CHAPTER 1

INTRODUCTION

1.1 An overview of the global water scenario

Earth is known as the "Blue Planet" because 71 percent of the Earth's surface is covered with water. Water also exists below land surface and as water vapour in the air. Water is a finite source. In fact, only 0.5 percent of the total water on Earth is readily available for human use. This water is in aquifers, lakes, reservoirs, rivers, streams, and rainfall. As for the rest of the planet's water, 97 percent is saltwater, which can be made accessible after desalination, and the remaining 2.5 percent is freshwater that is frozen as polar ice or stored as groundwater. The distribution and availability of water differs from region to region and country to country.

High demand for and continued misuse of water resources has increased widespread risks of water stress. Water stress occurs when the demand for water exceeds the available amount. This stress often occurs during a certain period of time or when water quality is poor, limiting safe water use.

About 60 percent of the available freshwater is found in just nine countries—Brazil, Canada, China, Columbia, the Democratic Republic of Congo, India, Indonesia, Russia, and the U.S. These nine countries represent about 44 percent of the earth's landmass and are home to 35 percent of the global population. Even within these countries, the distribution of water is uneven.

Figure 1.1 shows that 97% of the Earth's water occurs in oceans and is saline. Approximately three percent (3%) of the water on Earth is fresh water and its physical state varies from being a liquid, to becoming a gas or a solid. Approximately 69% of the Earth's fresh water is locked up in glaciers, ice caps and permanent snow cover in the Polar Regions. Groundwater accounts for 30% of the freshwater on Earth, while only 0.3% of all freshwater is contained in river systems, lakes and reservoirs (Kibona et al. 2009; Cassardo and Jones 2011; Lui et al. 2011).

GRAPHICAL REPRESENTATION OF GLOBAL WATERS DISTRIBUTION

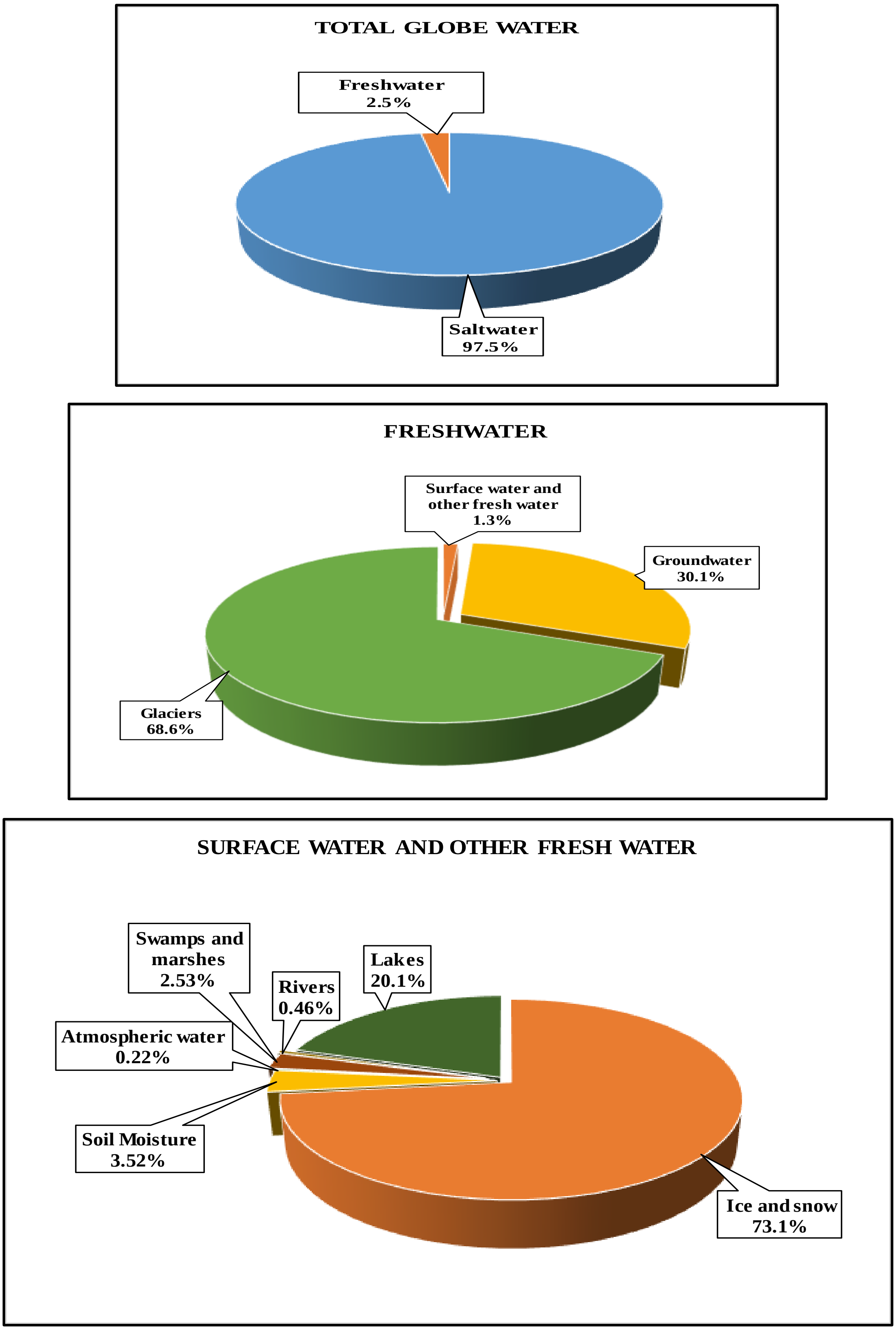

Figure 1.1 Distribution of the Earth's water (Gleick, P. H. et al. 1993)

Approximately 99% of water is described as unfit or unavailable for human consumption. The remaining one percent (1%) consists mainly of groundwater, which can be difficult and costly to obtain. Only 0.0067%of the total water on Earth is fresh surface water that can be used. This leaves a total of around 2120 km3 of freshwater that is available for human use and consumption (Cassardo and Jones 2011).

1.2 Groundwater scenario of India

Water is vital for life, living, and livelihood. Sustainable development and efficient management of water is an increasingly complex challenge in India. India is one of the most populous countries, it comprises 18% of the world's population, but has only 4% of the world's renewable water resources (National Water Policy, 2012). India is the highest consumer of groundwater in the world (Biswas et al., 2013). Rainfall is the main source of groundwater recharge in the country. However, the distribution of rainfall has a wide variation both in space and time. Groundwater resources of the country have been estimated based on the guidelines and recommendations of the groundwater estimation committee 1997 (GEC-97).

Due to rapid population growth, uneven Spatio-temporal distribution of water resources, economic development, and changing climate, the demand for the freshwater resource has increased rapidly over the years which have led to water scarcity in many parts of the world (Selvam et al., 2015; Jasrotia et al., 2016).

In India, 90% of rural and 50% of the urban population depends on groundwater for domestic water use. About 70% of groundwater in India used for the agriculture sector (GEC, 2015). Groundwater, a dynamic resource, depends on several factors such as geomorphology, lithology, topography, slope, precipitation, soil, drainage pattern, land use/land cover (LULC), and hydrological conditions of an area (Pradhan, 2009; Avtar et al., 2010; Singh et al., 2011a; Singh et al., 2009: Acharya, 2017). During the past two decades, the water level has been falling rapidly in several parts of the country (Jasrotia et al., 2016). According to the NITI Aayog (2018) report, 0.6 million people in India are facing high to extremely high water stress due to mismanagement and inadequate availability of freshwater.

(a) Availability of groundwater

Rainfall is the major source of groundwater recharge in India, which is supplemented by other sources such as recharge from canals, irrigated fields, and surface water bodies. A major part of the groundwater withdrawal takes place from the upper unconfined aquifers, which are also the active recharge zones and holds the replenishable groundwater resource. The replenishable groundwater resource in the active recharge zone in the country has been assessed by Central Ground Water Board jointly with the concerned State Government authorities. The assessment was carried out with Block/Mandal/Taluka/Watershed as the unit and as per norms recommended by the Ground Water Estimation Committee (GEC)-1997. As per the latest assessment, the annual replenishable groundwater resource in this zone has been estimated as 432 billion cubic meter (BCM), out of which 399 BCM is considered to be available for development for various uses after keeping 34 BCM for natural discharge during the non-monsoon period for maintaining flows in springs, rivers, and streams (Central Ground Water Board, 2006).

(b) Extraction and uses of groundwater

Groundwater extraction for various uses and evapotranspiration from shallow water table areas constitute the major components of the groundwater draft. In general, the irrigation sector remains the main consumer of groundwater. The groundwater draft for the country as a whole has been estimated as 231 BCM (Central Ground Water Board, 2006), about 92 percent of which is utilized for irrigation and the remaining 8 percent for domestic and industrial uses. Hence, the stage of groundwater development, computed as the ratio of groundwater draft to total replenish able resource, works out as about 58 percent for the country as a whole. However, the development of groundwater in the country is highly uneven and shows considerable variations from place to place.

(c) Categorization of assessment units

As a part of the resource estimation following the GEC norms, the assessment units have been categorized based on the stage of groundwater development and long term declining trend of groundwater levels. As per the assessment, out of the total of 5723 assessment units in the country, groundwater development was found to exceed more than 100 % of the natural replenishment in 839 units (14.7 %) which have been categorized as 'Over-exploited'.

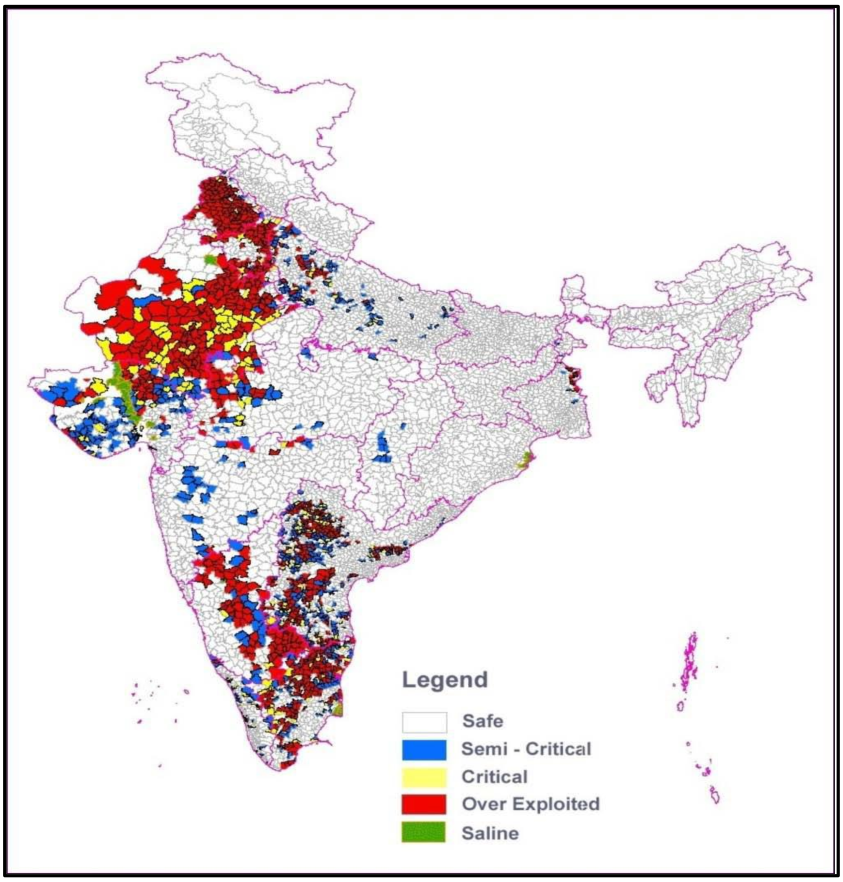

Figure 1.2 Geographical distribution of various categories of assessment units

(Sources: Ground water scenario in India, CGWB-2014)

Groundwater development was found to be to the extent of 90 to 100 % of the utilizable resources in 226 assessment units (3.9 %), which have been categorized as 'Critical'. 550 assessment units with the stage of groundwater development in the range of 70 to 100 % and long-term decline of water levels either during pre- or post-monsoon period have been categorized as 'Semi-Critical' and 4078 assessment units with the stage of groundwater development below 70% have been categorized as 'Safe'. 30 assessment units have been excluded from the assessment due to the salinity of groundwater in the aquifers in the replenishable zone. The geographic distribution of various categories of assessment units in India is shown in Fig. 1.2.

1.3 Status of groundwater and surface water quality in Singrauli coalfield

The present research work has been carried out in the Singrauli coalfields situated in central India is managed by the Northern Coalfields Ltd, (NCL). It is one of the biggest opencast coal mining complexes in the world, approx. 14% of India's coal production through mechanized opencast mining. With the availability of power grade coal reserves and nearby water reservoirs, it offers an excellent location for super thermal power plants (STPS), Aluminium plants, and cement industries.

The large scale mining operation coupled with thermal power plants and many different types of power-based industries in the nearby area of Singrauli coalfield has been releasing pollutants and thus posing a threat to the environment and ecosystem of the area, in which water pollution is an important one.

Several seasonal nallas, flowing from north to south and south to north drain through this area and meet the master drain, the Rihand Dam (Govind Ballabh Pant Sagar)which is located south of this area and Sone river located North of this area. Bijul Nalla, Motwani Nalla, Balia Nalla, Amjhar Nalla, and Tippa Jharia Nalla drain this area. One of the irrigation bund called Amjhor is located between Amlohri and Nigahi projects and another bund called Motwani Dam is located between Jayant and Nigahi projects.

The monitoring agencies such as CPCB and CMPDIL are carrying out regular environmental monitoring of environmental parameters such as ambient air quality, noise level, water quality and groundwater levels in Singrauli coalfield area. A few researchers have studied the quality of ground and surface water in Singrauli coalfield (Dhar et al., 1986., Dhar et al., 1987., Dhar et al., 1990., Jamal et al., 1991, Agrawal et al., 2010, Pandey et al., 2012, Khan et al., 2018).However, in depth study on groundwater is still lacking.

Earlier studies of this area, relating particularly to the physicochemical studies of surface and groundwater, include the work of Khan et al., 2018. This paper presented with the physicochemical studies of surface and groundwater samples carried out in surrounding areas of coal mines and thermal power plants in Singrauli belt. According to Khan et al., 2018, Baliya Nalla shows higher concentration due to water discharge from coal washeries through this Nalla which finally joins the GB Pant Sagar. Motwani dam shows higher concentration due to the iron sulphate in coal and other effluents emanating from coal mines and industries are disposed off to water bodies. A few locations around singrauli coalfield, the groundwater is highly contaminated (major ions and heavy metals) exceeds the WHO (2011) limit. The water quality in close vicinity to the coal mining region is unsuitable for domestic purposes. The intake of water around the coal mining and industrial area may cause health risks to the local residents. Industries must discharge their water effluents only after proper treatment, and district authorities, local government bodies, and municipal corporations should take appropriate steps to check the water contamination in this area.

1.4 Overview of the impacts of coal mining activities on environment and human health

Coal mining is one of the major industries that contribute to the economy of a country but it also impacts the environment (M. Dutta et al. 2017). Coal is a vital source of energy around the world-wide around 41% of the world's electricity is generated from outdoor coal combustion (Nataly Echevarria Huaman and Xiu, Jun. 2014).

The environmental problems arising due to extensive coal mining activities are Deterioration of natural drainage system, surface, and groundwater pollution, lowering of groundwater level, soil contamination, land degradation, deforestation, air pollution, noise, and vibrations, (Sumi et al., 2001; Das gupta, 2012; Mondal et al., 2014). It is well known that every aspect has to phases one is positive and the other is negative.

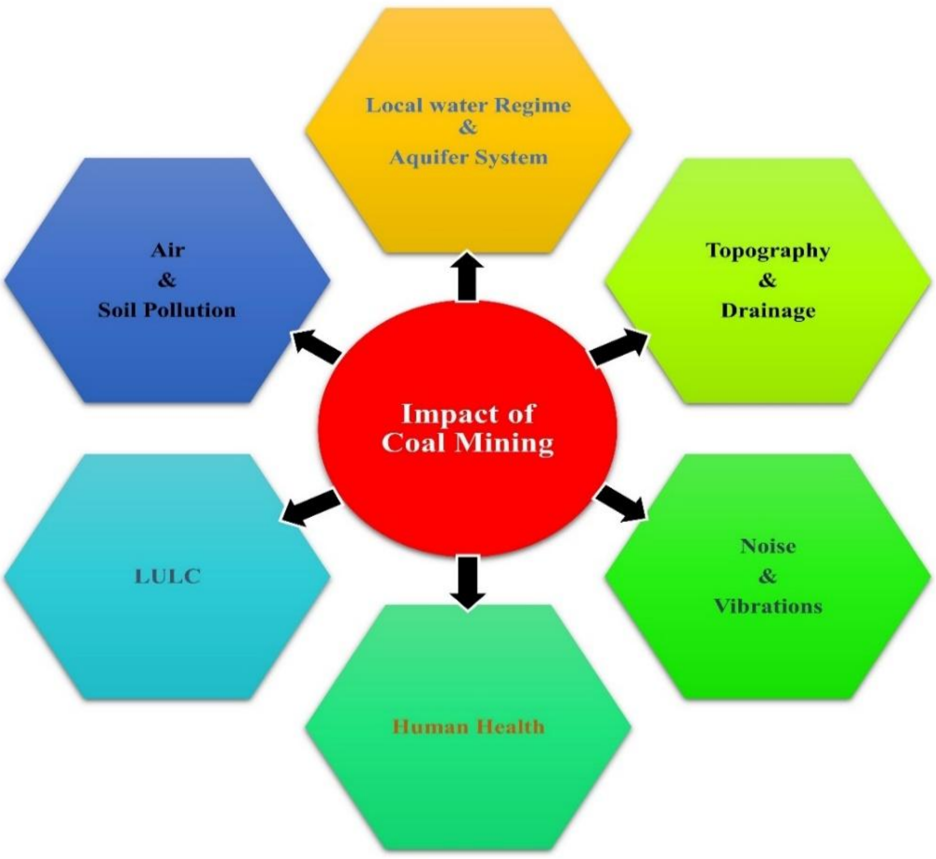

Figure 1.3 Impacts of coal mining on the environment and human health

1.4.1 Impact on topography & drainage

The primary environmental challenge of coal mining could be stated as the damage affecting surface water bodies (Pan et al. 2012; Bai et al. 2011). The mining of coal by opencast methods causes changes in topography. The opencast coal mining project is located on high elevated ground under forest cover and hills. The change of ground relief in a mine area influences the local drainage. This may alter the drainage of the area at the micro-level. Care is taken during mining activities to avoid any serious damage to surface water bodies.

1.4.2 Impact on groundwater quality and quantity

Open-cast coal mining activities, underground mining, or auxiliary projects usually impact on both hydrology and water quality (Zeng et al., 2018). The impact of opencast coal mining on local water regime is dependent mainly on hydro-meteorological, mine, and aquifer parameters. The impact on local water regime varies, in time and space, at different stages of mining. The infiltration of mine water associated with contaminants in groundwater is mainly due to the leaching process, increase of permeability due to excavation of aquifer materials, and extensional fracturing induced by blasting (Younger et al., 2002). Negrel et al. (2007) suggested that the mixture of pollutants transfer into groundwater up to the depth of 50m below the surface. Mining waste or overburden contains various types of toxic elements such as cadmium (Cd), copper (Cu), chromium (Cr), lead (Pb), nickel (Ni), fluoride (F), arsenic (As) and zinc (Zn) which may accumulate into water bodies and form most critical long term hazard for groundwater.

The mining activities may cause changes in aquifer potential, the water level in the vicinity of the mine and disturb groundwater flow direction. Due to blasting, the hydrogeological units close to the working face will get disturbed and the fractures and joints will get dilated. All the aquifers, including the water table aquifer, above the mineral to be extracted, are damaged because for exposing the mineral for extraction the overburden rocks area removed. Coal mining disturbs the underground water table in terms of its level, quantity, and quality. The groundwater levels in and around mining areas vary to a great extent from place to place. The groundwater level values (mbgl) during pre-monsoon and post-monsoon periods give the fluctuation values at any place. These values are obtained by regular (monthly) monitoring of water level into selected dug-wells and other water source structure.

1.4.3 Impact on aquifer system

The impact of opencast coal mining on local water regime largely depends on mine geometry, groundwater recharge, and aquifer parameters of the formations. The mining activities may cause changes in aquifer potential, the water level in the vicinity of the mine and disturb groundwater flow direction. Due to blasting, the hydrogeological units close to the working face will get disturbed and the fractures and joints will get dilated. This increase in secondary porosity and the development of a high permeability zone close to the working face.

In opencast coal mining, only the aquifer lying above the working seam (i.e. unconfined aquifer) gets affected and whereas, the lower aquifer is least affected. Due to stratification, the permeable beds act as individual hydrogeological units and develop a multi-aquifer system. With this, the propagation of drawdown cones is limited to small distance from the mine edge. With numerical modelling techniques, the impact on the aquifer system both under steady and transient conditions can be predicted precisely.

1.4.4 Impact on surface water quality

Water pollution problems in the mining area are caused by tailing pond, soil erosion, AMD, increased sediment levels in streams, land subsidence, disturbance on the hydrological cycle, and rainfall.

The contaminated mine water can persist more than 10 km from its source and might impact on the soil and water bodies of neighbouring area (Naicker et al., 2003). In rainy seasons, the run-off water from the areas surrounding the mines may carry with it a large load of suspended solids into the nearby surface water body. A long-term water quality database and regular monitoring of water quality parameters is required to assess the impact of mining on water resources.

1.4.5 Impacts of coal mining on air quality

The mining activities contribute to the problem of air pollution directly or indirectly (Baldauf et al., 2001; Collins et al., 2001). Opencast mining is more severe in the air pollution problem in comparison to underground mining. Sources of air pollution in the coal mining areas generally include drilling, blasting, overburden loading and unloading, coal loading and unloading, haul roads, transport roads, stockyards, exposed overburden dumps, coal handling plant, exposed pit faces and workshop (CMRI, 1998). These air pollutants reduce air quality and this ultimately affects the people, flora, and fauna in and around mining areas (Chaudhary and Gajghate, 2000; Crabbe *et al*., 2000; Wheeler *et al*., 2000; Nanda and Tiwary, 2001).

Generation of particulate matter (PM) is a concern in all types of mining activities and is considered as a dominating air pollutant in the mining area. The dispersion pattern of PM in the air plays an important role on the health of mineworkers and the nearby residents. The movement and spread of PM in surrounding depend on size, shape density, nature of particles, and as well as local meteorology. PM, especially $PM_{2.5}$ size, can be suspended in the air for a longer time and transported to long distances. $PM_{2.5}$ goes directly to the deeper parts of the lungs and affects the respiratory system during inhalation.

The burning of coal leads to the emission of poisonous gases with underlying health impacts and environmental problems (Clancy et al.; Katsouyanni et al., 2001; Gent et al., 2003). In coal combustion, the carbon, sulphur, and nitrogen react with oxygen and produce their respective oxides: carbon dioxide (CO_2) and carbon monoxide (CO), sulphur dioxide (SO_2) and sulphur trioxide (SO_3), and nitrogen dioxide (NO_2) and nitric oxide (NO), respectively.

1.4.6 Impacts of coal mining on soil properties

The mining activities may cause land subsidence, which destroys soil structure, changes its properties and causes eco-environmental damages such as a reduction in crop yields, restriction of vegetation growth, soil erosion, changes in topographic and hydrologic conditions, and loss of agricultural land and topsoil (Meng et al., 2009; Yang et al., 2016; Shi et al., 2017; Wang et al., 2017).

During surface mining, the excavated materials from depths of 0-200 m are stripped off and they vary substantially in physical and chemical properties, such as soil bulk density, water holding capacity, and water-absorbing capacity (Šourková et al., 2005). During excavation, transport, and dumping, the original soil structure and properties are drastically altered.

1.4.7 Impacts of coal mining on land use / land cover (LULC)

The mining activities result in change of topography (Manna and Maiti, 2014), drainage pattern (Akiwumi and Butler, 2008; Khan and Javed, 2012; Manna and Maiti, 2016) and principal environmental impact comes out as physical disturbance such as landscape change and degradation (Bajocco et al., 2012; Tadesseet al., 2017), soil erosion and degradation (Singh et al., 1997) and general environmental changes (Dhar et al., 1991; Prakash and Gupta, 1998).

Large pits are left after mining and large amounts of overburden material excavated during mining is dumped in the vicinity of the mine sites and continuous rehandling of the overburden dumps further modifies the general landscape of the area. The overburden of coal mines when dumped in unmined areas creates mine spoils which ultimately affects the surrounding vegetation.

Remote sensing data can provide information on changes to surface water and land cover over time, which is essential for environmental monitoring in mining areas. Remote sensing data are also ideal for environmental impact assessment due to their broad spectral range, affordable cost, and rapid coverage of large areas.

1.4.8 Impacts of coal mining on human health

Environmental pollution from mining activities has continued to generate unpleasant implications for health and economic development all over the world (Adamu, 2000; Adiuku-Brown and Ogezi, 1991; Chukwuma, 1995). Metal contamination of water resources is a serious issue in most of the mining regions across the world (Singh 1987; Olias et al. 2004; Bhuiyan et al. 2010a; Giri et al. 2010; Li et al. 2013; Utom et al. 2013; Howladar et al. 2014; Singh and Kamal 2017).The mining activities is the release of heavy metals into the environment are one of the most important threats to their degradation, because most of these metals are very toxic to humans, especially when they exceed the maximum admissible values set by international organizations (WHO).The most common heavy metals found in mine and industrial waste water include iron, manganese, arsenic, cadmium, chromium, copper, lead, nickel, and zinc, all of which cause risks for human health and the environment (Lambert et al. 2000).

These contaminants (heavy metals) enter into the human body through various pathways such as ingestion, inhalation, and dermal absorption. Once they enter the human body, the majority of toxic elements are adsorbed, accumulated, and biomagnified in the human body which emerges wide variety of diseases (Avigliano and Schenone, 2015). Severe human health issues are associated with these contaminants such as damaging neurological system, kidney function, ossification process, and various other health issues

(Lohani et al., 2008). This evidences signify that groundwater contamination due to mining activities could also harm the large population of the neighbouring area those who are dependent on the groundwater resources. However, there has been little research on human health risk analysis due to the exposure of contaminated groundwater to the population.

1.5 Application of remote sensing and GIS in water resources

Remote Sensing (RS) is a multidisciplinary integrated approach implemented to study and monitor the environment. In this study, application of remote sensing and GIS have also been taken into consideration. Satellite images have been used to prepare the hydrogeological parameters map and assessing the change in land use/ land cover of the study area. Landsat 5, Landsat 7 and Landsat 8 provides a well calibrated continuous dataset of moderate spatial resolution with reliable geometric integrity and validate radiometric quality and they are freely available; therefore, these images are perfect for the study of natural resources (Moran et al 2001).

The Geographic Information System (GIS) has emerged as a powerful tool in analyzing and quantifying such multivariate aspects of groundwater occurrence. It is very helpful in the delineation of groundwater prospects and deficit zones (Carver, 1991).Remote Sensing and Geographic Information System has become one of the leading tools in the field of hydrogeological science, which helps in assessing, monitoring and conserving groundwater resources. Using GIS and remote sensing data makes it easy to update water quality parameters, which allows continuous monitoring of water quality.

1.6 Statement of the Problems

Out of all the natural resources available mankind, water assume the important place. It is an integral component for biotic life both in way of direct consumption and maintaining the local urbanization, industrialization and population growth is damaging its quality along with quantity at place also. Among various impact, there is impact of opencast coal mining on groundwater resources also. Both quality and quantity of water would be deteriorated .The impact on water cycle in the mining area may also be there depending upon the magnitude of mining and other factors. The impact of coal mining on groundwater may be caused lowering of water level, reduction of moisture content in soil and atmosphere rise of temperature, hydrological cycle changes other related issues. The structure of aquifer, groundwater flow and recharge and discharge pattern in the area may also be disturbed. There may be chances that water supply sources in coal mining area be decreased along with other impact.

A few researchers have been studied the quality of ground and surface water in Singrauli coalfield (Dhar et al., 1986., Dhar et al., 1987., Dhar et al., 1990., Jamal et al., 1991, Agrawal et al., 2010, Pandey et al., 2012, Khan et al., 2018).However, in depth study on groundwater is still lacking.

So, in this study, an attempt has been to investigate the possible environmental impacts of coal mining activities on groundwater level, groundwater recharge potential, groundwater quality and land use /land cover in Singrauli coalfield area.

1.7 Organization of Thesis

The thesis mainly consist seven chapter in addition to the chapter containing references which have been cited in the entire thesis.

- Chapter 1: Provides a general introduction about the groundwater and impact of mining activities on the environment, describes the statement of the problem and objectives of the study.
- Chapter 2: The literature reviewed of past studies related to groundwater level, groundwater potential zone, groundwater quality and land use/land cover in this chapter.
- Chapter 3: Provides a detailed description of the study area.
- Chapter 4: Describes the various methodology adopted to accomplish the objectives of the study.
- Chapter 5: Explains the results and discussion of each objective.
- Chapter 6: Effective management techniques for groundwater and available contaminated water.
- Chapter 7: Reports the conclusions based on the research work. Finally, some suggestions for future work.

1.8 Objectives of the study

The main objectives of the study are summarized below:

1. Assessment of groundwater level fluctuation by using remote sensing and GIS techniques in Singrauli Coalfield.
2. Delineation of groundwater potential zones in Singrauli Coalfield, using remote sensing, GIS and Multi influencing factor (MIF) techniques.
3. Hydrogeochemical characterization and suitability analysis of groundwater for domestic and irrigation purposes in Singrauli Coalfield.
4. Analyses of land use / land cover (LULC) change dynamics using remote sensing and GIS techniques from 1990 to 2019 in the Singrauli Coalfield.
5. Suggested effective management techniques for groundwater in suitable region.

A detailed literature review of past studies related to the above objectives enlisted in the thesis is explained in the next chapter.