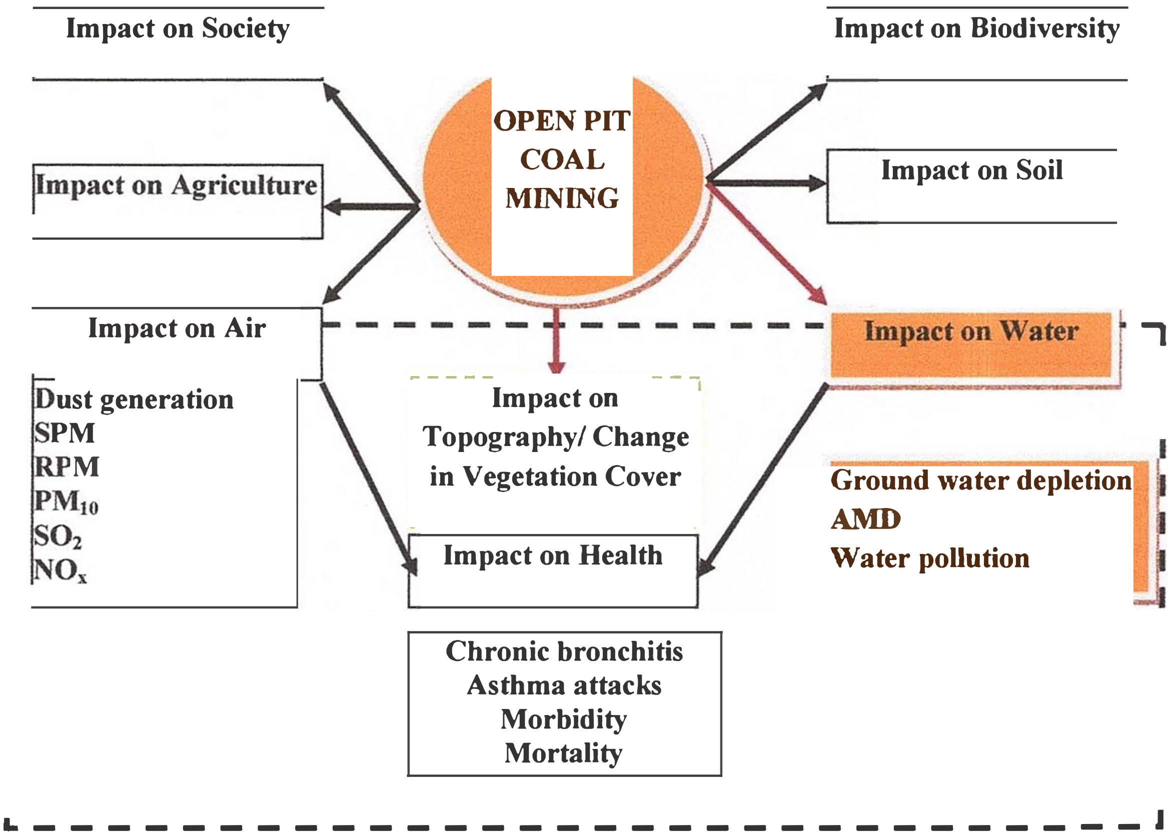

Figure 1.3: Conceptual framework

1.6 OBJECTIVES

The main objective is undertaken a research in order to find out the realities of Open Pit Coal Mining at Phulbari in terms of its environmental impacts. The detail objectives reflecting the main objectives are as follows:

- To depict the geo-environmental characteristics of study area
- To observe the trend of groundwater level with respect to proposed Phulbari Coal Project
- To overview the impacts of open pit coal mining elsewhere
- To assess the qualitative impacts on groundwater caused from the open pit coal mining project
- To assess the vulnerability of groundwater due to open pit coal mining activities

1.7 SCOPE AND JUSTIFICATION OF THE WORK

- ✓ This work will help in environmental management study for Phulbari open pit coalmining problem. This work will provide knowledge to rural people, environmentalist and transport planners.
- ✓ It will assist policy makers to make both short and long term actions for a better future. This study will provide knowledge to compensate of environmental impacts in that region.
- ✓ It may help to develop a comprehensive action plan for proper management and improvement of environment.
- ✓ The deposit is underling the Phulbari town. The mining will affect the town, the main railway and adjacent highway connecting Dinajpur and Rangpur with Khulna, Rajshahi.
- ✓ Relocation of railway and highway will be required in addition to rehabilitation of Phulbari town. Even the river in the north and south to the mining area needs to be diverted.
- ✓ In addition to above, the effects of opencast mining on environment need to be assessed properly.
- ✓ Dewatering from a large area may dry up the agricultural land around the mining area. The open pit mining may prove too dangerous once environmental points are not examined and evaluated properly.
- ✓ Cost of mitigating the danger should be included in the mining cost and investors should not allow ignoring the same.

1.8 LIMITATIONS OF THE STUDY AREA

The study has faced several problems while collecting information from field and different organizations. The study also faced different kinds of obstacles which hindered the accuracy and ability of the study. Bureaucratic lengthiness of retrieving data and information supported from governmental and concerned organizations were limited. Non-cooperation is faced during the time of collecting data. Lack of related secondary information is very acute and a few studies has been conducted on this field. Besides, there are other limitations in terms of accuracy and availability of information, information from secondary sources, people's participation and coordination by the individuals and different organizations.

CHAPTER TWO

LITERATURE REVIEW AND THEORITICAL BACKGROUND

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LITERATURE REVIEW AND THEORITICAL BACKGROUND

2.1 INTRODUCTION

The review of literature portrays a vivid picture about the investigating issue. It represents a background of the research issue and helps to understand it in a proper perspective. It enlarges, enriches and clarifies the work and the thinking. In this perspective some of the relevant books, articles and research works have been reviewed.

2.2 USE OF MODERN TECHNIQUES

Toren and Unal (2001) undertook a study for assessment of open pit coal mining impacts using remote sensing in Turkey. The study followed the multi-temporal LANDSAT TM data sets from the Soma coal basin. In this study the researcher found the cost and time effective opportunities of using high resolution satellite data for monitoring surface mining and reclamation process in Turkey.

Singh *et al.* (1997) had done detail study on the impact of coal mining and thermal power industry on land use pattern in and around Singrauli coalfields using remote sensing data and GIS. Database for land use was prepared for multispectral, multi-temporal data of years 1975, 1986 and 1991 of LANDSAT MSS and TM using PAMAP GIS software. The study revealed that areas mining and build up land increased from 1975 to 1991. There was substantial loss in agricultural and forest land which was due to rapid industrialization of the area.

Sarma *et al.,* (2005) worked on coal mining impact on land use/land cover in Jaintia hills district of Meghalaya, India using remote sensing and GIS technique used LANDSAT data of 1975, 1987, 1999 and 2007 to conclude that there was four fold increases in mining area from 1975 to 2007 accompanied by three fold decreases in forest area. Visual interpretation technique was used for land use/land cover mapping for the different data of four years.

Ololade *et al.,* (2008) have worked on land-use/cover mapping and change detection in the Rustenburg Mining region using LANDSAT image was carried out using remote sensed data; LANDSAT MSS in 1973 (4 bands), TM 1989, 1997, 1998 (6 bands) and ETM 2002 (6 bands) and topographic maps of 1969 and 2005, used as reference base maps of the region. Standard image enhancements and registration was performed on the images. Supervised classification was performed by using maximum likelihood method. Land-use classes; woodland, grassland, cultivated land, bare soil, rivers, dams, water ponds, built-up area, tailing dams and open cast mines were identified from satellite data and field surveys. Results showed that in the last three decades open cast mines, tailing dams; mine dumps and return water ponds have increased extensively in the Rustenburg region; vegetation has undergone a general decrease; woodland and grassland have been changed to cultivated land. An expansion of the built-up area can be explained by the fact that there was increase in the development of transport networks; settlements developed over the years due to the immigration of mine workers in the area. Consequently, the landscape became highly disturbed due to increased mining and agricultural activities.

Edward *et al.,* (2009) has undertaken a study on open pit gold mining and land use changes in Bogosu-Prestea area, south west Ghana. Land use change due to mining employed over a twenty year period (1986 – 2006) was analyzed within the Golden Star Resources Bogoso Prestea Limited (GSRBPL) concession. The study revealed that mining in the area increased by 12.1 % in land coverage from 1986 to 2006 with decrease in agricultural land use from 97.8% in 1986 to 82.7% in 2006. Settlements increased from 0.45 % in 1986 to 4.95 % in 2006 due to a rural – urban migration. Another interesting work was done by Byeong and Kwang-Hoon (2009) on forest reclamation monitoring in the abandoned mine of the Samtan coal mining area located in the southern part of Jeongseon-gun, Gangwon-do, Korea. Effects of vegetation health for abandoned and forest recovered period using multi-temporal satellite datasets was analyzed. Vegetation and forest health was analyzed using NDVI mapping on the three multi-temporal LANDSAT 5 and 7 satellite datasets. Results from NDVI map identified the new recovered forests and hence confirmed that the natural forests are restoring their vegetation health.

A work on land cover change study of the oil sands mining development in Athabasca, Alta, Canada was carried out by Natural Resources Canada (2005). The primary impact was assessed using an information extraction method applied to two LANDSAT scenes. The study was done using two LANDSAT images of 1990 and

2001. Land cover maps shows a decrease of natural vegetation in the study area for 2001 approximately 64% relative to that of 1992.

2.3 IMPACT ON GROUNDWATER

Libicki (2006) undertook a study that surface mining may often cause lowering of the groundwater table and in consequence could form a widely developed depression cone. It can also change hydrological balance of the region and result in a need to change the crop structure and to build substitute water intakes. Storage of coal refuse and ashes in open pits substantially affects the ground water quality.

Ngah *et al.* (2006) undertook a study on groundwater problems in surface mining in the United Kingdom. Sources of mine water in surface mining are described together with the operational problems created by adverse groundwater conditions.

Libicki (2006) chief geologist, institute of opencast mining, Poltegor, Poland, undertook a study on changes in the groundwater due to surface mining. He showed that opencast mining operations affect the drawdown of the water table over large areas which as a consequence change the natural regional hydrological balance and at ripping of waste affects ground water pollution. This was very important as the disposal was being washed by the rain water, so leaching and carrying pollutants down to the aquifer. First small symptoms of pollution were found in the immediate subsoil of the disposal site after one month of storage. The large amount of pollutants found downstream of the ground was about 7 months after storage, after a period of heavy rains. This content of particular components rose in groundwater as follows (max. value): Sodium from 3.0 to 500 mg/l, Chloride from 10 to 400 mg/l, Potassium from 2.0 to 40 mg/l, Magnesium from 10 to 30 mg/l, Sulphate from 100 to 900 mg/l, Phosphate from 0.05 to 0.3 mg/l, Boron from 0.2 to 2.0 mg/l, Molybdenum from 0.005 to 1.0 mg/l, Copper from 0.003 to .02 mg/l, Strontium from 0.07 to 0.4 mg/l, Cadmium from 0.002 to 0.005 mg/l and Cyanides from .002 to 0.008 mg/l ((Libicki., 2006).

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Khalequzzaman (2010) mentioned in his paper that water quality in Pennsylvania following coal mining- No fish in rivers & stream, more than 1000 miles of main stream and tributaries have significant AMD (Acid Mine Drainage). AMD treatment (active and passive) is very expensive and time consuming and some will never get done.

When an open pit intersects the water table, groundwater flows into the open pit. For mining to proceed, mining companies must pump and discharge this water to another location. Pumping and discharging mine water causes a unique set of environmental impacts that are well described in a study commissioned by European Union:

"Mine water is produced when the water table is higher than the underground mining workings or the depth of an open pit surfaces mine. When this occurs, the water must be pumped out of the mine. Alternatively, water may be pumped from wells surrounding the mine to create a cone of depression in the ground water table, thereby reducing infiltration. When the mine is operational, mine water must be continually removed from the mine to facilitate the removal of the ore. However, once mining operations end, the removal and management of mine water often end, resulting is possible accumulation in rock fractures, shafts, tunnels, and open pits and uncontrolled releases to the environment." "Ground water drawdown and associated impacts to surface waters and nearby wetlands can be a serious concern in some areas." "Impacts from groundwater drawdown may include reduction or elimination of surface water flows; degradation of surface water quality and beneficial uses; degradation of habitat; reduced or eliminated production in domestic supply wells; water quality/ quantity problems associated with discharge of the pumped ground water back into surface waters downstream from the dewatered area. The impacts could last for many decades. While dewatering is occurring, discharge of the pumped water, after appropriate treatment, can often be used to mitigate adverse effects on surface waters. However, when dewatering cease, the cones of depression may take many decades to recharge and may continue to reduce surface flows..... Mitigation measures that rely on the use of pumped water to create wetlands may only last as long as dewatering occurs.

Shahabpour *et al.,* (2005) analyzed the mine-drainage water from coal mines of Kerman region, Iran. They found that two types of mine-drainage water were recognized in Kerman coalfield, namely neutral to alkaline and acid (AMD). Both types contain a high level of trace metal concentrations with a higher level in AMD. Trace metals from the coal-mine waters of Kerman coalfield are mainly present as adsorption on Fe and Mn oxide and hydroxide particles, and to a lesser extent as sulfate, simple metal ions and as metal sorption on clay particles and hydrous aluminum oxides.

Singh *et al.*, (2010) performed a study on environmental geochemistry and quality assessment of mine water of Jharia coalfield, India. For this purpose, 92 mine water samples collected from different mining areas of Jharia coalfield were analysed for pH, electrical conductivity (EC), major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), anions (F^{-}, Cl^{-}, HCO_3^{-}, SO_4^{2-}, NO_3^{-}) dissolved silica ($H_4 SiO_4$) and trace metals. The pH of the analysed mine water samples varied from 6.2 to 8.6, indicating mildly acidic to alkaline nature. Concentration of TDS varied from 437 to 1,593 mg L^{-1}, and spatial differences in TDS values reflect the variation in lithology, surface activities and hydrological regime prevailing in the region. SO_4^{2-}, and HCO_3^{-} are dominant in the anion and Mg^{2+}, and Ca^{2+} in the cation chemistry of mine water. High concentrations of SO_4^{2-} in the mine water of the area zare attributed to the oxidative weathering of pyrites. Ca–Mg–SO_4 and Ca–Mg–HCO_3 are the dominant hydro-chemical facies. The drinking water quality assessment indicates that number of mine water samples have high TDS, total hardness and SO_4^{2-} concentrations and needs treatment before its utilization. Concentrations of some trace metals (Fe, Mn, Ni, and Pb) were also found to be above the desirable levels recommended for drinking water.

Opencast mining can be referred to as an activity with substantial impact on the environment. The consequences can be very detrimental to the environment, especially through the exploration of coal, alteration of the rock structure and groundwater regimen, pollution of the air, the effects of noise and dust, pollution of surface water and alteration and disruption of the landscape. With the exception of leftover rubbish dumps, the area in question is only needed for as long as the deep mine remains in operation.

A serious concern relating to open pit mining is its environmental impact. The open pit method requires the mine area to be completely dewatered so that the hollow of the mine does not get immersed in water. The average thickness of the coal layer in Phulbari is 38m. In order to reach the layer of the coal, overburden between 150 and 250m needs to be removed, leaving a thousand-foot deep hollow. The area filled up does not become useful in many years. Topsoil will be brought back and spread on the top of the area filled in. After 30 years of digging and other activities, will contain toxic substances. It may not be realistic to envision this polluted lake becoming a source of fresh water.

Coal dust will be a major source of air pollution. If the enormous amount of polluted water generated from washing of the coal is not properly treated before it is dumped into surrounding water bodies, it will kill fish and other forms of life. Further, the earth through such deep digging and many types of pollution will lose all its micro-organisms. Air pollution from burning of coal to produce electricity is a big concern. Air polluting agents such as sulphur dioxide, nitrogen oxide, volatile organic compounds (VOC), mercury, lead, cadmium, chromium and arsenic will contaminate earth, water, plants.

Groundwater is the main source of irrigation in the northern districts (Rangpur Division) of Bangladesh. About 75% water for irrigation in this region comes from groundwater (Bari and Anwar, 2000). According to recent Bangladesh Agricultural Development Corporation survey (BADC, 2002), the ratio of surface water and groundwater use for total irrigated agriculture has been changed drastically in last two decades in Bangladesh. The contribution of groundwater has increased from 41% in 1982-1983 to 75% in 2001-2002. The ratio of groundwater to surface water use is much higher in northern districts of Bangladesh compared to other parts of the country. Cross-country anthropogenic activities caused a severe negative impact on water resources and eco-systems of northern Bangladesh in the recent years. All the rivers and cannels of the area are dried up during the dry season and make the people completely dependent on groundwater for irrigation.

The studies show that upper aquifers in the region are unconfined or semi-confined in nature. The thickness of the exploitable aquifer ranges from 10 to 40 m. Jahan *et al.*, (2004) computed the specific yield of the aquifer in the area vary from 8% to 32%

with a general decreasing trend from north towards central portion. Groundwater is the main source for irrigation and drinking purpose of that region.

2.4 IMPACT ON AIR

Ghose and Majee (2000) assessed the dust generation due to opencast coal mining in India. Emission factors were utilized to estimate the dust generation due to topsoil removal, overburden removal, coal extraction, size reduction, dispatch of coal. As calculated the dust generation by utilization of emission factor data, top soil removal generation 69.9 kg of dust per day. Over burden removal operation generated 666.0 kg dust per day, extraction of coal contributed about 256.9 kg of dust per day. Dust generation due to size reduction contribute much more dust amounting 6812.5 kg of dust per day. Wind erosion generated dust of about 1568 kg per day and this depends on wind velocity, direction and other micrometeorological conditions. This dust generation has its main impacts on work zone air quality with gradual dilution.

Ghose and Majee (2002) conducted a study on assessment of the stats of work zone air environment due to opencast coal mining in Jharia coalfield of India. In this study they found that the average concentration of air pollutants were 1473.66 μgm^{-3} for SPM, 197.79 μgm^{-3} for RPM, 74.90 μgm^{-3} for SO_2 and 68.15 μgm^{-3} NO_x as found in annual average. The variations of maximum mixing heights were ranging from 1200-1600m and minimum mixing heights were ranging from 200-400m.

2.5 IMPACT ON SOIL

Singh and Singh (2004) have done experiments on ecological restoration of coal mine spoil using native trees in a dry tropical environment in India. He has found that microbial biomass in the redeveloping soil was lower compared to that in the natural forest soil.

2.6 IMPACT ON HEALTH

Stephens and Ahern (2001) undertaken on community studies in coal mining regions were predominantly concerned with respiratory illness caused by air pollution from mining activities. In their study of the Gardanne coal-basin evaluated the long-term effects of exposure to air pollutants in school children. The prevalence of pulmonary and ear, nose and throat symptoms was higher in the polluted communities, but a statistically significant difference was only observed for the symptom “wheezing in the chest". Depending upon speciation and concentration, heavy metals can be lethal to aquatic animals and prevent their reproduction or enter the food chain by accumulating in fish tissue. Toxicity can be acute or chronic due to exposure usually greater than one year (Tiwary, 2001). Coal mining by both opencast and underground method affects the environment of the area (Dhar, 1993). Acid leachate may have two-fold adverse effects upon aquatic biota; the lower P^H may harm aquatic organism and elevated heavy metals may have toxic effects upon aquatic life, wild life and surrounding vegetation (Tiwary, 2001).

2.7 GROUNDWATER CONTAMINATION

Trace metal contaminations are important due to their potential toxicity for the environment and human beings (Gueu *et al.,* 2007; Lee *et al.,* 2007; Adams *et al.,* 2008; Vinodhini and Narayanan, 2008). Some of the metals like Cu, Fe, Mn, Ni and Zn are essential as micronutrients for the life processes in animals and plants (Kar *et al*., 2008; Suthar and Singh, 2008; Aktar *et al.,* 2010)

A lot of studies are abound in the literature on heavy metal pollution of water sources. Such work include Brown-Adiuku and Ogezi (1991), Edet and Ntekim (1996), Xibao *et al.,* (1996), Yang *et al.,* (1996), Yiping (1996) and Znongyi (1996). All these workers concluded that there was the need to monitor water quality on a regular basis. This is because the increase in concentration of trace metals in potable water will increase the threat to man's health and life. Also, several methods exist in literature on the development and application of index methods for water quality assessment. Some of these include the work of Horton (1965), Joung *et al.,* (1979), Landwehr (1979), Nishidia *et al.,* (1982), Tiwary and Mishra (1985) and Prasad and Jaiprakas (1999).

2.8 GROUNDWATER VULNERABILITY ASSESSMENT USING DRASTIC MODEL

Pollution of groundwater is a major concern because aquifers and the enclosed groundwater are innately susceptible to contamination from land use and other anthropogenic impacts (Thirumalaivasan *et al*., 2003). Leaching of various pollutants through the vadose zone gives rise to pollution. Leaching processes differ from one location to another (Baalousha 2006; Sener *et al.,* 2009). Preventing groundwater pollution is necessary for effective groundwater resource management and groundwater- vulnerability assessment is important for such groundwater protection.

Vulnerability assessment methods divide a geographical area into subareas in terms of its susceptibility to groundwater contamination; then, in areas prone to contamination, effective groundwater protection measures should be carried out (Guo *et al.,* 2007). Two types of vulnerability are recognized in literature: intrinsic (or natural) and specific (or integrated) vulnerability. Intrinsic vulnerability is a term used to define the vulnerability of groundwater to contaminants generated by human activities taking into consideration the inherent geological, hydrological, hydrogeological and hydrogeochemical characteristics of an area. Specific vulnerability is used to define the vulnerability of groundwater to particular contaminants taking into consideration the contaminant properties and their relationship with the various components of intrinsic vulnerability (Hamerlinck and Arneson 1998; Doerfliger *et al.,* 1999; Gogu and Dassargues 2000; Varol and Davraz 2010). In general, overlay and index methods are quite effective to determine groundwater vulnerability and these methods are particularly suitable for use with geographic information systems (GIS), since they usually involve the overlaying and aggregation of multiple maps (Tilahun and Merkel 2010). An overlay and index method is a multicriteria model that aggregates the hydrogeological factors that control the migration of pollutants into the aquifer. It combines factors controlling the movement of pollutants from the ground surface into the saturated zone resulting in vulnerability indices at different locations. The main advantage is that some of the factors such as rainfall and depth to groundwater can be available over large areas, which makes them suitable for regional scale assessments (Thapinta and Hudak 2003). However, a major drawback is the subjectivity in assigning numerical values to the descriptive entities and relative weights for the different attributes (Babiker *et al.*, 2005). There has been rapid development of groundwater vulnerability assessment in the past 10 years, as well as the introduction of various new techniques and methods applied to the assessment (Meinardi *et al.,* 1995; Secunda *et al.*, 1998; Lasserrea *et al.*, 1999; Al-Adamat *et al.*, 2003; Lake *et al,*. 2003; Thapinta and Hudak 2003; Zhou *et al.*, 2010). One of the most widely used standard groundwater vulnerability methods is DRASTIC, developed by the United States Environmental Protection Agency (USEPA) as a method for assessing groundwater pollution potential. This method uses seven parameters in its calculation of a 'vulnerability index'. Some researchers have tried to correlate the vulnerability index with contaminant parameters and/or have controlled the assessment with sensitivity analyses (Rupert 1999; Mclay *et al.,* 2001; Javadi *et al.*, 2011). Also, in recent years, the DRASTIC method has been modified by using additional parameters and/or by ignoring the existing parameters according to the characteristics of the study area (Umar *et al*., 2009; Lee 2003; Simsek *et al*., 2006; Wang *et al*., 2007; Guo *et al.*, 2007; Martínez-Bastida *et al*., 2010; Awawdeh and Jaradat 2010). A analysyis was shown by Hoque *et al.,* (2007) for Dhaka metropolitan area that the patterns of groundwater level change largely replicates the patterns of change in the rate of groundwater abstraction. Contribution of the aquifer storage to the abstraction is estimated to be more than 15% in the year 2002. This abstraction has caused a sharp drop in the water level throughout the city and turned into two cones of depression in the water level.

The proposed Phulbari coal mining area has been selected as a study area. It is important to evaluate groundwater vulnerability in the basin from the point of view of both groundwater protection in the basin and protection of the Phulbari mine water quality. In previous studies, the groundwater vulnerability was evaluated using the DRASTIC model based on GIS in the Senirkent-Uluborlu plain, which is located within the Egirdir Lake basin, and it was determined that the obtained results are realistic and representative of the actual situation in the field (Sener *et al.,* 2009).

Since the end of the 1980s, a U.S. Environmental Protection Agency (EPA) system named DRASTIC has been increasingly used to evaluate pollution migration from the land surface to groundwater. This system consider aspects of the geologic environment of the study area, such as: depth of the groundwater, head of infiltration water recharge and characteristics of the strata within the aquifer, such as hydraulic conductivity, characteristic of the soil and water zone structure, and the land slope assessment.

DRASTIC has been most commonly used for mapping aquifer vulnerability in porous aquifers (Aller *et al.,* 1987). Javadi *et al*., (2011) showed that the modified DRASTIC is better than the original method for nonpoint source pollutions in agricultural areas. For the modified model, the correlation coefficient between vulnerability index and nitrate concentration was 68 percent that was substantially higher than 23 percent obtained for the original model.

In recent years, groundwater contamination has been discussed continuously by water quality agencies of all levels of government (Dixon, 2005). The quality of groundwater is important because it is the primary source of drinking water for over half of the nation. Groundwater is an important contributor to irrigation, streams and rivers, and wetland habitats affecting many species of plants and animals. Groundwater may be a reliable resource in many places today, but to keep the groundwater supply sustainable, risk assessments need to be conducted to keep groundwater a renewable resource (Twarakavi and Kaluarachchi, 2006). Groundwater contamination can be minimized by delineating and monitoring vulnerable areas. Determining how to delineate areas susceptible to contamination is difficult due to the many variables that may or may not affect groundwater contamination in certain areas (Dixon, 2005).

Today, groundwater vulnerability is one of the key elements in decision making and it is considered in multi-criteria decision making tools in river basins and wastewater management systems (Kholghi, 2001). Vulnerability assessments must be specific, scientific, and based on accurate evidence. Different methods have been introduced to estimate groundwater vulnerability. In most cases, these methods are analytical tools that try to relate groundwater contamination to land use activities. These assessment methods may be divided into three general categories: Process-based simulation models, statistical methods (Harbugh *et al.*, 2000) and overlay and index methods. The influence of regional characteristics is not accounted for in the method and so the same weights and rating values are used everywhere. In addition, there is no standard algorithm to test and validate the method for an aquifer. Some researchers have tried to correlate the vulnerability index with chemical or contaminant parameters (Kalinski *et al.*, 1994; Rupert, 1999; Maclay *et al.*, 2001). Some other researchers have correlated land use to vulnerability (Secunda, 1998; Worrall and Koplin, 2004), but, they did not use it to correct the rates or weights of the DRASTIC model.

Wang (2014) describe in his project term paper that the analysis on groundwater vulnerability to landfill leachate induced arsenic contamination in mine was conducted using a modified DRASTIC approach that combines the traditional DRASTIC model for intrinsic aquifer vulnerability with impacts from both the human factor, i.e. the risk of landfill leachate migration, and the natural factor, i.e. probability of naturally-occurring arsenic in bedrocks. The results provided a preliminary screening tool to identify potential areas with high risks of arsenic contamination in groundwater caused by the degradation of migrating landfill leachates and subsequent release of adsorbed arsenic from reductively dissolved iron oxide minerals. The proposed methodology can also be applied in groundwater vulnerability studies for other contamination problems in regional scales. Abdulla *et al*., (2013) summarized the DRASTIC values together into low, moderate, and high pollution potential classes. These classes represent the relative pollution potential within the study area. The vulnerability map shows approximately more than 69.18% of the area is classified as having low pollution potential with DRASTIC index values ranged between 65-96. The aquifer vulnerability map was prepared by overlapping the layers by means of GIS. Three different vulnerability zones were determined in the Gumushacikoy basin according to DRASTIC scores low (<100), medium (100-140) and high (>140). It was established that 16% of the basin had high vulnerability and 47% low vulnerability (Erosy, 2013).

CHAPTER THREE

MATERIALS AND METHODOLOGY

CHAPTER THREE

MATERIALS AND METHODS

3.1 METHODS TO IDENTIFY THE IMPACTS ON GROUNDWATER DUE TO OPEN PIT COALMINING

3.1.1 Time Series

Arrangement of time dependent data in chronological order *i.e.*, in accordance with occurrence of time, is known as '*Time Series*'. A time series is a set of observations collected at a specified times, usually at equal intervals. It depicts the relationship between two variables, one of them being time e.g., groundwater level (GWL) (U_t) of a place on different years (t); rain fall (U_t) of a place on different years (t) etc. Mathematically, a time series is defined by the functional relationship (Gupta and Kapoor, 2005).

$U_t = f(t)$……………………………………3.1

Where, U_t is the value of the phenomenon (or variable) under consideration at time t. Conceptual Framework for time series analysis and it is shown in a flow diagram (Figure 3.1).

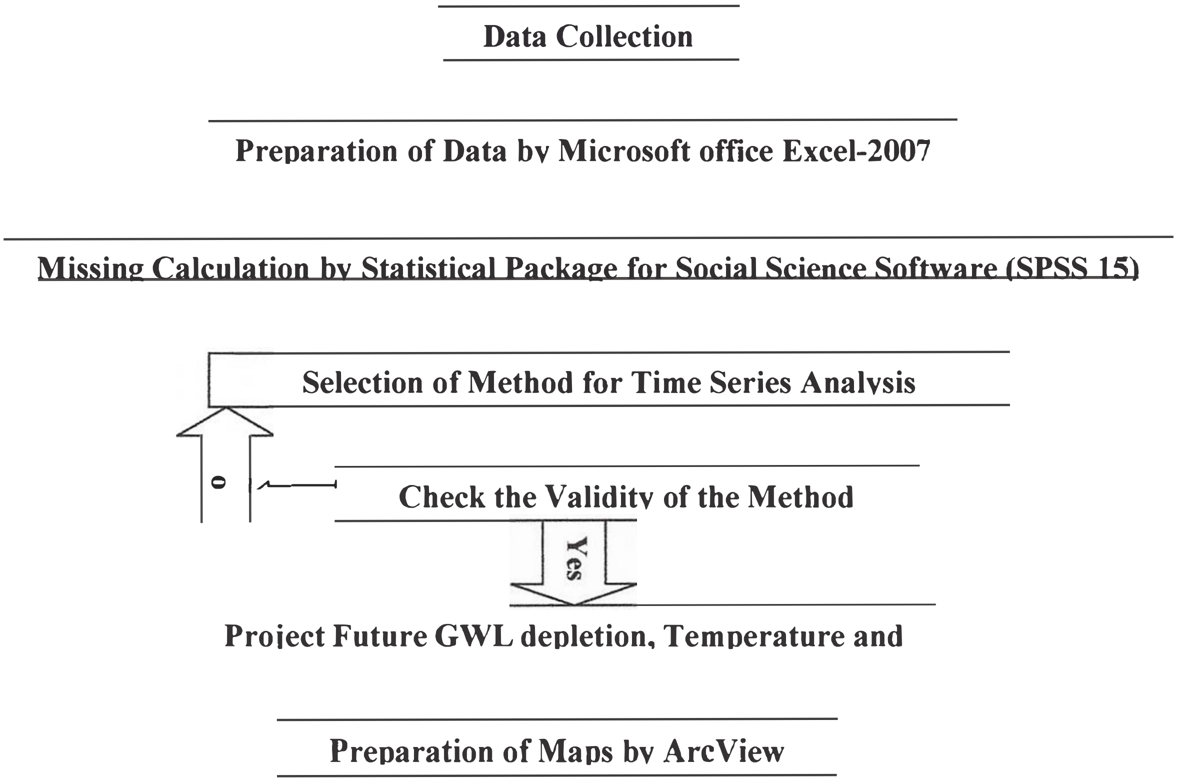


Figure: 3.1 Flow chart of time series analysis

3.1.2 Curve Fitting

Let (X_i, Y_i); i =1, 2, ... n, be a given set of a n pairs, X being independent variable and Y the dependent variable (Gupta and Kapoor, 2005).

The term best fit is interpreted in accordance with Legender's PLS which consists in minimizing the sum of the squares of the deviations of actual values of Y and computed values Y_c. The trend line is fitted to the data in such a manner that the following two conditions are satisfied

$\sum(Y-Y_c) = 0$

i.e., the sum of deviations of the actual values of Y is zero.

$\sum(Y-Y_c)^2$ is least,

i.e., the sum of square of the deviations of the actual and computed values is least. That is why this method is called the method of "Least Square".

3.1.3 Fitting of Straight Line by Least Square Method

Let U_t is the value of the variable corresponding to time t. A straight line equation is given by the following (Gupta and Kapoor, 2005)

$U_t = a+bt$ 3.2

According to the PLS, we have to find a and b such that for given values of U_t corresponding to n different values of t,

$Z = \sum (U_t - a - bt)^2$...........................3.3

is minimum. For a maxima or minima of Z, for variations in a and b, we should have

$$\frac{\delta Z}{\delta a} = 0 = -2\sum (U_t - a - bt)$$

$$\frac{\delta Z}{\delta b} = 0 = -\sum t(U_t - a - bt)$$

$\sum U_t = na + b\sum t$ 3.4

$$\sum tU_t = b\sum t + b\sum t^2$$

Which are the normal equations for estimating a and b.

The values of $\sum U_t$, $\sum tU_t$, $\sum t$ and $\sum t^2$ are obtained from the observed data and the equation (3.4) can now be solved for a and b. With these values of a and b, the equation 3.2 gives the desired trend line.

3.1.4 Data Collection

To analyze hydro-meteorological parameters for the study area, secondary data have been collected. Hydro-meteorological collected from Bangladesh Meteorological Department (BMD) and Groundwater Level (GWL) data collected from Bangladesh Water Development Board (BWDB). In developing the data analysis for time series analysis missing calculations have been done by Statistical Package for Social Science (SPSS 15) Software, projection of future GWL scenarios by Microsoft Office Excel, GIS based technologies such as ArcGIS 9.2, ArcView and Cartalinx have been used.

3.1.5 Missing Data Calculation

Data were collected from BMD contains missing. Missing data were calculated to time series by SPSS 15 software. The single month missing values are calculated by linear interpolations. The entire months missing values for a year are calculated by time series analysis and the developed method is the auto regressive moving average (ARIMA). The original time series is ARIMA (p, d, q) where p denotes the number of autoregressive terms, d the number of times the serious has to be differenced before it becomes stationary, and q the number of moving average terms (Gujarati, 2003).

3.1.6 Model Validation

Before projecting the future temperature, rainfall and humidity the validity and sensitivity of the method were checked. According to the IPCC (1994), validation involves the comparison of model prediction with real world observations to test model performance. The studies have done always check the validity of the method. To check the validity of the method, collected observed data from 2001 to 2010 were compared with the projected result for the same period. For the different parameters, data is available from different period. Therefore, to check the validity for individual parameter, individual calculation has been done with respect to the observed date of the stations by the "*Methods of Curve Fitting by Principle of Least Squares*".

3.1.7 Temperature

During the validation of the method for temperature data from 1960 to 2000 were used for time series analysis by the selected method and monthly temperature data have been projected from 2001 to 2010. The comparison of observed and projected temperature is shown in figures 3.2. The projected monthly temperatures are almost coincided with the observed data. The projected temperature is 0.52% lower than the observed temperature. Thus future temperature of study area are projected by *"Methods of Curve Fitting by PLS"*.

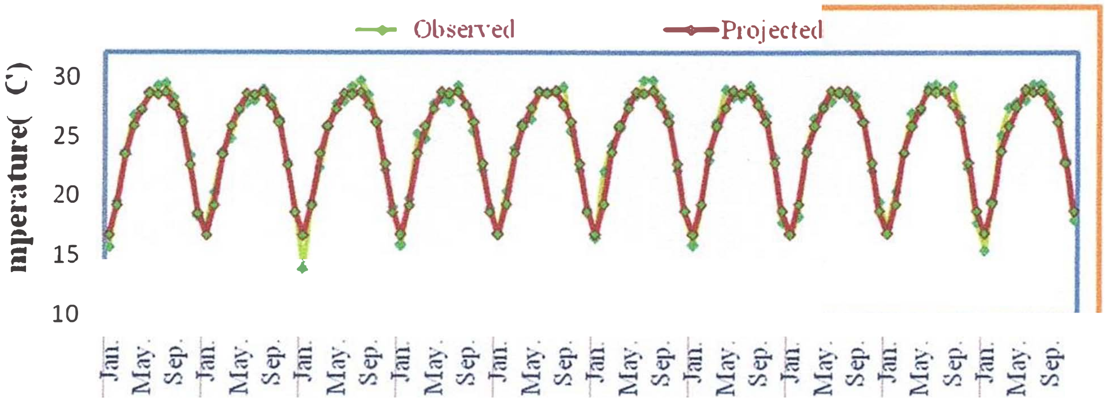


Figure 3.2: Comparison of observed and projected temperature of the study area (2001-2010)

3.1.8 Rainfall

Rainfall data is available from 1954 to 2010. Observed rainfalls for a period of 46 years from 1954 to 2000 have been considered for time series analysis by the selected method and monthly rainfall from 2001 to 2010 is projected. The comparison between monthly projected and observed rainfall from 2001 to 2010 are shown in figures 3.3. It is obvious from the figures 3.3 that the projected rainfalls are approximately coincide with observed rainfall for the period. The observed rainfall is 3.14% lower than the calculated rainfall. From the result of the rainfall validation, the method can be considered as reliable one for future prediction.

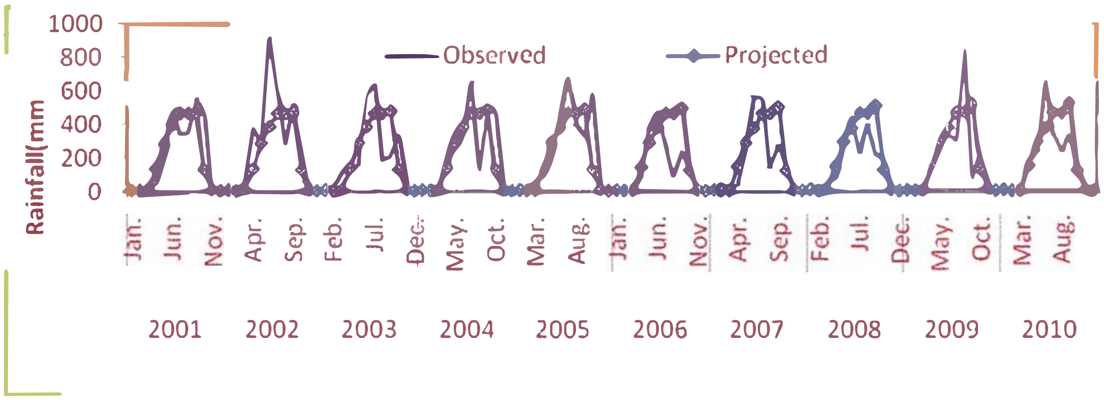


Figure 3.3: Comparison of observed and projected rainfall (2001-2010)

3.1.9 Humidity

During the validation of the method for humidity, data from 1960 to 2000 ware used for time series analysis by the selected method. Monthly projected data are compared with observe data from 2001 to 2010. The comparison of observed and projected humidity reflects in figure 3.4 of the study area respectively. The projected monthly humidity is very close to the observed data. The projected humidity is only 0.35% higher than observed data for the period. Therefore, for the projection of future humidity "*Methods of Curve Fitting by PLS*" is valid.

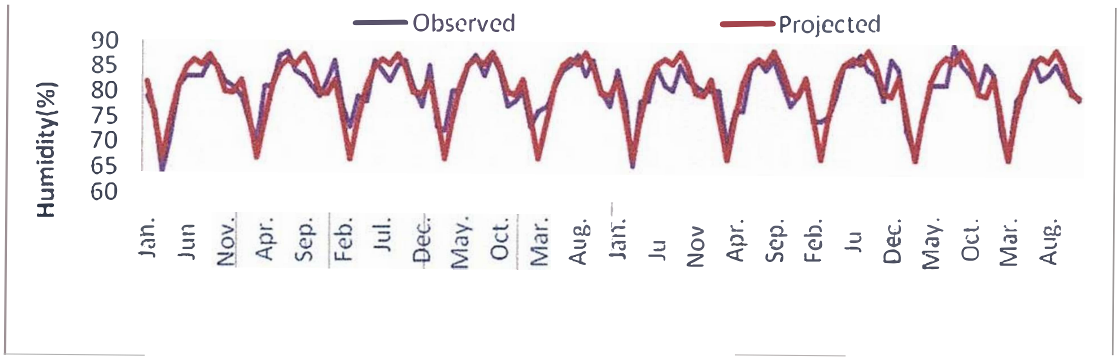


Figure 3.4: Comparison of observed and projected Humidity (2001-2010)

3.1.10 Effective Rainfall Calculation

Effective rainfall have been calculated in the present study by following formulas (Shid *et al.*, 2008) from monthly rainfall data

$Pe = 0.8P - 25$ ……………………………..3.5

If $P > 75$ mm/month

$Pe = 0.6P - 10$ …………………………….3.6

If $P < 75$ mm/month

Where, Pe = Effective Precipitation and P = Precipitation

The main annual rainfall of Bangladesh is about 2300 mm, but there exists a wide spatial and temporal distribution. Annual rainfall ranges from 1200 mm in the extreme west to over 5000 mm in the east and north-east (MPO, 1991).

3.1.11 Recharge Calculation

Rainfall is the most important source of groundwater recharge in the country. The most commonly used methods for estimation of natural groundwater recharge in

Bangladesh include empirical methods, groundwater level fluctuation and groundwater balance method. Based on water level fluctuation and rainfall amount derived Chaturvedi (1973) an empirical relation to arrive at recharge as a function of annual precipitation (When rainfall exceeds 40 cm).

$R = 2\,(P\text{-}15)^{0.4}$ ……………………………3.7

Where,

R = Net recharge due to precipitation during the year in inches

P = Annual precipitation in inches

During the calculation annual rainfall mm converted to inches and result value again converted in mm.

3.1.12 Potential Evapotranspiration Calculation

Thornthwaite (1948) proposed the concept of Potential Evapotranspiration (PET). PET is the maximum possible evapotranspiration rate that is limited only by weather or climatic factors. PET thus can be defined as the water loss due to evaporation (by various mechanisms). PET is also the concept of consumptive water requirement (CWR) - the water use rate required by a plant or crop to meet its evapotranspiration without any deficiencies because of lack of water (Nzewi, 2001). In the model, a heat index I is defined for a given month as

$I_n = \left(\frac{T_n}{5}\right)^{1.514}$ for a particular month n ……………………….3.8

For n = 1,2,……….12 (Excluding negative mean temperatures)

Where, T is the mean monthly temperature, ^{0}C

The heat index I reflects Thornthwaite classification of climates

The annual temperature efficiency index J is defined as

$J = \sum_{t=1}^{n} I_t$ ………………………..3.9

Thus PET is given by

$PET(0)\left[\frac{cm}{month}\right] = 1.62\left(\frac{10T_n}{I}\right)^c$ For month n …………………3.10

Where PET (0) is the PET at 0^0 latitude.

The number 1.62 is a value that results if each month is assumed to be 30 days long and each day has exactly 12 hours of sunshine. This situation would occur theoretically at the equator.

$C = 6.75 \times 10^{-7}J^3 - 7.71 \times 10^{-5}J^2 + 0.01792J + 0.49239$ ………………..3.11

To adjust PET for locations with latitude other than, a factor K is used, thus
PET = KPET, K values have been used from the Thornthwaite table during the calculation.

3.2 METHODS TO QUALITATIVE ANALYSIS OF GROUNDWATER

Eight groundwater samples were collected from different locations in Phulbari coalmine area. Attitude of sample locations were acquired using GPS to create location map of the studied area. Groundwater samples collected from Phulbari and its adjacent area, which mainly are used for household purposes (drinking) and irrigation.

All analytical reagents and chemicals used in this experiment were of high purity analytical grade. Deionized double distilled water was used throughout the experimental work. Laboratory glassware was kept overnight in 10% (v/v) nitric acid. Before use, the glassware were rinsed with deionized water and dried in a dust free environment. All the apparatus like conical flask, burette, pipette and screw caped polyethylene bottle used in this work were washed with detergent solution and then rinsed with tap water and finally with distilled water. Several standard solutions, ternary acid mixture and other solutions were prepared according to the following procedure.

3.2.1 Standard Stock Solutions Preparation

(a) As (Arsenic) 1.0mg As/ml Standard material: Arsenic (III) trioxide 99.9% up preparation method of solution: Arsenic (III) trioxide is heated at 105°C for about two hours and is cooled with the desiccators. Its 1.320g is dissolved in the smallest possible sodium hydroxide solution (1N) and is diluted with water to1000m*l* accurately.

(b) Cu (Copper) 1.0mg Cu/ml Standard material: Metal copper 99.9% up preparation method of solution: 1.000g of metal copper is heated and dissolved with nitric acid (1+1)30m*l* and is diluted to 1000m*l* accurately with 50m*l* if nitric acid (1+1) and water after it has cooled.

(c) Fe (Iron) 1.0mg Fe/ml Standard material: Pure iron 99.9% up preparation method of solution: 1.000g of pure iron is heated and dissolved with 20m*l* of aqua regia and is diluted to 1000m*l* accurately after it has cooled.

(d) Zn (Zinc) 1.0mg Zn/ml Standard material: Metal zinc 99.9% up preparation method of solution: 1.000g of metal zinc is heated and dissolved with nitric acid (1+1)30m*l* and is diluted with water to 1000m*l* accurately after it has cooled. The samples were analyzed 3 times for accuracy in central chemistry laboratory, University of Rajshahi). Selected eight metal had been analyzed like Arsenic (As), Copper (Cu), Iron (Fe), Zinc (Zn), Manganese (Mn), Chromium (Cr), Lead (Pb) and Cadmium (Cd) using AAS (Atomic Absorption Spectrophotometer).

(e) Mn (Manganese)1.0mg Mn/m*l* Standard material : Metal manganese 99.9% up preparation method of solution: 1.000g of metal manganese is heated and dissolved with 20m*l* of aqua regia and is diluted to 1000m*l* accurately after it has cooled.

(f) Cr (Chromium) 1.0mg Cr/m*l* Standard material: Metal chromium 99.9% up preparation method of solution: 1.000g of metal chromium is heated and dissolved with 20m*l* of aqua regia and is diluted with water to 1000m*l* accurately after it has cooled.

(g) Pb (Lead) 1.0mg Pb/m*l* Standard material : Metal lead 99.9% up preparation method of solution: 1.000g of metal lead is heated and dissolved with nitric acid (1+1)30m*l* and is diluted with water to 1000m*l* accurately.

(h) Cd (Cadmium) 1.0mg Cd/ml Standard material : Metal cadmium 99.9% up preparation method of solution: 1,000g of metal cadmium is heated and dissolved with nitric acid (1+1)30 m*l* and is diluted with water to 1000m*l* accurately after it has cooled.

3.2.2 Evaluation Method

Two documented methods evaluated in this study are the Contamination Index (C_d) developed by Backman *et al.,* (1998) and the Heavy metal Pollution Index (HPI) proposed by Mohan *et al.,* (1996).

3.2.2.1 The contamination index (C_d)

Quality of water takes interest of the researchers and consumers (for drinking and irrigation), through which populations are exposed to harmful elements from industrial, anthropogenic and/ or geological origin. Many techniques are used for assessment and visualization of hazardous defined elements. One of the approaches to calculate contamination of water bodies is through contamination index, which takes into consideration both the number of parameters exceeding the upper permissible limits or guide values of the potentially harmful elements (Backman *et al.*, 1998). Calculation of the contamination degree (C_d) was carried out separately for each analyzed sample of water, as a sum of the contamination factors of individual components exceeding the upper permissible values. Hence, the contamination index summarizes the combined effects of several quality parameters considered harmful to household water. According to (Backman *et al.*, 1998), the calculation scheme of contamination index (C_d) is as follows:

$$C_d = \sum_{i=1} C_{fi} \qquad \text{...3.12}$$

Where,

$$C_{fi} = \frac{C_{Ai}}{C_{Ni}} - 1$$

C_{fi} = Contamination factor for the i-th component

C_{Ai} = Analytical value of the i-th component

C_{Ni} = Upper permissible concentration of the i-th component (N denotes the 'normative value')

In this study, for uniformity sake all analytical values were considered irrespective whether above or below upper permissible concentration value. Secondly, the values were not normalised since this is the first ever study in the area. The upper permissible concentration value (CN_i) was taken as the maximum admissible concentration (MAC). The components considered include As, Cu, Fe, Zn, Mn, Cr, Pb and Cd.

3.2.2.2 Heavy metal pollution index (HPI)

The HPI represent the total quality of water with respect to heavy metals. The HPI is based on weighted arithmetic quality mean method and developed in two steps. First by establishing a rating scale for each selected parameter giving weightage and second by selecting the pollution parameter on which the index is to be based. The rating system is an arbitrarily value between zero to one and its selection depends upon the importance of individual quality considerations in comparative way or it can be assessed by making values inversely proportional to the recommended standard for the corresponding parameter (Horton, 1965; Mohan *et al.,* 1996). In computing the HPI, Prasad and Bose (2001) considered unit weightage (W_i) as a value inversely proportional to the recommended standard (S_i) of the corresponding parameter as proposed by Reddy (1995).

The HPI model (Mohan *et al.,* 1996) is given by

$$HPI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1} W_i} \text{ ....3.13}$$

Where,

Q_i = The sub index of the i^{th} parameter

W_i =The unit weightage of ith parameter and

N = The number of parameters considered.

Weighted arithmetic index method has been used for calculation of HPI. The unit weight (W_i) has been found out by using formula

$$W_i = \frac{K}{S_i} \text{ ....3.14}$$

Where,

K = proportionality constant

Si = standard permissible value of ith parameter.

The sub index (Q_i) of the parameter is calculated by

$$Q_i = \sum_{i=1}^{n} \frac{|M_i - I_i|}{(S_i - I_i)} \times 100 \text{ ....3.15}$$

Where,

M_i = The monitored value of heavy metal of i-th parameter

I_i = The ideal value of the i-th parameter and

S_i = The standard value of the i-th parameter.

The sign (-) indicates numerical difference of the two values, ignoring the algebraic sign. The critical pollution index of HPI value for drinking water as given by Prasad and Bose (2001) is 100.

3.3 METHODS TO ASSESSING THE VULNERABILITY OF GROUNDWATER DUE TO OPENPIT COALMINING USING DRASTIC MODEL

3.3.1 Description of the DRASTIC Method

Several aquifer vulnerability mapping methods have been developed by different researchers since 1970. However, DRASTIC has been the most commonly used for mapping aquifer vulnerability in porous aquifers (Aller *et al.*, 1987). In this study, the DRASTIC method was selected for determination of aquifer vulnerability in the basin because the main contamination sources are mine leaching to groundwater and intersection of aquifer by top soil removing due to open pit mining.

A DRASTIC method was derived from ratings and weights associated with the seven parameters. These are depth to groundwater (D), net recharge (R), and aquifer media (A), soil media (S), topography (T), influence of the vadose zone (I) and hydraulic conductivity (C). Each parameter is subdivided into ranges and is assigned different ratings in a scale of 1 (least contamination potential) to 10 (highest contamination potential) based on functional curves (Table 8.1). This rating is scaled by a groundwater contamination due to coal mining activities and DRASTIC weighting factors ranging between 1 (least significant) and 5 (most significant). In this study, contamination weight was used for alluvium areas and DRASTIC weight was used for the other areas of the basin. The linear additive combination of the above parameters with the ratings and weights was used to calculate the DRASTIC Vulnerability Index (DVI) as given below (Aller *et al.*, 1987):

$$DVI = D_rD_w + R_rR_w + A_rA_w + S_rS_w + T_rT_w + I_rI_w + C_rC_w \ldots\ldots\ldots\ldots 3.16$$

Where,

D_r	Rating for the depth to water table
D_w	Weight assigned to the depth to water table
R_r	Rating for aquifer recharge
R_w	Weight for aquifer recharge
A_r	Rating assigned to aquifer media
A_w	Weight assigned to aquifer media
S_r	Rating for the soil media
S_w	Weight for the soil media
T_r	Rating for topography (slope)
T_w	Weight assigned to topography
I_r	Rating assigned to impact of vadose zone
I_w	Weight assigned to impact of vadose zone
C_r	Rating for rates of hydraulic conductivity
C_w	Weight given to hydraulic conductivity

The rating ranges were determined depending on the properties of the study area only. The range component divides each DRASTIC parameter into several classes, or significant media types that may affect the potential for pollution (Ehteshami *et al.*, 1991). This rating range may change from one study area to another. Good knowledge of the geology and hydrogeology of the research area is a prerequisite to determine rating ranges of the parameters.

3.3.2 The Modified DRASTIC-C_dHPI Model

The modified DRASTIC model was done followed by Sener E. and Davraz A. (2012). The DVI was calculated using new rating and weight values for each of the nine parameters and two new vulnerability maps were prepared before and after mining activities using the modified DRASTIC-C_dHPI method with GIS techniques mentioned previously. The weights of specific criteria are established by ranking their importance and suitability (Sener *et al.*, 2010). Modifying the DRASTIC model to accommodate local hydrological settings and combining the use of GIS made it possible to create a visual tool representing areas of risk (Klug, 2009). By adding two parameters contamination index (C_d) and heavy metal pollution index (HPI) with DRASTIC model a new name has been proposed such as Modified DRASTIC-C_dHPI.

The DRASTIC method was developed using 4 assumptions (Al-Zabet, 2002);

1. The pollutant is introduced at the ground surface
2. The pollutant is flushed into the groundwater by rainfall
3. The pollutant has the velocity of water
4. The area evaluated using DRASTIC is 40 hectares or larger.

A database was established in order to input the collected data into Arcview 3.3 GIS, which offers the ability to store, manipulate and analyse data in different formats and at different scales (Rahman, 2008; Sener *et al.,* 2009). Once in the database, it is then possible to register all data as data layers with a common coordinate system and manipulate them to produce thematic maps, including the overall study area vulnerability map.

CHAPTER FOUR

THE STUDY AREA

CHAPTER FOUR
THE STUDY AREA

4.1 INTRODUCTION

Geography of the study area has been discussed in the light of atmospheric and topographic condition. Bangladesh occupies a unique geographic location - spanning a relatively short stretch of land between the mighty Himalayan mountain chain and the open ocean. It is virtually the only drainage outlet for a vast river basin complex made up of the Ganges, Brahmaputra and Meghna rivers and their network of tributaries. These rivers, which cause almost regular and serious floods over much of the country during the summer monsoons, are reduced seriously during the dry winter months. Three broad physiographic regions are discernible - floodplains occupy about 80%, terraces (slightly uplifted fault blocks) about 8% and hills about 12% of the land area. Each of these regions exhibits its own geo-morphological characteristics.

The Phulbari basin is located in the Phulbari Upazilla and its adjacent Upazila like Birampur, Nowabgonj and Parbattipur Upazila of Dinajpur district in the northwestern part of Bangladesh (Figure 4.1). Total coal bearing area of the basin covers about Phulbari Upazila 229.55 km^2 and adjacent area is 281.77 km^2 and total about 511.32 km^2. But my selected study area is four Upazila and their total area is about 1151.18km^2. Detailed sedimentological study on the Gondwana sediments of Bangladesh is very limited (Uddin and Islam, 1992; Islam, 1993, 1994). In present study a detailed lithofacies analysis was aimed in order to understand depositional environments of the Gondwana sequence in the basin as it has never been done before since its discovery in 1989.

Phulbari area is situated on the north-eastern part of Barind Tract and characterized by plain land of Pleistocene terraces with low relief. The average elevation is about 30m above mean sea level. The study area is selected according to the objectives of the study. The study area is selected because of the enormous and devastating environmental disaster which will be caused by the Phulbari Opencast coalmining activities blow out preceded by an even more disastrous and damaging Northern region has indisputably brought into focus. The affected Phulbari Upazila and its adjacent areas including Mostafapur, Habra and Hamidpur in Parbattipur Upazila;

Joypur union in Nawabgonj Upazila; Benail, Jotbani, Palitreagpur and Khanpur in Birampur Upazila of the Dinajpur district are included in my study area.The study area is extended from $25^0 24'$ North to $25^0 34'$& $88^0 48'$East to $88^0 69'$ East. It is well connected by metal led road with Rangpur and Dinajpur. The nearest Railway Junction is Parbattipur which is 20 km (approx.) to the north. The nearest air port is Saidpur and it is 40 km (approx.) to the north.

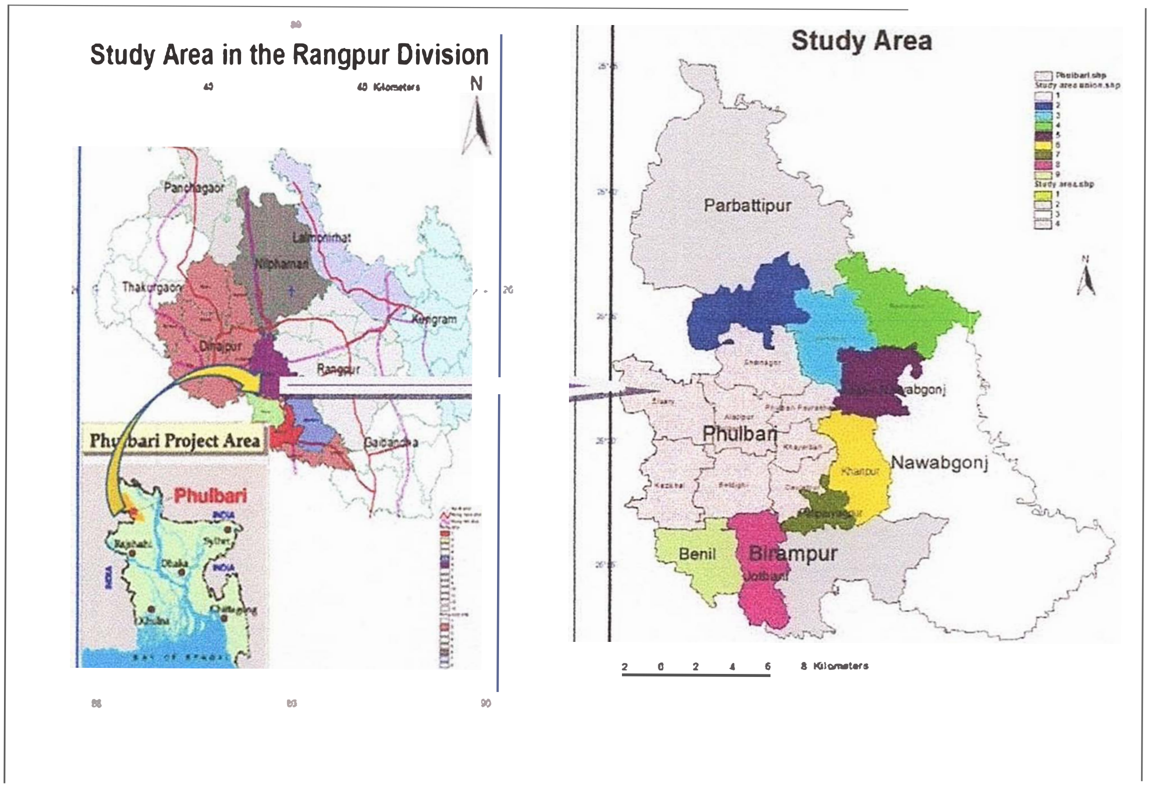


Figure 4.1: Location of the Study Area

4.2 GEOGRAPHICAL CHARACTERISTICS OF THE STUDY AREA

4.2.1 Physiography

The area can be divided into the following sub regions (Figure 4.2) on the basis of physical features and drainage pattern (Rashid, 1991).

4.2.1.1 Himalayan piedmont plains

These plains, rolling in parts, are the alluvial cones of the many rivers issuing from the Terai region at the foot of the Himalayan ranges. The interflows of the rivers are slightly dome shaped. This sub-region is bounded by the Mahananda River in the west and Dinajpur-Karatoa in the east. There are some the Duars. The rivers in this sub region are entrenched in the recent alluvial deposits, mostly sandy silt. They flow towards the south, for the land slopes from a height of 97 m at Tetulia Upazilla to 34 m, at Dinajpur. The gradient is considerable, being 0.91 m/km. In the south, deposits overlie the Pleistocene clays of the Barind Tract. The plain is undulating in parts being most marked on either bank of the Kulik river.

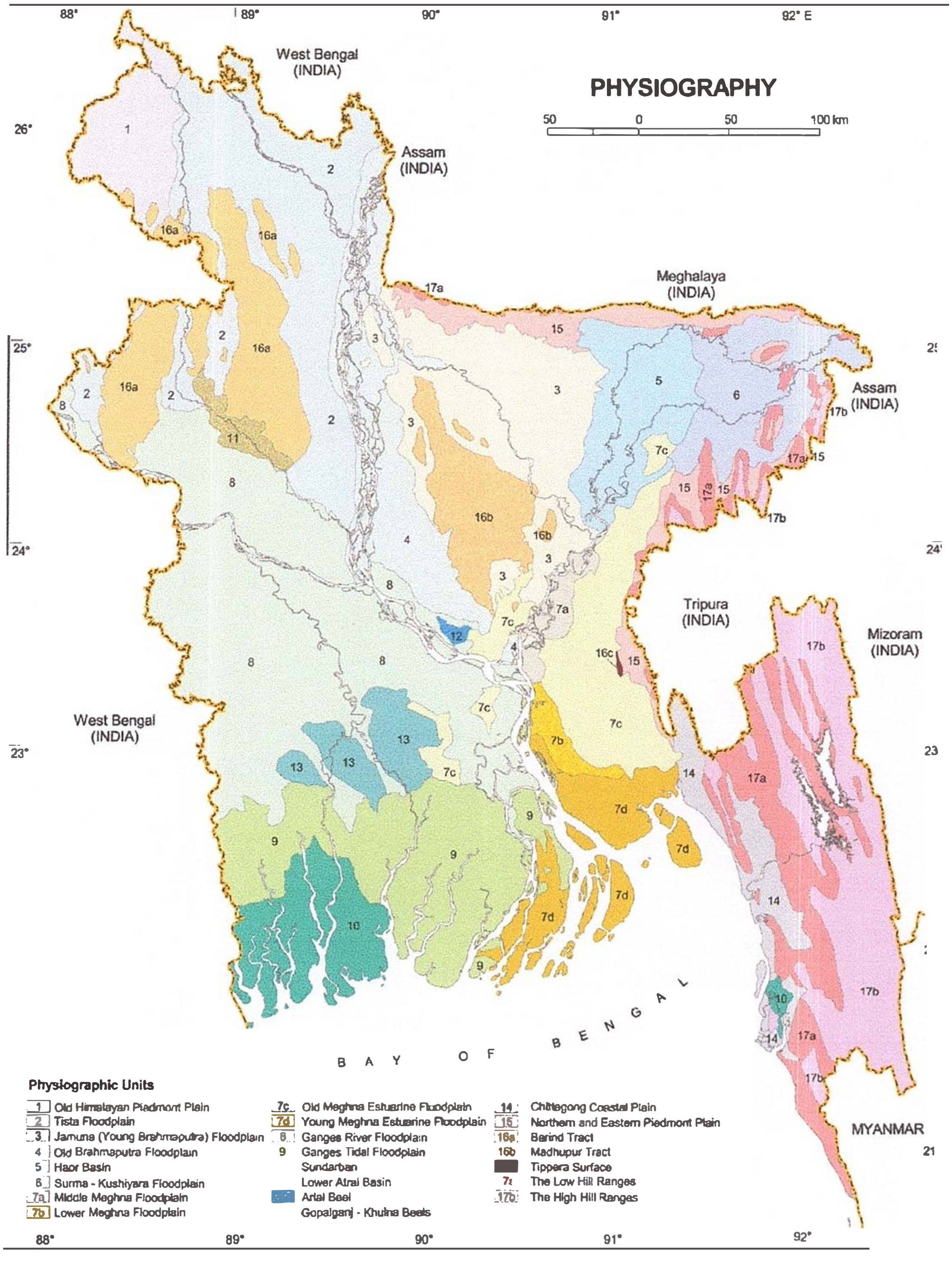


Figure 4.2: Physiographic map of Bangladesh including the study area

(Source: Modified from SRDI, 1997; Rashid, 1991; Reimann, 1993)

4.2.1.2 Tista floodplain

This big sub-region stretches from the high sandy levees of the Dinajpur Karatoa to the right bank of the Brahmaputra. The relief is that of medium level ridges and shallow basins. Most of the land is shallowly flooded. There is a slight depression along the Ghaghat river where flooding is of medium depth. The big river courses of the Tista, the Dharla and the Dudkumar cut through the plain.

4.2.1.3 Barind tract

The Barind Tract is one of the several terraces of Pleistocene age within the Bengal Basin. This tract is characterized by its comparatively high elevation, reddish and yellowish clay soils, entrenched dendrites stream pattern and a relative paucity of vegetation.

(a) North-eastern Outliers: Three separate sections of the Barind Tract are surrounded by Tista deposits. These outliers are different from the main tract in having deep red-brown soils.

(b) Eastern Barind: In the north, the eastern and east-central parts of the Barind are nearly joined together for the dividing line between them, the western Jamuna river is very narrow from northwards. From this place southwards the valley of this river is much wider. In the north, this part of the Barind extends up to Darwani and Badarganj. The north-eastern boundary is roughly a line drawn from a point between Badarganj and Shamur to Gobindaganj, Gobindaganj-Palashbari, Priganj, Mithapukar, Badarganj, Saidpur, Parbatipur, Nawabganj, Ghoraghat and Hakimpur. This part of the Barind is mainly a level plain with few undulations.

(c) The East-Central Barind: The East-Central Barind is narrowest of the four parts, being only twelve kilometers in average width. Its length is 97 km from Chrirbandar Upazilla to Mahadevpur Upazilla. Between Chirirbandar and Parbatipur in Dinajpur District, there is no distinct break between if (a) and (c): the tiny western Jamuna in its upper reaches is the partition.

(d) West-Central Barind: The recent alluvial deposits of the Piedmont plains just south of Dinajpur, appears as a stiff high northern (life) bank for about eight kilometers.

4.2.1.4 Little Jamuna Floodplain

The Little Jamuna was once a large river, being one of the former channels of the Tista. Its valley is very narrow in Dinajpur district, but south of Hili, it is 8 to 16 km. wide. The recent alluvial soil is a grayish sandy-silt and greatly contrasts with the clays of the Barind.

4.2.1.5 Lower Purnabhaba Valley

This valley, separating the West-Central Barind from the Western Barind begins 26 km. south of Dinajpur town, in Indian Dinajpur district. The Barind on either side of it is higher than the terraces to the east, with the result that this valley looks more entrenched than the Atrai.

4.2.1.6 Lower Mahananda Floodplain

The Mahananda river forms the western boundary of Bangladesh in two place along the Piedmont plain in Dinajpur district.

4.2.1.7 Brahmaputra-Jamuna Floodplain

A dual name is used for the mighty Brahmaputra river, because the Jamuna channel is comparatively new and this course must be clearly distinguished from that of the older Brahmaputra. Before 1787, the Brahmaputra's course swung east to follow the course of the present old Brahmaputra, thereby received an enormous accession of water.

(a) Diaras and Chars: There is a continuous line of Chars from where this river enters Bangladesh to the off-take point of the Dhaleshwari river. Both banks are punctuated a profusion of Diaras. There are other large Diaras on the opposite bank in Chilmari Upazila. Below Fulchari ghat there are several stretches with on Chars.

(b) Jamuna-Dhaleswari floodplain: This is the left bank floodplain of the Brahmaputra-Jamuna. Several distributaries of the Jamuna flow through here of which the Dhaleswari is by far the largest.

4.2.2 Topography and Relief

The major striking topographic feature of the study area is a north-south elongated dome shape region standing high above the adjacent areas with an average width of 20.0-25.0 km in east-west direction. In the central and north-western part of the Barind area, the elevation is higher whereas the elevation decreases in eastern, western and southern sides and pleistocene terraces are merged in all the sides to recent flood plain. Most of the area in high and medium Barind is flood free and low Barind is subject to flood and drainage congestion. The digital elevation map of the study area is shown in figure 4.3.

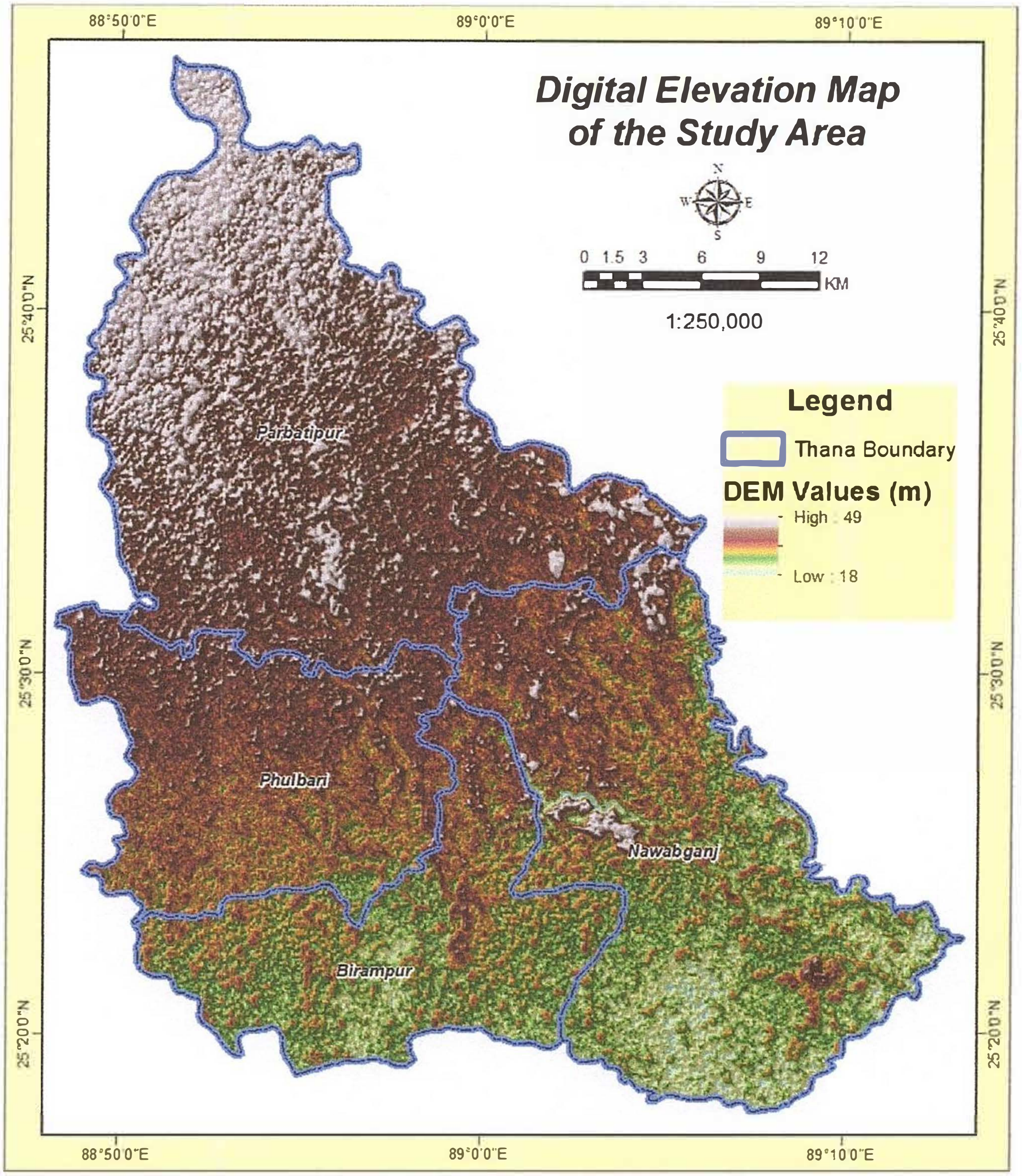


Figure 4.3: Digital elevation map of the study area (Source: CEGIS, 2014)

Edged by river valleys as the Chotto Jamuna sharply demarcate the topography across the region. The Mahananda river valley flowing by its western side is described to be fault controlled and this probably resulted in the presence of large *beels* along the western margin. These beel areas are characterized by active subsidence. The eastern edge is also characterized by the presence of numerous depressed areas aligned parallel to the central elevated zone. In Parbattipur the ground elevation above MSL is about 49 m in the northwestern side and it decreases from 20 to 31 m into the river valley situated in southern, western and eastern sides. In figure 4.4 the 2D elevation withcolor band has been shown and represent in UTM and meter.

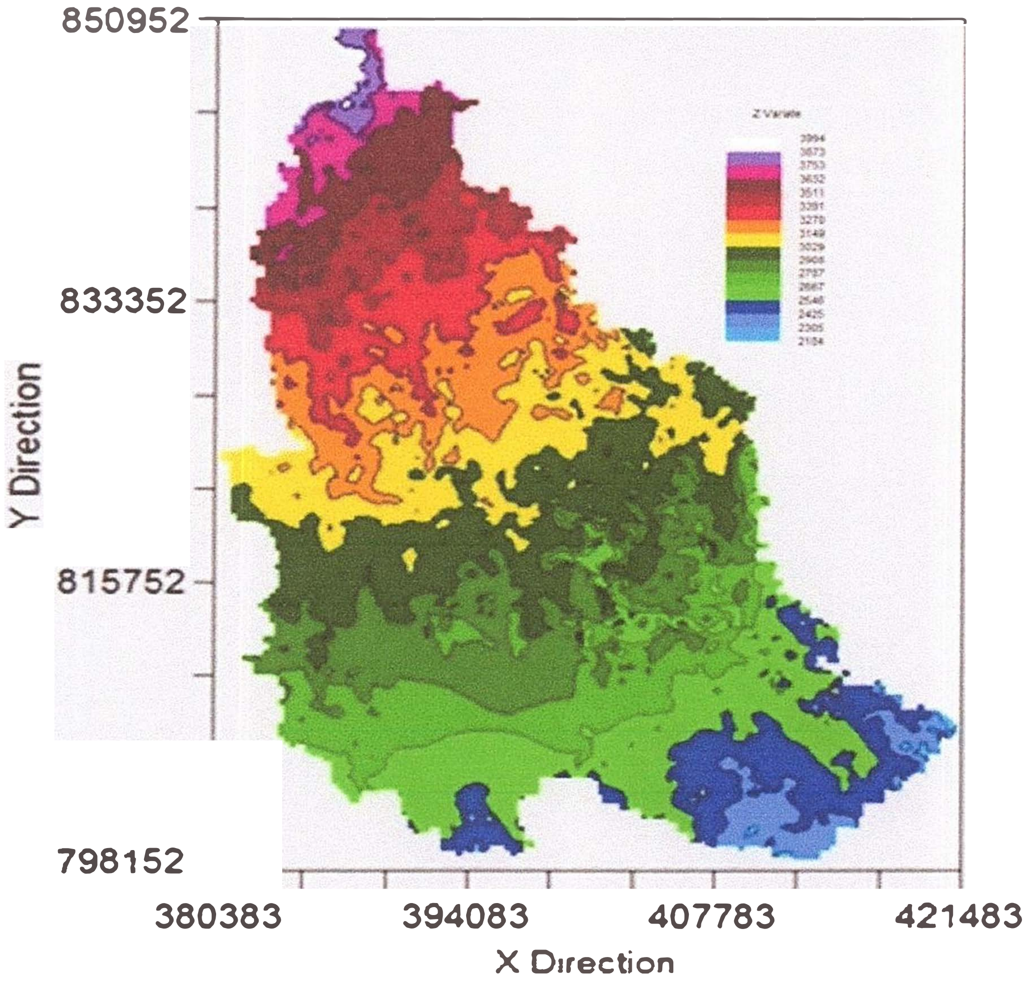


Figure 4.4: 2D elevation with colorband

4.3 LAND USE PATTERN

The present land use pattern in the study area is agriculture 20%, forestry 8%, settlement 71%, water bodies 1% and river 0.03%. Figure 4.5 show the details of land use pattern in the study area.

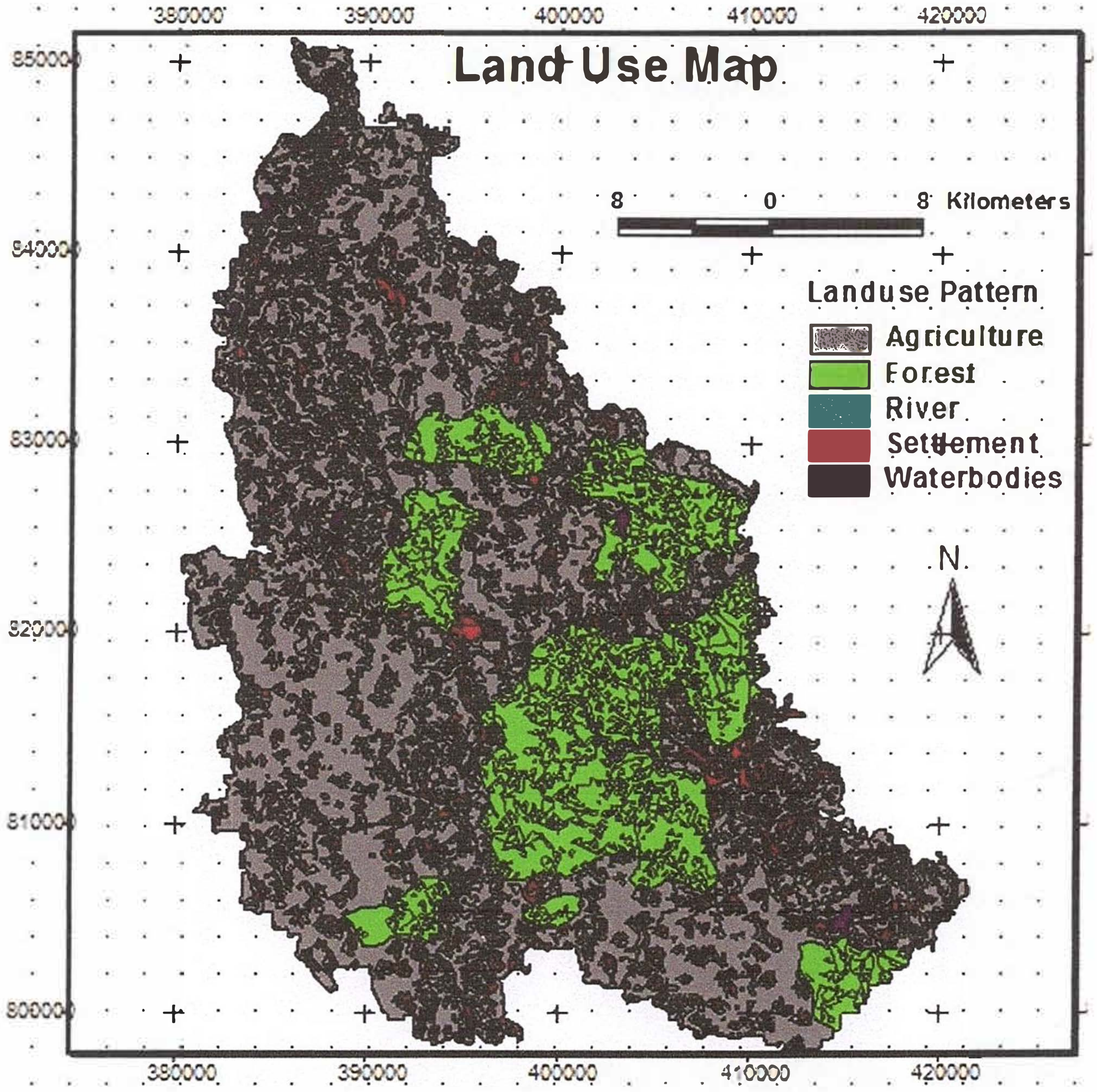


Figure 4.5: Land use map of study area (Data source: CEGIS, 2014)

4.4 RAINFALL PATTERN

The method of curve fitting by principle of least square is used for time series analysis of rainfall of two stations of Rangpur Division. The magnitude of change is assessed by fitting a straight line. Annual rainfall trend of study area is shown in figure 4.6.

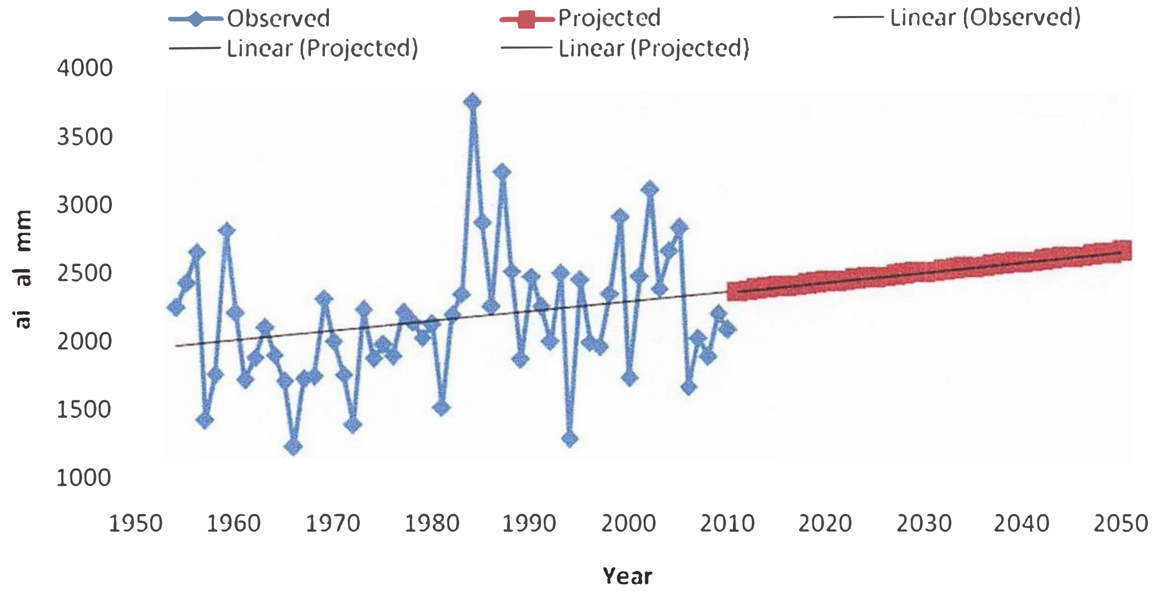


Figure 4.6 Annual rainfall trend of Rangpur for observed (1954 – 2010) and projected data (2011- 2050)

The annual rainfall trend analysis is to predict the annual rainfall until 2050 using the data of Rangpur station from 1954 to 2010 indicate that the magnitude of change of rainfall is approximately +7.4 mm per year. The base line average rainfall is about 2140 mm. The recent eleven years mean annual rainfall (2000- 2010) is almost 2295 mm and the projected rainfall using PLS techniques for the years 2020, 2030, 2040, 2050 are 2451, 2526, 2601, and 2680 mm respectively (Figure 4.7).

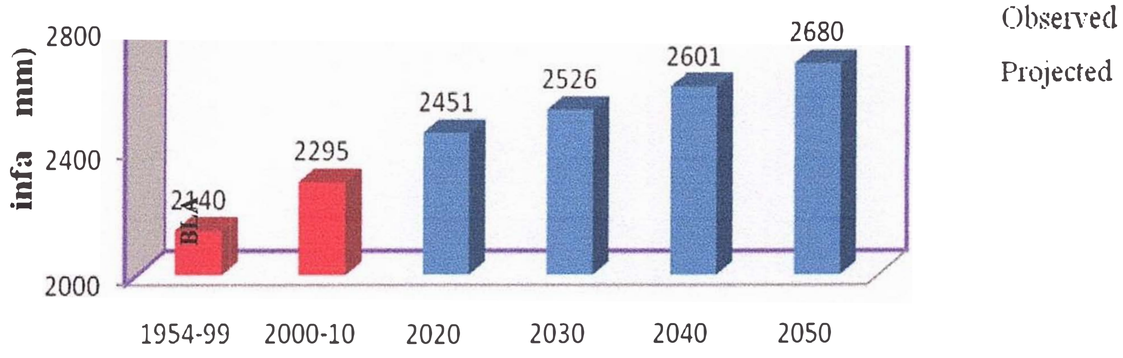


Figure 4.7 Comparison of base line average rainfall with recent eleven years mean rainfall (2000-2010) and projected rainfall of Rangpur

Almost 7.24 % of mean annual rainfall is increased in the recent eleven years mean (2000-2010) in comparison to the second half of the last century (BLA). The rainfall in the years of 2020, 2030, 2040 and 2050 may increase by 311, 386, 461 and 540 mm respectively with respect to the long term mean annual rainfall (1954-1999) and by 156, 231, 306 and 385 mm with respect to that of the first eleven years of the 21st century (Figure 4.7). Rainfall of Rangpur may increase approximately by 25% with respect to BLA rainfall by 2050.

The monthly variations of projected rainfall for the years 2020, 2030, 2040 and 2050 ; and observed long term mean (BLA) and recent eleven years mean rainfall (2000-2010) are shown in figure 4.7. The magnitude of change is the highest in September. Over the years the highest amount of rainfall may also increase in September. Moreover significant magnitude of rainfall per month may increase steadily in the months April, May and October. Rainfall may also go up in February, June, July and August. However rainfall may follow downward trend in January, March, November and December and the magnitude is not significant.

4.4.1 Mean Annual Rainfall of the Study Area

Rainfall data of Rangpur is available for the period from 1954 to 2010. For this period the mean annual rainfall of Rangpur station is 2170 mm. The maximum rainfall is recorded in July, though in July, August and September record nearly as much maximum rainfall and the lowest in December. The long term mean (57 years) values are 460 and 8 mm respectively. During the summer-monsoon approximately 96.63% of rainfall is recorded. The sixty three years (1948 to 2010) average rainfall of Dinajpur is about 1889 mm. The month July also receives the highest amount of rainfall and though July, August and September record nearly as much maximum rainfall and the lowest in December.

For the mapping of spatial extent of rainfall and also temperature, humidity from point data inverse distance weighting technique (inverse distance interpolation) is used. Geostatistical analysis tool of Arc Map 9.3 is used for these purposes. Inverse distance interpolation is forced to be an exact interpolator because it produces infinities (Burrough, and Mc Donnell, 1998). For the convenience of the study data of all station of North West (NW) Bangladesh have been used to produce spatial distribution maps from point data. The spatial distribution map of rainfall is shown in figure 4.8. The mean annual rainfall of Rangpur division varies between 1850 and 2170 mm (Figure 4.8). From the figure 4.8, it is evident that north eastern and south eastern part of Rangpur division received more rainfall relative to the north western and south western part.

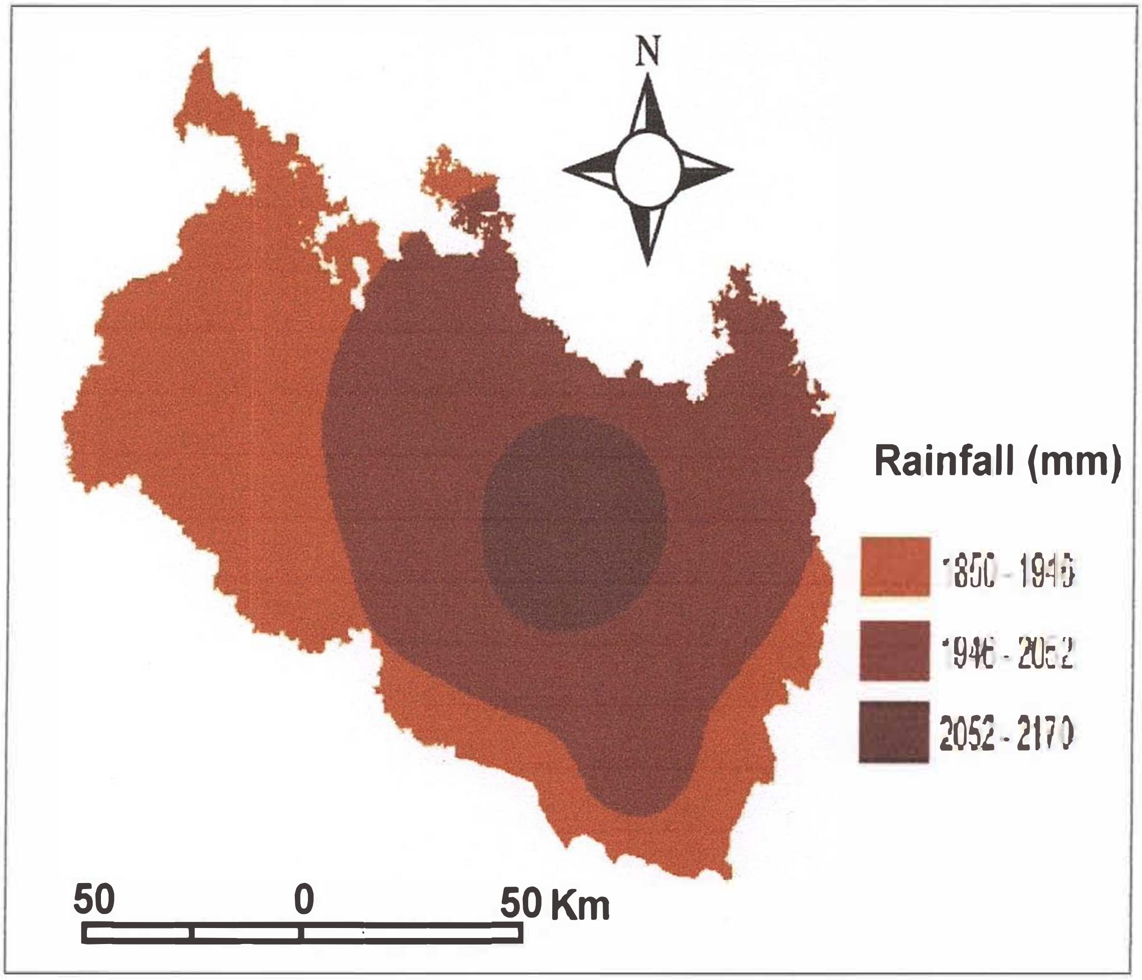
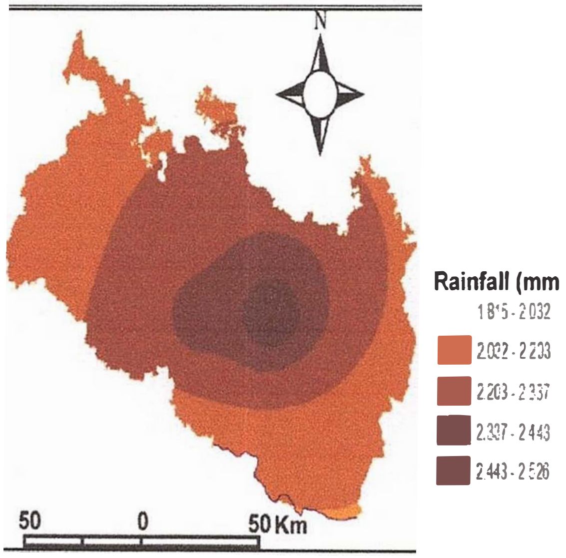


Figure 4.8 Spatial distribution of mean annual rainfall of Rangpur division

4.4.2 Spatial Distribution of Projected Rainfall

The spatial distribution of projected rainfall for the year 2030 of the study area is shown in figure 4.9. As time series analysis of rainfall using PLS techniques show upward trend, the spatial distribution of annual rainfall for 2030 shows higher rainfall in different places in comparison to the mean annual rainfall (Figure 4.8). In 2030, rainfall of the study area may vary from 2032 to 2203 mm whereas the average rainfall varies from 1850 to 2170 mm.

Spatial distribution of projected rainfall for the 2050 is shown in figure 4.9 (b) and revels that in 2050 annual rainfall of the study area may vary from 2028 to 2680 mm whereas the mean annual rainfall varies from 1850 to 2170 (Figure 4.8). From the figures 4.9 (a) and 4.8, it is evident that the whole area of Rangpur division may receive more rainfall in 2050 and the areal extent of heavy precipitation may increase as shown in figure 4.9 (b).



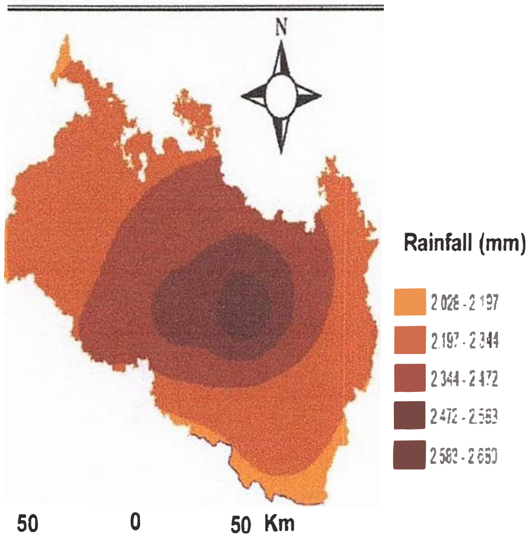


Figure 4.9 (a) Spatial distributions of projected annual rainfall for 2030

Figure 4.9 (b) Spatial distributions of annual rainfall for 2050

4.5 TEMPERATURE SCNERIO

4.5.1 Temperature Increasing Trend

The trend analysis of mean annual temperature to project future temperature until 2040 using mean annual, drought season and monsoon season temperature data from 1970 – 2010 of the study area indicates that the magnitude of change of temperature + 0.14 ^{0}C per year. Mean annual temperature trend of study area for projected (2011-2040) and observed (1970-2010) data are shown in figure 4.10. The mean annual BLA temperature is 25.23^{0}C. The maximum temperature is 29.21^{0}C and minimum is 17.30^{0}C respectively.

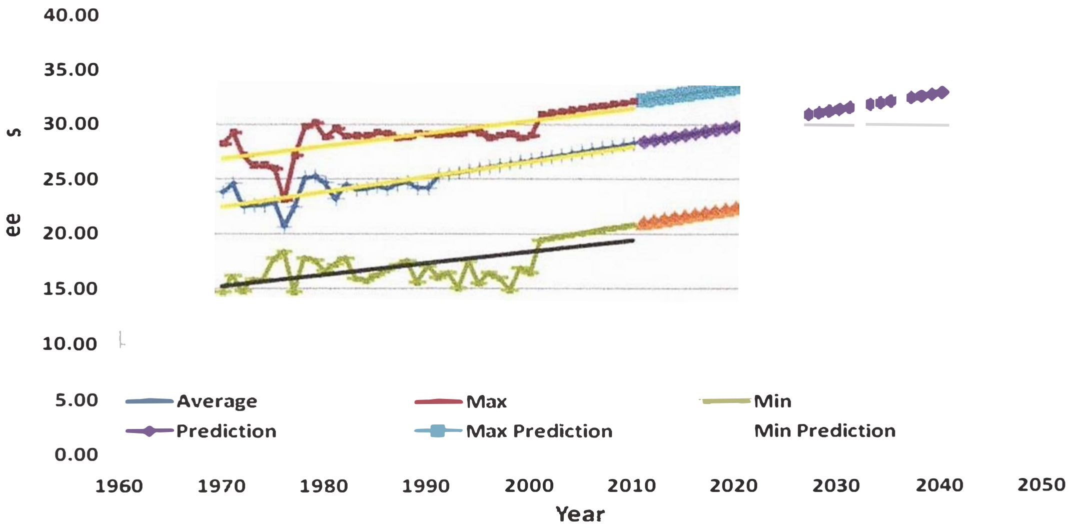


Figure 4.10: Annual, Maximum and minimum temperature trend for observed (1970-2010) and projected (2011-2050)

The mean annual temperature of Rangpur (1960 to 2010) is 24.15. The cold temperate months in Rangpur are also observed January and December between 1960 and 2010. The long term means observed average temperatures for these months are 16.29 and 18.20^{o}C respectively. The long term mean observed average temperature is above 28^{o}C for the months of July and August and the values are 28.16 and 28.47^{o}C respectively. The distribution of mean annual average temperature of Rangpur division is shown in figure 4.11. From figure 4.10, the annual average temperature of Rangpur division varies from 24.15 to 24.98^{o}C .Temperature of Rangpur division shows reverse trend of mean annual rainfall. The area towards the south west (Dinajpur district) of Rangpur division experienced the highest temperature. The north-west districts (Thakurgaon, Panchaghoar and part of Dinajpur district) of Rangpur division experienced mean annual average temperatures ranges from 24.64 to 24.86^{o}C (Figure 4.11). Temperature gradually decrease towards the north east and the lowest experienced mean annual average temperature of Rangpur division ranges from 24.15 to 24.74^{o}C (Figure 4.11).

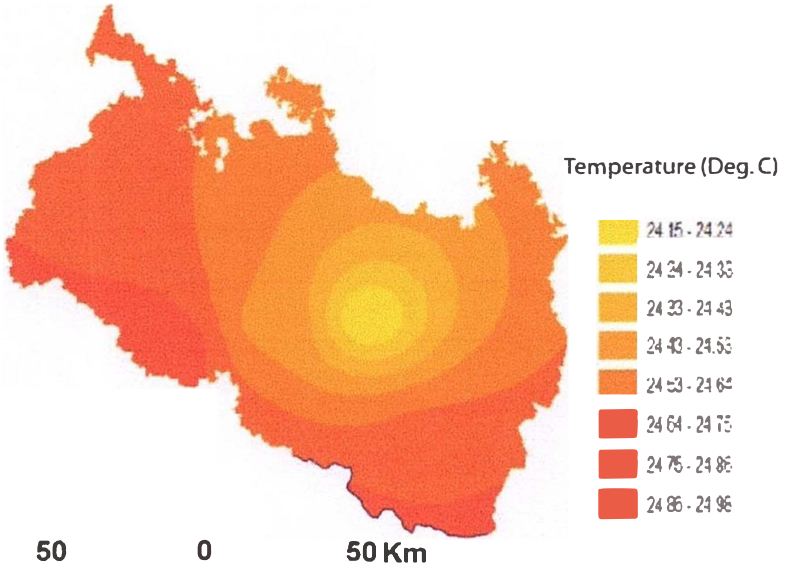


Figure 4.11: Spatial distributions of mean average annual temperature (^{0}C) (1960 to 2010).

4.5.2 Spatial Distribution of Projected Temperature

The temperature of Rangpur station shows significant increase. As result spatial distribution map of annual average temperature shows reverse pattern in comparison to mean annual average temperature. In 2030, the mean annual average temperature of

Rangpur division may ranges from 24.83 to 25.62°C. The south eastern part of Rangpur division may experience higher temperature relative to the other parts of Rangpur division. The spatial distribution of annual temperature of Rangpur division is shown in figure 4.11. From the figures 4.11, 4.12 (a) and 4.12 (b), it is evident that the temperature of north east and south east part of Rangpur division may experience higher temperature relative to the south west and northern part. From these figures, temperature of Rangpur division may increase in 2050.

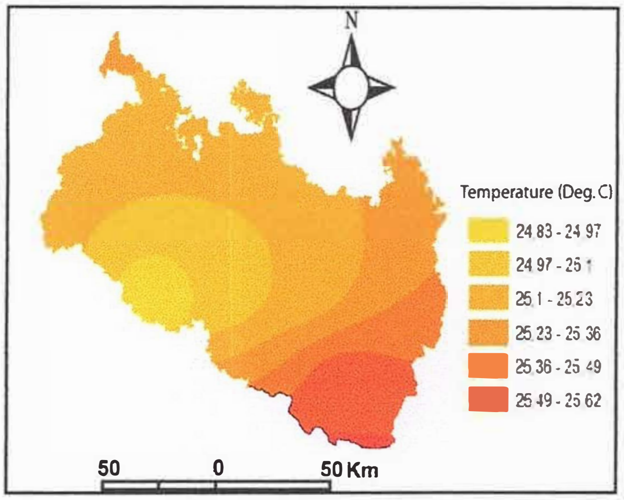


Figure 4.12(a): Spatial distributions of projected annual temperature for 2030

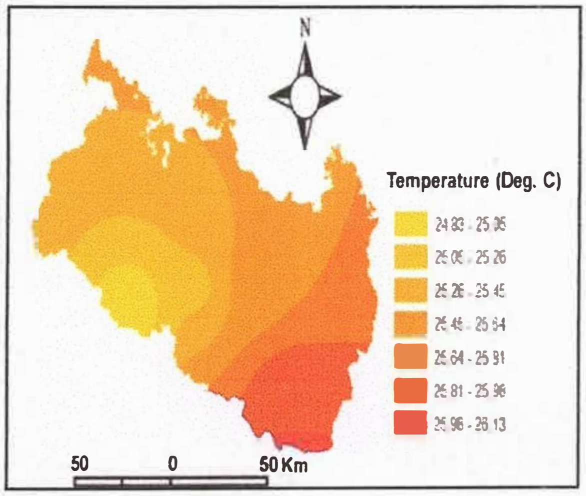


Figure 4.12 (b): Spatial distributions of projected mean annual temperature for 2050

4.6 HUMIDITY PATTERN

In Rangpur the humidity is high throughout the year. Between 1960 and 2010 the lowest mean humidity observed in March is 68.82%. The humidity is above 70% throughout the year except March. The annual mean humidity of Rangpur is 80.49% in the period. The spatial distribution of annual average humidity of Rangpur division is shown in figure 4.13.

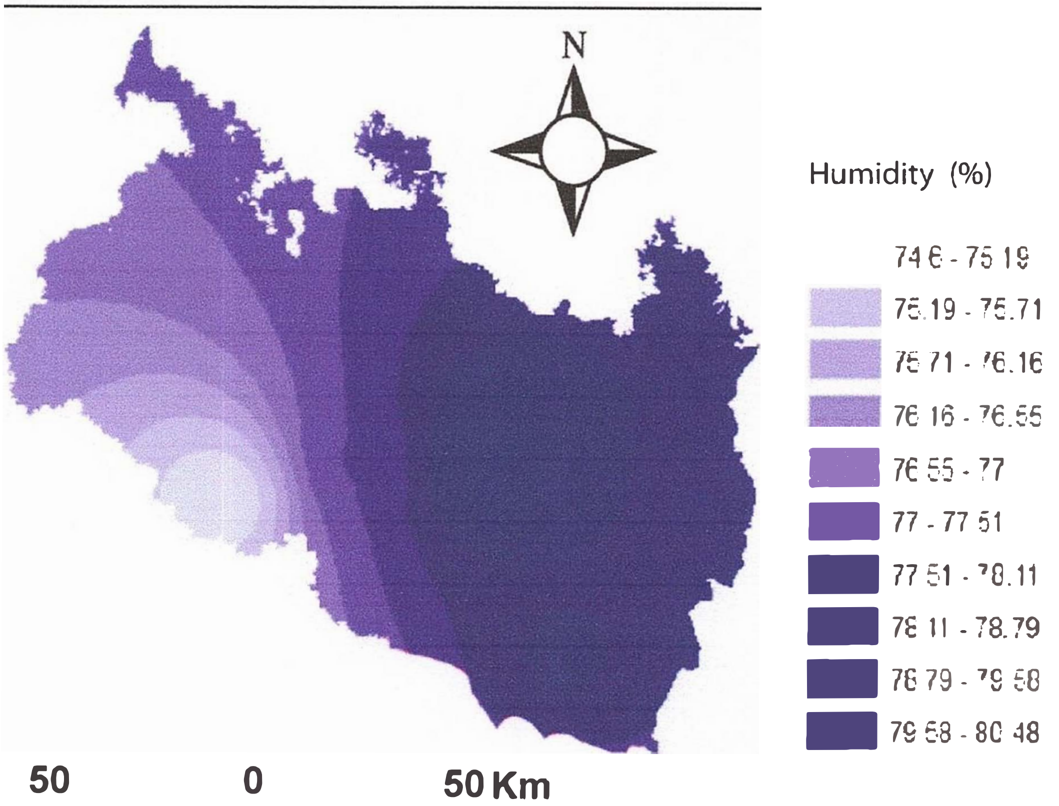


Figure 4.13: Spatial distributions of average annual humidity (%) of Rangpur division

From the figure 4.13, it is evident that the humidity of Rangpur division various from 74.6 to 80.46 %.

4.6.1 Spatial Distribution of Projected Humidity

The spatial distribution of annual humidity for the year 2030 is shown in figure 4.14(a). From figure 4.14(a), it is evident that the humidity of Rangpur division in 2030 may vary from 81.29 to 80.31% whereas mean annual humidity ranges from 74.6 to 80.48% (Figure 4.13). By 2030, the spatial variation of humidity of Rangpur division may become very small and the whole area may experience humidity above 80%. The mean humidity of south western part of Rangpur division was above 74%. By 2030, these areas may experience humidity above 80% figure 4.14(b).

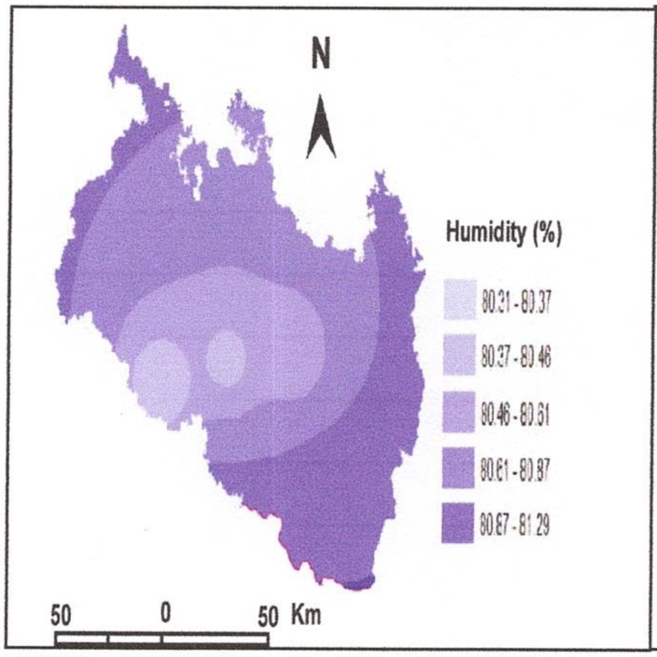


Figure 4.14(a): Spatial distributions of projected annual humidity (%) for 2030

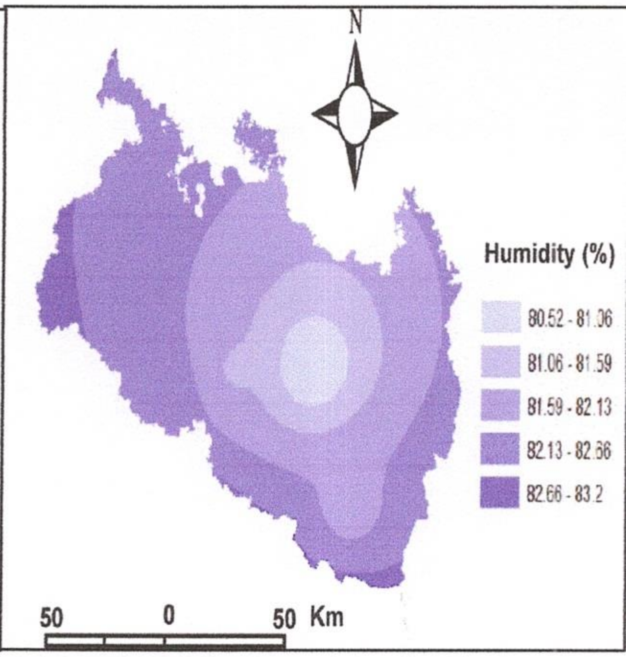


Figure 4.14(b): Spatial distributions of projected annual humidity (%) for 2050

The spatial distribution of projected humidity for the year 2050 is shown in figure 4.14 (a). From figure 4.14 (b), the area may experience annual humidity ranges from 80.52 to 83.2 % in 2050.

4.7 EFFECTIVE RAINFALL AND POTENTIAL EVAPOTRANSPIRATION

Temperature of the study area may change so that potential evapotranspiration (PET) will change. Equations 3.6 to 3.9 have been used to calculate the base line average and project potential evapotranspiration and for the years 2020, 2030, 2040 and 2050 (Table 4.1). PET is the maximum possible evapotranspiration rate that is limited only by weather or climatic factors. PET thus can be defined as the water loss due to evaporation (by various mechanisms). PET is also the concept of consumptive water requirement (CWR) - the water use rate required by a plant or crop to meet its evapotranspiration need without any deficiencies because of lack of water (Nzewi, 2001). Change in potential evapotranspiration due to increase in temperature, base line average potential evapotranspiration and first eleven years mean potential evapotranspiration of drought and monsoon season given in table 4.1 and 4.2.

4.8.1 Drought Season

During the drought season (March, April and May) the effective rainfall as well as potential evapotranspiration may increase. Base line average effective rainfall for this season is 556 mm when the potential evapotranspiration is only 6 mm higher than effective rainfall (Table 4.1). However effective rainfall exceeded mean potential evapotranspiration of the first eleven years of 21st century. *In drought season* potential evapotranspiration and effective rainfall of the study area are given in table 4.2.

Table 4.1: *Drought season* potential evapotranspiration and effective rainfall

	Effective rainfall (mm)	**Potential evapotranspiration (mm)**
Base Line Average	556	562
Mean (2000-10)	691	599
2020	657	624
2030	680	660
2040	702	664
2050	724	683

By 2050, potential evapotranspiration may be 41 mm, lower than effective rainfall. Effective rainfall in the month of March may decrease and due to increase of temperature potential evapotranspiration may increase so consumptive crop water requirement go up in the month. Moreover potential evapotranspiration of April may near constant and time series analysis of April rainfall shows upward.

Table 4.2: *Drought season* monthly potential evapotranspiration and effective rainfall

		Base line Average	**Mean (2000-10)**	**2020**	**2030**	**2040**	**2050**
March	PET	88	97	103	110	113	117
	ER	10	9	0	0	0	0
April	PET	137	138	136	139	136	135
	ER	40	95	108	123	139	154
May	PET	158	172	179	190	192	198
	ER	182	200	207	213	219	225

PET = Potential evapotranspiration (mm) ER = Effective rainfall (mm)

Due to the climate change in April and May rainfall shows upward trend.

4.8.2 Monsoon Season

Effective rainfall may increase during *monsoon* season (July, August and September) due to increase of rainfall and potential evapotranspiration may go up due to increase of temperature. The potential evapotranspiration and effective rainfalls of *monsoon* season are given in table 4.3.

Table 4.3: *Mossoon* season potential evapotranspiration and effective rainfall

	Effective rainfall	**Potential evapotranspiration**
BaseLine	929	649
Average	934	706
2020	1094	723
2030	1137	768
2040	1181	764
2050	1227	788

Base line average, first eleven years mean effective rainfall of this century indicate that effective rainfall during *monsoon* period always higher than the potential evapotranspiration and this trend may remain same over the years (Table 4.4). The monsoon season may become wetter in the future. From table 4.4 it is clear that significant amount potential evapotranspiration or consumptive water requirement of crop may increase in July, August and September.

Table 4.4: *Monsoon* season monthly potential evapotranspiration and effective rainfall in the study area

		Baseline average	**Mean (2000 -10)**	**2020**	**2030**	**2040**	**2050**
July	PET	182.79	202.16	210.27	227.28	224.51	235.36
	ER	348.30	320.96	343.03	343.03	343.03	346.06
August	PET	182.64	200.93	206.99	221.90	220.14	228.80
	ER	266.06	214.56	257.25	257.55	257.85	258.15
September	PET	159.44	172.92	173.77	182.17	182.54	185.73
	ER	224.91	221.47	336.71	366.30	395.89	425.49

PET = Potential evapotranspiration (mm) ER = Effective rainfall (mm)

Rainfall may not change in July and August and as a result there will no significant change in effective rainfall. Significant increase of rainfall will increase significant effective rainfall in September. Increase in duration of heavy rainfall period causes inundation of more area during this cropping season period and as result more farms land may shrink especially flood plains areas under water.

4.9 LETHOLOGICAL CHARACTERISTICS OF THE STUDY AREA

To describe the lethological characteristics of the study area six bore logs data were used to prepare different types of lethological model and lethological crosssection using workwork15. The lethological bore log location map is shown in figure 4.15. The Phulbari basin is situated in the Rangpur saddle of the stable shelf zone of the Bengal basin (Khan and Rahman, 1992; Reimann, 1993; Samsuddin and Abdullah, 1997). The gondwana rocks in this basin developed in a more or less NW-SE elongated fault bounded half graben, intracratonic basin, within crystalline basement (Islam *et al.,* 1992). The embryonic paleotopographic depression gradually became large basin to accommodate the large volumes of sediments deposited during the Permian. The present structures are due to tectonic activity during the Cretaceous, the gondwana break up, and the tertiary Himalayan upliftment. The The Phulbari basin is a more or less covered with recent alluvium and pleistocene barind clay formation. The sedimentary rocks of the borehole consist of gondwana group, surma group, dupi tila formation, barind clay formation and alluvium of permian, miocene, pliocene, pleistocene and recent ages respectively (Table 4.5). On the basis of dominant lithology the gondwana sequence has been sub-divided into six lithostratigraphic units (Table 4.5).

Within the basement in the Rangpur platform/Dinajpur platform and Bogra shelf areas, a number of small intra-crationic basins (Graben and half Graben) have been identified by the gravity survey. It is believed that these grabens were formed as a result of post gondwana rifting in the gondwana land. These basins are thought to be down warped blocks of the platform into basement complex and are formed to contain coal bearing gondwana sediments in different continents.

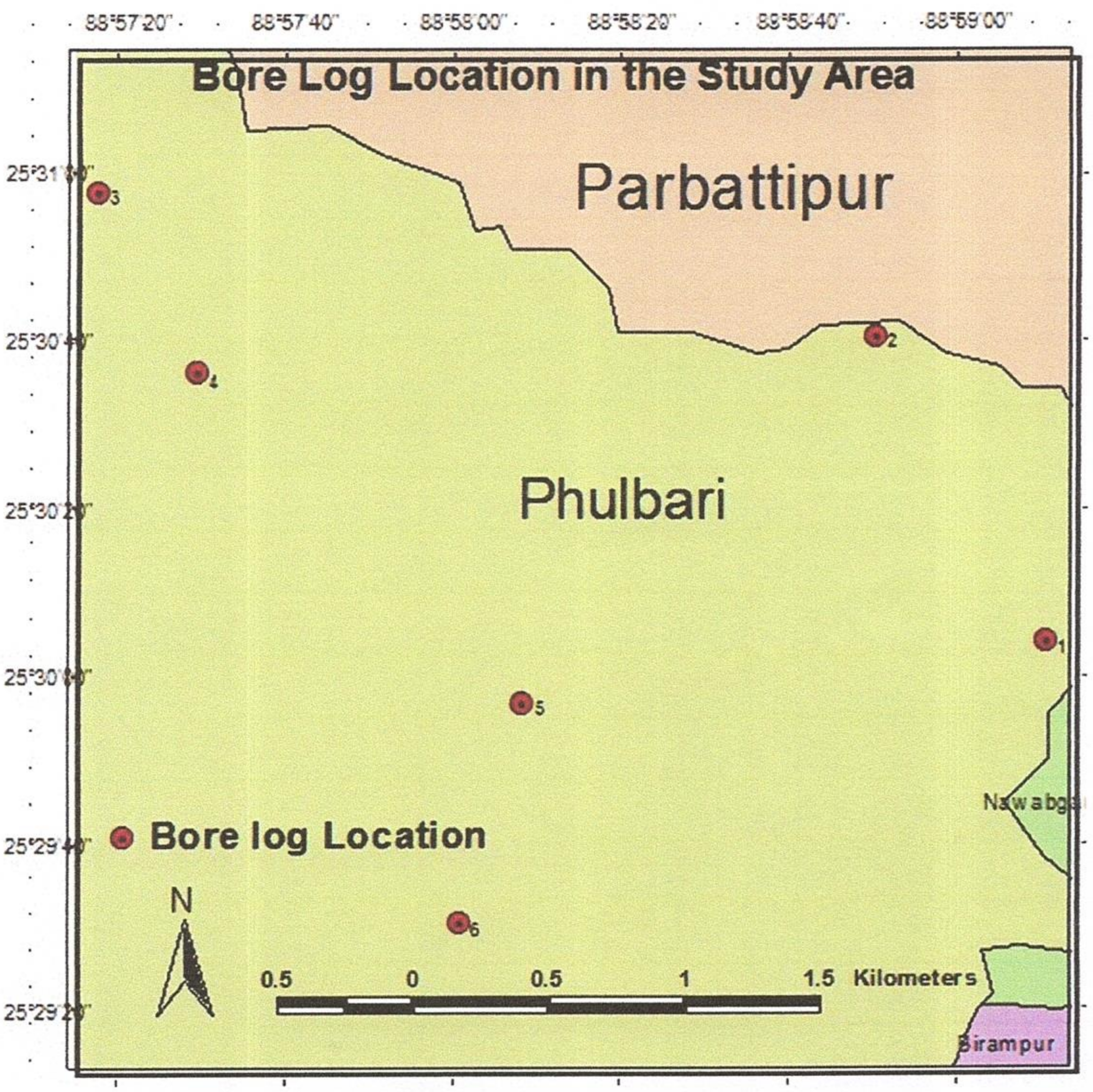


Figure 4.15: Bore log locations

Barapukuria basin north of Phulbari is asymmetrically half-graben type intra cratonic bain. This half graben structure is imparted by a major N-S trending eastern boundary north fault. The existence of this fault along with two other normal faults (NNE-SSW and NNW-SSE fault) have been proved by the bore hole data of GSB which may extends southwards till phulbari.

Table 4.5: Lithology of the study area

Borelog-1: Chakchaka			Borelog-2: Tentulia			Borelog-3: Koraipara		
Depth (ft)		**Lithology**	**Depth (ft)**		**Lithology**	**Depth (ft)**		**Lithology**
0	10	Clay	0	10	Clay	0	20	Clay
10	40	F Sand	10	300	Sand	20	240	Sand
40	110	F-M Sand	300	439	Clay	240	410	Clay
110	140	M-C Sand	439	440	Diorite	410	460	Sandstone
140	295	C Sand				460	500	Mudstone
295	300	Clay				500	545	Sandstone
300	330	Mudstone				545	560	Diorite
330	400	Sandstone						
400	410	Claystone						
410	510	Coal Fragment						
510	520	Clay						
520	530	Diorite						

Borelog-4:Sajanpukur			Borelog-5:Kanahar			Borelog-6: Tentulia Ara		
Depth (ft)		**Lithology**	**Depth (ft)**		**Lithology**	**Depth (ft)**		**Lithology**
0	10	Clay	0	25	Clay	0	10	Clay
10	280	Sand	25	333	Sand	10	400	F Sand
280	400	Clay	333	340	Clay	400	440	Clay
400	690	Sandstone	340	395	Mudstone	440	460	Sandstone
690	770	Mudstone	395	440	C	720	760	Mudstone
770	850	Coal	440	445	Mudstone	760	800	C
			445	515	Sandstone	800	847	Claystone
			515	607	Coal			
			607	620	Mudstone			

Data Source: BWDB, 2003

Lithology of the study area carried out by well log data. For preparing the figure 4.16 five litho log data were used out of six. From these data stratigraphy has been carried out. The cross section has been done NW to SE direction (Figure 4.17).

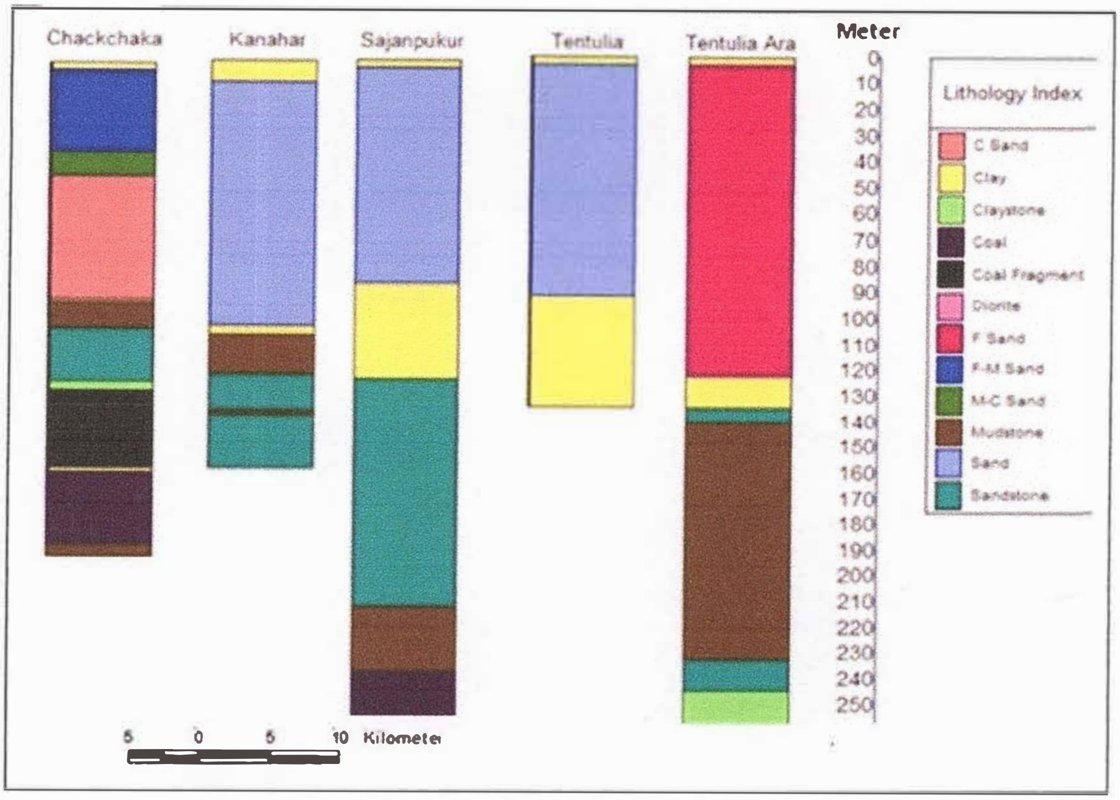


Figure 4.16: Lithology of the study area prepared by using Rockwork

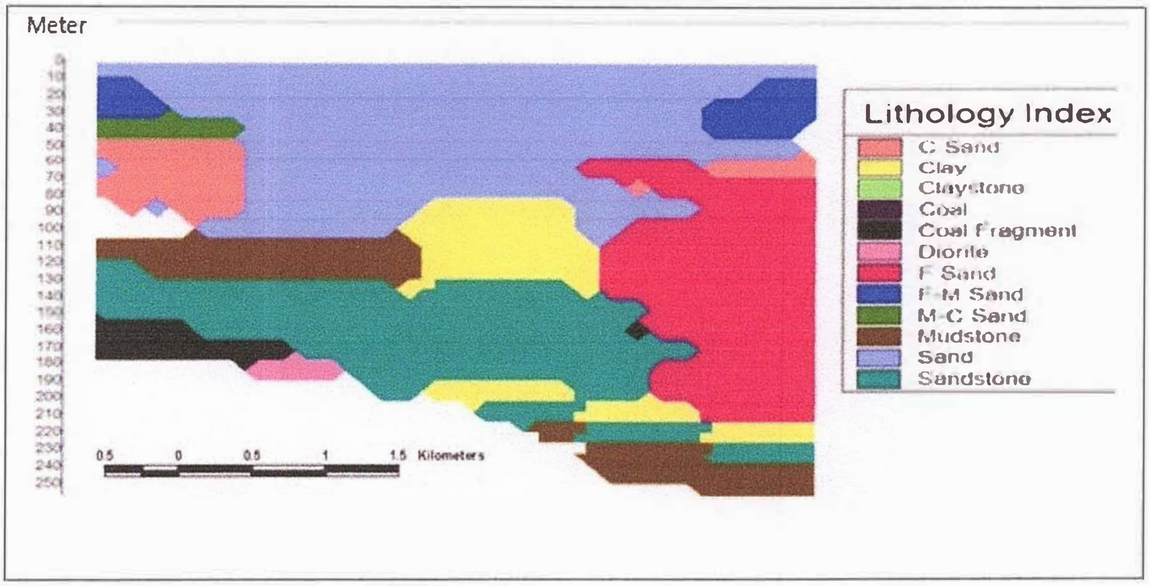


Figure 4.17: Lithological cross section of the study area

4.10 DEPOSITIONAL MODELS

In the present study, a model has been constructed by using Rockwork15 to provide an idea about the paleogeography and environments of deposition of the gondwana group of Phulbari basin (Figure 4.18.). Internal sedimentary structures, boundary conditions lithofacies, their interrelationship, sequence and association are taken into consideration for the interpretation of depositional environments. Sedimentation history of the lower part of the group is not known owing to lack of information. Like other Gondwana basins in Bangladesh (Uddin and Islam, 1992; Islam, 1993, 1994, 1996, 2002) and India (Basu and Srivastava, 1981; Mitra and Rao, 1987), the deposition in the basin was most probably started with the onset of glacial and fluvio-glacial sedimentation on the basement. In the studied portion of the sequence the sedimentation was started with the deposition of trough to planar cross-stratified sandstones in moderately sinuous fluvial regime. This sequence is overlaid by a thick conglomerate and alternated sequence of conglomerates and trough to planar cross-stratified sandstones. All these suggest deposition under channelized condition in moderately sinuous stream in an alluvial fan-fluvial setting (Figure 4.18). Consequently, the gradient of the stream reduced to form comparatively finegrained and small-scale sequences with several horizons of thin coal seams. The peat-forming swamps were very short lived and most probably were moderate to well drained, which is indicated by the presence of repeated sequence of coarse to fine clastics with intervening thin coal seams. Gradually, this situation changed to more peneplain condition to deposit thick coal seams in a comparatively long persistent moderately drained to poorly drained and densely vegetated peat-forming back swamps along a comparatively more sinuous stream. The mudstone/shale and siltstone were deposited in natural levee, flood basin or on bar top.

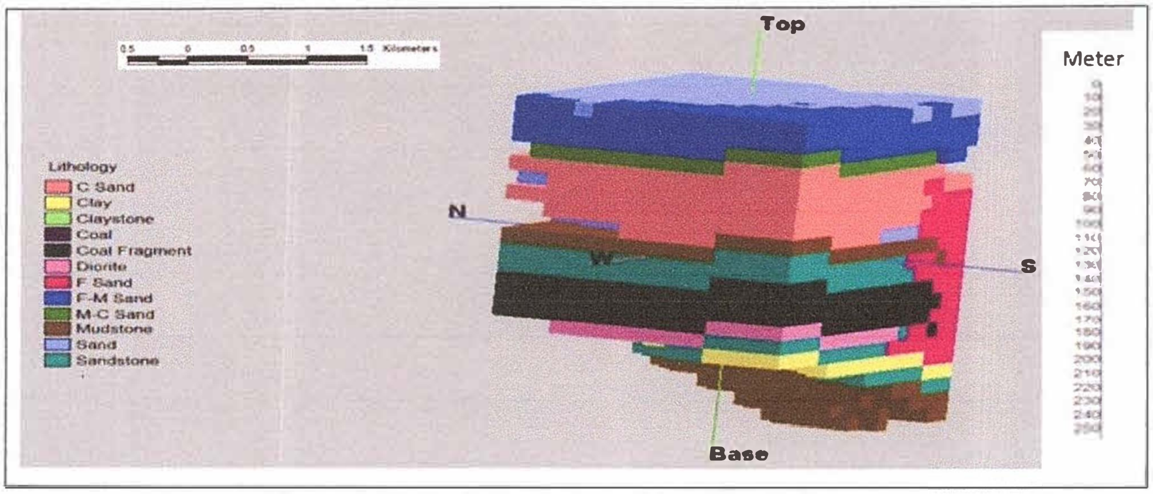


Figure 4.18: Lithological model of the study area

4.10.1 Stratigraphy

The stratigraphic succession of the area has been drawn on the basis of bore hole data considering the gross lithology, grain size variarion, sedimentary structures etc. The detailed description of the lithology for 6 bore holes given in the table 4.6 and the lithological cross section are given in the figures 4.19 to 4.22.

Table 4.6: Stratigraphic succession of Phulbari basin (studied area) based on 6 bore hole logs

Age	**Group**	**Formation**	**Generalized Lithology**	**Thickness (approx. in ft)**
Holocene		Alluvium	Silty clay, lightly weathered	5-10
--Unconformity--				
Pleistocene		Barind clay residium	Clay and silty/ sandy clay	5-20
--Unconformity--				
Pliocene		Dupi Tila	Sand, pebbly sand and clay	350-400+
--Unconformity--				
Permian	Gondwana		Sandstone, carbonaceous mudstone, claystone and coal	200-450+
--Unconformity--				
Precambrian	Basement complex		Diorite, quartz diorite etc.	3+

Data source: BWDB, 2003

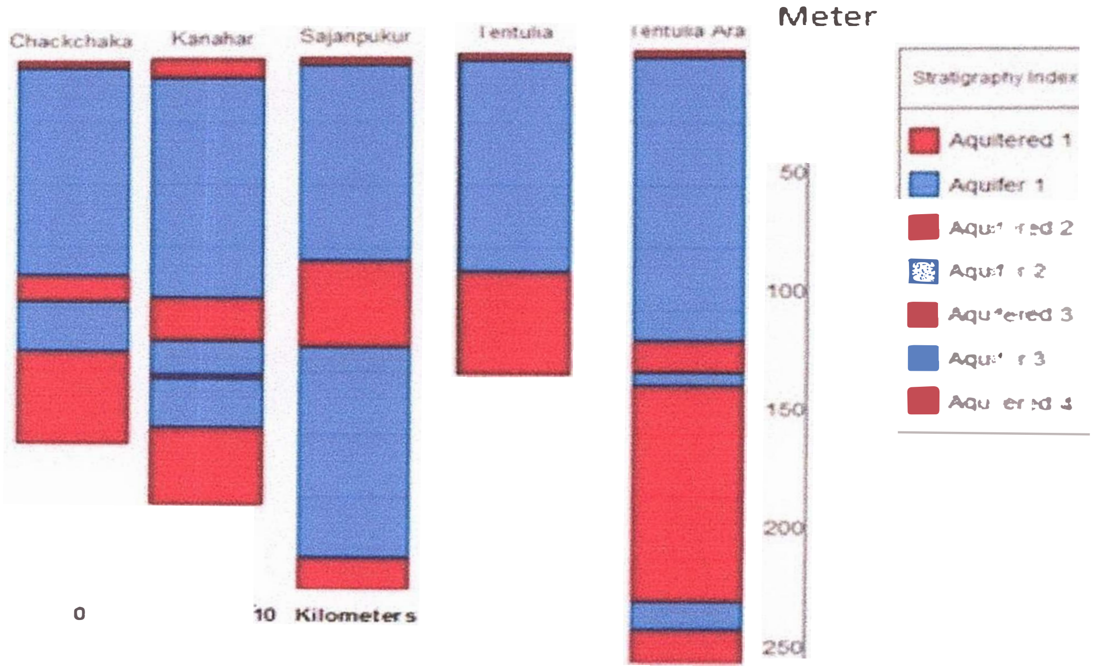


Figure 4.19: The stratigraphy of the study area prepared by Rockwork 15

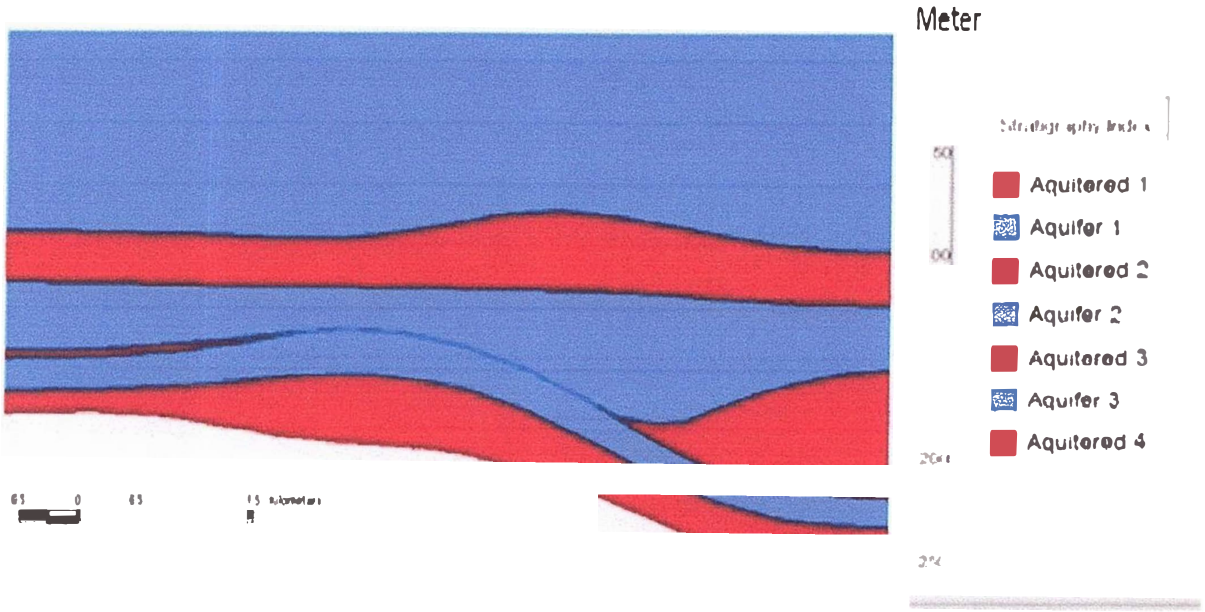


Figure 4.20: Stratigraphic cross section of the study area

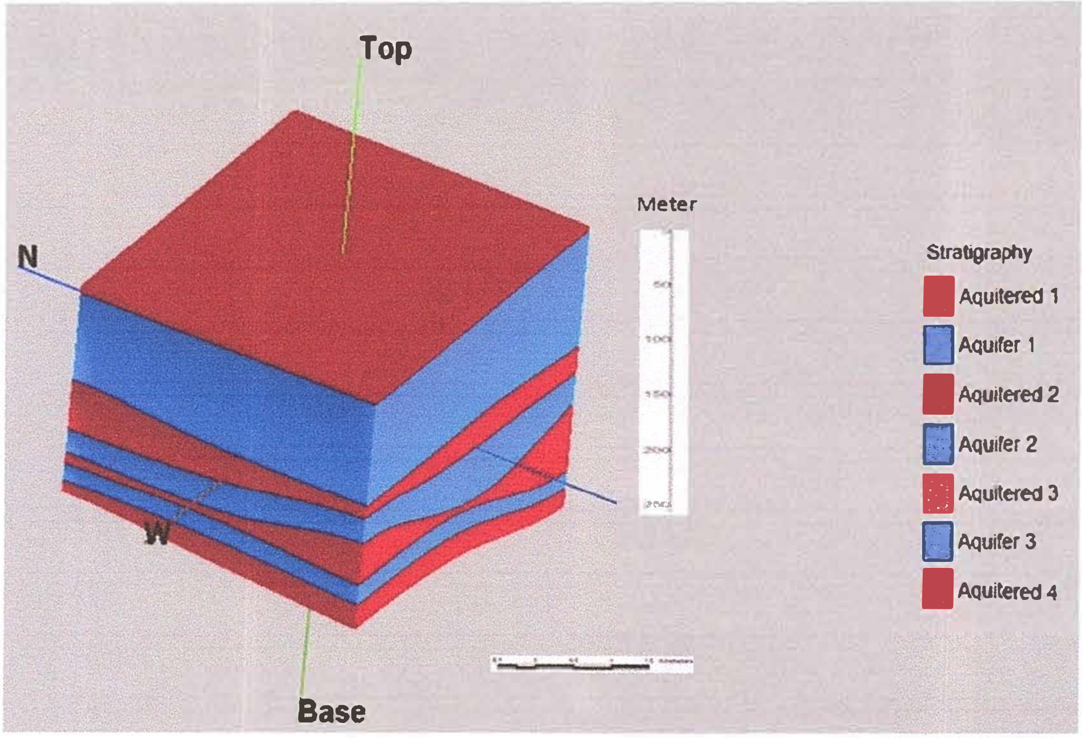


Figure 4.21: Stratigraphic model of the study area

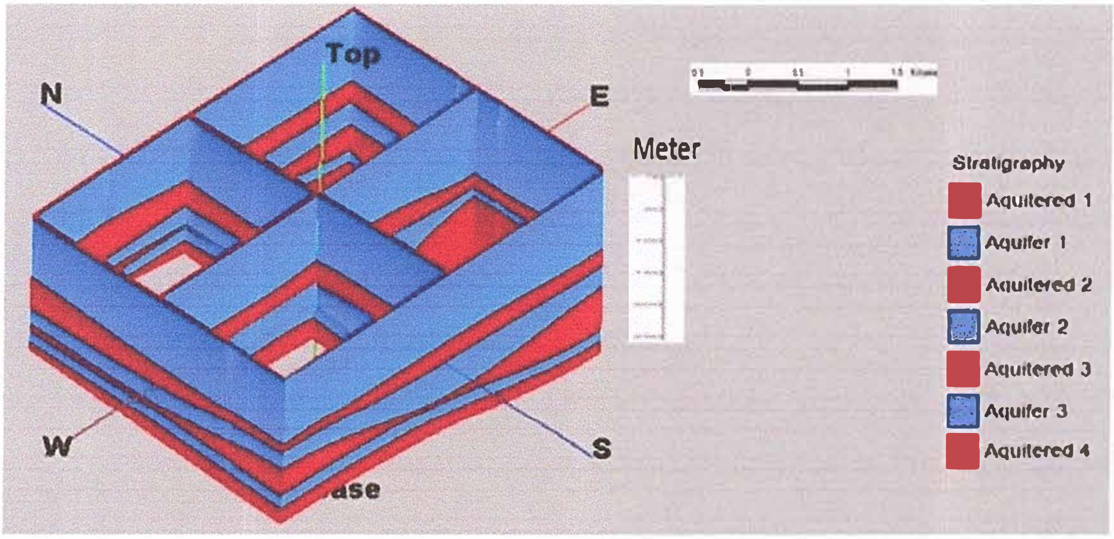


Figure 4.22: Fence diagram of the stratigraphy

A computer program (Rock ware) is used in completing a model hydro-structure of the study area depending on the geological data of lithological sections (Figure 4.17) of the wells shown in figure 4.19. The results of the model (Figure 4.20 to Figure 4.22) show that the water bearing horizons are affected by some faults. According to the fact of the horizontal movement of the fault, the hypothesis of a break in aquifer extension (Hussien and Fayyadh, 2011).

4.10.2 Basement Complex

The oldest rocky Basement Complex has been encountered in hole 1, 3, 4 and 5 below the depth of 530, 440, 560 and 870 ft respectively. Distinct variation of depths between holes indicates in between these holes. This complex consists of diorite, quartz diorite etc. Basement rocks in Barapukuria Basin, about 4km north of invested area, is composed of light grey, holocrystalline, equigranular coarse grained granodiorite and quartz diorite light colored holocrystalline granite, equigranular medium granied diorite, gneiss and schists.

4.10.3 Gondwana Group

The basement complex is overlaid by the Gondwana Group of Permian age. The Gondwana rocks in Phulbari consists of feldspathic sandstone, carbonaceous sandstone, carbonaceous clay/mudstone and coal. Thickness of these sediments varies from 200 to 450+ft below the depth of about 250ft from ground surface. The unconformity is well marked at the top of the Gondwana sediment.

4.10.4 Coal Seams

Gondwana coal deposites have been identified in 2 holes (1 and 4) out of 6 at the depth of 770 and 514ft respectively with the thickness of about 80 and 92ft. Coal fragments associated with sandstone beds are also reported in holes 1 below the depth of 410. In holes-5 the coal seam is overlain by alternation of carbonaceous mudstone and sandstone.

4.10.5 Dupi Tila Formation

The dupi tila formation unconformably overlies the gondwana group. The thickness of this formation in the study area ranges from 350 to 400+ft below the depth of 5 to 20ft from the surface. This formation consists of light grey fine to medium and medium to coarse sand with gravels, pebbles and clay at different depths and is of Pliocene age.

4.10.6 Barind Clay Residuum

The thickness of barind clay is about 5 to 20ft and unconformably lies over the dupi tila formation. The clay is yellowish brown to reddish brown, mottled and contains brown ferruginous nodules and partly decomposed organic matter (Figure 4.23).

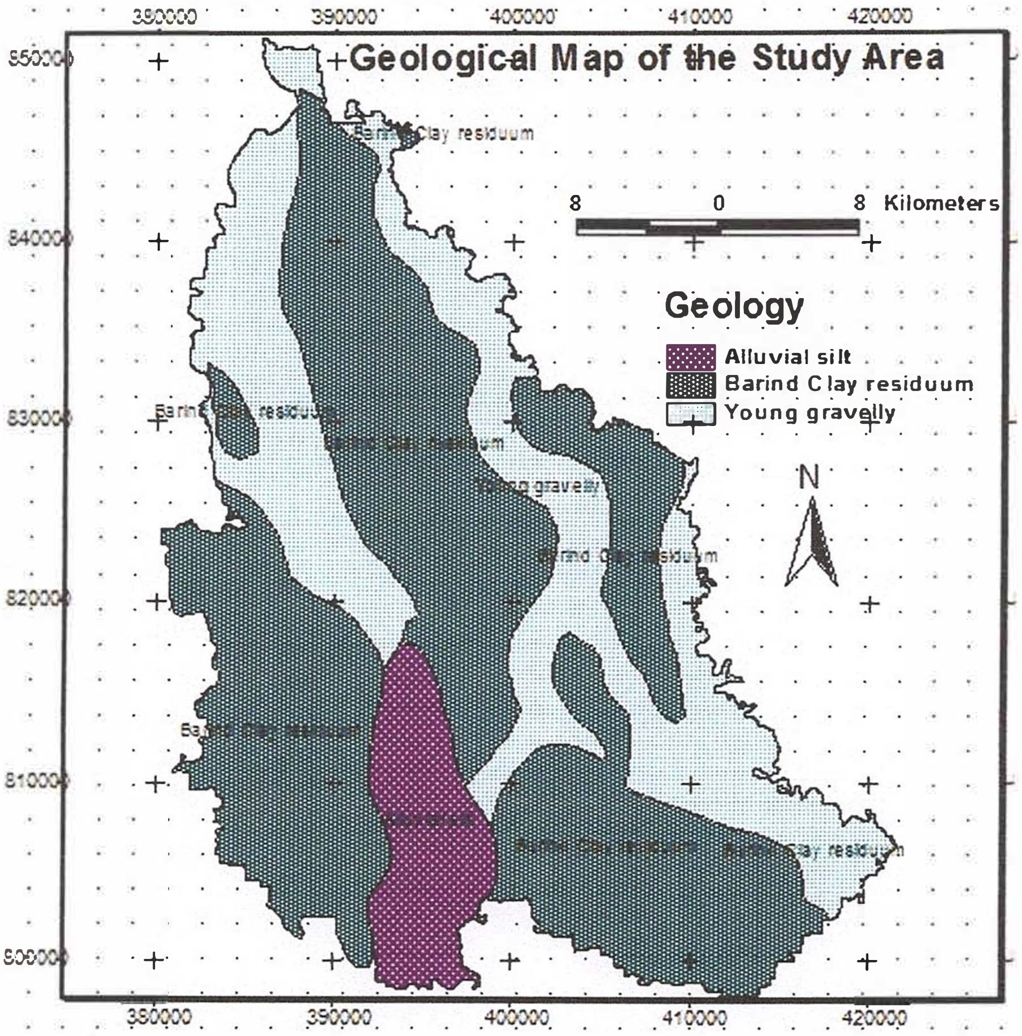


Figure 4.23: Geology of the study area (Data source: Modified from CEGIS, 2014)

4.10.7 Alluvium

The upper most layer with the thickness of about 5ft is the alluvium and consists silty clay and weathered finer materials.

The Phulbari basin is a NW-SE elongated and fault bounded asymmetric half-graben within the basement complex. Lithology of the 6 bore log of the studied part of the permian gondwana group in the basin is carried out to interpret its depositional environments. On the basis of dominant lithologic associations the group is divided into twelve lithostratigraphic units. The units are clay, sand, fine sand, fine to medium sand, medium to coarse sand, coarse sand, mudstone, sandstone, clay stone, coal, coal fragment and diorite. These units consist of five broad lithofacies, i.e., conglomerate, sandstone, siltstone, mudstone/shale and coal lithofacies. Each lithofacies was deposited in different sub-environments (channel, floodplain, flood basin/back swamp) within the fluvial regime. This lithofacies indicates deposition in lowlying back swamps flanked by densely vegetated overbank. Thick coal seams indicate long persistent and moderately drained back swamps, whereas, thin seams indicate a short lived and well drained back swamps condition. Increased proportion of fine clastics and coal seam number and thickness in the upper part suggests gradual abandonment of active fluvial channel and formation of densely vegetated back swamps for the formation of thick coal seams.

CHAPTER FIVE

GROUNDWATER CHARACTERISTICS

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5.1 INTRODUCTION

5.1.1 Groundwater Level Alignment

Groundwater level data has analyzed to assess the groundwater level scenario in the study area during 1985 to 2010. Time series analysis has been carried out by *'Principal of Least Square'* (*PLS)* method of selected 6 groundwater observation wells located at 4 Upazilla in Dinajpur District. Groundwater level data is collected for the period of 1985 to 2010 in 6 observation wells from Bangladesh Water Development Board (BWDB) of mine area and these are used for three types of trend analysis *i.e.*, yearly trend, drought season trend (March, April and May) and monsoon season trend (July, Aught and September). The map shows the groundwater well location (Figure 5.1). In the study area the average groundwater level is declining 0.166m each year. During the drought season groundwater depletion rate is 0.209 m and during monsoon period this rate is 0.112 m/year. During the twenty five years period (1985–2010) total depletion of groundwater is 4.15 m.

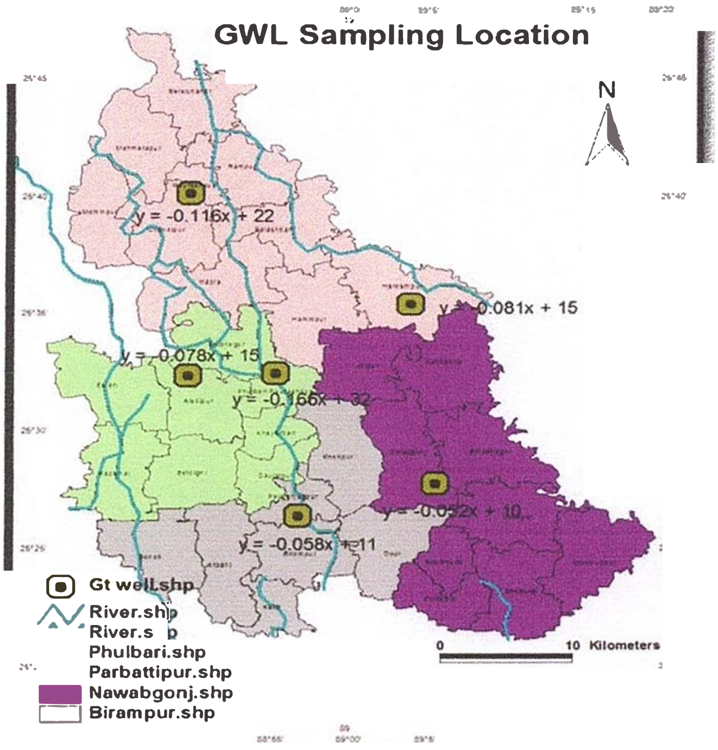


Figure 5.1: GWL sampling location in the study area

5.1.2 Present Water Abstraction in the Study Area

The present water demand for the study area mainly comprises of domestic demand and agricultural demand. Detailed calculation for each category is described below:

5.1.2.1 Agricultural demand

Total irrigated crop agricultural land of the study area is 230.236 sq. km. For agricultural purpose, a thin film of 5mm water over cultivated area should be maintained for good yield as per the standard norm (Chaulya, 2003). The irrigation is required during lean period of six months (January, February, March, April, May and December) for agricultural production. Barind Multipurpose Development Authority (BMDA) installed 21149 shallow tube wells and 388 deep tube wells for irrigation purpose in the study area. The total groundwater abstraction per year by the shallow tube wells are $1.5075x10^{11}$ litters (Table 5.1) and by the deep tube wells are $4.4x10^{9}$ litters (Table 5.2).

Table 5.1: Present water abstraction by shallow tube wells in the study area

Name of Thana	NO. STW	Discharge	Pumph STW	PumpD STW	Abstraction (L/year)
Phulbari	5125		11	180	36531000000
Birampur	1807		11	180	12880296000
Nawabgonj	4760		11	180	33929280000
Parbattipur	9457		11	180	67409496000

Data Source: Barind Multipurpose Development Authority (BMDA)

Table 5.2: Present water abstraction by deep tubewell in the study area

Name of Thana	NO. DTW	Discharge	Pumph DTW	PumpD DTW	Abstraction (L/year)
Phulbari	103	2	9	175	1168020000
Birampur	66	2	9	175	748440000
Nawabgonj	92	2	9	175	1043280000
Parbattipur	127	2	9	175	1440180000

Data Source: Data Source: Barind Multipurpose Development Authority (BMDA)

5.1.2.2 Domestic demand

Total population within the area is 941269. Considering 46 liters per day (1ld) per head water consumption (UNDP, 2014) for Bangladesh (Table 5.3). The total annual domestic water demand for the watershed becomes: (941269x46x365) L =15803906510 litter.

Increased withdrawal of groundwater for irrigation has adversely affected the domestic water supply and it has become necessary to go for deep bored-wells with power pumps to maintain rural water supply systems in almost all the villages in the area. However, no rules and regulation to install a new bore well, as a result no statistics are available for the number of bored-irrigation wells constructed by the farmers in the study area. It is a common sight to find three or four bored-wells within an acre of land under irrigation. The above situation has to be mitigated by immediate initiation of suitable long-term water supply augmentation strategy for enhancing the groundwater recharge.

Table 5.3: Present water requirement by human being in the Study Area

Name of Thana	Population	Daily Need	Total W for People	Total Abstraction (L)
Phulbari	176023	46	2914940880	40613960880
Birampur	170806	46	2828547360	16457283360
Nawabgonj	229337	46	3797820720	38770380720
Parbattipur	365103	46	6046105680	74895781680

Data Source: UNDP and BBS

5.2 IMPACTS ON GROUNDWATER

For time series analysis yearly groundwater level data of four Upazila of Dinajpur District have been collected. The data of Parbattipur and Nawabgonj Upazila were mentioned during 1985 to 2004, Birampur Upazila was mentioned upto 1993 to 2004 and the data of Phulbari has been mentioned during 1985 to 2010 due to their availability.

5.2.1 Parbattipur Upazla

In Parbattipur Upazilz groundwater table depth vary from 5.89 m to 2.24m from surface during the period 1985- 2004. Figures 5.2 and 5.3 show the water table fluctuation of Parbattipur Upazila which indicates the decreasing trend. Time series analysis shows that ground water level declines at a rate of 0.116 m/year in well GT2777043 and 0.081 m/year in the well GT2777042 and in last 20 years the groundwater level decreases about 2.22m and 1.62 m. The groundwater depletion rate in drought season is 0.120 m/year and 0.098m/year and in monsoon season this 0.163m/year and 0.062m/year.

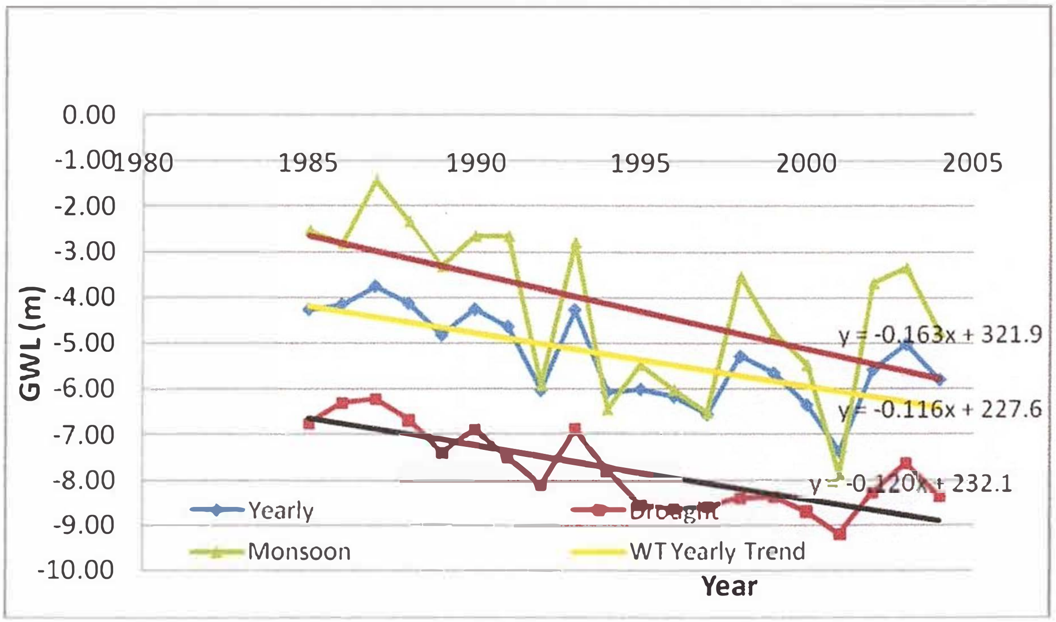


Figure 5.2: Water table fluctuation along with trend line in Parbattipur Upazila (Well Id: GT2777043)

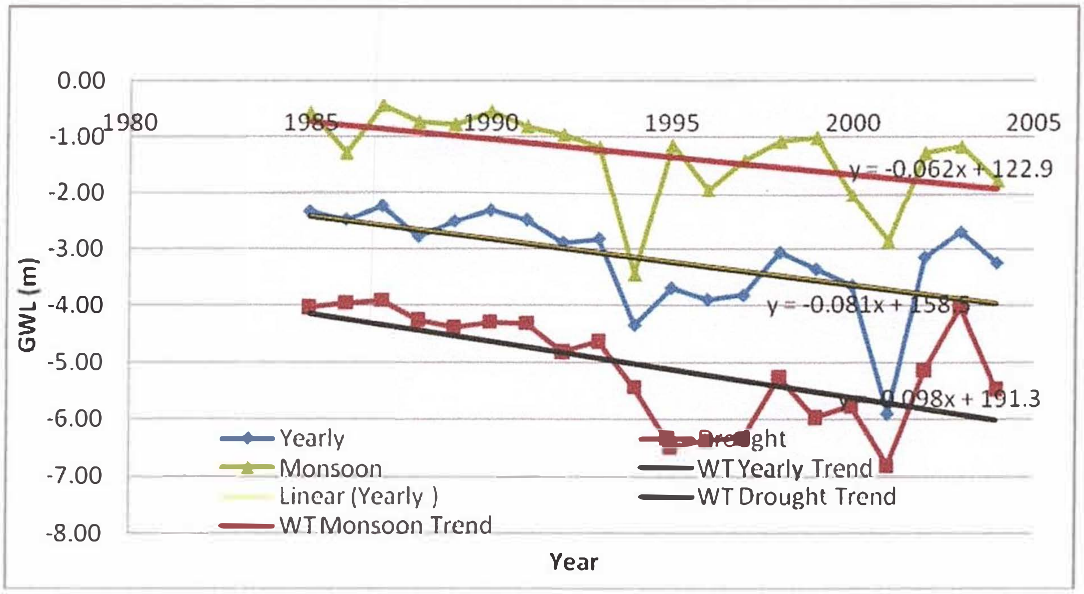


Figure 5.3: Water table fluctuation along with trend line in Parbattipur Upazila(Well Id: GT2777042)

5.2.2 Nawabgonj and Birampur Upazila

In Nawabgonj and Birampur Upazilz groundwater table depth from surface are 4.19 m and 5.89m respectively during the period 1985- 2004. Figures 5.4 and 5.5 show the water table fluctuation of Nawabgonj and Birampur Upazila which indicates the decreasing trend. Time series analysis shows that ground water level declines at a rate of 0.052m/year in Nawabgonj and 0.058 m/year in the Birampur Upazila and in last 20 years the groundwater level decreases about 1.04 m in Nawabgonj and in Birampur it is1.16m. The groundwater depletion rate in drought season is 0.054m/year in Nowabgonj and in Birampur this rate is 0.053m/year. On the other hand in monsoon season groundwater depletion rate is 0.062m/year in Nowabgonj and in Birampur this rate is 0.054m/year.

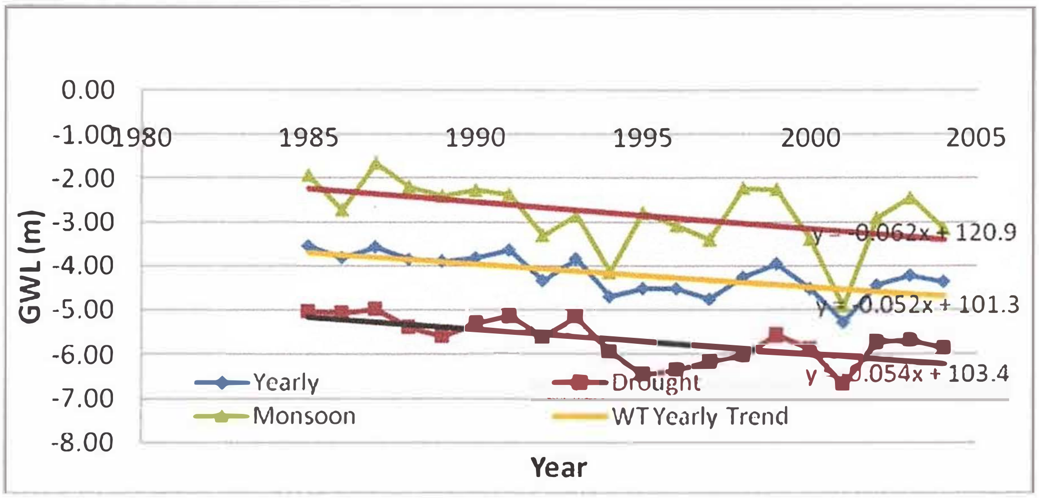


Figure 5.4: Water table fluctuation along with trend line in Nawabgonj Upazila (Well ID: GT2769040)

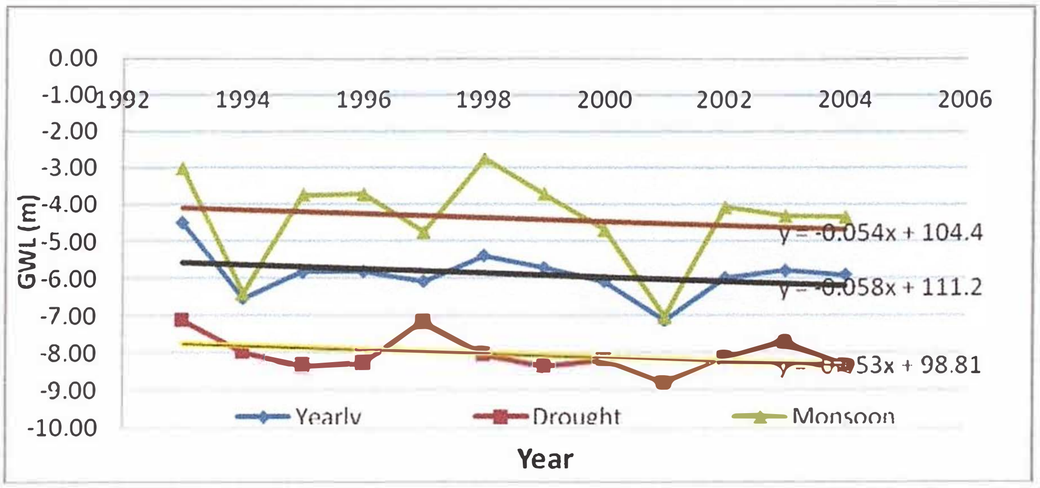


Figure 5.5: Water table fluctuation along with trend line in Birampur Upazila (Well ID: GT2710001)

5.2.3 Phulbari Upazila

In Phulbari Upazila groundwater table depth from ground surface is 5.04 m during the period 1985- 2010. Figures 5.6 and 5.7 show the water table fluctuation of Phulbari Upazila which indicates the decreasing trend. Time series analysis shows that ground water level declines at a rate of 0.166m/year in well GT2738017 and 0.078 m/year in the well GT2738018 and in last 20 years the groundwater level decreases about 3.32m. The groundwater depletion rate in drought season is 0.209m and in monsoon season is 0.152m in well GT2738017 and the groundwater depletion rate in drought season is 0.104m and in monsoon season is 0.080m in well GT2738018.

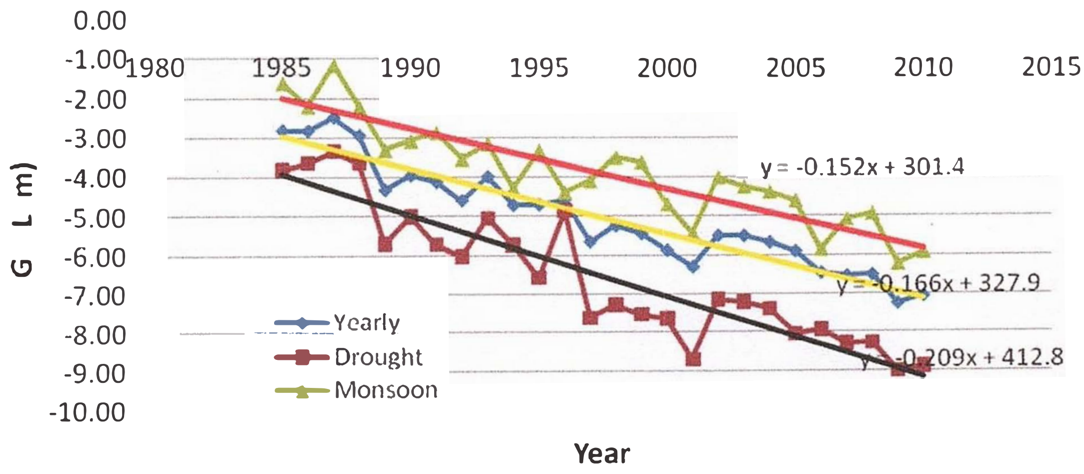


Figure 5.6: Water table fluctuation along with trend line in Phulbarir Upazila(Well ID:GT2738017)

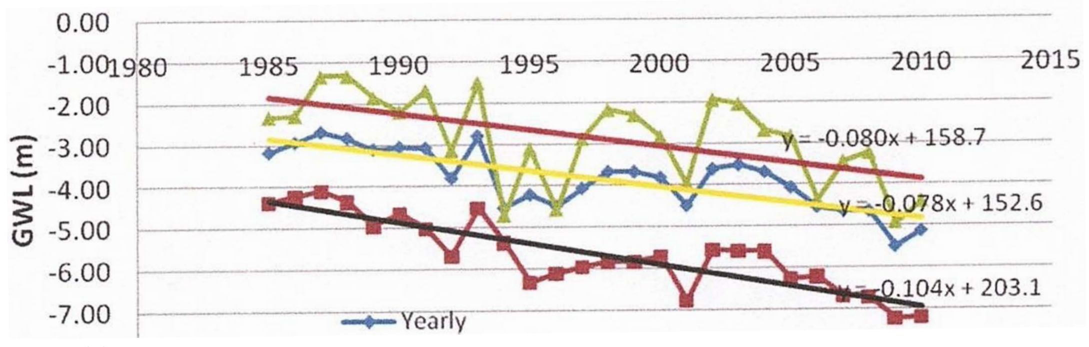


Figure 5.7: Water table fluctuation along with trend line in Phulbarir Upazila(Well ID: GT2738018)

5.2.4 3D Presentation of GWL in Different Years in Monsoon and Drought Season

A complete scenario of groundwater table gradient of 6 wells shows a progressive declining trend in 4 Upazilla Maximum depth to groundwater table occurs in the months of March, April and May mainly due to irrigation abstraction and natural drainage. The 3D figure of groundwater table depth from surface in the study area is very from 2m to 8m. The 3D figures show five years interval situation i.e. 1993, 1998 and 2003 of monsoon season and drought season. In drought season it shows a convergence and in monsoon season it shows divergence condition (Figures 5.8.a to 5.8.f).

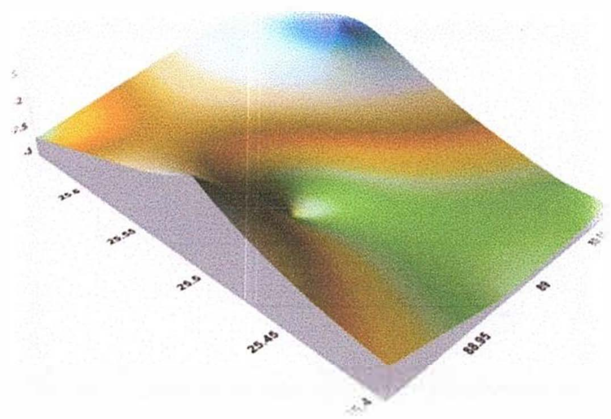


Figure 5.8 (a): GWL in Monsoon Season, 1993

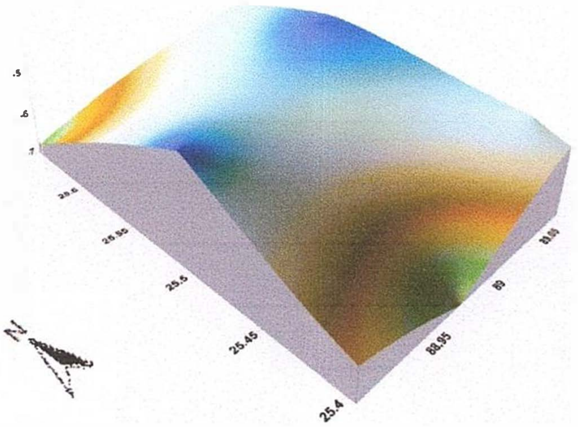


Figure 5.8 (b): GWL in Drought Season, 1993

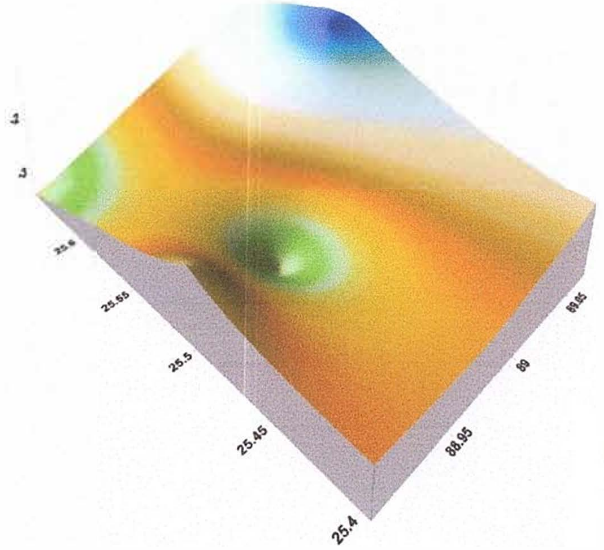


Figure 5.8 (c): GWL in Monsoon Season, 1998

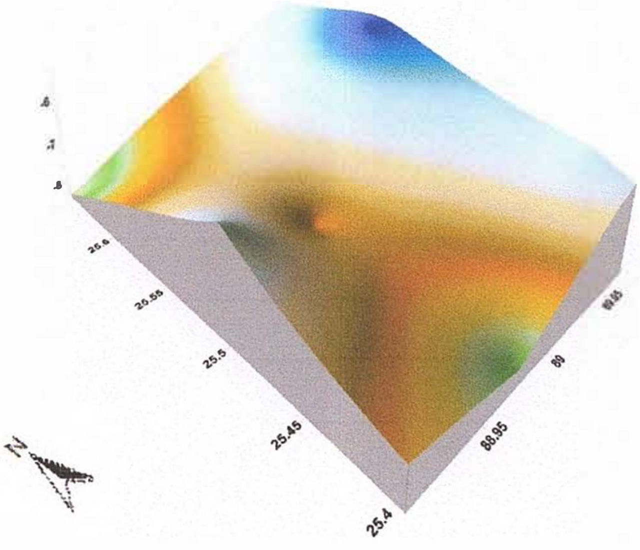
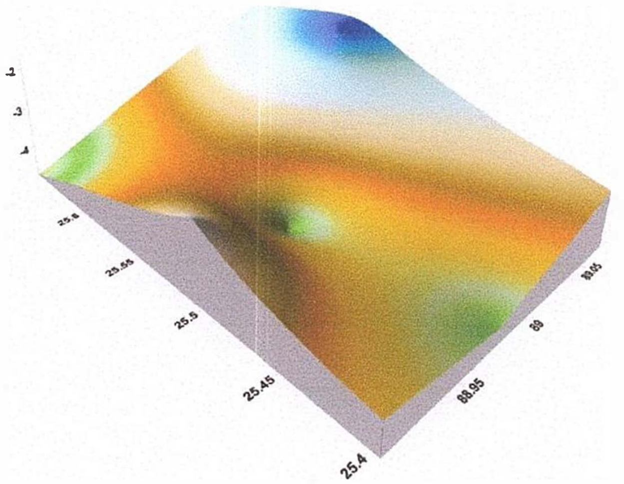


Figure 5.8 (d): GWL in Drought Season, 1998



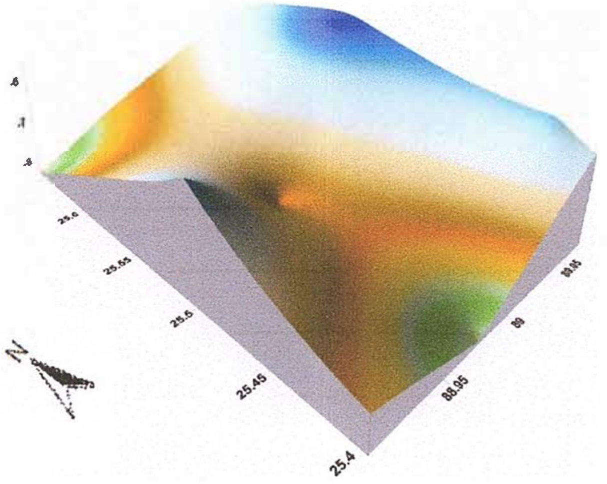


Figure 5.8 (e): GWL in Monsoon Season, 2003 Figure 5.8 (f): GWL in Drought Season, 2003

The 3D figure of groundwater table depth from surface in the study area is very from 2m to 8m. In drought season it shows a convergence and in monsoon season it shows divergence condition Water table fluctuation shows that during the peak time of monsoon, groundwater table almost remains to its original position before 1998 but after 1998 groundwater table do not return to its original position during the peak time of monsoon especially in the northern areas and recent trend shows that the rate of depletion is much more prominent.

This situation is further deteriorated in extreme dry condition. Water table in the study area has been going down steadily. This is mainly due to higher abstraction for irrigation and other causes like upstream diversion of water from common rivers are also responsible. Therefore hydrological or groundwater drought will occur in the study area. For preparing the 3D we have to use the data during 1993 to 2003 because the data of all six wells were available in this time.

5.2.5 Preparation of groundwater Level and Grid Vector using Surfer

Groundwater drought is a particular type of hydrological drought that occurs when groundwater recharge heads or discharge deviate from normal. Groundwater direction was identified by using contour and vector grid map using surfer 8 in drought season. Figures 5.9 to 5.11 show the groundwater level (left) and grid vector (right) of drought season of ten years interval and figures 5.12 to 5.14 show the groundwater level (left) and grid vector (right) of monsoon season of five years interval during 1985 to 2004.

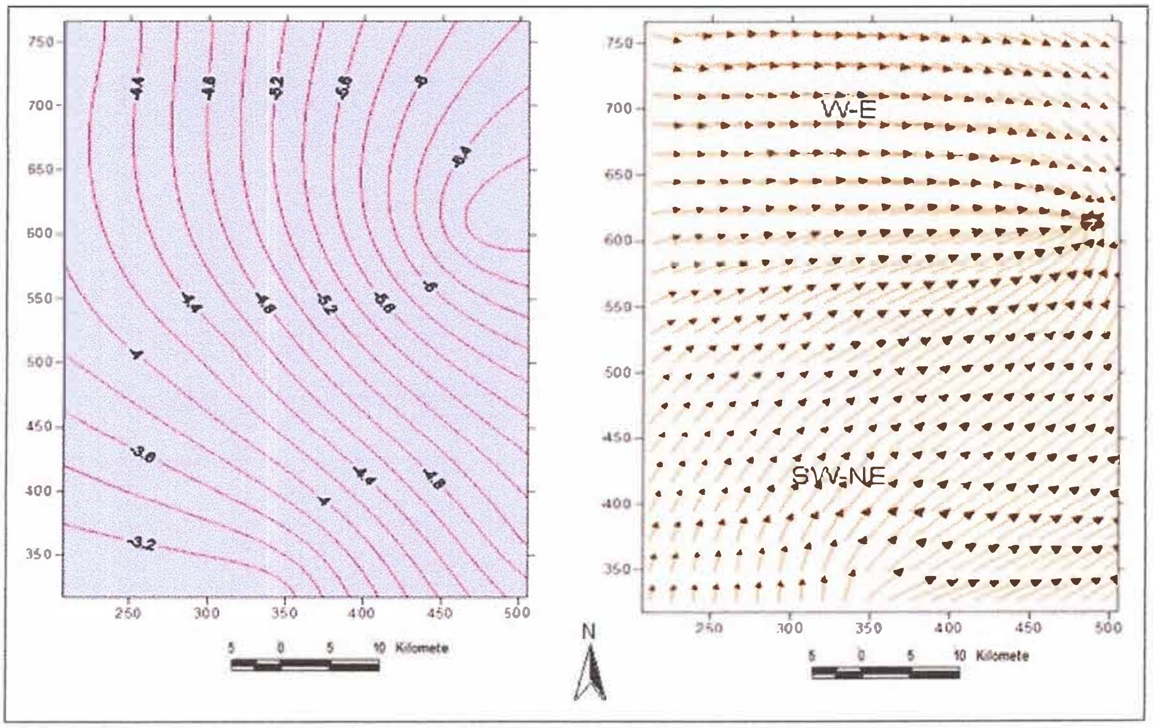


Figure 5.9: Level of ground water (Left) and grid vector map (right) in draught season, 1985

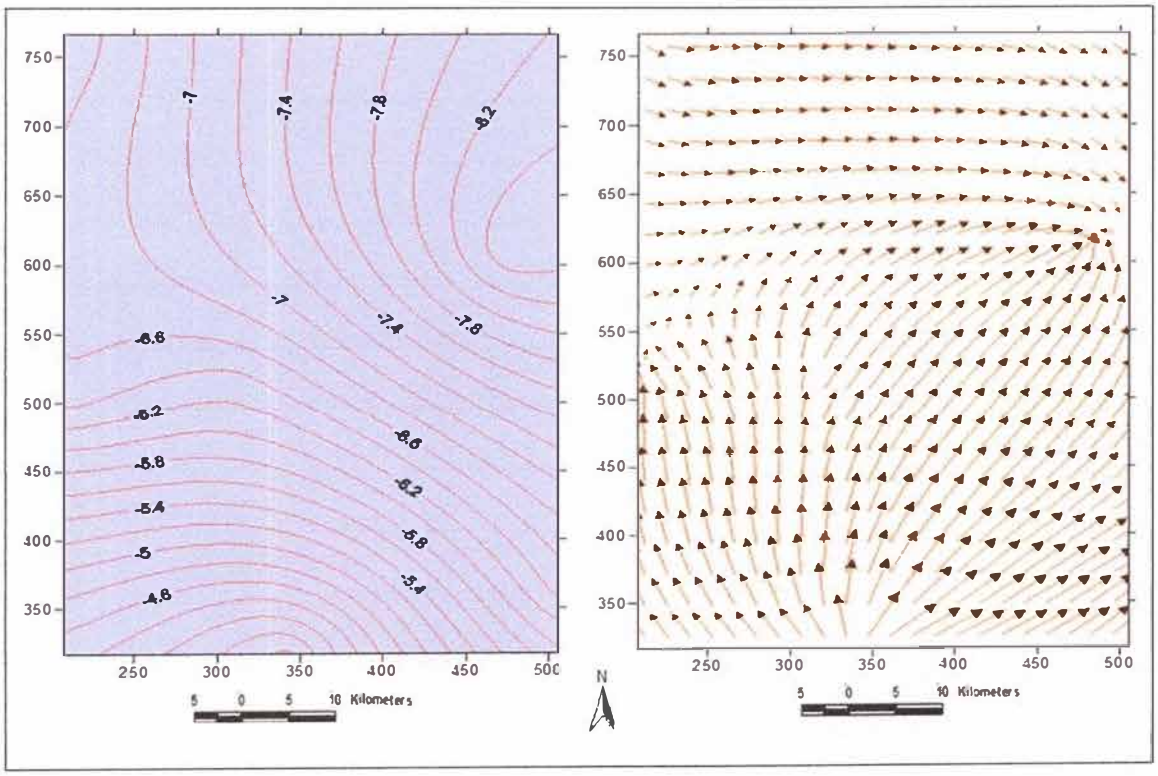


Figure 5.10: Level of ground water (Left) and grid vector map (right) in draught season, 1995

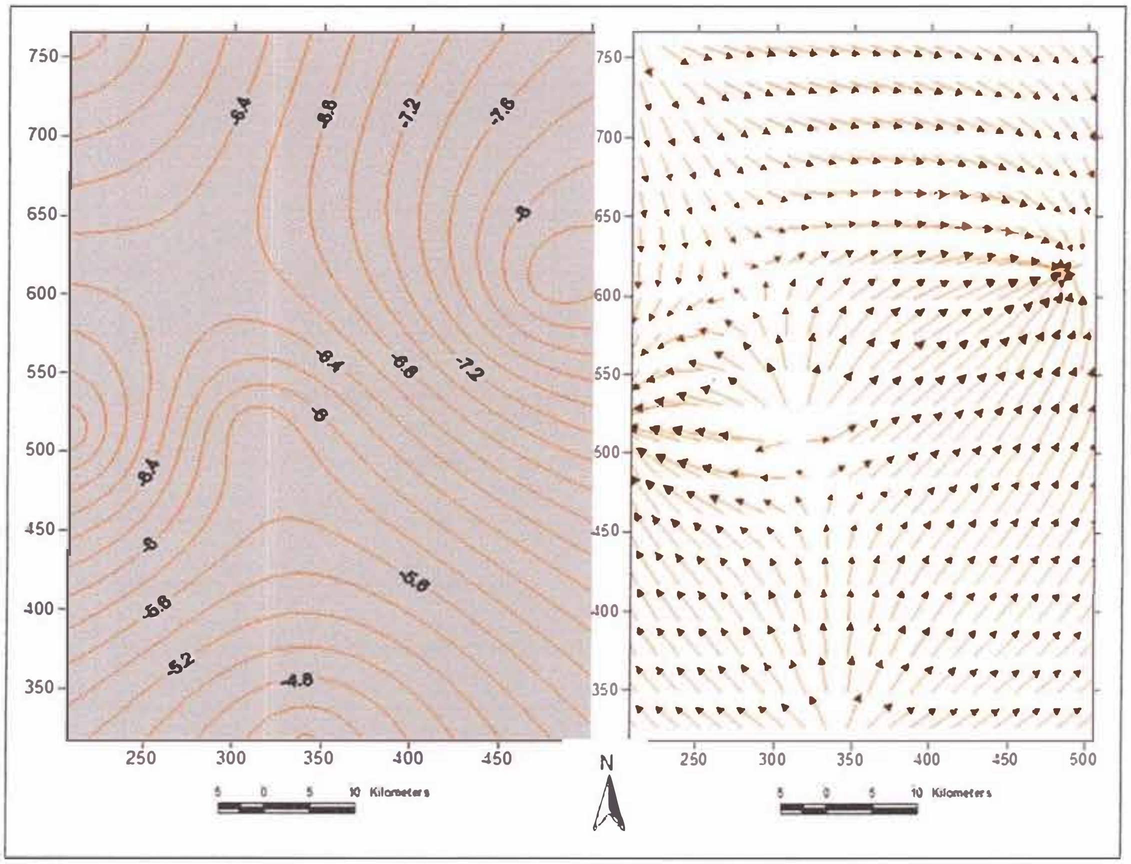


Figure 5.11: Level of ground water (Left) and grid vector map (right) in draught season, 2004

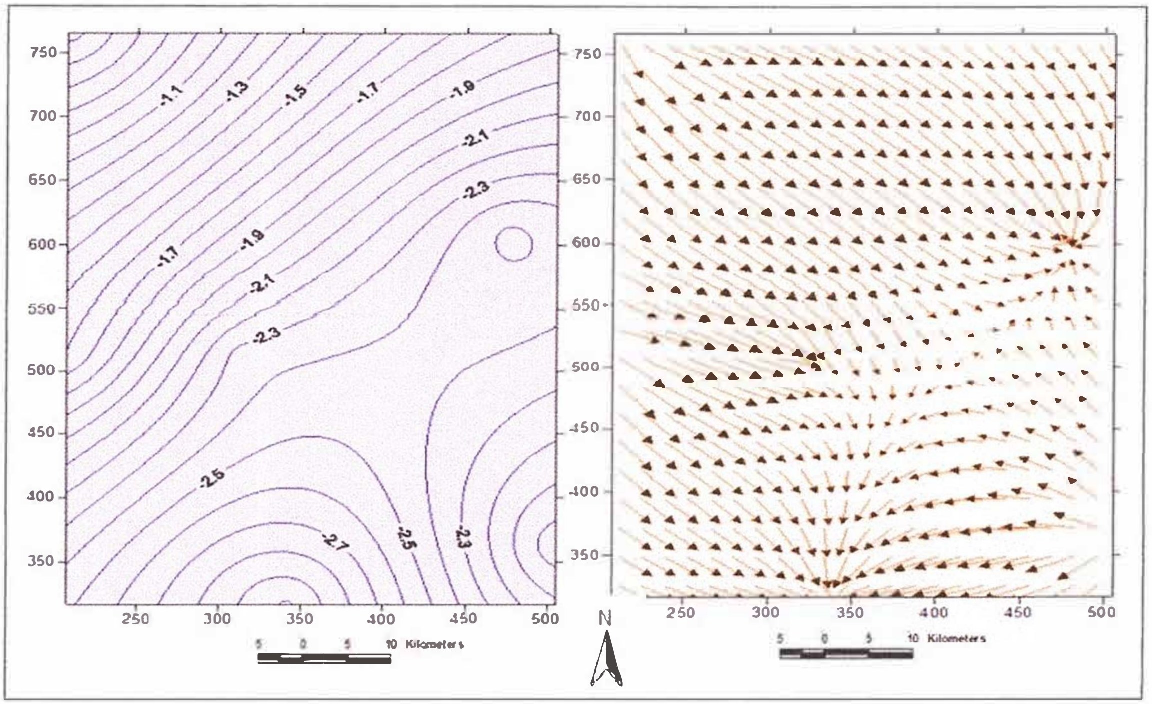


Figure 5.12: Level of ground water (Left) and grid vector map (right) in monsoon season, 1985

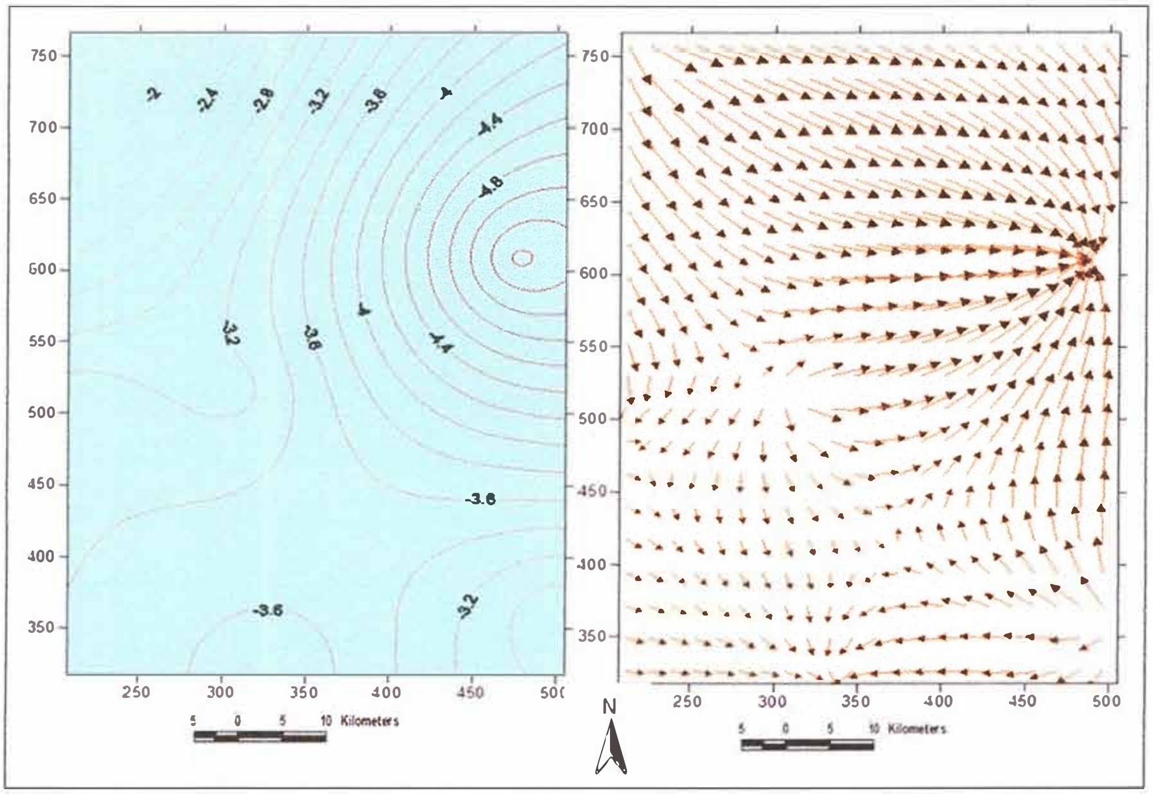


Figure 5.13: Level of ground water (Left) and grid vector map (right) in monsoon season, 1995

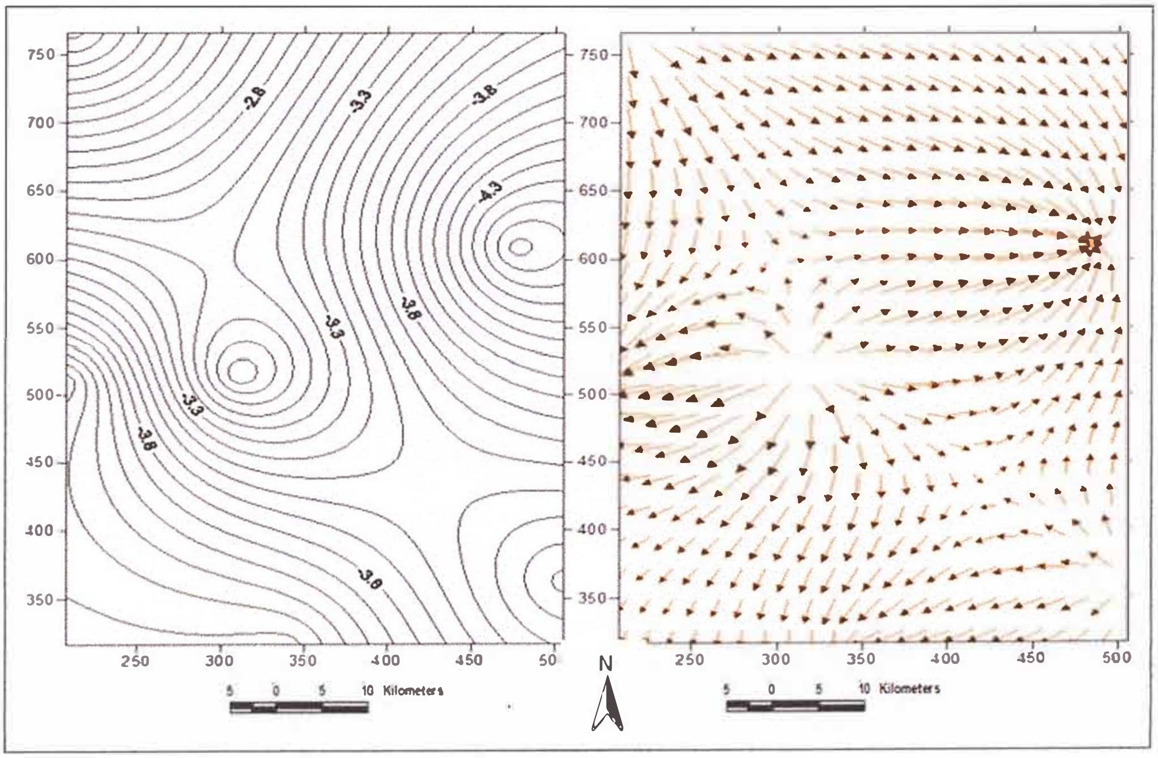


Figure 5.14: Level of ground water (Left) and grid vector map (right) in monsoon season, 2004

Water table fluctuation shows that during the peak time of monsoon, groundwater table almost remains to its original position before 1998 but after 1998 groundwater table does not return to its original position during the peak time of monsoon especially in the northern areas and recent trend shows that the rate of depletion is much more prominent. This situation is further deteriorated in extreme dry condition. Water table in the study area has been going down steadily. This is mainly due to higher abstraction for irrigation and other causes like upstream diversion of water from common rivers are also responsible. Therefore hydrological or groundwater drought occurred in the study area. Though surface water increases during monsoon but decreases in the winter, resulting more water will be required for irrigation in winter. Irrigation would be more dependent on groundwater withdrawal. Overexploitation of groundwater to meet the growing irrigation requirement has lead to environmental problems.

A progressive declining trend of groundwater level possibly due to lack of replenishment and/or over exploitation of groundwater resources. The increasing demand for irrigation may result in decline of groundwater level. The ultimate effect of such a condition of declination shall be sagging of inter-granular void or pore space within the aquifer resulting in poor aquifer system (Jahan *et al.,* 2010).

According to the IPCC (2008), by 2030 groundwater demand in the developing countries may increase by 30%. Another study carried by MPO (1991) cumulative water demand of Bangladesh may increase 44% by 2025. Considering the maximum recharge calculation as one third of the rainfall, by 2030 the present study reveals that rainfall may increase about 16% in study area. Groundwater recharge calculated by equation 3.5 indicates that long term mean (1954-2010) recharge of study area is 279 mm per year. Groundwater recharge in the study area from rainfall may become 300 and 308 mm by 2030 and 2050 respectively. In Phulbari recharge may increase by 7.5mm.

5.3 GROUNDWATER LEVEL DEPLETION DUE TO COAL MINING

In order to explore the coal a hole of 1.2 x 1.2 sq. km. has to be dug at a time. The over burden have to be dumped backward of the hole and the hole will be migrated from north to southward (Figure 5.15).

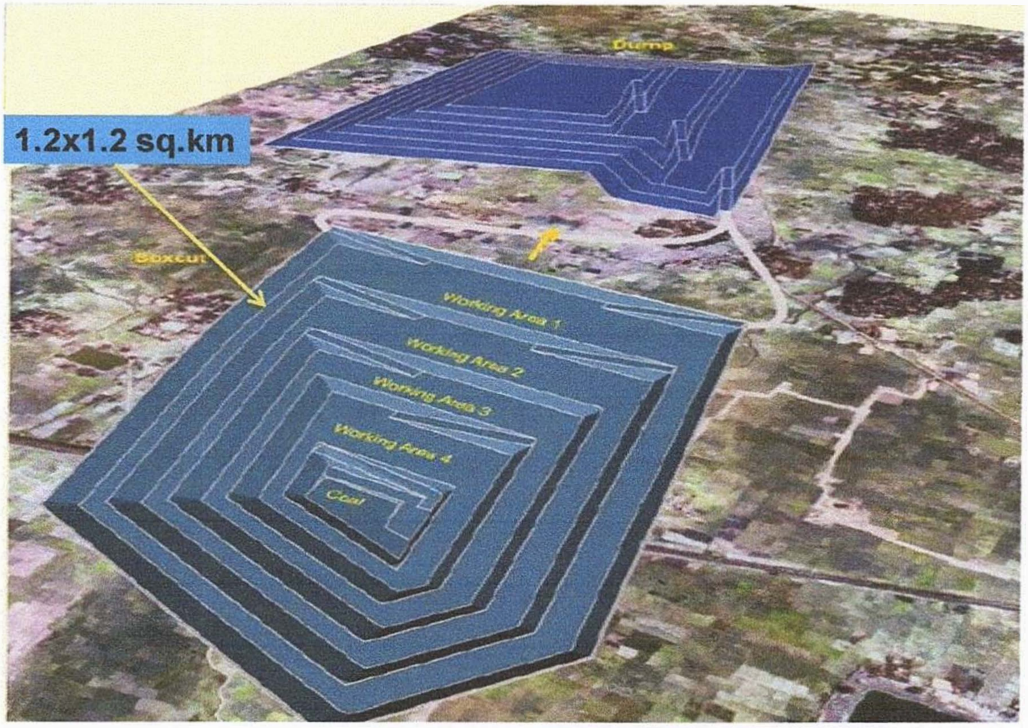
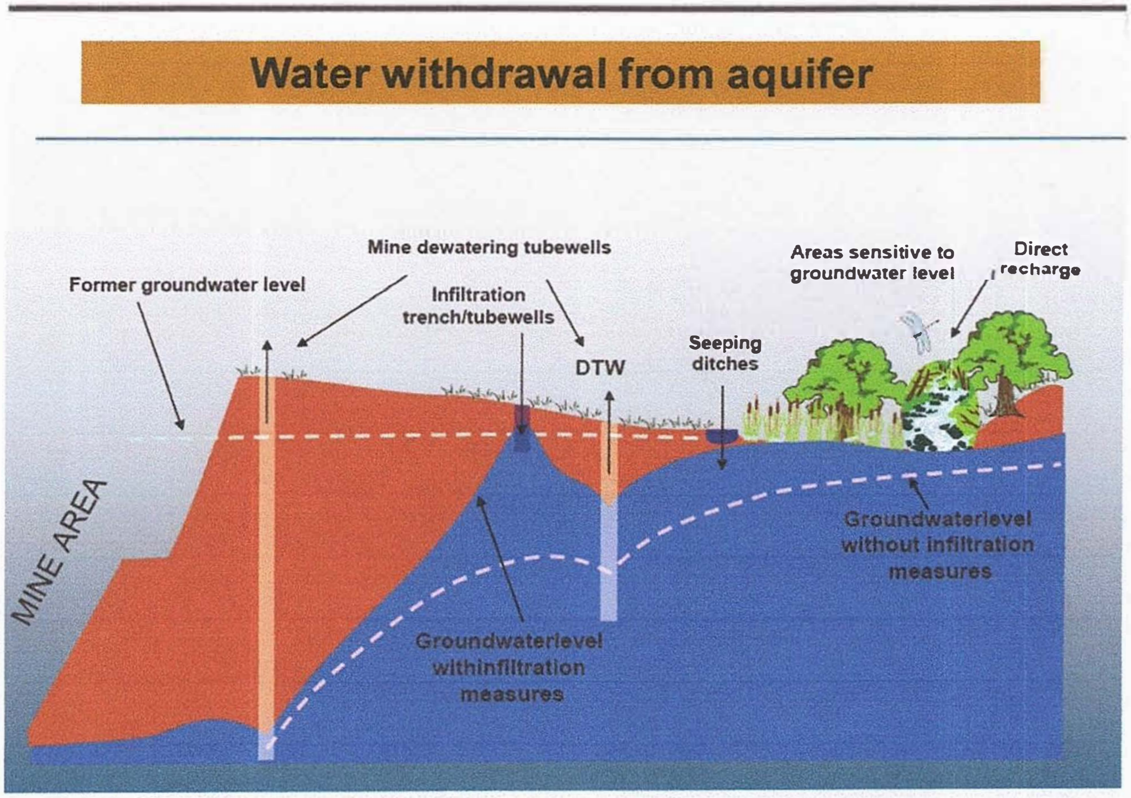


Figure 5.15: Mining process of AEC

As coal seam lie beneth the groundwater table the hole will fil up by the groundwater. And before reching to hole water have to pump out. As a result water level has to be drawdown and a cone of depression will be created (Figure 5.16).



Courtesy by AEC, 2005

Figure 5.16: Water withdrawal from aquifer

The rivers of the study area have to be diverted from N-S direction to W-E direction (Figure 5.17). This will cause the hamparing on nature. As a result unexpected natural disaster may caused such as land subsedences, earth quake, land slide etc.

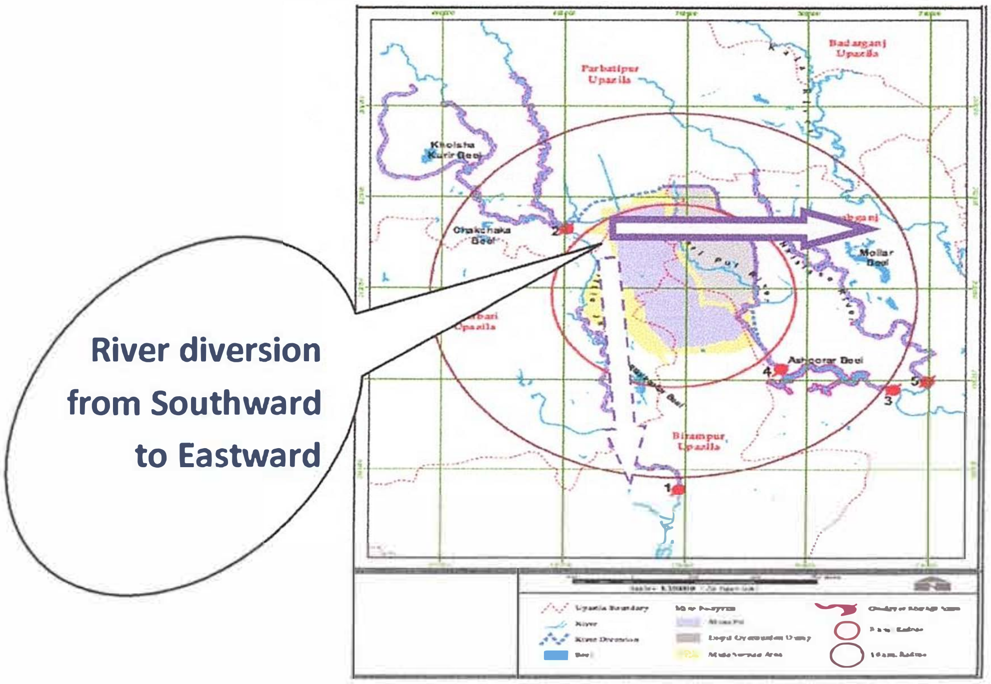


Figure 5.17: River diversion *(Courtesy by AEC, 2005)*

As the mine migrates southwards, the ring of dewatering bores will expand as well (Figure 5.18).

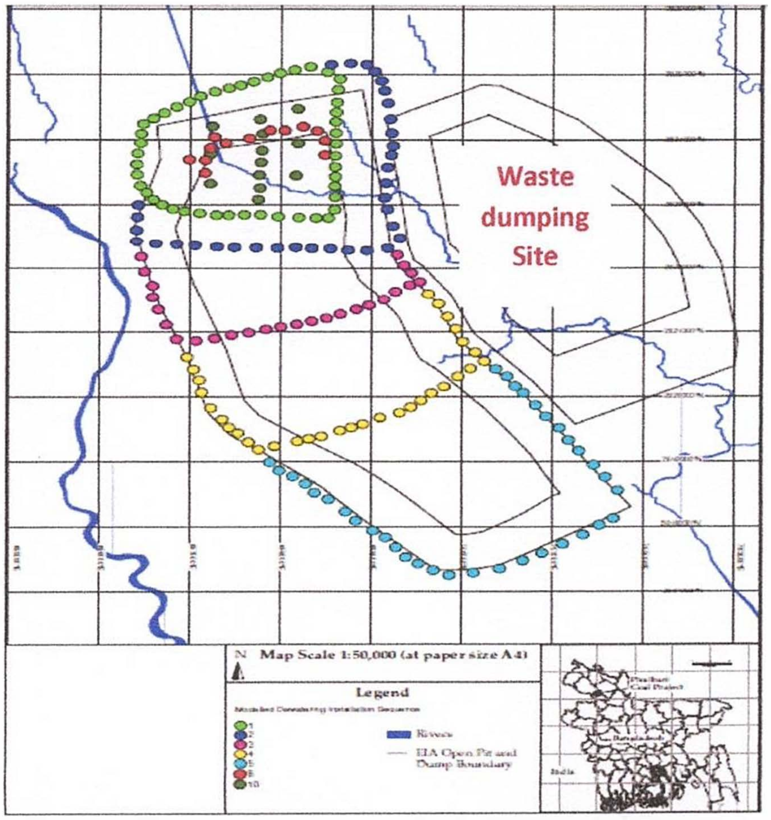


Figure 5.18: Dewatering Plan of AEC and modified by Author

Table 5.4 shows the mine dewatering plan by Asia Energy Corporation in proposed Phulbari open pit coal mine for thirty years.

Table 5.4: Mine dewatering by AEC in proposed Phulbari open pit mine

Mine Life(yr)	No of Bores	Extraction (L)	Mine Life(yr)	No of Bores	Extraction (L)
1	41	8.71×10^{10}	16	97	20.15×10^{10}
2	86	18.85×10^{10}	17	101	20.15×10^{10}
3	85	15.53×10^{10}	18	110	21.22×10^{10}
4	88	13.40×10^{10}	19	114	21.22×10^{10}
5	94	13.50×10^{10}	20	114	23.67×10^{10}
6	81	16.51×10^{10}	21	86	19.27×10^{10}
7	85	17.29×10^{10}	22	86	19.27×10^{10}
8	92	19.32×10^{10}	23	91	19.27×10^{10}
9	92	18.87×10^{10}	24	91	20.57×10^{10}
10	92	18.62×10^{10}	25	91	20.57×10^{10}
11	87	19.13×10^{10}	26	91	19.49×10^{10}
12	89	19.67×10^{10}	27	91	19.49×10^{10}
13	90	19.94×10^{10}	28	91	19.46×10^{10}
14	97	21.66×10^{10}	29	91	19.46×10^{10}
15	97	21.66×10^{10}	30	91	19.46×10^{10}

Data source: AEC, 2005

5.3.1 Scale and Impact of Mine Dewatering

All of the mines propose to take substantial volume of ground water in order to dewater underground mines and open pit mine. The scale of proposed mine dewatering in the Phulbari basin means that permanent changes are expected to groundwater levels, flow direction, hydrochemistry, recharge and discharge mechanisms of regional aquifers and potentially first aquifers that is shallow aquifer. The projection has shown that groundwater drawdown from mining is conical, diminishing with distance from the centre of extraction. However, the special radius of influence of a drawdown cone is always significantly greater than the target area of dewatering. Contour line (Figures 5.19 to 5.21) indicates that groundwater drawdown impacts for the Phulbari open pit mine may be experienced at a distance up to 20km from the mine, elongated along the open pit length in a north-east direction. Before mining activities already the groundwater is showing the decreasing trend (Figure 5.22) due to irrigation and domestic use extensively. The depression in the water table in the vicinity of the proposed mine has been estimated to eventually be up to 105m below pre-mining levels (Figure 5.23).

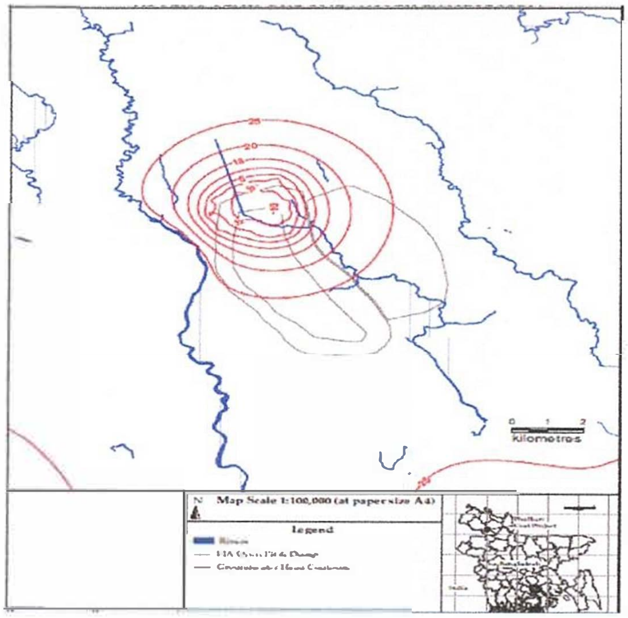


Figure 5.19: Groundwater depletion after 1 year

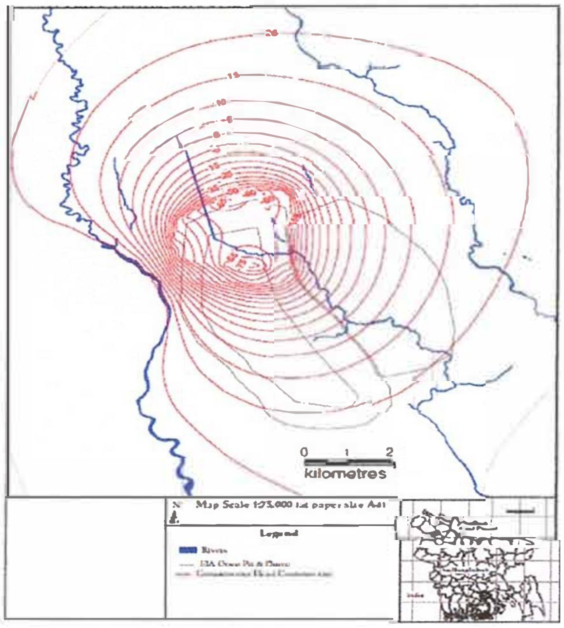


Figure 5.20: Groundwater depletion after 5 years

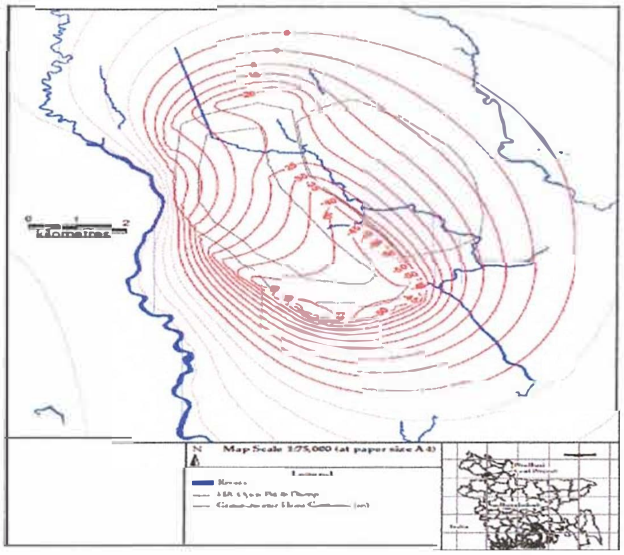


Figure 5.21: Groundwater level depletion after 10 years

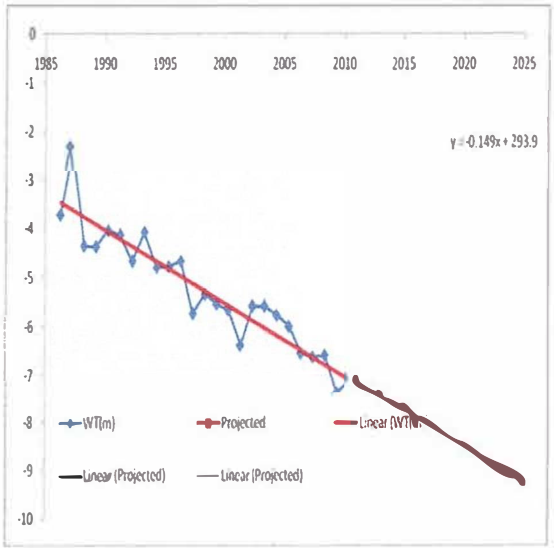


Figure 5.22: Groundwater level decreasing trend

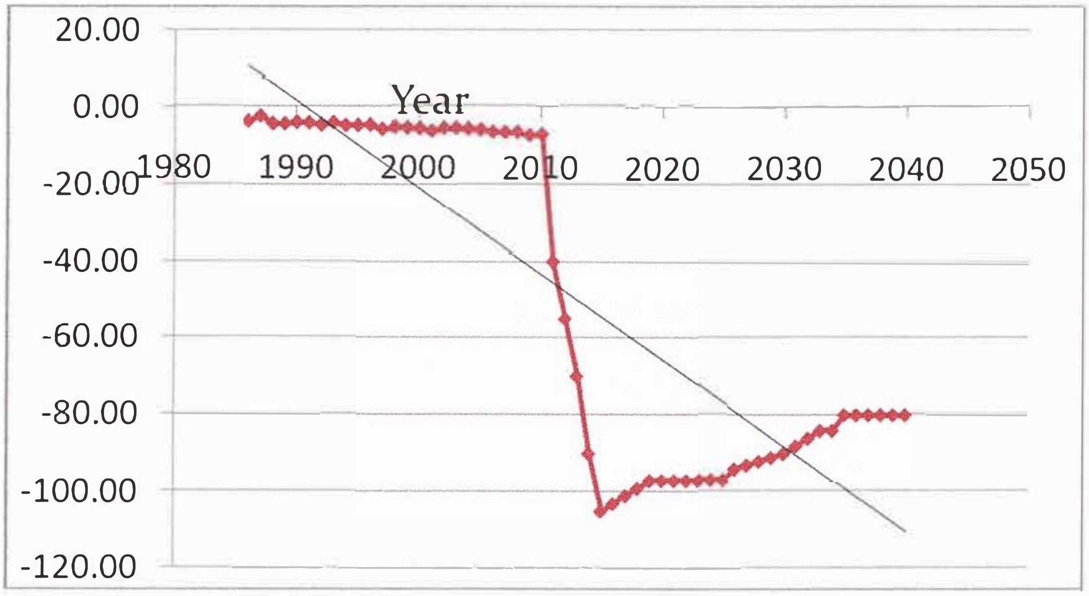


Figure 5.23: After mining activities the decreasing trend of groundwater level

"Mine water is produced when the water table is higher than the underground mining workings or the depth of an open pit surfaces mine. When this occurs, the water must be pumped out from the mine. Alternatively, water may be pumped from wells surrounding the mine to create a cone of depression in the groundwater table, thereby reducing infiltration. When the mine is operational, mine water must be continually removed from the mine to facilitate the removal of the ore. However, once mining operations end, the removal and management of mine water often end, resulting is possible accumulation in rock fractures, shafts, tunnels, and open pits and uncontrolled releases to the environment." "Ground water drawdown and associated impacts to surface waters and nearby wetlands can be a serious concern in some areas." "Impacts from groundwater drawdown may include reduction or elimination of surface water flows; degradation of surface water quality and beneficial uses; degradation of habitat; reduced or eliminated production in domestic supply wells; water quality/ quantity problems associated with discharge of the pumped ground water back into surface waters downstream from the dewatered area. The impacts could last for many decades. While dewatering is occurring, discharge of the pumped water, after appropriate treatment, can often be used to mitigate adverse effects on surface waters. However, when dewatering cease, the cones of depression may take many decades to recharge and may continue to reduce surface flows. Mitigation measures that rely on the use of pumped water to create wetlands may only last as long as dewatering occurs.

CHAPTER SIX

OPEN PIT COAL MINING:
A QUALITATIVE AND COMPERATIVE STUDY

CHAPTER SIX

OPEN PIT COAL MINING: A QUALITATIVE AND COMPERATIVE STUDY

6.1 INTRODUCTION

Mining threatens the quality and quantity of surface and ground water resources in many part of the world (Allen *et al.*, 1996; Choubey 1991; Gupta 1999; Khan *et al.*, 2005; Singh *et al.*, 2008; Singh 1998; Tiwary 2001). Mining, by its nature consumes, diverts, and can seriously pollute water resources. There, it may pollute the natural surface drainage and other water resources, including ground water (Singh *et al.*, 2007). Mine water can vary greatly in the concentration of contaminants present, and some mine water discharges can be a potential water resource, where the local water demands for industrial, irrigation, and even drinking and domestic uses can be fulfilled by effective utilization (Cidu *et al.*, 2007; Singh 1994). In the present study, the water samples were collected from the proposed Phulbari coal mine site, those were analyzed for selected eight heavy metal and compared them with the respective heavy metals to those area having the open pit coal mine and whose geographical and geological characteristic more or less equal.

6.1.1 Sampling Site and selection of parameters

Eight groundwater samples were collected from the study area (Figure 6.1). In this study all the parameters both physical and chemical have not selected. Because all the parameters are not so important for doing this study. Also to do analyze of all the parameters are time consuming and expensive. The elements which are responsible for polluting groundwater, and which could be come from the coal mining activities take under consideration. Edet and Offiong (2003) calculated the contamination index (C_d) and heavy metal pollution index (HPI) using nine heavy metal. Selected eight heavy metals such as As, Cu, Fe, Mn, Zn, Cr, Pb and Cd were analyzed to make a comparison and calculating the contamination index and heavy metal pollution index.

6.1.2 Qualitative Analysis

By using atomic absorption spectrophotometer (AAS) the groundwater chemical data were generated for selected eight heavy metals and the results were presented in table 6.1.

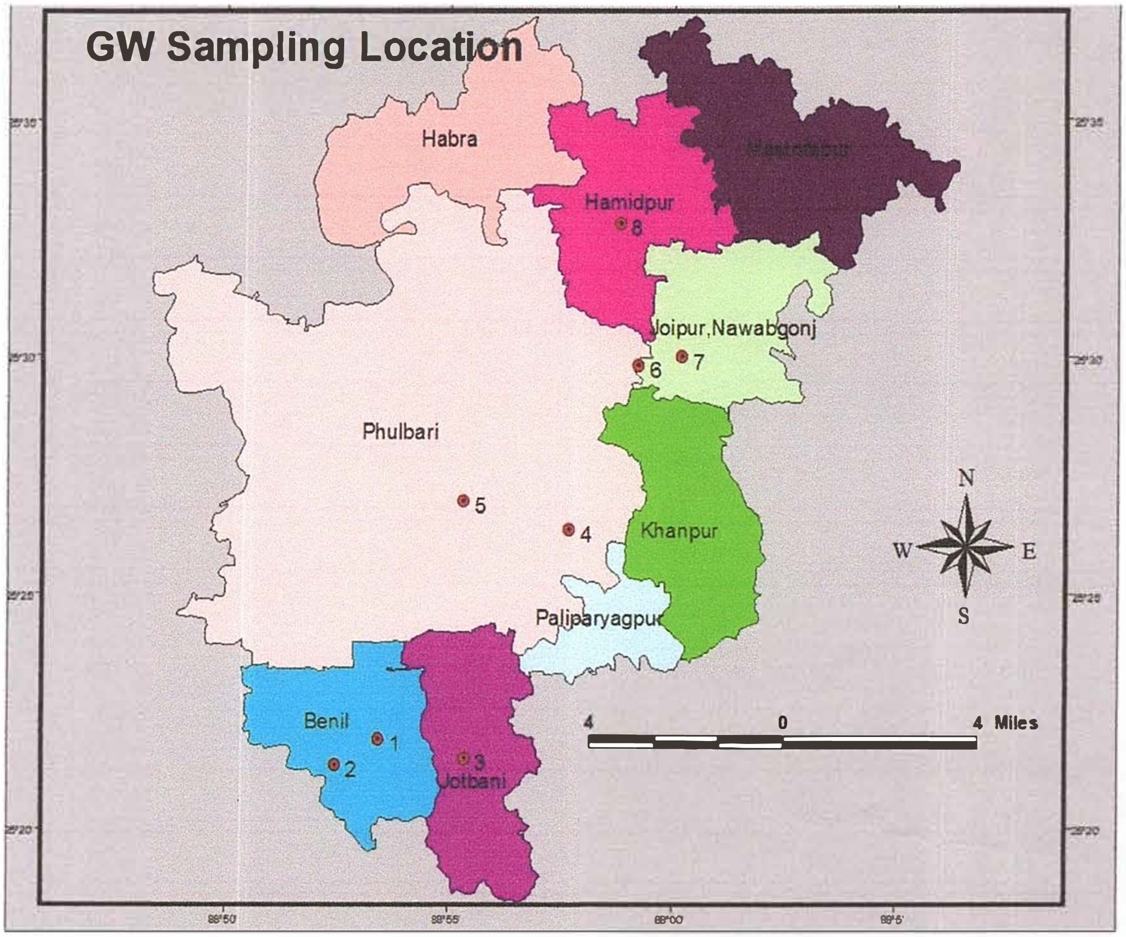


Figure 6.1: Groundwater sampling location

Table 6.1: Groundwater chemical data of study area before mining activities

Sample ID	As (ppm)	Cu (ppm)	Fe (ppm)	Zn (ppm)	Mn (ppm)	Cr (ppm)	Pb (ppm)	Cd (ppm)
1	0.01097	0.0124	0.0895	0.0403	0.0324	0.0144	0.0195	0.01
2	0.00241	0.0067	0.1404	0.0311	0.3441	0.0144	0.0785	0.0092
3	0.0199	0.0038	0.0702	0.0148	0.0154	0.0192	0.0586	0.005
4	0.00316	0.0052	0.1948	0.0835	0.0462	0.0168	0.0781	0.0103
5	0.00177	0.0038	0.0509	0.0173	0.055	0.024	0.0293	0.0139
6	0.00109	0.0029	0.2966	0.0148	0.0583	0.0216	0.039	0.0157
7	0.01958	0.0019	0.0009	0.0132	0.0627	0.0264	0.0586	0.0163
8	0.00382	0.0143	0.4686	0.009	0.0055	0.0204	0.0878	0.0164
Max	**0.0199**	**0.0143**	**0.4686**	**0.0835**	**0.3441**	**0.0264**	**0.0878**	**0.0164**
Min	**0.00109**	**0.0019**	**0.0009**	**0.009**	**0.0055**	**0.0144**	**0.0195**	**0.005**
Mean	**0.0078375**	**0.006375**	**0.1639875**	**0.028**	**0.07745**	**0.01965**	**0.056175**	**0.0121**

It was found that the analyzed value of Pb and Cd have exceeded the WHO standard before mining activities and concentration of other six heavy metal remain below the WHO standard (Table 6.2).

Table 6.2: Groundwater quality of the study area

Elements (ppm)	**Average Concentration before mining in Phulbari,Bangladesh**	**Bangladesh drinking water quality Standard**	**WHO drinking water quality standard (1997)**	**Remarks**
As	0.0078375	0.01	o.05	Below the acceptable limit
Cu	0.00637	1	2	“
Fe	0.164	0.3 - 1.0	0.3	“
Zn	0.028	5	4	“
Mn	0.077	0.1	0.5	“
Cr	0.0197	0.05	0.05	“
Pb	0.0561	0.05	0.01	5.6 times higher than who standard
Cd	0.0121	0.005	0.003	4 times higher than who standard
Source: Sample analysis result by AAS		*Source: Produced data form Singh et.al. 2010*		

6.3 CASE STUDY 1: RANIGONJ COAL FIELD, INDIA FOLLOWED BY Singh *et al.*, 2010

6.3.1 Geography and Geology of Ranigonj Coalfield, India

The Raniganj coalfield lies in the easternmost part of the Damodar Valley Coalfield and is bounded by 23^{0}25$^{'}$ N to 23^{0}50$^{'}$N latitude and 86^{0}38^{0}E to 87^{0}20$^{'}$E longitude. It covers about 1,530 km^{2} geographical areas, spreading over the Burdwan, Birbhum, Bankura, and Purulia districts in West Bengal and Dhanbad district in Jharkhand. A network of roads and railway branches link the area with other part of the country. The topography of the Raniganj coalfield is gently undulating and the elevation generally ranges from 65 to 75 m above sea level. The highest elevations are the Panchet (643 m) and Biharinath hills (451 m). The drainage pattern is mainly dendritic to subdentritic in nature (Srivastava and Mitra 1995) and most mines of this coalfield lie between two rivers, the Damodarand Ajay, which flow almost parallel to each other. The Damodar River traverses the southern part of the coalfield, flowing due east, while the Ajay River flows in the northern part. The area is a tropical region with fairly wide temperature variations. The climate of the Raniganj area is characterised by very mild winters and hot wet summers. The maximum temperature peaks at about 44^0 C during May–June and dips to 5^0 –7^0 C in December–January. Most of the rainfall (80%) occurs during the monsoon period (June–September); the annual rainfall varies from 1,200 to 1,400 mm. The Raniganj coalfield is the birth place of coal mining in India; mining started in this coalfield in 1774. Coal is currently being produced by underground as well as opencast mining methods by the Eastern Coalfield Ltd (ECL), a subsidiary of Coal India Ltd. In addition, a small portion of the coalfield is operated by BCCL (Bharat Coking Coal Ltd), SAIL (Steel Authority of India), and other private companies. The Raniganj coalfield is a part of the Gondwana Supergroup, which extends here over a rectangular area greater than 1,000 km^2. A full succession of lower gondwana and younger rocks occurs, attaining a maximum thickness of more than 3,200 m. A large part of the coalfield is occupied by coal-bearing horizons of the Barakar and Raniganj Formations. A fluvio–lacustrine coal barren sequence known as the Iron Stone Shale separates these two coal-bearing horizons. The Panchet Formation (also barren of coal) overlies the Raniganj Formation, and comprises feldspathic sandstone and red clays (Table 6.3). The Raniganj coalfield is surrounded by Archaean rocks on all sides except in the east, where its boundary is not clear, as it is covered by alluvium. The dip of the strata is generally southerly; the oldest rocks are exposed along the northern margin, and successively younger strata outcrop towards the south. The northern margin represents the normal depositional boundary between the basal Gondwana and the basement Archaeans while the western and southern boundaries are faulted. The Talchir Formation is exposed in the northwest and northern border of the field and comprises a boulder bed overlain by greenish sandstone and shales. The Barakar Formation occupies an irregular 155 km^2 area along the northern half of the field and consists of white and buff massive sandstones and grits with occasional shale beds. It includes many workable coal seams in the Mugma, Salanpura, and Tara mining areas. The Ironstone Shales comprise about 365 m of carbonaceous shales containing nodules of clay ironstone. The Raniganj formation outcrops along the central and southern part of the field, consisting of greyish fine sandstone, carbonaceous shales, and extensive coal seams, including the Sodepur, Sripur, Satgram, Kunustoria, Pandaveswar, Kajora, Bankola, Sonepur Bazari, and Jhanjra mining areas (Table 6.3).

Water for irrigation should satisfy the needs of soil and plants of the area for normal growth and crop production.

Table 6.3: Stratigraphic succession of Raniganj coal mine area

Geological age	Formation	Major lithology
Recent	River alluvium	Sand, clay and limestone
Jurassic to Cretaceous	Rajmahal Trap/Intratrappeans	Dolerite, mica peridotite dykes and sills
Upper Triassic	Supra Panchet	Sandstone and shales
....	Unconformity	....
Lower Triassic	Panchet Series	Medium- to coarse-grained feldspathic sandstone and red clays
Upper Permian	Raniganj measures	Fine- to medium-grained sandstone, sandy or micaceous shale, coal seams, siltstone, and carbonaceous shale
Middle Permian	Iron Stone Shale	Carbonaceous shale containing nodules of clays
Lower Permian	Barakar measures	Massive sandstones and grits with shale beds and coal seams
Upper Carboniferou	Talchir series	Tillites to boulder conglomerate, yellowish green sandstone, etc.
....	Unconformity	....
Archaean	Metamorphic rocks with igneous intrusive	Granites, granitic gneiss, hornblend schist traversed by bands and patches of amphibolite, pegmatite, and veins of quartz

Table 6.4 represents the groundwater quality of Raniganj coal field and table 6.5 represents the groundwater quality of Parli thermal power plant in India.

Table 6.4: Groundwater quality of Ranigang Coalfield area, West Bengal

Elements (ppm)	Minimum Concentration	Maximum concentration	Average Concentration
As	0.0008	0.0337	0.01725
Cu	0.0067	0.0519	0.0293
Fe	0.071	0.973	0.522
Zn	0.0174	0.2017	0.10955
Mn	0.004	0.356	0.18
Cr	0.0052	0.0836	0.0444
Pb	0.0102	0.0611	0.03565
Cd	0.0001	0.0054	0.00275

Source: Singh et al., 2010

Table 6.5: Groundwater quality of Parli Thermal Power Plant, Maharashtra

Samples	Heavy Metals (ppm)											
	Arsenic		Copper		Cadmium		Lead		Mercury		Zinc	
	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
GW 1	5.14	1.26	0.13	0.02	0.18	0.05	0.05	0.01	6.23	0.04	4.35	0.2
GW 2	8.55	0.67	0.04	0.005	0.25	0.03	0.05	0.02	1.42	0.21	3.78	0.3
GW 3	6.53	0.49	0.07	0.005	0.19	0.02	0.07	0.02	1.96	0.04	4.36	0.4
GW 4	5.08	0.26	0.05	0.005	0.16	0.02	0.05	0.015	2.78	0.15	4.07	0.4

(Source: Nalawade *et al.,* 2012) GW – Groundwater, Avg – Average Value of Heavy Metals, SD – Standard Deviation,

6.4 CASE STUDY 2: OPEN PIT COAL MINE OF POLTEGOR, POLAND FOLLOWED BY Libicki, 2006

6.4.1 Geography and Geology of Poltigor, Poland

The test disposal site was located in an old sand pit situated in Boguszowice, about 200km southwest of Wroclaw. The sand was exploited for back filling of underground bituminous coal mines until 1969. The disposal site is situated on a morphological elevation. The natural surface elevation varies from 275m to 280m above the sea level. The surrounding area is covered with meadows and arable fields, and at a distance of about 1 km toward the east there is a forest.

6.4.1.1 Climate

Since the disposal site was located above the groundwater table, the amount of precipitation (which is the source of the aquifer recharge as well as the medium for pollutant leaching and transportation into groundwater) was a great importance in the investigation. The presentation of these data should be helpful for applying the research results of different or similar conditions in other of the world.

The average precipitation for the region during the investigated period was 788.0mm and varied from 633.0 mm (in 1979) to 958.0mm (in 1975). The height monthly precipitation was observed in August 1977 (156.5mm) and the lowest in February 1976 (3.6mm). The maximum daily precipitation (62.5mm) was observed in August 1975.

The highest average monthly temperature was $+19^0$c and was recorded in July 1976, while the lowest monthly temperature was -4.2^0c and was observed in January 1979. The average yearly temperature were from $+7.8^0$c (in 1978) to $+9.2^0$c (1975).

The above characteristics show that the disposal site under investigation was located in a moderate climate typical for central Europe and the central and northern United States. However, the influence this climate exerts on the research is comparable to the influence of climatic condition on other areas.

6.4.2 Geology and Hydrogeology

The geologic structures of Poltegor include Carboniferous, Tertiary and Quaternary formation are described below:

6.4.2.1 Carboniferous Formation

The carboniferous formation is represented by technically disturbed shales and sandstones with coal deposits in the upper carbon area. It occurs at a depth of over 100m.

6.4.2.2 Tertiary formation

Tertiary formation lies directly over the carboniferous formation is composed of mainly clays containing small deposits of sand and gypsum. The thickness of this formation varies from 50 to 150m.

6.4.2.3 Quaternary formation

The quaternary formation lays on the impermeable tertiary subsoil and is formed from sand and clays 10-40m thick.
Specific yield: Between 0.12 and 0.18.
Permeability coefficient: from 3 to 10 meters per 24 hrs
The thickness of the aquifer is between 1 and 12 m.

Groundwater table occurs at a depths from 6.5 to 15 m below the ground surface. The absolute value of the position of the water table within the disposal site fluctuated within a range of 262 to 266m above the sea level. Velocity of the flow of groundwater 0.15 to 3m/day

6.4.2.4 Central Disposal Pit

The central pit, where waste were disposed first, was about 500m long and 170m wide, and had an average depth 16.5m. The pit bottom and slopes were sand, sometimes containing clay and silt. The thickness of the sand layer in the northern part of the disposal area has about 7.5m and in the southern part it increased to about 9m but in some places decreased to zero. The groundwater table was from 0 to 2m below the pit bottom.

6.4.2.5 Western disposal pit

The western pit, planned as a reserve disposal area, was about 580m long, about 150m wide and had an average depth of about 7m. Its bottom and sides were sand, sometimes containing clay and silt. The thickness of the sand layer in the pit bottom varied from about 1m at its eastern end to about 6m in its western end. The groundwater table was from 0.5 to 3m below the pit bottom.

6.5 COMPARISON OF GROUNDWATER QUALITY BANGLADESH VS ELSEWHERE

Table 6.6 shows the heavy metal concentration before mining activities and after mining activities in Poland and also shows the how much increased their concentration after mining than before.

Table 6.6: Groundwater concentration before and after mining activities in Poltegor, Poland

Elements (ppm)	Average Concentration before mining activities in Poltegor,Poland	Average Concentration after five years of starting mining activities in Poltegor,Poland	Incrised by percentage	Increased (folded)
As	0.0168	0.057	239.29	3.3929
Cu	0.023	0.0313	36.09	1.3609
Fe	4.6	8.75	90.22	1.9022
Zn	0.36	0.497	38.06	1.3806
Mn	0.24	0.79	229.17	3.2917
Cr	0.0064	0.075	1071.88	11.7188
Pb	0.0165	0.047	184.85	2.8485
Cd	0.0024	0.0058	141.67	2.4167

Source: EPA, 1979 and modified by Author, 2014

Table 6.7 shows the heavy metal concentration of before mining activities in Bangladesh and Poland.

Table 6.7: Heavy metal concentrations before mining activities of different countries

Heavy Metals	Phulbari, Bangladesh	Poltigor, Poland
As	0.007525	0.0168
Cu	0.00637	0.023
Fe	0.164	4.6
Zn	0.028	0.36
Mn	0.077	0.24
Cr	0.0197	0.0064
Pb	0.0561	0.0165
Cd	0.0121	0.0024

Table 6.8 represents the average concentration of heavy metals after mining activities of India and Poland. From this table the suitable data were taken and adapted for Bangladesh.

Table 6.8: Heavy metal concentrations after mining activities of different countries

Heavy Metals	Average Concentration after five years of starting mining activities in Poltegor,Poland	Average Concentration after mining activities in Ranigonj,India	Coal storage sites of Parli Thermal Power Plant, Maharasta, India
As	0.057	0.01725	6.324863
Cu	0.0313	0.0293	0.072484
Fe	8.75	0.522	-
Zn	0.497	0.10955	4.14008
Mn	0.79	0.18	-
Cr	0.075	0.0444	-
Pb	0.047	0.03565	0.055052
Cd	0.0058	0.00275	0.155969

The predicted values were determined by multiplying the analyzed heavy metal values with the average value that was increased after mining in India and Poland (Table 6.8). The predicted value of As, Cu, Cd, Pd and Zn were adopted with Nalawade *et al.,* 2012 (India), Fe was adopted with Singh *et al.,* 2010 (India) and Mn and Cr were adopted with the value of Poltegor Coalmine, Poland. All those values that were increased by fold from the initial value of Poltehor, Poland were used as conastant value for each heavy metal for each location after mining activities in Phulbari coal mine in Bangladreh (Table 6.9).

Table 6.9: The predicted value of different location in study area

Location	As	Cu	Fe	Zn	Mn	Cr	Pb	Cd
	ppm	ppm	ppm	Ppm	ppm	ppm	Ppm	ppm
1	8.85279	0.140988	0.2685	5.958758	0.064476	0.0288	0.01911	0.1289
2	1.94487	0.076179	0.4212	4.598446	0.684759	0.0288	0.07693	0.118588
3	16.0593	0.043206	0.2106	2.188328	0.030646	0.0384	0.057428	0.06445
4	2.55012	0.059124	0.5844	12.34631	0.091938	0.0336	0.076538	0.132767
5	1.42839	0.043206	0.1527	2.557978	0.10945	0.048	0.028714	0.179171
6	0.87963	0.032973	0.8898	2.188328	0.116017	0.0432	0.03822	0.202373
7	15.80106	0.021603	0.0027	1.951752	0.124773	0.0528	0.057428	0.210107
8	3.08274	0.162591	1.4058	1.33074	0.010945	0.0408	0.086044	0.211396
Max	**16.0593**	**0.162591**	**1.4058**	**12.34631**	**0.684759**	**0.0528**	**0.086044**	**0.211396**
Min	**0.87963**	**0.021603**	**0.0027**	**1.33074**	**0.010945**	**0.0288**	**0.01911**	**0.06445**
Mean	**6.324863**	**0.072484**	**0.491963**	**4.14008**	**0.154126**	**0.0393**	**0.055052**	**0.155969**

6.6 CONCENTRATION OF SELECTED EIGHT HEAVY METALS BEFORE AND AFTER MINING ACTIVITIES

The groundwater sample was analyzed for determining the concentration of selected eight heavy metals (As, Cu, Fe, Zn, Mn, Cr, Pd and Cd) in the study area. Each pollutant is discussed with respect to the change which occurred before and after mining activities in different locations which have the same geographical and geological characteristics.

6.6.1 Arsenium (As)

The content of As in groundwater varied from 0.00109 ppm to 0.0199 ppm and the average was 0.0078375 ppm before starting mining activities (Table 6.1). Three studies were carried out to predict the concentration of heavy metal in Phulbari after mining activities and found in Raniganj the lowest concentration was 0.0008 ppm and height concentration was 0.0337 ppm and average value was found 0.01725 ppm (Table 6.4) which is 2.20 times higher than initial value of Bangladesh. In Maharashtra it was found lowest value was 5.08 ppm and height value was 8.55 ppm and the average value was found 6.324 ppm (Table 6.5) which is 806.89 times higher than initial value of Bangladesh, but in Poltegor, Poland it was found that before mining activities the concentration was 0.0168 ppm and after five years of starting mining activities this value was found 0.057 ppm which is 3.40 times higher than initial value (Table 6.6). After mining activities this concentration could be considerable change because of arsenic prone country. As arsenic was identified more or less all the districts of this country, so this concentration could be same as the concentration of Maharashtra, India.

6.6.2 Copper (Cu)

The content of Cu in groundwater varied from 0.0019 ppm to 0.0143 ppm and the average was 0.006375 ppm before starting mining activities (Table 6.1). Three studies were carried out to predict the concentration of heavy metal in Phulbari after mining activities and found in Raniganj the lowest concentration was found 0.0067 ppm and height concentration was found 0.0519 ppm and average value was found 0.0293 ppm (Table 6.4) which is 4.596 times higher than initial value of Bangladesh. In Maharashtra it was found lowest value was 0.04 ppm and height value was 0.13 ppm and the average value was found 0.085 ppm (Table 6.5) which is 13.33 times higher than initial value of Bangladesh, but in Poltegor, Poland it was found that before mining activities the concentration was 0.023 ppm and after five years of starting mining activities this value was found 0.0313 ppm which is 1.3609 times higher than initial value (Table 6.6). After mining activities this concentration could be considerable change and it could be considered as same as the value of Maharashtra.

6.6.3 Iron (Fe)

The content of Fe in groundwater varied from 0.0009 ppm to 0.4686 ppm and the average was 0.1639875 ppm before starting mining activities (Table 6.1). Two studies were carried out to predict the concentration of heavy metal in Phulbari after mining activities and found in Raniganj the lowest concentration was found 0.071 ppm and height concentration was found 0.973 ppm and average value was found 0.522 ppm (Table 6.4) which is 3.183 times higher than initial value of Bangladesh. In Poltegor, Poland it was found that before mining activities the concentration was 4.6 ppm and after five years of starting mining activities this value was found 8.75 ppm which is 1.9022 times higher than initial value (Table 6.6). After mining activities this concentration could be considerable change and it could be considered as same as the value of Raniganj, India.

6.6.4 Zinc (Zn)

The content of Zn in groundwater varied from 0.009 ppm to 0.0835 ppm and the average was 0.028 ppm before starting mining activities (Table 6.1). Three studies were carried out to predict the concentration of heavy metal in Phulbari after mining activities and found in Raniganj the lowest concentration was found 0.0174 ppm and height concentration was found 0.2017 ppm and average value was found 0.10955 ppm (Table 6.4) which is 3.9125 times higher than initial value of Bangladesh. In Maharashtra it was found lowest value was 0.2 ppm and height value was 0.4 ppm and the average value was found 0.3ppm (Table 6.5) which is 10.714 times higher than initial value of Bangladesh, but in Poltegor, Poland it was found that before mining activities the concentration was 0.36 ppm and after five years of starting mining activities this value was found 0.497 ppm which is 1.3806 times higher than initial value (Table 6.6). After mining activities this concentration could be considerable change and it could be considered as same as the value of Maharashtra.

6.6.5 Manganese (Mn)

The content of Mn in groundwater varied from 0.010945 ppm to 0.684759 ppm and the average was 0.154126 ppm before starting mining activities (Table 6.1). Two studies were carried out to predict the concentration of heavy metal in Phulbari after mining activities and found in Raniganj the lowest concentration was found 0.004 ppm and height concentration was found 0.356 ppm and average value was found 0.18 ppm (Table 6.4) which is 1.1678 times higher than initial value of Bangladesh. In Poltegor, Poland it was found that before mining activities the concentration was 0.24ppm and after five years of starting mining activities this value was found 0.79 ppm which is 3.2917 times higher than initial value (Table 6.6). After mining activities this concentration could be considerable change and it could be considered as same as the value of Poltegor, Poland.

6.6.6 Chromium (Cr)

The content of Cr in groundwater varied from 0.0144 ppm to 0.0264 ppm and the average was 0.01965 ppm before starting mining activities (Table 6.1). Two studies were carried out to predict the concentration of heavy metal in Phulbari after mining activities and found in Raniganj the lowest concentration was found 0.0052 ppm and height concentration was found 0.0836 ppm and average value was found 0.0444 ppm (Table 6.4) which is 2.259 times higher than initial value of Bangladesh. In Poltegor, Poland it was found that before mining activities the concentration was 0.0064 ppm and after five years of starting mining activities this value was found 0.075 ppm which is 11.719 times higher than initial value (Table 6.6). After mining activities this concentration could be considerable change and it could be considered as same as the value of Poltegor,Poland.

6.6.7 Lead (Pb)

The content of Pb in groundwater varied from 0.0195 ppm to 0.0878 ppm and the average was 0.056175 ppm before starting mining activities (Table 6.1). Three studies were carried out to predict the concentration of heavy metal in Phulbari after mining activities and found in Raniganj the lowest concentration was found 0.0102 ppm and height concentration was found 0.0611 ppm and average value was found 0.03565 ppm (Table 6.4) which is below the initial value of Bangladesh. In Maharashtra it was found lowest value was 0.05 ppm and height value was 0.07 ppm and the average value was found 0.06 ppm (Table 6.5) which is more or less similar to the initial value of Bangladesh, but in Poltegor, Poland it was found that before mining activities the concentration was 0.0165 ppm and after five years of starting mining activities this value was found 0.047 ppm which is 2.8485 times higher than initial value (Table 6.6). After mining activities this concentration could be considerable change and it could be considered as same as the value of Maharashtra.

6.6.8 Cadmium (Cd)

The content of Cd in groundwater varied from 0.005 ppm to 0.0164 ppm and the average was 0.0121ppm before starting mining activities (Table 6.1). Three studies were carried out to predict the concentration of heavy metal in Phulbari after mining activities and found in Raniganj the lowest concentration was found 0.0001 ppm and height concentration was found 0.0054 ppm and average value was found 0.00275 ppm (Table 6.4) which is below the initial value of Bangladesh. In Maharashtra it was found lowest value was 0.16 ppm and height value was 0.25 ppm and the average value was found 0.21 ppm (Table 6.5) which is 17.35 times higher than initial value of Bangladesh, but in Poltegor, Poland it was found that before mining activities the concentration was 0.0024 ppm and after five years of starting mining activities this value was found 0.0058 ppm which is 2.4167 times higher than initial value (Table 6.6). After mining activities this concentration could be considerable change and it could be considered as same as the value of Maharashtra.

Health metal contamination and human health risk assessment was done by Wongsasuluk *et al.,* they suggested that people living in warmer climates are more susceptible to and at great risk of groundwater contamination because of their increased daily drinking water intake. This may lead to an increased number of cases of non-carcinogenic and carcinogenic health defects among local people exposed to heavy metal by drinking the groundwater. Health impacts, both for miners and for the communities living around the mining sites are amongst the most important issues for local communities who rely on mining. Even when a mine is gone, the men and women who have worked in the mine may continue to experience health impacts for many years, if not generations. Some mined substances, such as uranium, will continue to create health impacts for miners up to 30 years after the miner has left the mine. It is likely that many impacts related to some of the more carcinogenic minerals are still to be discovered (Stephens and Ahern, 2002).

CHAPTER SEVEN

GROUNDWATER POLLUTION DUE TO OPEN PIT COAL MINING ACTIVITIES

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GROUNDWATER POLLUTION DUE TO OPEN PIT COAL MINNING ACTIVITIES

7.1 INTRODUCTION

According to Asia Energy Corporation Ltd. (2005) Phulbari Coalmine contains 572 million ton coal of which 532 million ton is explorable and this work will be run for thirty eight years. During this time, a lot of coal have to be deposited by occupying agricultural land. Beside a lot of coal waste will be produced. The waste disposal will become severe problem in that area. This could be very important as disposal will be washed by rain water, so leaching and carrying pollutants down to the aquifer (Libicki, 2006). The impact of coal ash leachates on receiving waters, apart from increased elemental concentrations cause changes in water pH with implications for trace element mobility (Carlson, 1990). This is main source of leaching of different heavy metals in the surrounding area and it contaminates ground water resources. The different parameters of ground water has been analyzed from different water samples obtained from proposed Phulbari Coal Mine site. The trace elements like As, Cu, Fe, Zn, Mn, Cr, Pb, and Cd have relatively high amount in Kolaghat ashes and these elements was significantly enrich the pond ash (Mandal and Sengupta, 2005).

The open pit coal mining changes the hydraulic gradient, thus affecting ground water flow regimes their quality and quantity. The presence of water in mining sites create a range of operational and stability problems and requires drainage to avoid slope stability problems and action to minimize oxidation of metallic sulfides and corrosion of mining machinery and equipment. The quality of the mine water depends on a series of geological, hydrological and mining conditions, which vary significantly from mine to mine[1]. Mining by its nature consumes as well as diverts water and can also pollute water resources of the area. The origin and impacts of mining on water resources arise at several stages of the mining cycle: the mining processes itself and/or at mineral processing and operational stage. It is one of the major activities causing water pollution and most of the mining areas are facing acute problems of potable water both in terms of quality. During mining operation, huge quantities of water are generated and discharged in to natural drainages without any beneficial use, leaving these areas as water deficit. Coal is exploited by both opencast as well as underground mining methods and during this process, a huge quantity of water is discharged from coal mines to the natural drainage to facilitate safe mining. The discharged mine water varies greatly in the concentration of contaminants present, and in some cases it may even meet the drinking water specification. Many times the discharged mine water as such is not usable and may contain unacceptable levels of heavy metals, toxic anions, organic and biological contaminants. In the present study, an attempt has been made to generate water quality data base for mine water discharges from the coal mines of Phulbari Coal Mining assess its suitability for drinking and irrigation uses.

Trace metal contaminations are important due to their potential toxicity for the environment and human beings (Gueu *et al.,* 2007; Lee *et al.,* 2007; Adams *et al.,* 2008; Vinodhini and Narayanan, 2008). Some of the metals like Cu, Fe, Mn, Ni and Zn are essential as micronutrients for the life processes in animals and plants (Suthar and Singh, 2008; Aktar *et al.,* 2010)

A lot of studies were found in the literature on heavy metal pollution of water sources. Such work include Brown-Adiuku and Ogezi (1991), Edet and Ntekim (1996), Xibao *et al.,* (1996), Yang *et al.,* (1996), Yiping (1996) and Znongyi (1996). All these workers concluded that there was the need to monitor water quality on a regular basis. This is because the increase in concentration of trace metals in potable water will increase the threat to man‘s health and life. Also, several methods exist in literature on the development and application of index methods for water quality assessment. Some of these include the work of Horton (1965), Joung *et al.,* (1979), Landwehr (1979), Nishidia *et al.,* (1982), Tiwary and Mishra (1985) and Prasad and Jaiprakas (1999). This study evaluates the applicability of two documented pollution indices and compare with a third proposed for the study area using some heavy element. In addition, the present level of pollution is assessed using these indices.

7.2 DISCUSSION

Coal leachates and ash could be the probable source of heavy metal ingredients in groundwater. Therefore to get an idea about the intensity of heavy metal pollution the heavy metal pollution index of the selected study area was calculated. Groundwater samples were taken for study to calculate heavy metal pollution index before mining activities. The eight sample sites were selected for the determination of selected heavy metal ingredients. Table 7.1 shows the groundwater chemical data of phulbari before mining activities. These data will be used for determining C_d and HPI before and after mining activities.

Table 7.1: Groundwater chemical data of Phulbari coal mining area before mining

Sample ID	As (ppm)	Cu (ppm)	Fe (ppm)	Zn (ppm)	Mn (ppm)	Cr (ppm)	Pb (ppm)	Cd (ppm)
1	0.01097	0.0124	0.0895	0.0403	0.0324	0.0144	0.0195	0.01
2	0.00241	0.0067	0.1404	0.0311	0.3441	0.0144	0.0785	0.0092
3	0.0199	0.0038	0.0702	0.0148	0.0154	0.0192	0.0586	0.005
4	0.00316	0.0052	0.1948	0.0835	0.0462	0.0168	0.0781	0.0103
5	0.00177	0.0038	0.0509	0.0173	0.055	0.024	0.0293	0.0139
6	0.00109	0.0029	0.2966	0.0148	0.0583	0.0216	0.039	0.0157
7	0.01958	0.0019	0.0009	0.0132	0.0627	0.0264	0.0586	0.0163
8	0.00382	0.0143	0.4686	0.009	0.0055	0.0204	0.0878	0.0164
Mean	**0.0078375**	**0.006375**	**0.1639875**	**0.028**	**0.07745**	**0.01965**	**0.056175**	**0.0121**
Median	**0.00349**	**0.0045**	**0.11495**	**0.01995**	**0.0506**	**0.0198**	**0.0586**	**0.0121**
StDev	**0.0079554**	**0.004566**	**0.1538140**	**0.0247390**	**0.109690**	**0.004347**	**0.024938**	**0.0041196**

7.2.1 Heavy Metal Distribution

In the groundwater samples studied, As, Cu, Fe, Zn, Mn, Cr, Pb and Cd are the most dominant heavy metals at the proposed Phulbari coal mine area. The concentration of As ranged from a minimum of 0.00109 ppm - to a maximum of 0.0199 ppm, Cu from a minimum of 0.0019 ppm - to a maximum of 0.0143 ppm, Fe from 0.0009 to 0.4686 ppm , Zn from 0.009 to 0.0835 ppm, Mn from 0.0055 to 0.3441 ppm, Cr from 0.0144 to 0.0264 ppm, Pb from 0.0195 to 0.0878 ppm and Cd from 0.005 to 0.0164 ppm table 7.2. Concentration of neither of those metals exceeds the WHO: 1997, Bangladesh or Indian limits before mining activities.

Table 7.2: Maximum and minimum concentration of heavy metals before mining

Elements	**Units**	**Max**	**Min**	**Mean**	**Bangladesh drinking water quality Standard**	**WHO drinking water quality standard (1997)**	**Indian drinking water quality standard**
As	ppm	0.0199	0.00109	0.010495	0.01	0.05	0.05
Cu	ppm	0.0143	0.0019	0.00638	1	2	0.05
Fe	ppm	0.4686	0.0009	0.16399	0.3 - 1.0	0.3	0.3
Zn	ppm	0.0835	0.009	0.028	5	4	5
Mn	ppm	0.3441	0.0055	0.07745	0.1	0.5	0.4
Cr	ppm	0.0264	0.0144	0.01965	0.05	0.05	0.05
Pb	ppm	0.0878	0.0195	0.05618	0.05	0.01	0.05
Cd	ppm	0.0164	0.005	0.0121	0.005	0.003	0.01

MAC maximum admissible concentration (Adapted from Edet and Offing, 2003) and WHO (1997)

A prediction was made after mining activities in Phulbari comparing with Ranigonj Coal Mine and a coal-fired power plant at Maharasta of India and the Poltegor Coal Mine of Poland (Singh *et al.,* 2010, Nalawade *et al.,* 2012 and Libicki, 2006).

If the open pit coal mine will be done in Phulbari, the concentration of maximum heavy metals will exceed the WHO, Bangladesh or Indian standard. The value will be increased As from a minimum of 0.87963 ppm to a maximum of 16.0593, Cu from a minimum of 0.022 ppm - to a maximum of 0.163 ppm, Fe from 0.003 to 1.406 ppm , Zn from 1.331 to 12.35ppm, Mn from 0.011 to 0.6882 ppm, Cr from 0.029 to 0.053 ppm, Pb from 0.019 to 0.086 ppm and Cd from 0.064 to 0.211 ppm (Table 7.3).

Table 7.3: Maximum and minimum concentration of heavy metals after mining

Elements	**Units**	**Max**	**Min**	**Mean**	**Bangladesh drinking water quality Standard**	**WHO drinking water quality standard (1997)**	**Indian drinking water quality standard**
As	ppm	16.06	0.88	6.325	0.01	0.05	0.05
Cu	ppm	0.163	0.022	0.072	1	2	0.05
Fe	ppm	1.406	0.003	0.492	0.3 - 1.0	0.3	0.3
Zn	ppm	12.35	1.331	4.14	5	4	5
Mn	ppm	0.685	0.011	0.154	0.1	0.5	0.4
Cr	ppm	0.053	0.029	0.039	0.05	0.05	0.05
Pb	ppm	0.086	0.019	0.055	0.05	0.01	0.05
Cd	ppm	0.211	0.064	0.156	0.005	0.003	0.01

7.2.2 Statistical Analysis

The descriptive statistics including maximum admissible concentration (MAC) were given in table 7.4. The concentration of As, Cu, Fe, Zn, Mn and Cr are below the MAC in drinking water.

Table 7.4: Descriptive statistics for elements before mining

Elements	Units	Max	Min	Mean	Median	Std. Dev	MAC
As	ppm	0.0199	0.00109	0.008369	0.00349	0.007955	0.05
Cu	ppm	0.0143	0.0019	0.00672	0.0045	0.0045663	2
Fe	ppm	0.4686	0.0009	0.17814	0.11495	0.1538141	0.3
Zn	ppm	0.0835	0.009	0.03165	0.01605	0.0247391	4
Mn	ppm	0.3441	0.0055	0.09692	0.0506	0.1096902	0.5
Cr	ppm	0.0264	0.0144	0.0198	0.0198	0.0043474	0.05
Pb	ppm	0.0878	0.0195	0.05567	0.0586	0.024938	0.01
Cd	ppm	0.0164	0.005	0.01182	0.0121	0.0041196	0.003

MAC miximum admissible concentration (Adapted from Edetand Offing, 2003) and WHO (1997)

On the other hand, after mining activities; the concentration of Cu, Mn and Cr were below the MAC value in drinking water. The concentration of As (0.87963-16.0593 ppm), Fe (0.0027 – 1.4058 ppm), Zn (1.33074 -12.34631 ppm), Pb (0.01911-0.086044 ppm) and Cd (0.06445- 0.211396 ppm) were found to be greater in all the locations than the MAC value after mining activities (Table 7.5).

Table 7.5: Descriptive statistics for elements after mining

Elements	Units	Max	Min	Mean	Median	Std. Dev	MAC
As	ppm	16.0593	0.87963	6.324863	2.81643	6.42004	0.01
Cu	ppm	0.162591	0.021603	0.072484	0.051165	0.051918	2
Fe	ppm	1.4058	0.0027	0.491963	0.34485	0.461442	0.3
Zn	ppm	12.34631	1.33074	4.14008	2.373153	3.657923	4
Mn	ppm	0.684759	0.011	0.1549	0.1012	0.21938	0.5
Cr	ppm	0.0528	0.0288	0.0393	0.0396	0.008695	0.05
Pb	ppm	0.086044	0.01911	0.055052	0.057428	0.024439	0.01
Cd	ppm	0.211396	0.06445	0.155969	0.155969	0.053102	0.003

MAC maximum admissible concentration (Adapted from Edet and Offing, 2003) and WHO-1997

7.2.4 Contamination Index Calculation (C_d)

By using equation 3.12 the C_d was calculated. For calculating C_d, contamination factors for eight components (C_{fi}), analytical values of eight heavy metals (C_{Ai}) and upper permissible concentration of eight heavy metals were used (Table 7.6).

Table 7.6: Analytical value (CA_i), contamination factor (Cf_i) and contamination index (C_d) of samples before mining activities

Sample ID	**As**		**Cu**		**Fe**		**Zn**		**Mn**		**Cr**		**Pb**		**Cd**		C_d
	C_{Ai} (ppm)	**C_{fi}**	**C_{Ai} (ppm)**	**C_{fi}**	**C_{Ai} (ppm)**	**C_{fi}**	**C_{Ai} (ppm)**	**C_{fi}**	**C_{Ai} (ppm)**	**C_{fi}**	**C_{Ai} (ppm)**	**C_{fi}**	**C_{Ai} (ppm)**	**C_{fi}**	**C_{Ai} (ppm)**	**C_{fi}**	
1	0.011	0.097	0.012	-0.994	0.0895	-0.702	0.040	-0.990	0.032	-0.935	0.014	-0.712	0.020	0.950	0.010	2.333	0.952
2	0.0024	-0.759	0.007	-0.997	0.1404	-0.532	0.031	-0.992	0.344	-0.312	0.014	-0.712	0.079	6.850	0.009	2.067	4.613
3	0.0199	0.99	0.004	-0.998	0.0702	-0.766	0.015	-0.996	0.015	-0.969	0.019	-0.616	0.059	4.860	0.005	0.667	2.171
4	0.0032	-0.684	0.005	-0.997	0.1948	-0.351	0.084	-0.979	0.046	-0.908	0.017	-0.664	0.078	6.810	0.010	2.433	4.661
5	0.0018	-0.823	0.004	-0.998	0.0509	-0.830	0.017	-0.996	0.055	-0.890	0.024	-0.520	0.029	1.930	0.014	3.633	0.506
6	0.0011	-0.891	0.003	-0.999	0.2966	-0.011	0.015	-0.996	0.058	-0.883	0.022	-0.568	0.039	2.900	0.016	4.233	2.785
7	0.0196	0.958	0.002	-0.999	0.0009	-0.997	0.013	-0.997	0.063	-0.875	0.026	-0.472	0.059	4.860	0.016	4.433	5.912
8	0.0038	-0.618	0.014	-0.993	0.4686	0.562	0.009	-0.998	0.006	-0.989	0.020	-0.592	0.088	7.780	0.016	4.467	8.619

For predicting the C_d after mining activities the predicted value of C_{Ai}, and C_{fi} was used (Table 7.7).

Table 7.7: The predicted value (CA_i), contamination factor (Cf_i) and contamination index (C_d) of samples after mining

Sample ID	**As**		**Cu**		**Fe**		**Zn**		**Mn**		**Cr**		**Pb**		**Cd**		Cd
	C_{Ai} (ppm)	**C_{fi}**	**C_{Ai} (ppm)**	**C_{fi}**	**C_{Ai} (ppm)**	**C_{fi}**	**C_{Ai} (ppm)**	**C_{fi}**	**C_{Ai} (ppm)**	**C_{fi}**	**C_{Ai} (ppm)**	**C_{fi}**	**C_{Ai} (ppm)**	**C_{fi}**	**C_{Ai} (ppm)**	**C_{fi}**	
1	8.8528	884.28	0.141	-0.930	0.2685	-0.105	5.959	0.490	0.064	-0.871	0.029	-0.424	0.019	0.911	0.129	41.967	925.317
2	1.9449	193.49	0.076	-0.962	0.4212	0.404	4.598	0.150	0.685	0.370	0.029	-0.424	0.077	6.693	0.119	38.529	238.247
3	16.059	1604.9	0.043	-0.978	0.2106	-0.298	2.188	-0.453	0.031	-0.939	0.038	-0.232	0.057	4.743	0.064	20.483	1627.256
4	2.5501	254.01	0.059	-0.970	0.5844	0.948	12.346	2.087	0.092	-0.816	0.034	-0.328	0.077	6.654	0.133	43.256	304.841
5	1.4284	141.84	0.043	-0.978	0.1527	-0.491	2.558	-0.361	0.109	-0.781	0.048	-0.040	0.029	1.871	0.179	58.724	199.783
6	0.8796	86.963	0.033	-0.984	0.8898	1.966	2.188	-0.453	0.116	-0.768	0.043	-0.136	0.038	2.822	0.202	66.458	155.868
7	15.801	1579.1	0.022	-0.989	0.0027	-0.991	1.952	-0.512	0.125	-0.750	0.053	0.056	0.057	4.743	0.210	69.036	1649.698
8	3.0827	307.27	0.163	-0.919	1.4058	3.686	1.331	-0.667	0.011	-0.978	0.041	-0.184	0.086	7.604	0.211	69.465	385.282

The predicted values were determined by multiplying the analyzed heavy metal value with the value that was increased after mining in Ranigonj, India, a coalfired power plant in Maharasta and those values were compared with the value of Poltegor Coalmine , Poland, before and after mining. The WHO drinking water standard was taken as Maximum Admissible Concentration/upper permissible limit.

Calculated values of contamination index for water samples are shown in table 7.6. Degree of water contamination is classified into three grades (Backman *et al*., 1998) (Table 7.8). Water samples with:

$Cd < 1$ represents low contamination level
$Cd = 1 - 3$ medium represent contamination level
$Cd > 3$ represents high contamination level

Table 7.8: Classification of Contamination Index (Backman *et al*., 1998)

C_d	Class
$d < 1$	Low Contamination
1 – 3	Medium Contamination
$d > 3$	High Contamination
Cd = Contamination Index	

Four water samples out of eight show high contamination level ($C_d > 3$) ranging between 4.613- 8.619 (Table 7.6), two samples show medium contamination level (C_d 1-3) ranging between 2.171-2.785 and two show the low contamination level ($C_d < 1$) ranging between 0.506-0.952 value before mining activities.

After mining activities the predicted concentration index for groundwater samples are shown in table 7.7. The degree of water contamination was classified into three grades followed by Backman *et al*., (1998), all the samples show the very high contamination level ($C_d > 3$) ranging between 155.868– 1627.256. All the values are very much higher compare with the critical pollution index value of 100.

Very less work has been done on HPI related to fly ash dumping site, but Prasad and Jaipraksh (1999) studied the mining area filled with fly ash and found to be 11.25 while Prasad and Singita (2008) reported 36.67 which was below critical index.

HPI calculation process was shown for location 1(sample Id 1), both before (Table 7.9) and after mining (Table 7.10) activities. Before mining activities the HPI was found 2.396 and after mining activities it was found 115.447 in location 1.

Table 7.9: Heavy metal pollution index calculation before mining activities (Location-1)

Heavy Metal	**Mean Concentation, ppm (M_i)**	**Highest permitted value for drinking water (S_i)**	**Desirable maximum value (I_i)**	**Unit weightage (W_i)**	**Sub index (Q_i)**	**W_i x Q_i**	**HPI**
As	0.011	0.05	0.05	20	3.903	78.060	2.396
Cu	0.012	1.5	0.05	0.667	2.593	1.729	
Fe	0.089	1	1	1	91.050	91.050	
Zn	0.040	15	5	0.067	49.597	3.306	
Mn	0.032	0.3	0.3	3.333	26.760	89.200	
Cr	0.014	0.05	0.05	20	3.560	71.200	
Pb	0.019	0.05	0.05	20	3.050	61	
Cd	0.010	0.01	0.01	100	0.000	0	
Sum				165.067	180.513	395.545	

Table 7.10: Heavy metal pollution index calculation after mining activities (Location-1)

Heavy Metal	**Mean Concentation, ppm (M_i)**	**Highest permitted value for drinking water (S_i)**	**Desirable maximum value (I_i)**	**Unit weightage (W_i)**	**Sub index (Q_i)**	**W_i x Q_i**	**HPI**
As	8.853	0.05	0.05	20	880.3	17606	115.447
Cu	0.141	1.5	0.05	0.667	6.276	4.186	
Fe	0.269	1	1	1	73.1	73.1	
Zn	5.959	15	5	0.067	9.59	0.643	
Mn	0.064	0.3	0.3	3.333	23.6	78.659	
Cr	0.029	0.05	0.05	20	2.1	42	
Pb	0.019	0.05	0.05	20	3.1	62	
Cd	0.129	0.01	0.01	100	11.9	1190	
Sum				165.067	1009.966	19056.590	

Table 7.11 shows that before mining activities C_d ranges between 0.51 -8.62 and HPI ranges between 2.04-4.42, but after mining activities C_d will be found 155.86 – 1649.7 and HPI will be found between 22.53-204.58.

Table 7.11: Contamination indix and heavy metal pollution indices before and after mining activities for eight locations

Sample ID	**Before Mining Activities**		**After Mining Activities**	
	C_d	**HPI**	**C_d**	**HPI**
1	0.95	2.396	925.32	115.447
2	4.61	2.04	238.25	31.27
3	2.17	2.30	1627.30	198.88
4	4.66	4.05	304.84	39.39
5	0.51	2.49	199.79	28.57
6	2.79	2.36	155.86	22.53
7	5.91	2.26	1649.7	204.58
8	8.62	2.71	385.28	50.64
Mean	**3.7775**	**2.8288**	**685.79**	**86.41625**
Median	**3.7**	**2.425**	**345.06**	**45.015**
StDev	**2.5421**	**0.8365**	**0.8365**	**71.950544**

CHAPTER EIGHT

ASSESSING THE VULNERABILITY OF GROUNDWATER DUE TO OPEN PIT COALMINING USING DRASTIC MODEL

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ASSESSING THE VULNERABILITY OF GROUNDWATER DUE TO OPEN PIT COALMINING USING DRASTIC MODEL

8.1 INTRODUCTION

Groundwater is the most important source of water supply in arid and semi-arid regions due to it large volumes and its low susceptibility to contamination when compared to surface waters (USEPA, 1985). Due to wide-ranging high population growth and industrialization, greater amounts of domestic and industrial effluents are being discharged, which has lead to the pollution of groundwater (Rahman, 2008). There are several types of pollutants that appear to prevail in groundwater such as heavy metals, nutrients, pesticides and other organic chemicals, and fertilizers.

Pollution of groundwater is a major concern because aquifers and the enclosed groundwater are innately susceptible to contamination from land use and other anthropogenic impacts (Thirumalaivasan *et al.*, 2003). Leaching of various pollutants through the vadose zone gives rise to pollution. Leaching processes differ from one location to another (Baalousha 2006; Sener *et al.,* 2009). Preventing groundwater pollution is necessary for effective groundwater resource management and groundwater- vulnerability assessment is important for such groundwater protection. Vulnerability assessment methods divide a geographical area into subareas in terms of its susceptibility to groundwater contamination; then, in areas prone to contamination, effective groundwater protection measures should be carried out (Guo *et al.*, 2007). Two types of vulnerability are recognized in literature: intrinsic (or natural) and specific (or integrated) vulnerability. Intrinsic vulnerability is a term used to define the vulnerability of groundwater to contaminants generated by human activities taking into consideration the inherent geological, hydrological, hydro-geological and hydro-geochemical characteristics of an area. Specific vulnerability is used to define the vulnerability of groundwater to particular contaminants taking into consideration the contaminant properties and their relationship with the various components of intrinsic vulnerability (Hamerlinck and Arneson 1998; Doerfliger *et al.*, 1999; Gogu and Dassargues 2000; Varol and Davraz 2010). In general, overlay and index methods are quite effective to determine groundwater vulnerability and these methods are particularly suitable for use with geographic information systems (GIS), since they usually involve the overlaying and aggregation of multiple maps (Tilahun and Merkel 2010). An overlay and index method is a multicriteria model that aggregates the hydro-geological factors that control the migration of pollutants into the aquifer. It combines factors controlling the movement of pollutants from the ground surface into the saturated zone resulting in vulnerability indices at different locations. The main advantage is that some of the factors such as rainfall and depth to groundwater can be available over large areas, which makes them suitable for regional scale assessments (Thapinta and Hudak 2003). However, a major drawback is the subjectivity in assigning numerical values to the descriptive entities and relative weights for the different attributes (Babiker *et al.,* 2005). There has been rapid development of groundwater vulnerability assessment in the past 10 years, as well as the introduction of various new techniques and methods applied to the assessment (Meinardi *et al*., 1995; Secunda *et al.,* 1998; Lasserrea *et al*., 1999; Al-Adamat *et al.,* 2003; Lake *et al.,* 2003; Thapinta and Hudak 2003; Zhou *et al*., 2010). One of the most widely used standard groundwater vulnerability methods is DRASTIC, developed by the United States Environmental Protection Agency (USEPA) as a method for assessing groundwater pollution potential. This method uses seven parameters in its calculation of a 'vulnerability index'. Some researchers have tried to correlate the vulnerability index with contaminant parameters and/or have controlled the assessment with sensitivity analyses (Kalinski *et al.,* 1994; Rupert 1999; Mclay *et al.,* 2001; Javadi *et al.,* 2011). Also, in recent years, the DRASTIC method has been modified by using additional parameters and/or by ignoring the existing parameters according to the characteristics of the study area (Umar *et al.,* 2009; Lee 2003; Simsek *et al.,* 2006; Wang *et al.* 2007; Guo *et al.,* 2007; Martínez-Bastida *et al.,* 2010; Awawdeh and Jaradat 2010).

The proposed Phulbari coal mining area has been selected as a study area. It is important to evaluate groundwater vulnerability in the basin from the point of view of both groundwater protection in the basin and protection of the Phulbari mine water quality. In previous studies, the groundwater vulnerability was evaluated using the DRASTIC model based on GIS in the Senirkent-Uluborlu plain, which is located within the Egirdir Lake basin, and it was determined that the obtained results are realistic and representative of the actual situation in the field (Sener *et al.,* 2009).

Since the end of the 1980s, a U.S. Environmental Protection Agency (EPA) system named DRASTIC has been increasingly used to evaluate pollution migration from the land surface to groundwater. This system consider aspects of the geologic environment of the study area, such as: depth of the groundwater, head of infiltration water recharge and characteristics of the strata within the aquifer, such as hydraulic conductivity, characteristic of the soil and water zone structure, and the land slope assessment.

DRASTIC has been most commonly used for mapping aquifer vulnerability in porous aquifers (Aller *et. al.*, 1987). In this study, the DRASTIC method was selected for determination of aquifer vulnerability in Phulbari Coal Mine area, because the main contamination sources could be the mining activities such as clearing of vegetation, top soil removal, overburden excavation, dewatering and then coal extraction.

In this study, the range of each parameter resulted in five or six classes (Table 8.1and 8.2). If minimum and maximum rating values do not change, the number of range classes will not affect the obtained result. For example, the depth to water table parameter is divided into three classes and rating values of 9, 5 and 1 were assigned for depths 0–10, 10–20 and 20–30 m, respectively. Then, the same parameter was divided into six classes and rating values of 9, 8, 7, 5, 3 and 1 were assigned for depths 0–5, 5–10, 10–15, 15–20, 20–25 and 25–30 m, respectively. When the DVI value was calculated and the vulnerability classes (high, medium, low) were determined using the quartile classification method, nearly the same results were obtained. This shows that rating value is more important than the range classes in the DRASTIC applications. The DRASTIC system allows the user to determine a numerical value of the DVI that shows areas more likely to be susceptible to groundwater contamination relative to others. A higher DRASTIC index shows greater groundwater pollution vulnerability (Lee, 2003).

Rating and weighting values for conventional DRASTIC was used in table 8.1. By using these values of seven parameters seven thematic maps have been prepared.

Table 8.1: Rating and weighting values used in DRASTIC

Parameters	Range	DRASTIC		
		Rating	Weight	Total weight
Groundwater depth (m) D	0-1.5	10	5	50
	1.5-3	9		45
	3-5	8		40
	5-7	7		35
	7-10	6		30
	10-20	5		25
Net Recharge (mm/year) R	450-550	3	4	12
	550-625	5		20
	625-650	6		24
	650-675	7		28
	675-700	8		32
	700-725	9		36
	725-750	10		40
Aquifer media A	Alluvium	4	3	12
	Sandy braided river	5		15
	Sand	9		27
Soil media S	Gravel	9	2	18
	Sedimentation	8		16
	Sand-clay	3		6
	Clay	1		2
Topograpgy (slope^0) T	0-2	10	1	10
	2-6	9		9
	6-12	5		5
	12-20	3		3
	20-32	1		1
Impact of vadose zone I	Gravel	9	5	45
	Silt	3		15
	Clay	1		5
Hydraulic conductivity (m/s) C	3×10^{-4}-3×10^{-2}	10	3	30
	10^{-9}-2×10^{-5}	3		9
	10^{-11}-4.7×10^{-9}	1		3

Also rating and weighting values were used for modified DRASTIC-C_dHPI both for before and after mining activitoies (Table 8.2). And using these values of nine parameters the thematic maps have been prepared.

Table 8.2: Rating and weighting values used in the before and after mining in modified DRASTIC-C_dHPI methods

Parameters	Before Mining Modified DRASTIC-C_dHPI				After Mining Modified DRASTIC-C_dHPI			
	Range	Rating	Weight	Total weight	Range	Rating	Weight	Total weight
Groundwater depth (m) D	0-1.5	10	5	50	3-5	10	5	50
	1.5-3	9		45	5-10	9		45
	3-5	8		40	10-20	8		40
	5-7	7		35	20-30	7		35
	7-10	6		30	30-50	6		30
	10-20	5		25	50-100	5		25
Net Recharge (mm/year) R	450-550	3	4	12	450-550	5	5	25
	550-625	5		20	550-625	7		35
	625-650	6		24	625-650	8		40
	650-675	7		28	650-700	9		45
	675-700	8		32	700-750	10		50
	700-725	9		36				
	725-750	10		40				
Aquifer media A	Alluvium	4	3	12	Alluvium	5	5	25
	Sandy braided river	5		15	Sandy braided river	7		35
	Sand	9		27	Sand	10		50
Soil media S	Gravel	9	2	18	Gravel	10	5	50
	Sedimentation	8		16	Sedimentation	9		45
	Sand-clay	3		6	Sand-clay	5		25
	Clay	1		2	Clay	1		5
Topograpgy (slope^0) T	0-2	10	1	10	0-2	10	5	50
	2-6	9		9	2-6	9		45
	6-12	5		5	6-12	8		40
	12-20	3		3	12-20	7		35
	20-32	1		1	20-32	5		25
Impact of vadose zone I	Gravel	9	5	45	Gravel	9	5	45
	Silt	3		15	Silt	7		35
	Clay	1		5	Clay	3		15
Hydraulic conductivity (m/s) C	3×10^{-4}-3×10^{-2}	10	3	30	3×10^{-4}-3×10^{-2}	10	5	50
	10^{-9}-2×10^{-5}	3		9	10^{-7}-2×10^{-5}	1		5
	10^{-11}-4.7×10^{-9}	1		3	10^{-11}-4.7×10^{-8}	3		15
Contamination Index (C_d)	0-2	1	2	2	100-200	7	5	35
	2-5	2		4	200-300	8		40
	5-7	3		6	300-500	8		40
	7-10	4		8	500-1000	9		45
	10-50	5		10	1000-2000	10		50
Heavy Metal Pollution Index (HPI)	0-1	1	2	2	10--30	1	5	5
	1-2.30	2		4	30-50	3		15
	2.30-3	3		6	50-100	5		25
	3-4	4		8	100-150	8		40
	4-5	5		10	150-200	9		45
	5-10	6		12	>200	10		50

DRASTIC has been the most commonly used aquifer vulnerability assessment method; however, it is not intended to predict the occurrence of groundwater contamination (USEPA 1985). Recent work has further improved upon this method, evolving the method beyond a simple rating of vulnerability, to a descriptive approach identifying areas with similar hydro-geologic characteristics (i.e. hydrologic setting) and assessing individually these areas for groundwater susceptibility to potential contamination (Hearne *et al.,* 1992).In this type of vulnerability analysis, data obtained from hydro-geological field investigations should be used for weighting of DRASTIC parameters. Thus, disadvantages of the DRASTIC method may be reduced to a negligible level. Accuracy of the vulnerability map should be checked with available pollutant data obtained from field investigations such as As, Cu, Fe, Zn, Mn, Cr, Pb and Cd concentration. In this study, all parameter maps were prepared in a GIS environment and vulnerability classification of the basin was performed using GIS techniques. Seven data layers were digitized and were converted to raster data sets using ArcGIS. Then, the DVI was computed and the vulnerability map of the basin was prepared taken into consideration hydro-geological field observations and investigations. Weighting factors of the seven parameters were determined depending on location properties which are shown in Table 8.1. The DRASTIC and mining activities weights were used in the DVI calculation of mining weights were specifically designed to address the important processes offsetting the fate and transport of contamination in the soil (Wang *et al*., 2007). In the study area, an open pit coal mining activities will occur in the alluvium areas.

Evaluation of the DRASTIC vulnerability map was carried out using groundwater quality data such as As, Cu, Fe, Zn, Mn, Cr, Pb and Cd. Hence, these heavy metals can be a good water-quality parameter to evaluate the DRASTIC index (Jamrah *et al.,* 2007). In this study, groundwater from high, medium and low vulnerability aquifer media was checked for heavy metal content. This evaluation was performed using analysis results which were obtained by Seyman (2005).

8.2 ASSESSMENT OF AQUIFER VULNERABILITY WITH DRASTIC METHOD

The seven hydro-geological parameter (depth to water, net recharge, aquifer media, soil media, topography, impact of vadose zone and hydraulic Conductivity) should be considered when determining aquifer vulnerability with the DRASTIC method. These input data were obtained from literature, field studies, the State Hydraulic Works, the State Meteorology Works and the Management of Agriculture and Village Works. To carry out the aquifer vulnerability analysis using DRASTIC, seven thematic maps were prepared using these input data based on GIS and explained in the following:

8.2.1 Depth to Water Table (D)

This is an important factor because it determines the depth of materials through which contaminants must pass before reaching the water table. It also affects the time available for contamination to undergo chemical and biological reactions such as dispersion, oxidation, natural attenuation, sorption etc. (Chakraborty *et al.*, 2007). Hence, the greater the depth to the water table the lesser the chance of pollutants arriving at the water table and the greater for chance for pollutants to be attenuated. Data from 6 piezometers were used to prepare the groundwater depth map.

According to data collected, the groundwater depth varies from 3.39 to 6.1 m in the Phulbari Upazila, 2.77–6.42 m in the Parbattipur Upazila, 2.82–5.68 m in the Nawabgonj and 4.38– 8.04 m in the Birampur Upazila. The groundwater depth map of the study area is classified areas into six groups (0-1.5, 3-5, 5-7, 7-10 and 10-20 m). The groundwater depth weight is determined as 5. The rating values of the groundwater depth classes vary from 1 to 10. The values for weight and rating are presented in table 8.1 and figure 8.1(a) and 8.1 (b)

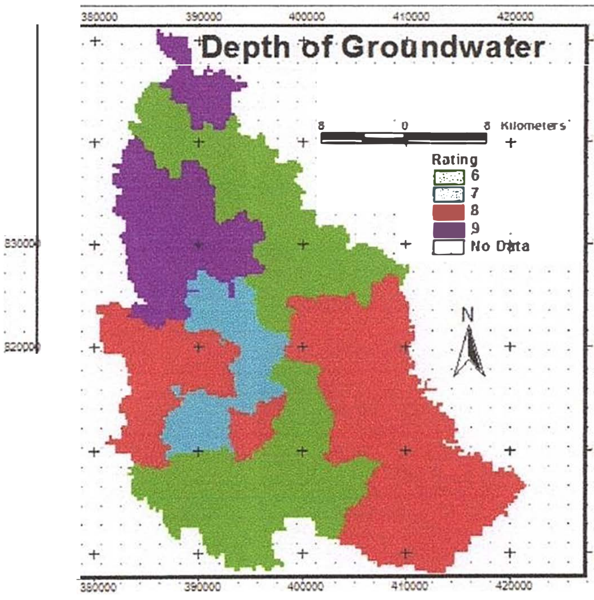

Figure 8.1(a): Depth of the water table rating

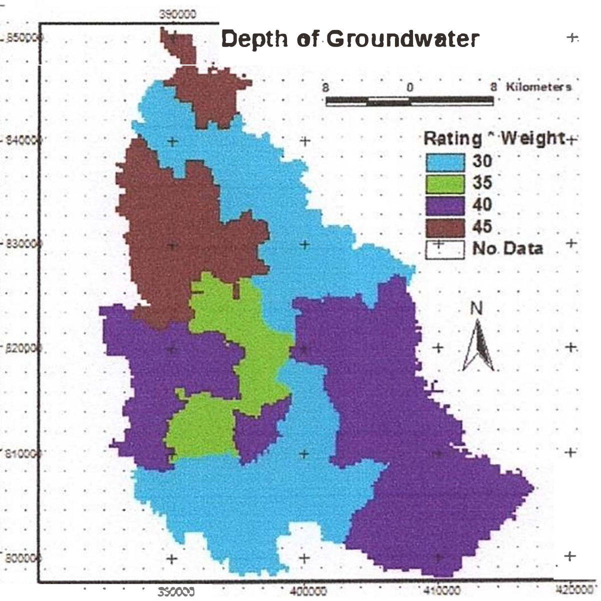

Figure 8.1(b): Depth of the water table weight

8.2.2 Net Recharge (R)

Net recharge represents the total quantity of water applied to the ground surface through precipitation and infiltration to the aquifer. The higher the net recharge is, the less the vulnerability to the aquifer. Annual rainfall data were obtained from the Bangladesh Meteorological Department (BMD). The rainfall map of the basin was prepared using these data; rainfall varies from 1889 to 2199 mm in the study area. The ratings and weighting for net recharge are presented in table 8.1 and figure 8.2 (a) and 8.2(b).

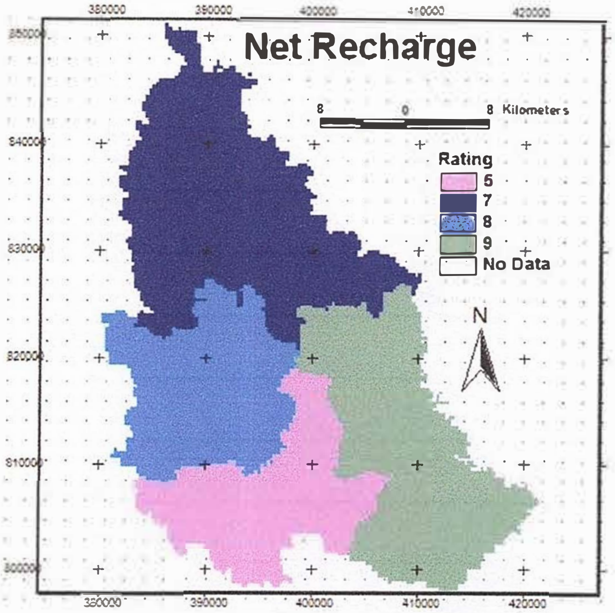

Figure 8.2(a) : Net recharge rating map

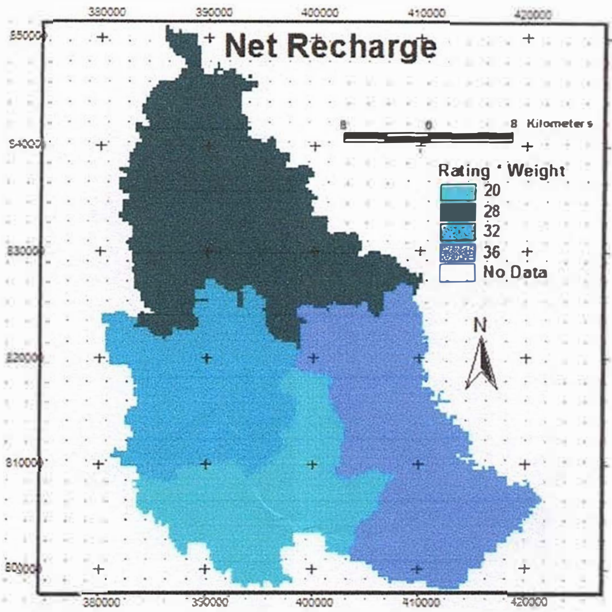

Figure 8.2(b):Net recharge weighting map

8.2.3 Aquifer Media (A)

Groundwater flow, contaminant fate and transport modeling are important components of most aquifer remediation studies (Rahman, 2008). The aquifer map of the basin was prepared taking into account hydro-geological properties of the lithologic units. Three hydro-geologic units were determined in the study area. Alluvium and slope deposits were classified as alluvium aquifer, which is the most vulnerable unit in the basin, sandy braided river and sand assigned with a rating of 4 to 9 respectively. According to DRASTIC standards, the rating of aquifer media varies between 4 for sandy and 9 for alluvium aquifer table 8.1and figure 8.3 (a) and 8.3 (b).

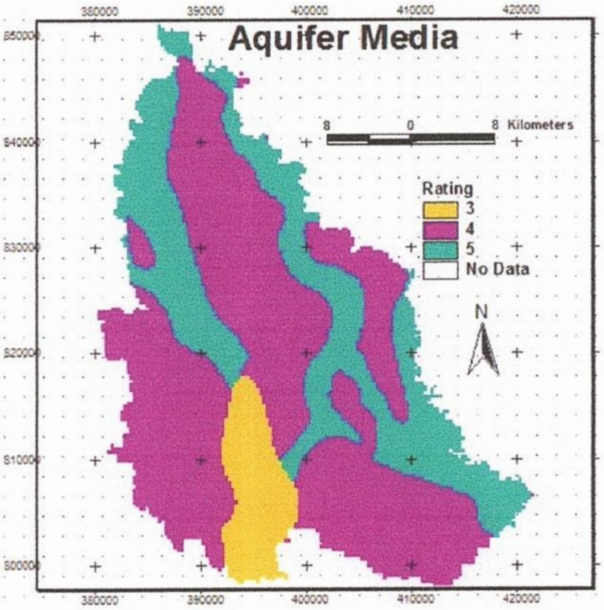

Figure 8.3(a): Aquifer media rating map

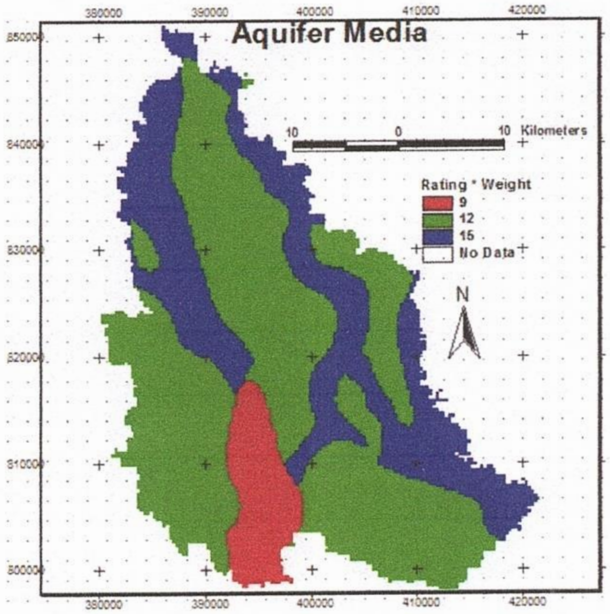

Figure 8.3(b):Aquifer media weighting map

8.2.4 Soil Media (S)

The type of soil cover has a significant impact on the recharge of the aquifers and it controls the movement of contaminants in the vadose zone, making this parameter quite important in determining aquifer vulnerability. A hardcopy of the soil map was obtained from the Brandra Multipurpose Authority (BMDA) was digitized for use in GIS. The study area was classified into four groups—clay, sandy clay, gravels and gravel-sand and sedimentation-according to soil type. The clays can decrease relative soil permeability and restrict contaminant migration; hence, the class of clay has the lowest rating value. The rating and weight values of this parameter are shown in table 8.1 and figure 8.4 (a) and 8.4 (b).

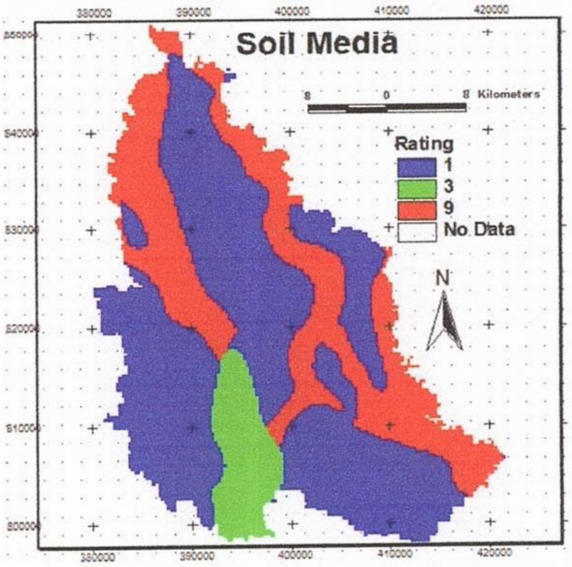

Figure 8.4(a): Soil media rating map

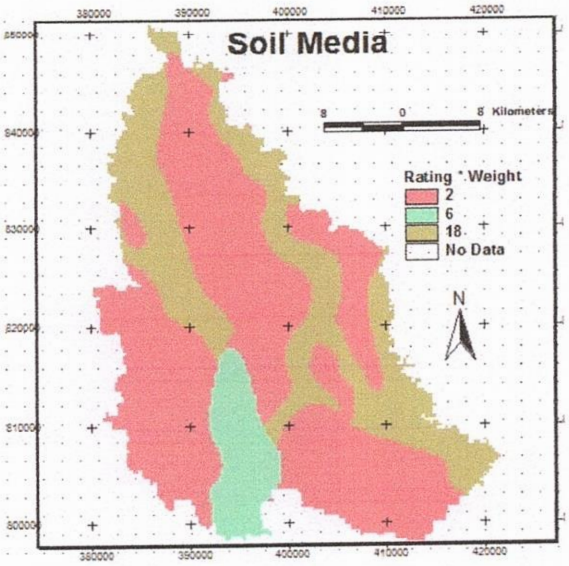

Figure 8.4(b): Soil media weighting map

8.2.5 Topography (T)

Topography is described in the form of slope. Slope degree has quite a high significance, as it determines the extent of runoff of the pollutant and the amount of settling a pollutant might experience before infiltrating the soil. A digital elevation model (DEM) of the study area was prepared using digitized 1:25,000 scale topographical maps. Five slope classes were designated to apply to the DRASTIC method. Each class was assigned with a rating from 10 (>20°) to 1 (0–2°), which has been shown in table 8.1 and figure 8.5 (a) and 8.5 (b).

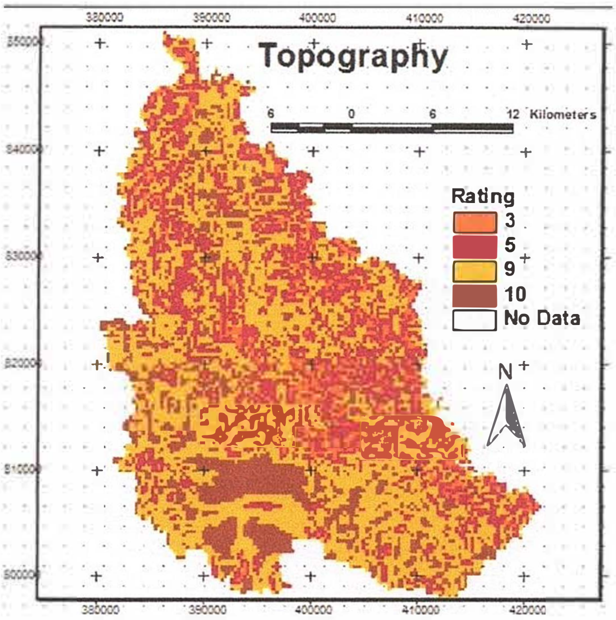

Figure 8.5(a): Topographic rating map

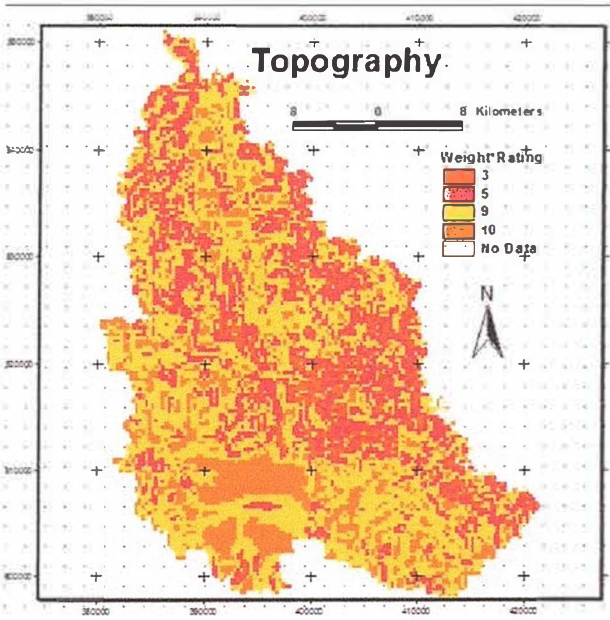

Figure 8.5(b): Topographic rating map

8.2.6 Impact of Vadose Zone (I)

The vadose zone (unsaturated zone) has an important role in the percolation of rainfall and in surface-water flow. Data on the vadose zone were extracted from the logs and boreholes provided by the Bangladesh Water Development Board (BWDB) and the geology map of the study area. Gravel, silt and clay are the main classes of the vadose zone observed in the basin. These units are evaluated by the DRASTIC method; the highest weight value was given in the sand-gravel areas. The rating and weight values of this parameter are shown in table 8.1 and figure 8.6 (a) and 8.6 (b).

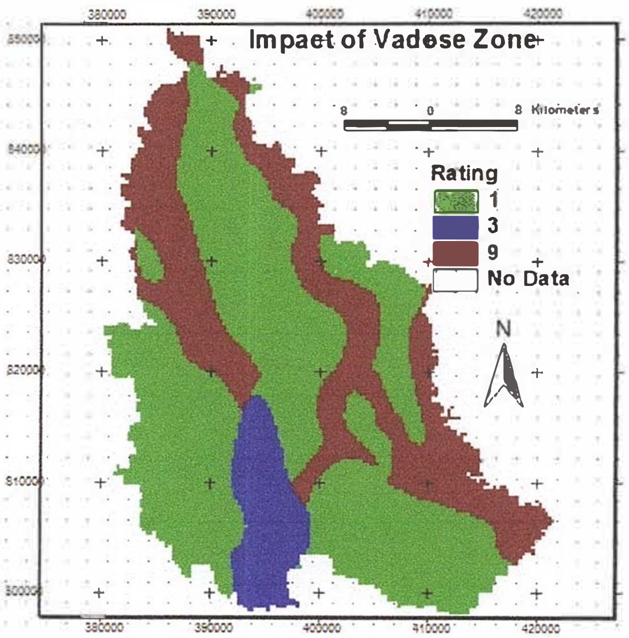

Figure 8.6(a): Impact of vadose zone rating

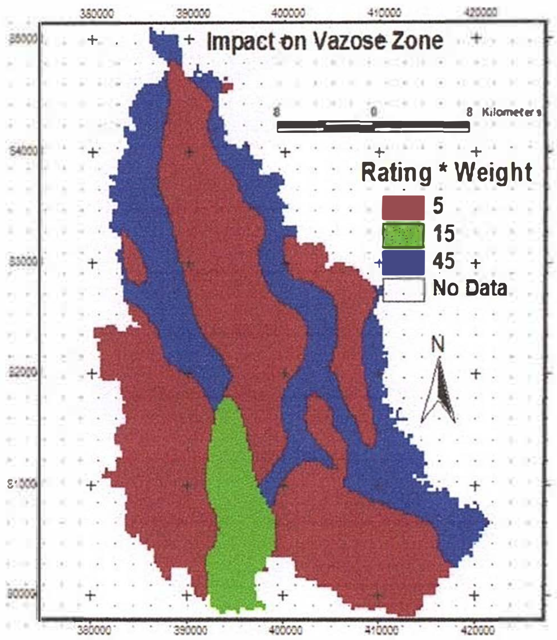

Figure8.6(b): Impactof vadose zone weighting

8.2.7 Hydraulic Conductivity (C)

Aquifer hydraulic conductivity is the ability of the aquifer formation to transmit water. Contamination is controlled by the rate at which groundwater flows. Based on pumping tests of wells in the study area, hydraulic conductivity data were obtained. Hydraulic conductivity determined in the central of the study area varies between 3×10^{-4}-3×10^{-2} (m/s) to 10^{-11}-4.7×10^{-9} (m/s). The rating and weighting values of this parameter are shown in table 8.1 and figure 8.7 (a) and 8.7 (b).

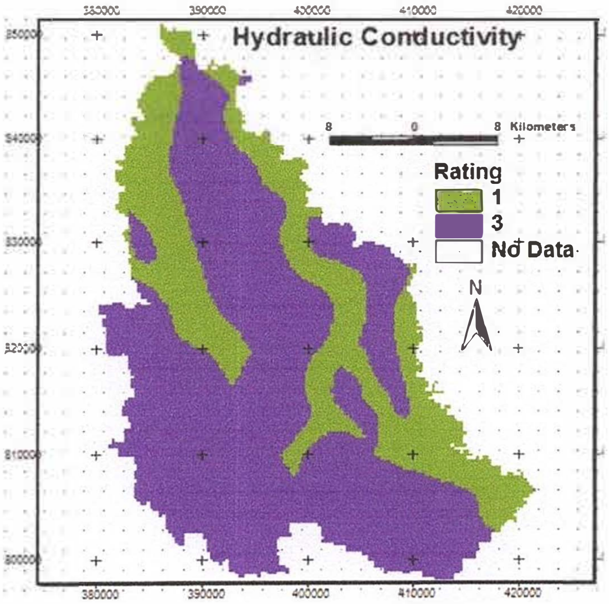

Figure 8.7(a): Hydraulic conductivity rating

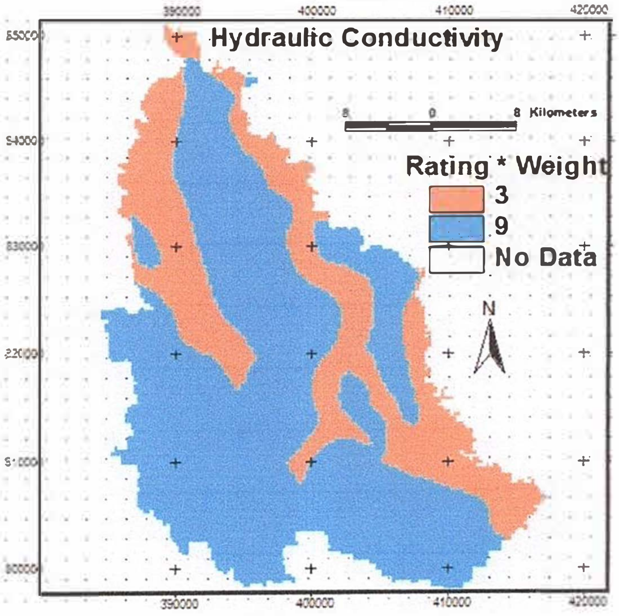

Figure 8.7(b):Hydraulic conductivity weighting

The DRASTIC vulnerability index was computed according to Eq. (3.16) and is between 81 and 167. Also, the DRASTIC vulnerability map of the study area was prepared using overlay analyses of the seven hydro-geological parameter maps mentioned previously. According to the results of the groundwater vulnerability assessment, the proposed Phulbari coal mine has high contamination potential (Figure 8.8).

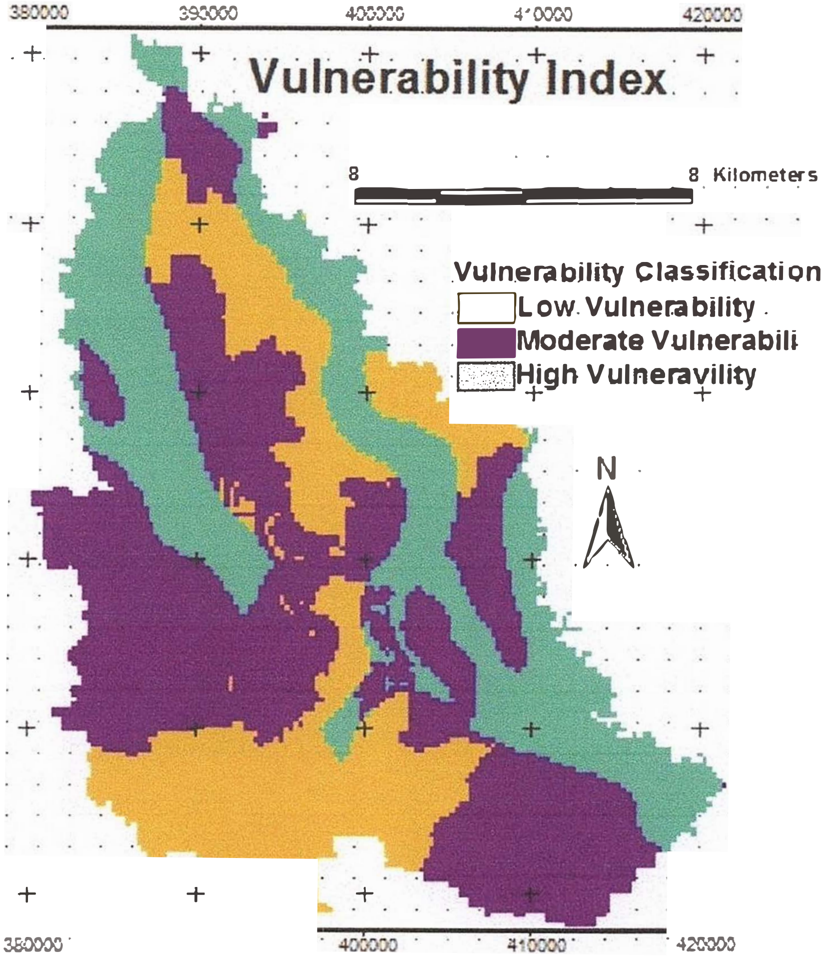

Figure 8.8: Vulnerability map of proposed Phulbari coalmine area before mining activities

According to the conventional DRASTIC vulnerability classification, about 27% areas is low vulnerable, 42% area is moderate vulnerable and 31% areas is high vulnerable (Figures 8.8 and 8.9).

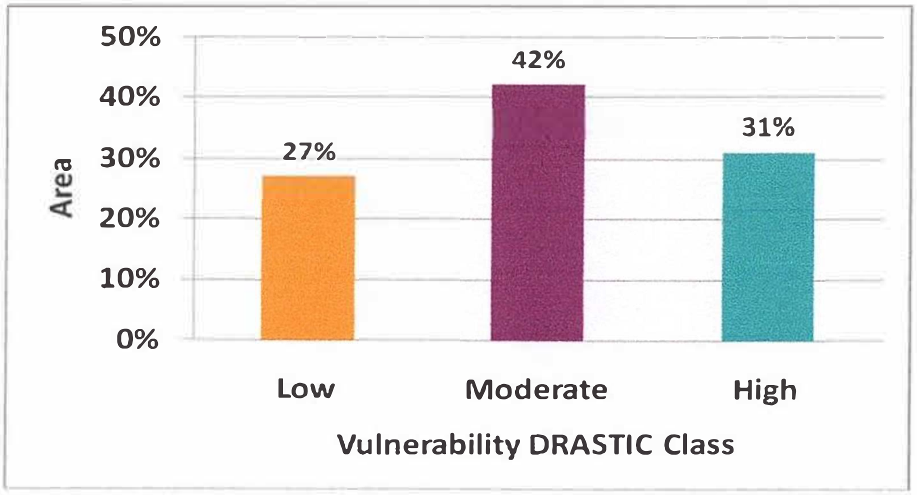

Figure 8.9: Vulnerability area classification before mining activities

8.3 COMPARISON OF MODIFIED DRASTIC-C$_d$HPI BEFORE AND AFTER MINING ACTIVITIES

8.3.1 Depth to Water Table (D)

Before mining the depth of water table is as usual as conventional drastic figure 1. But after mining activities the depth of water table will be changed. The coal seam is laid 38 to 150m beneath the earth surface. Also the aquifer is situated above the coal seam. The mining activities will intersect the aquifer. So in order to do the open pit mine, the areas have to be completely dewatered. All these activities will drawdown the water table at least 38m. Despite an increase in depth to groundwater drainage, the overburden aquifers can be vulnerable to pollution owing to depletion of water resources and disturbances of flow of surface and groundwater. The mine water reservoir is considered as a pollution source for the deposite strata and poorly isolated overburden aquifers (Bukowski *et al.*, 2006). So after mining the DRASTIC range, rating and weighting have to be changed in figure 8.10.

8.3.2 Net Recharges (R)

Net recharge will be varied due to mining operations. Post mine subsidence (horizontal strains of the compression and tension zones) can cause infiltration condition zonally. Damage to hydro-technical infrastructure and riverbeds, post mine subsidence increase net recharge and generally increase natural water infiltration (Figure 8.11).

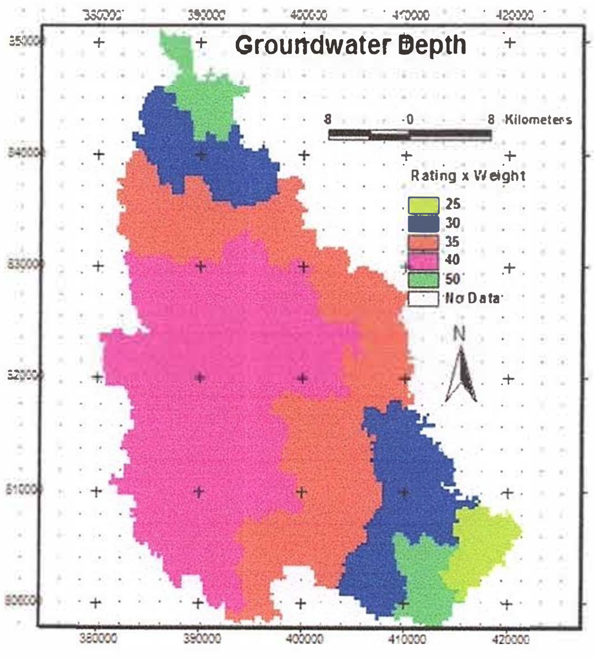

Figure 8.10: Groundwater depth after mining

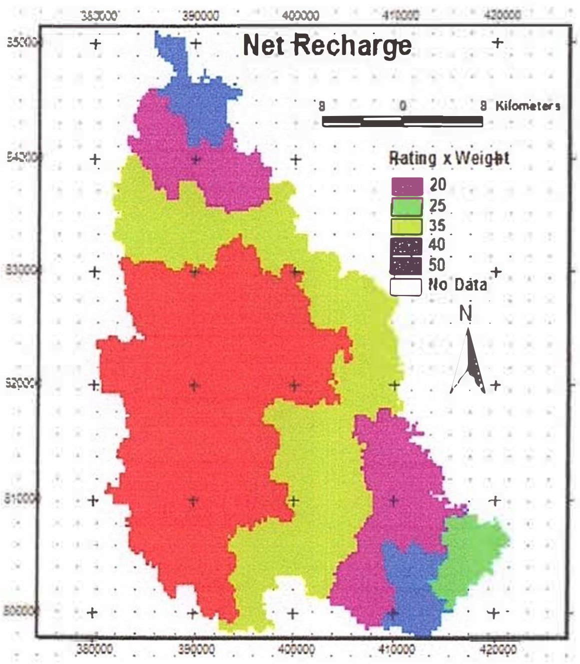

Figure 8.11: Net recharge after mining

8.3.3 Aquifer Media (A)

Open pit coal mining involves clearing the vegetation, top soil removal, overburden excavation, river devastation and step by step back filling. All these process will greatly affect the aquifer media. The lithology and strategraphy will change. So rating and weighting have to be changed in figure 8.12.

8.3.4 Soil Media (S)

In the case of overburden strata and the first water horizon, modification of the point ranges and weighting values may be needed because of secondary zones of compaction and rock fracturing. Depending on the behavior of empty spaces in mine dewatered zone, the point ranges assigned to the factor and weighting values may have to be adjusted (Figure 8.13).

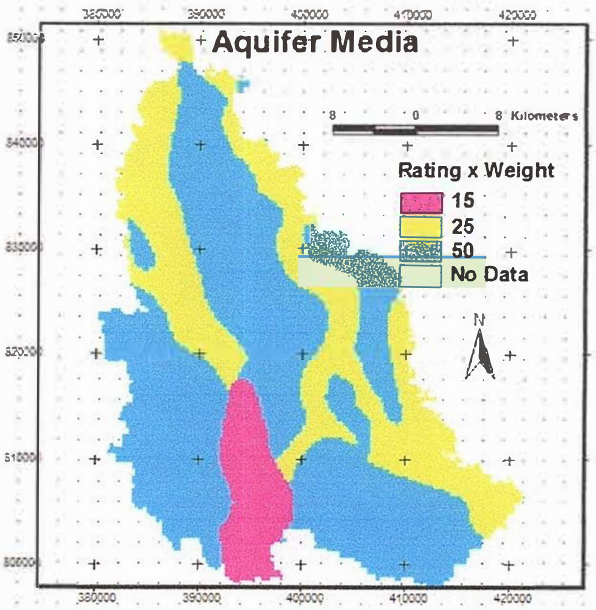

Figure 8.12: Aquifer media after mining

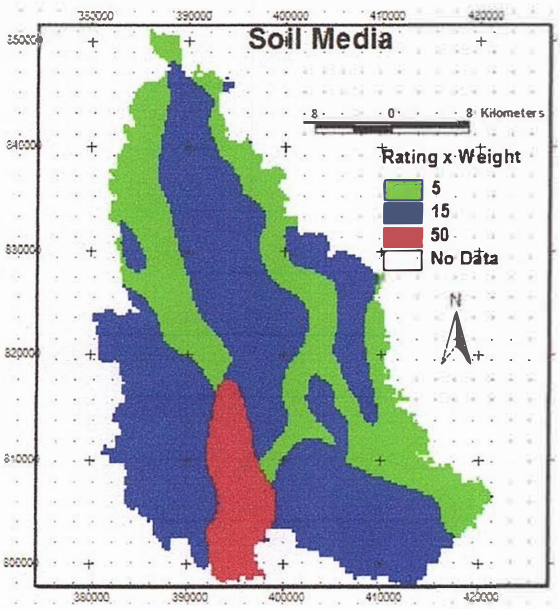

Figure 8.13: Soil media after mining

8.3.5 Topography (T)

The point ranges and weighting values generally need modification only when subsidence significantly affects the original ground surface relief; such effects tend to be more significant in terrain that is less variable and generally flat-lying (Bukowski *et al.*, 2006) which has been shown in figure 8.14.

8.3.6 Impact of Vadose Zone (I)

Generally requires a change in approach, to consider the changes in water quality (e.g. the inorganic sulphur content, heavy metal pollution in the deposit strata), and development of new parameter characteristics, including weighting and scoring ranges. It is necessary to consider the impact of weathering and dissolution of pyrite oxidation products, as well as the progress of mine flooding and the decrease in vadose zone thickness (Bukowski *et al.*, 2006) which has been shown in figure 8.15.

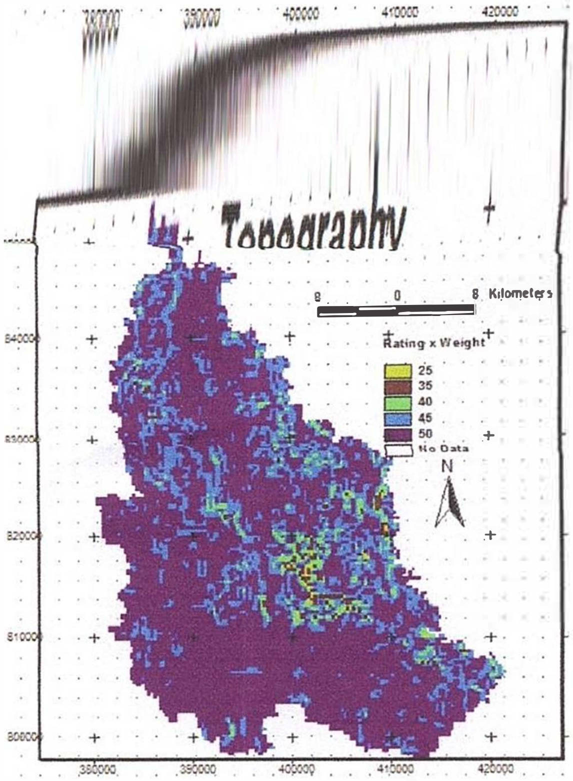

Figure 8.14: Topography after mining

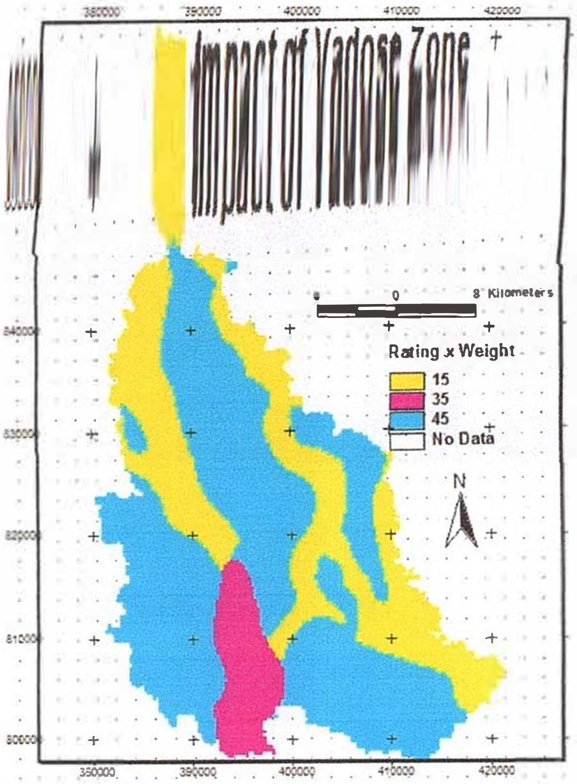

Figure 8.15: Impact of vadose zone after mining

8.3.7 Hydraulic Conductivity (C)

It varies with the changes in depth and the post mine overburden deformations. So a new component and new ranges and weights are needed (Figure 8.16).

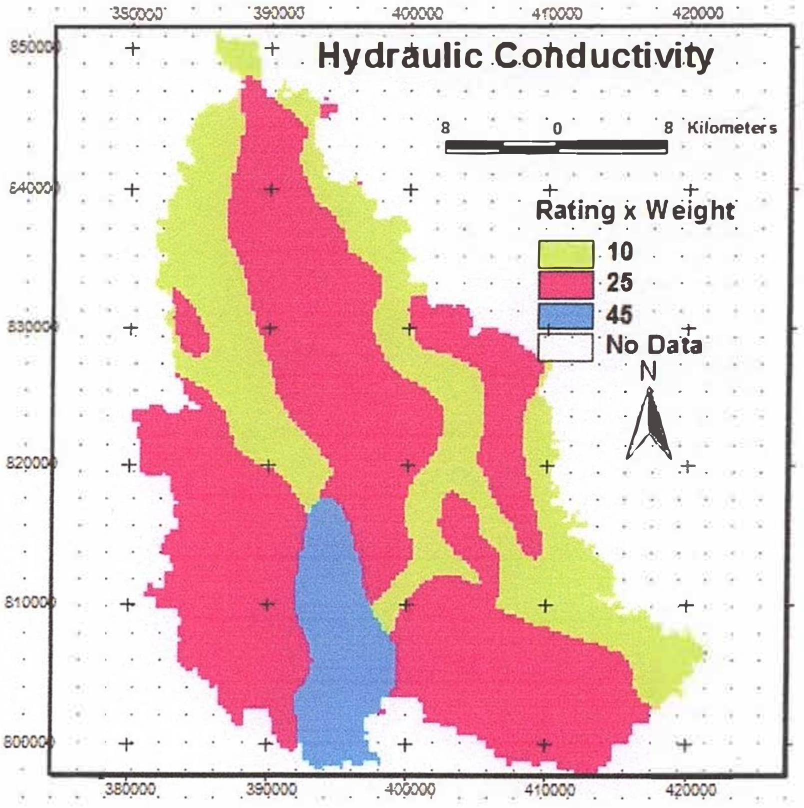

Figure 8.16: Hydraulic conductivity after mining

8.4 ASSESSMENT OF AQUIFER VULNERABILITY WITH THE MODIFIED DRASTIC-C_dHPI METHOD

To modify the known DRASTIC method, the Contamination Index (C_d) and Heavy Metal Pollution Index (HPI) were added to the assessment both before mining and after mining activities and, thus, aquifer vulnerability in the study area were reevaluated. DRASTIC parameters are described in detail in the preceding and the rating and weight values of these were used just the same. Weighting factors of the Contamination Index (C_d) and Heavy Metal Pollution Index (HPI) parameters were determined and used in the vulnerability mapping (Table 8.2 and Figure 8.17(a), 8.17 (b) and 8.18 (a), 8.18 (b)).

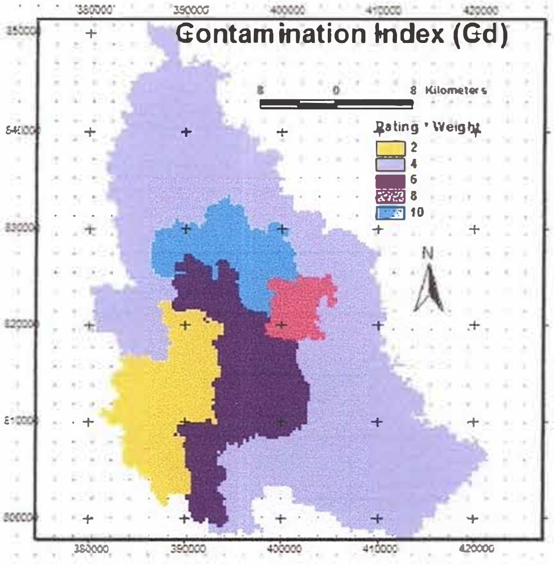

Figure 8.17(a): C_d rating x weight before mining

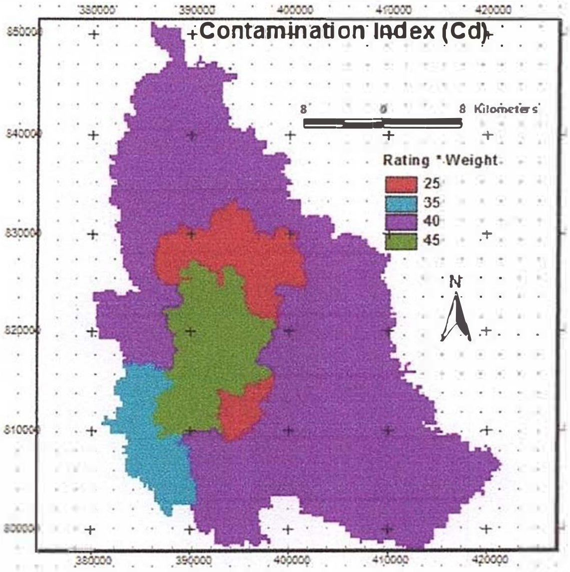

Figure 8.17(b): C_d rating X weight after mining

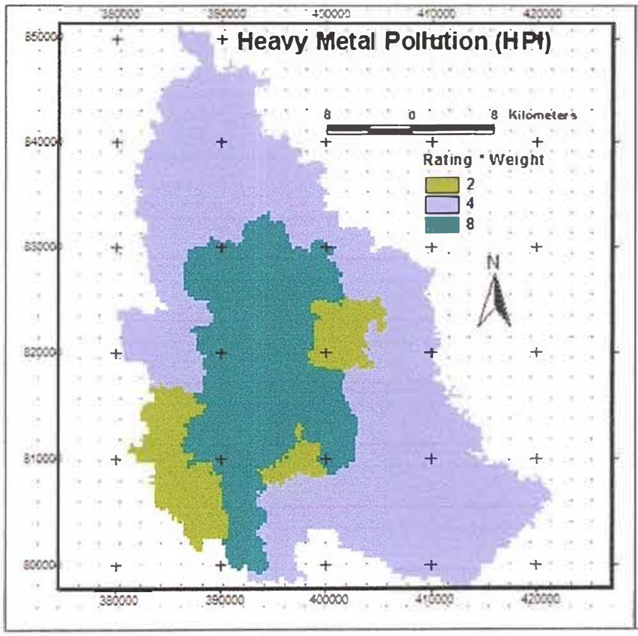

Figure 8.18(a): HPI rating x weight map before mining

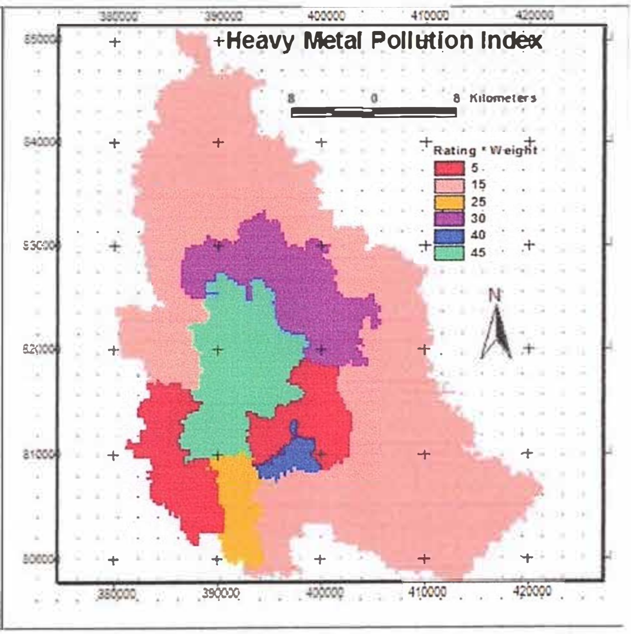

Figure 8.18(b): HPI rating x weigh map after mining

These added parameters are explained in the chapter seven. The DRASTIC weight of the C_d and HPI parameter were given as 2 and 5 before mining and after mining activities respectively (Table 8.2) and the highest rating (10) was assigned to after mining activities because of the high potential impact.

The modified-DRASTIC-C_dHPI vulnerability map of the study area was prepared using overlay analyses of the depth to water, net recharge, aquifer media, soil media, topography, impact of vadose zone, hydraulic conductivity, C_d and HPI parameters both for before and after mining activities figure 8.19 (a) and 8.19 (b). The calculated DVI value for the modified-DRASTIC-C_dHPI map is between 87 and 182 before mining activities (Figure 8.19 (a) and between 185 to 375 after mining activities (Figure 8.19(b)). High index values correspond to areas with high potential of vulnerability.

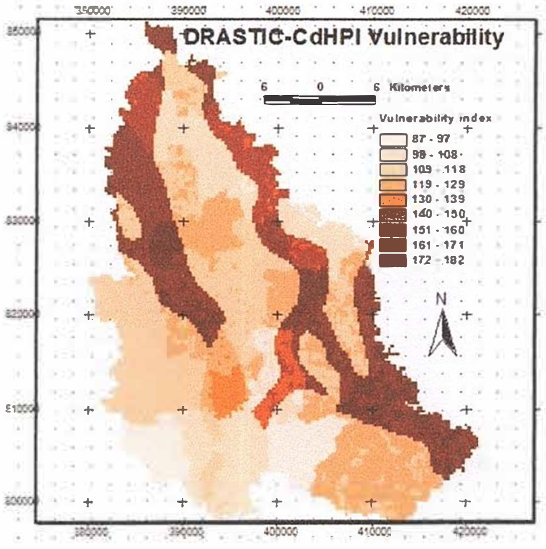

Figure 8.19(a): Modified DRASTIC-CdHPI vulnerability class before mining activities

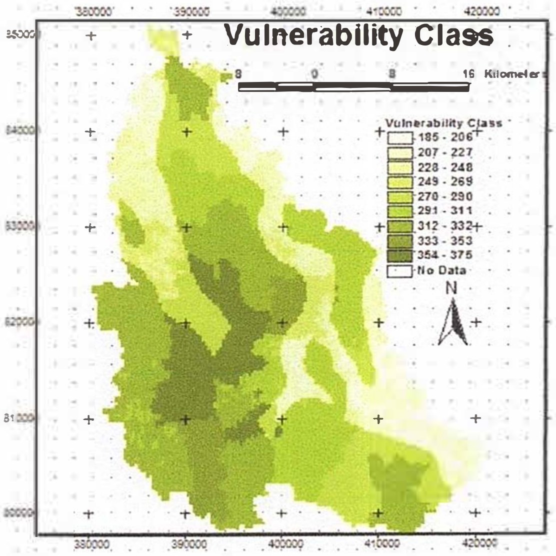

Figure 8.19(b): Modified DRASTIC-CdHPI vulnerability class after mining activities

Rawabdeh *et al*., (2013) calculated DRASTIC index of Amman-Zerqa water basin, which are likely susceptible to groundwater contamination relative to each other. They got maximum DRASTIC value is 210 and the minimum is 24. They divided the DRASTIC index into five categories: No vulnerable (24-61), low (62-99), moderate (100-137), high (138-175) and very high (>175). Sener and Davraz (2011) calculated DVI value for the modified DRASTIC map is between 71 and 256. Ersoy and Gultekin (2013) found DRASTIC score ranged from 58 to 177.

Accordingly, when the modified DRASTIC-C_dHPI vulnerability map of before mining activities was compared with the DRASTIC vulnerability map, similar results were obtained with both maps and almost the same areas in the basin had the same high, medium, and low-contamination potential (Figure 8.20 (a)). But when the modified DRASTIC-C_dHPI vulnerability map of after mining activities was compared with the DRASTIC vulnerability map (Figure 8.20 (b)) with before mining vulnerability map, a vast difference in results were obtained with extreme vulnerability potential most of the study area. The modified DRASTIC$_d$HPI vulnerable area was compared between before and after mining activities.

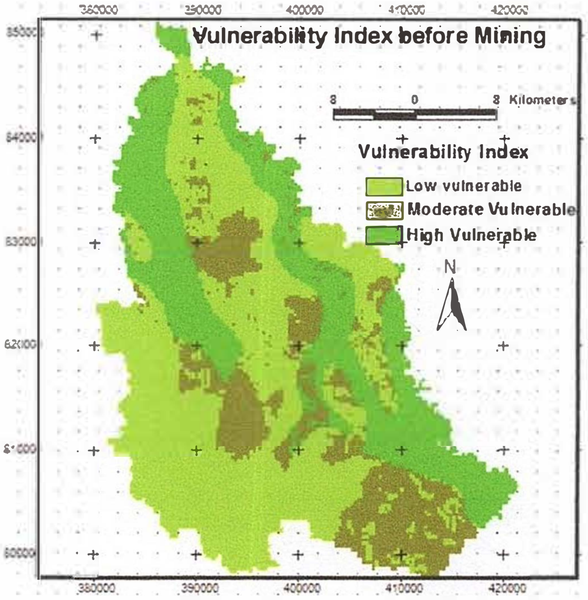

Figure 8.20(a): Modified DRASTIC-C_dHPI vulnerability index before mining activities

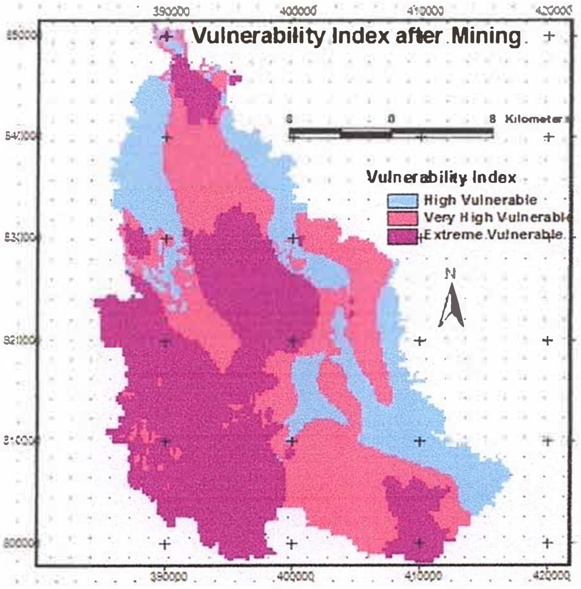

Figure 8.20(b):Modified DRASTIC-C_dHPI vulnerability index after mining activities

The result was found that before mining activities low vulnerable area was 48%, moderate vulnerable area was 22% and high vulnerable area was found 30% (Figure 8.21).

But after mining activities the drastic vulnerable area will be predicted that high vulnerable area will 24%, very high vulnerable area will 35% and extreme vulnerable area will 41% in the study area (Figure 8.22).

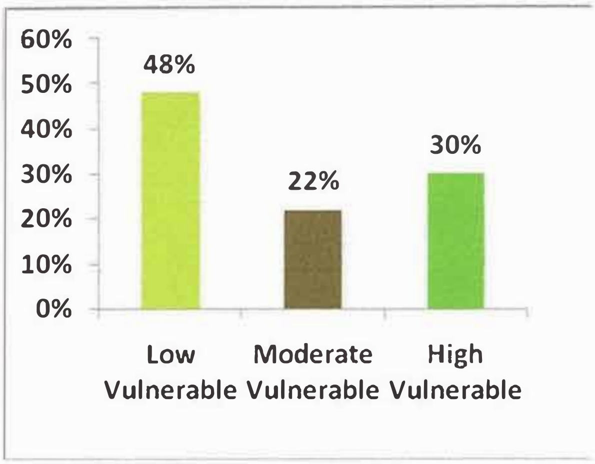

Figure 8.21: Modified DRASTIC-C_dHPI vulnerable area before mining activities

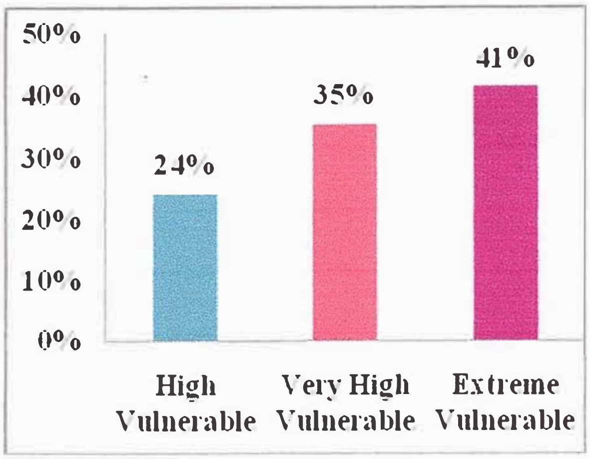

Figure 8.22: Modified DRASTIC-C_dHPI vulnerable area after mining activites

CHAPTER NINE

CONCLUSION AND RECOMMENDATIONS

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9.1 CONCLUSION

9.1.1 Impact on Water Table

Impacts on groundwater have been carried out for an open pit coal mining area located in Phulbari under Dinajpur District in Bangladesh. The Phulbari coalmine covers an area of 511.18 square kilometers. The thickness of coal seam is 38m which is laying between 50 to 250m below the earth surface. The exploration of coal following the open pit method will influence the ground water resources in and around the mine due to pumping of groundwater as well as precipitated water which will be accumulated in the floor or sump of the open pit. Groundwater is the main source for irrigation and drinking purpose of that region. During the dry season, groundwater levels range from 3.22 to 9.01m below the earth surface whereas during the rainy season it varies from 0.93 to 6.23 m during the twenty five years period (1985–2010). On the other hand, during the summer season temperature range from 22^0C to 38^0C and during the winter season it varies from 5.4^0C to 16^0C during the forty years period (1970–2010). Hydrographically we see the close relationship between water table and rainfall from the time series analysis. We observe that temperature is increasing with time and water level is decreasing with time. Here we found a reverse relationship between water table and temperature. But if open pit coal mine is done in that area, this abruptly changes the water table, because total water of mine area have to pump out. As a result drying up of wells, reduction of water in streams and lakes, deterioration of water quality, increased pumping costs and land subsidence occur the around the mine buffer area of twenty Kilometers.

The study area is totally depends on groundwater for irrigation and domestic purposes. By installing the shallow and deep tube well for irrigation by BMDB without following the rules and regulation the groundwater is declining day by day. And it could be the alarming for that area if open pit coal mine is done. By open pit mining the whole area have to be dewatered, as a result groundwater decline up to 105m down from 10m during 38 years of mine life time though very few meters will be recovered after mine closing.

9.1.2 Impact on Groundwater Quality

The content of As in groundwater varied from 0.00109ppm to 0.0199 ppm and the average was 0.0078375 ppm before starting mining activities (Table 6.1). Three studies were carried out to predict the concentration of heavy metal in Phulbari after mining activities and found in Raniganj the lowest concentration was found 0.0008 ppm and height concentration was found 0.0337 ppm and average value was found 0.01725 ppm (Table 6.4) which is 2.20 times higher than initial value of Bangladesh. In Maharashtra it was found lowest value was 5.08 ppm and height value was 8.55 ppm and the average value was found 6.324 ppm (Table 6.5) which is 806.89 times higher than initial value of Bangladesh, but in Poltegor, Poland it was found that before mining activities the concentration was 0.0168 ppm and after five years of starting mining activities this value was found 0.057 ppm which is 3.40 times higher than initial value (Table 6.6). After mining activities this concentration could be considerable change because of arsenic pron country. As arsenic was identified more or less all the districts of this country, so this concentration could be same as the concentration of Maharashtra, India.

The content of Cu in groundwater varied from 0.0019 ppm to 0.0143 ppm and the average was 0.006375 ppm before starting mining activities (Table 6.1). Three studies were carried out to predict the concentration of heavy metal in Phulbari after mining activities and found in Raniganj the lowest concentration was found 0.0067 ppm and height concentration was found 0.0519 ppm and average value was found 0.0293 ppm (Table 6.4) which is 4.596 times higher than initial value of Bangladesh. In Maharashtra it was found lowest value was 0.04 ppm and height value was 0.13 ppm and the average value was found 0.085 ppm (Table 6.5) which is 13.33 times higher than initial value of Bangladesh, but in Poltegor, Poland it was found that before mining activities the concentration was 0.023 ppm and after five years of starting mining activities this value was found 0.0313 ppm which is 1.3609 times higher than initial value (Table 6.6). After mining activities this concentration could be considerable change and it could be considered to same as the value of Maharashtra.

The content of Fe in groundwater varied from 0.0009 ppm to 0.4686 ppm and the average was 0.1639875 ppm before starting mining activities (Table 6.1). Two studies were carried out to predict the concentration of heavy metal in Phulbari after mining activities and found in Raniganj the lowest concentration was found 0.071 ppm and height concentration was found 0.973 ppm and average value was found 0.522 ppm (Table 6.4) which is 3.183 times higher than initial value of Bangladesh. In Poltegor, Poland it was found that before mining activities the concentration was 4.6 ppm and after five years of starting mining activities this value was found 8.75 ppm which is 1.9022 times higher than initial value (Table 6.6). After mining activities this concentration could be considerable change and it could be considered to same as the value of Raniganj, India.

The content of Zn in groundwater varied from 0.009 ppm to 0.0835 ppm and the average was 0.028 ppm before starting mining activities (Table 6.1). Three studies were carried out to predict the concentration of heavy metal in Phulbari after mining activities and found in Raniganj the lowest concentration was found 0.0174 ppm and height concentration was found 0.2017 ppm and average value was found 0.10955 ppm (Table 6.4) which is 3.9125 times higher than initial value of Bangladesh. In Maharashtra it was found lowest value was 0.2 ppm and height value was 0.4 ppm and the average value was found 0.3ppm (Table 6.5) which is 10.714 times higher than initial value of Bangladesh, but in Poltegor, Poland it was found that before mining activities the concentration was 0.36 ppm and after five years of starting mining activities this value was found 0.497 ppm which is 1.3806times higher than initial value (Table 6.6). After mining activities this concentration could be considerable change and it could be considered to same as the value of Maharashtra.

The content of Mn in groundwater varied from 0.010945 ppm to 0.684759 ppm and the average was 0.154126 ppm before starting mining activities (Table 6.1). Two studies were carried out to predict the concentration of heavy metal in Phulbari after mining activities and found in Raniganj the lowest concentration was found 0.004 ppm and height concentration was found 0.356 ppm and average value was found 0.18 ppm (Table 6.4) which is 1.1678times higher than initial value of Bangladesh. In Poltegor, Poland it was found that before mining activities the concentration was 0.24 ppm and after five years of starting mining activities this value was found 0.79 ppm which is 3.2917 times higher than initial value (Table 6.6). After mining activities this concentration could be considerable change and it could be considered to same as the value of Poltegor, Poland.

The content of Cr in groundwater varied from 0.0144 ppm to 0.0264 ppm and the average was 0.01965 ppm before starting mining activities (Table 6.1). Two studies were carried out to predict the concentration of heavy metal in Phulbari after mining activities and found in Raniganj the lowest concentration was found 0.0052 ppm and height concentration was found 0.0836 ppm and average value was found 0.0444 ppm (Table 6.4) which is 2.259 times higher than initial value of Bangladesh. In Poltegor, Poland it was found that before mining activities the concentration was 0.0064 ppm and after five years of starting mining activities this value was found 0.075 ppm which is 11.719 times higher than initial value (Table 6.6). After mining activities this concentration could be considerable change and it could be considered to same as the value of Poltegor, Poland.

The content of Pb in groundwater varied from 0.0195 ppm to 0.0878 ppm and the average was 0.056175 ppm before starting mining activities (Table 6.1). Three studies were carried out to predict the concentration of heavy metal in Phulbari after mining activities and found in Raniganj the lowest concentration was found 0.0102 ppm and height concentration was found 0.0611ppm and average value was found 0.03565 ppm (Table 6.4) which is below the initial value of Bangladesh. In Maharashtra it was found lowest value was 0.05 ppm and height value was 0.07 ppm and the average value was found 0.06 ppm (Table 6.5) which is more or less similar to the initial value of Bangladesh, but in Poltegor, Poland it was found that before mining activities the concentration was 0.0165 ppm and after five years of starting mining activities this value was found 0.047 ppm which is 2.8485 times higher than initial value (Table 6.6). After mining activities this concentration could be considerable change and it could be considered to same as the value of Maharashtra.

The content of Cd in groundwater varied from 0.005 ppm to 0.0164 ppm and the average was 0.0121 ppm before starting mining activities (Table 6.1). Three studies were carried out to predict the concentration of heavy metal in Phulbari after mining activities and found in Raniganj the lowest concentration was found 0.0001 ppm and height concentration was found 0.0054 ppm and average value was found 0.00275 ppm (Table 6.4) which is below the initial value of Bangladesh. In Maharashtra it was found lowest value was 0.16 ppm and height value was 0.25 ppm and the average value was found 0.21 ppm (Table 6.5) which is 17.35 times higher than initial value of Bangladesh, but in Poltegor, Poland it was found that before mining activities the concentration was 0.0024 ppm and after five years of starting mining activities this value was found 0.0058ppm which is 2.4167 times higher than initial value (Table 6.6). After mining activities this concentration could be considerable change and it could be considered to same as the value of Maharashtra.

9.1.3 Groundwater Pollution Index

Four water samples out of eight show high contamination level ($C_d > 3$) ranging between 4.613- 8.619 (6.6), two samples show medium contamination level (C_d 1-3) ranging between 2.171-2.785 and two show the low contamination level ($C_d <1$) ranging between 0.506-0.952 value before mining activities.

After mining activities the predicted concentration index for groundwater samples are shown in table 6.7. The degree of water contamination was classified into three grades followed by Backman *et al.*, (1998), all the samples show the very high contamination level ($C_d > 3$) ranging between 155.868– 1627.256. All the values are very much higher compare with the critical pollution index value of 100.

Very less work has been done on HPI related to fly ash dumping site, but Prasad and Jaipraksh (1999) studied the mining area filled with fly ash and found to be 11.25 while Prasad and Singita (2008) reported 36.67 which was below critical index. HPI calculation process was shown for location 1, both before (Table 6.9) and after mining (Table 6.10) activities. Before mining activities the HPI was found 4.4246 and after mining activities it was found 115.47 in location 1.

Table 6.11 shows that before mining activities C_d ranges between 0.51 -8.62 and HPI ranges between 2.04-4.42, but after mining activities C_d was found 155.86 – 1649.7. The two existing methods, the Contamination Index (C_d) and the Heavy Metal Pollution Index (HPI) provide two extreme results although the values show significant correlation using data from the study area with no major industry. The difference can be attributed to the variation in the concentration of the heavy metal used for the different evaluation schemes.

The C_d (>3) places all the samples as of high contamination level. The HPI on the other hand consider the level of contamination as not critical (<100).

Heavy metal pollution index is useful tool in evaluating overall pollution of ground water pollution. The results indicated that leachate from the ash and coal waste dumping site will be apparently contaminated the ground water. The HPI of ground water samples collected from study area are low as compare with critical pollution index value of 100 before mining activities. It has been observed that, the higher the heavy metal pollution index value, greater the threat to the living organism consuming contaminated water generally, the critical heavy metal pollution index value.

9.1.4 Groundwater Vulnerability Assessment by DRASTIC and Modified DRASTIC-C_dHPI

According to the conventional DRASTIC vulnerability classification, about 27% areas is low vulnerable, 42% area is moderate vulnerable and 31% areas is high vulnerable (Figure 8.8 and 8.9). The modified DRASTIC-C_dHPI vulnerable area was compared between before and after mining activities. The result was found that before mining activities low vulnerable area was 48%, moderate vulnerable area was 22% and high vulnerable area was found 30% (Figure 8.21). But after mining activities the drastic vulnerable area was predicted that high vulnerable area was 24%, very high vulnerable area was 35% and extreme vulnerable area was found 41% in the study area (Figure 8.22). In this study, the DRASTIC method was used for evaluation of groundwater vulnerability in the proposed Phulbari coal mine area. However, despite its success in some case studies, the DRASTIC method has some disadvantages. The influence of regional characteristics (geology, hydrology, hydrogeology, contamination index etc.) is not accounted for in the method and so the same weights and rating values are used everywhere. If the detailed hydro-geological properties such as aquifer type, aquifer thickness, groundwater level and groundwater flow direction etc., are well known, more reliable results can be obtained with this method. In order to better address local issues for refined representation of local hydro-geologic settings, researchers envisaged several modifications of the original DRASTIC model. The modifications were in the form of additional parameters, removal of certain parameters and usage of different ratings and weights for the parameters. The calculated DVI value for the modified-DRASTIC-C_dHPI map is between 185 and 375 after mining activities where as 87 and 182 before mining activities. From the using of DRASTIC method, after mining activities, the study area will be highly contaminated. The accuracy of weights and rating values of the

DRASTIC parameters is important for validity of this method. The DRASTIC method is rigid in the assignment of ratings and weights to the model parameters. In this study, detailed hydro-geological field studies were performed to reduce the margin of error. The rating values of the parameters were determined, dependent on field and regional properties of the study area.

Finally, it is found that the geo-environment such as lithology and stratigraphy will be completely destroyed due to open pit coal mining activities. It is also shown that the groundwater level is gradually decreasing day by day before mining activities and after mining activities it will be declined drastically. The results of analyzed groundwater of the study area show that the concentration of trace elements will become bad to worst due to open pit coal mining. The groundwater vulnerability assessment also shows that before mining activities high vulnerable area was found only 30% and if open pit coal mining will be done the total area will be high vulnerable to extreme vulnerable. The hypothesis of this study was "open pit coal mining will be the environmentally damaging for Bangladesh." All the results mentioned above support the hypothesis. Phulbari as it is will be more sustainable and results also proved the sustainability of the study area.

9.2 RECOMMANDATIONS

9.2.1 Preventive and Corrective Measures for Mine Drainage Pollution

Several actions can be taken to lessen the chances of ground-water pollution occurring because of surface mining. Ground water should be directed away from the mine site both during and after mining, where possible. This objective should be easier to achieve for contour mines than for area mines. In contour mines, drainage pipes can be installed in ditches dug at the foot of the high walls just prior to reclamation. This will result in lower water tables after reclamation, and less ground-water contact with fill material. Ground-water drainage could then be directed in pipes towards a nearby stream channel. Another approach would be to install an impermeable barrier in the backfill material, a few feet below the surface. This would have the effect of directing infiltrating rainfall down slope away from the mine and buried toxic overburden. Where possible, surface mining should be kept at least 200 feet away from any well or spring water supply, especially those supplies located downhill from the mine. Also, all bore holes created by coring operations and all old abandoned wells should be filled with concrete grout at the mine site during mining. Otherwise, polluted mine drainage may recharge aquifers underlying the mine. Likewise, wells drilled near the mine to monitor ground water should be grouted following mine reclamation.

Certain corrective measures can be taken after ground-water pollution is detected. One should first locate and stop discharges from specific pollution sources on the surface mine site, if possible, before reclamation is completed. This could include channeling mine surface water into treatment ponds that are lined with impermeable bottoms. Second, new water supplies should be located for persons whose wells or springs have become polluted. The most dependable water supply would be piped water from a water service district. If piped water is too far away to be economically feasible, then the choices would be a new well, a cistern or a nearby spring. Of these, a new well is definitely preferable. It should be located as far away from the mine as possible and away from other potential pollution sources such as septic tanks, acid streams and other mines; it should also be properly constructed and sealed, and have enough casing to seal off the upper shallow ground-water zone. If possible, a deeper aquifer with potable ground water should be tapped for a water supply. New well drilling and construction should be handled by an experienced water-well driller.

9.2.2 Acidic Drainage Minimization

Acidic drainage from mines is observed at many mine sites and the undesirable consequences of acidification are well known. Every effort should be employed to minimize the causes of acid generation. Because mineralogy and other factors (particle size, reactivity of NP and presence of oxidizers) that influence AMD formation are highly variable from one mine to another, and among different geologic materials within a proposed mine site, accurate prediction of future acid generation is difficult at best. Predicting the potential for AMD formation is costly, and of questionable reliability (Kuipers *et al.* 2006). In addition, concern has arisen over the lag time between waste emplacement and observation of an acid drainage problem. With acid generation, there is no general method to predict its long-term duration or to predict when acidic drainage will commence. There are historic, and now modern mining examples of long-term AMD generation requiring active treatment in perpetuity. There are two primary approaches to addressing AMD: circumvent mining sulfide rich ore deposits with high AMD potential, and implementing mitigation measures to limit potential AMD impacts. It is noted that avoiding mining of sulfide ores with the potential to form AMD may be difficult because they are most often associated with the mineral resource of interest. Selective handling and avoidance of sulfide ore and overburden is a strategy for minimizing the risk of future acid generation (Skousen *et al.,* 1998). In a review of selective handling of acid-forming materials in coal mining in the Eastern U.S., Perry and others (1997) found that selective handling had not eliminated acid formation due in part to the inherent difficulty in segregating benign overburden from acid-forming waste. In some mining operations acid-forming minerals can be avoided through the mine planning process or through using underground mining rather than surface mining.

Mine waste isolation and avoidance of oxidizing conditions can be performed using several methods that keep sulfides isolated from oxygen. Sub-aqueous disposal of tailings and waste rock below the water table is commonly practiced in Canada as a protocol for mine reclamation (Samad and Yanful, 2005). Paste backfill is a mining methodology for minimization of acid formation by backfilling mine workings using a mixture of mine tailings, Portland cement and other binders to create a waste disposal option that is both geo-technically stable and geochemically non-reactive since sufficient NP can be added to neutralize any future acidity (Benzaazoua, T.B. and B. Bussiere, 2002). Depyritization of tailings can be accomplished to remove sulfide minerals from waste products to create a benign sand fraction suitable to use as a general backfill and a companion low-volume sulfide concentrate requiring careful disposal. Most mine tailings contain small amounts of sulfide minerals that can be readily separated from non-acid forming silicate minerals using conventional mineral processing equipment to create a cleaned material with sufficient NP to ameliorate any future acidity (Benzaazoua, B. *et al.,* 2000).

In many cases, the measures described above are most effective when used in combination and adapted to the situation at a specific site. For the most part, only limited data are available to document the long-term effectiveness of any of these controls. The Kuipers Report (2006) provides a unique view of the failure to predict the formation of AMD at many hard rock mines. There are many research investigations being conducted by university, government, and industrial entities to develop new treatment strategies for AMD. The transfer of laboratory data to site-specific conditions (climate, geology, physical properties of ores, etc.) can be problematic and significantly impact their feasibility and performance in the field.

Thorough baselines studies of the biological, hydrologic, and geochemical conditions characteristic of the unique site are required to provide a basis for long-term monitoring and provide an insight into mechanistic processes involved in AMD evolution (Edwards *et al.,* 2000). Associated financial assurances for resource mitigation in the event of default of a mine property are also required (NRC, 1999) to ensure both short-term and long-term mitigation of AMD and the associated impacts to water quality and fisheries. Based on review of the acid mine drainage literature it is clear that severe world-wide ecological consequences, especially for aquatic resources, have resulted from mining ore deposits with acid-forming minerals. Accurate prediction of the onset and aggressiveness of low-quality acidic water discharge is perilously difficult using the best available science. Multiple complex geochemical, biological and hydrologic factors create a daunting task for mining engineers to profitably recover mineral resources while preventing discharges of metals and acidity to surface and ground water. The deleterious effects of elevated metals levels and acidity to salmonids are clearly reported in the scientific literature. The inevitability of impacts to fisheries from AMD caused by mining is an open question and dependent on the outcome of complex geochemical reactions and human attempts to understand and mitigate their consequences. The track record of industry is replete with problems, thus little comfort is afforded by extensive pre-mine studies.

9.2.3 Some Legal Aspects of Groundwater Pollution by Surface Mining

Surface mine operators and companies are concerned about ground water with respect to their legal obligations for protection of groundwater quality and quantity. I interpret three types of legal obligations regarding ground-water quality. First, there are requirements for certain data and plans in the surface mining permit application. Second, there will be monitoring requirements during surface mining, and third, there are water quality standards which must not be violated. Only water quality standards will be reviewed in detail.

(1) pre-mining surveys of ground water, including sampling of all water supply wells 1000 feet of the mine site, and chemical analyses of these waters for at least pH, total suspended solids, iron, and manganese; (2) characterization of water quality for each aquifer between land surface and the lowest mined coal (including the aquifer just beneath this coal), for pH, suspended solids, iron, and manganese. If wells are not available for sampling and analysis to represent some aquifers, then new wells must

be drilled; (3) description of how the potential for ground-water pollution will be minimized, and what pollution is likely to occur; (4) a plan for treatment of pond, pit, or stream waters before they infiltrate, to correct future ground-water pollution should it occur; (5) identification of alternate water-supply sources for ground-water users whose present supplies may become polluted; and (6) a plan for ground-water quality monitoring, involving wells, to be implemented where future pollution is judged probable for areas within 1000 feet of the mine site. It is likely that easily-pollutable ground water at wells will have to be monitored at least once every three months, for at least pH, total suspended solids, iron, and manganese. Probably at least one new well will have to be drilled downhill from the mine site, if no other nearby wells are present.

9.2.4 Mining Legislation and Our Concept

A "Mining law" is the principal regulatory instrument governing mineral exploitation activities and it defines both the rights and obligations of the mining title-holder and the power of government officers. Coal Act is the first and foremost work to develop a coal mine. We have to establish "Inspectorate of Mines".

As our coal is lying under ground, so we have not to hunger for exploring it by the foreigner. So I want to recommend that our man power is spread all over the country. We have to make them skill by train up. When we ensue that our resources can be explore by our own man power, and then we can take appropriate action.

9.2.5 Local Environmental Health Concerns

Public health services often have to deal with reported clusters of adverse health events. An important characteristic of disease clusters is that the involved community often is concerned about environmental factors influencing health. To facilitate cluster investigations, a stepwise protocol was developed in the Netherlands, based on international literature. Essential is the two-way approach, consisting of a disease-track and an environment-track. Attention to potential environmental exposures is as important as attention to the reported diseases, not only because environmental pollution often is the reason of public concern and thus relevant for risk communication, but also for deciding about the boundaries of the population at risk. Moreover, environmental information is necessary for judgment of the plausibility of a causal relation and for advising measures to prevent exposure. Within this two-way approach, three stages are distinguished: orientation stage, verification stage and quantification stage. Only if an increased risk as well as an elevated exposure is verified, under certain conditions a case–control study may be useful to study causality between exposure and adverse health events. During all stages of the investigation, good risk communication strategies have to be taken into account. However, even then it might be difficult to prevent conflicts, because of the differing interests between experts and the community involved. One of the most important aspects that determine judgments about risks by threatened people is controllability; that is why community participation is essential. Therefore it can be concluded that cluster management is a mutual endeavor for experts, public and media, where experts are judged on three characteristics: expertise, credibility and empathy.

In order to avoid the adverse impact of noise and vibration, their potential should be evaluated with a view to providing appropriate sound reduction schemes. Noise is best controlled at source by choosing machinery and equipment suitably by their proper installation and by providing noise insulating padding. The application of silencers, reactance mufflers, absorption mufflers etc. in appropriate cases would considerably reduce the noise levels. Similarly, the use of explosives of required strength and density only, careful monitoring of blast vibrations with a view to understanding explosive characteristics of the rock, use of proper delay/relays in detonation and adopting safe levels of blasting vibrations for the residential type structures, would help in minimizing damage caused by blasting (Sinha,1988).

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