I would like to dedicate this thesis to my family who has supported and encouraged me throughout this endeavour: thank you for your love and support throughout my entire life and helping me to realize who I am today!

CERTIFICATE

It is certified that the work contained in the thesis titled *"Assessment of impact of coal mining on groundwater with reference to Singrauli Coalfield"* by ***ASHWANI KUMAR SONKAR*** has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

It is further certified that the student has fulfilled all the requirements of Comprehensive Examination, Candidacy and SOTA for the award of Ph.D. Degree.

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I declare that I have faithfully acknowledged and given credits to the research workers wherever their works have been cited in my work in this thesis. I further declare that I have not will fully copied any other's work, paragraphs, text, data, results, etc., reported in journals, books, magazines, reports dissertations, theses, etc., or available at websites and have not included them in this thesis and have not cited as my own work.

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(ASHWANI KUMAR SONKAR)

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List of Abbreviations/Symbols

AMD	Acid Mine Drainage
APHA	American Public Health Association
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BCM	Billion cubic meter
BIS	Bureau of Indian Standards
CCME	Canadian Council of Ministers of the Environment
CGWB	Central Ground Water Board
CMPDI	Central Mine Planning and Design Institute
CPCB	Central Pollution Control Board
D_d	Drainage density
DEM	Digital Elevation Model
DW	Dug-Well
EC	Electrical Conductivity
EDTA	Ethylene Diamine Tetra Acetic Acid
FCC	False Colour Composite
GEC	Groundwater Estimation Committee
GIS	Geographic Information System
GPS	Global Positioning System
GSI	Geological Survey of India
GW	Groundwater
GWPZ	Groundwater Potential Zone
HCA	Hierarchical Cluster Analysis
IC	Ion Chromatography
ICP	Inductively Couple Plasma
IDW	Inverse Distance Weighting
IMD	India Meteorological Department
IS	Indian Standards
KR	Kelly’s Ratio
L_d	Lineament density
LISS	Linear Imaging Self Scanner sensor
LULC	Land Use/ Land Cover

mbgl	Meter below ground level
mg/l	Milligram per litre
MH	Magnesium Hazard
MIF	Multi-Influencing Factor Technique.
MSL	Mean Sea Level
NCL	Northern Coalfield Limited
NTPC	National Power Thermal Corporation
OLI	Operational Land Imager
PM	Particulate Matter
RWHS	Rainwater Harvesting Structure
SAR	Sodium Adsorption Ratio
TDS	Total Dissolved Solids
TH	Total Hardness
TM	Thematic Mapper
USGS	United States Geological Survey
WHO	World Health Organisation
WLF	Water Level Fluctuation
WQI	Water Quality Index

Abstract

Water is essential for the survival of all forms of life and the livelihood of the human population. Water trapped in ice caps, glaciers and lakes providing fresh water for life on earth. Among them, groundwater preserved as freshwater is the source of supply for almost all places. Groundwater has steadily emerged as the backbone of India's agriculture and drinking water security. Groundwater has made significant contributions to the growth of India's Economy. Increasing population, growing urbanization and rapid industrialization combined with the need for raising agricultural production generate competing water demands. Both quality and quantity of groundwater are at risk due to rapid industrialization and urbanization.

Opencast coal mining activities have caused major environmental impacts throughout the world in the last few decades. The mining activities may cause changes in aquifer potential, change in topography and land disturbance. Impacts of open cast coal mining on groundwater generally comprise two phenomena occurring simultaneously viz., water contamination and declination in the groundwater level.

The present research work has been carried out in the Singrauli coalfields situated in central India under Northern Coalfields Ltd, (NCL). The Singrauli coalfield has been divided into ten active mining blocks viz. Kakri, Bina, Krishnashila, Khadia, Dudhichua, Jayant, Nigahi, Amlohri, Block-B and Jhingurdah. These mines were contributed 101.50 MT in 2018-19, approx. 14% of the total coal production through large scale mechanized opencast mining. Several pollutions producing industries such as Singrauli super thermal power plant, Vindhyachal super thermal power plant, Northern coal limited, Sasan coal of Reliance, Kanoria chemicals and many others are regularly increasing the amount of pollution via disposing of different nature of the material in the nearby environment, which affects groundwater resources of the area.

The main aim of this research work is to study the impact of open-cast coal mining activities on groundwater level, groundwater recharge potential, groundwater quality and land use /land cover in singrauli coalfield area.

The groundwater level is one of the most important parameters to understand the groundwater availability status of any area. The coal mining activities have profound impact on hydrogeological factors, which was affecting the aquifer recharge in the coal mining areas. The objective of this research was to assess the impact of various hydrogeological factors on groundwater level fluctuation in the study area. These factors area soil, geology, drainage pattern, elevation and slope have been considered to accomplish the objective. The preparation of thematic maps of various hydrogeological factors by using remote sensing and GIS techniques. A comparative analysis was performed by comparing the groundwater level fluctuation map with the GIS-based various hydrogeological factors maps to estimate the aggregate effect of the various hydrogeological factors on groundwater level fluctuation. A total of eighty-six (86) dug-wells were selected for monitoring the groundwater level around ten blocks of Singrauli coalfield and these wells were monitored during the dry (April) and wet seasons (November) for the year 2016.It has been observed that in the pre-monsoon, the depth to the groundwater level in the study area varied between 0.83 to 25 meters below ground level (mbgl). In the post-monsoon, the depth to the groundwater level ranged from 0.83 to 25 (mbgl). The depth to water level is observed is very high (>20 mbgl) at few locations such as Khadia Tola (490 m) and Mukhiya Tola (482 m), This may be due to the elevation at these points is relatively high. The fluctuation map has been revealed that south-west region and a small portion of the north-east region in study area have indicated higher water level fluctuation (WLF >1.5m), whereas north-west, south-east and central areas have indicated lower WLF and ranging from 0.59m to 1.5m.The

negative and positive value of water level fluctuation provide important interpretation. The WLF map showed that the negative water level fluctuation found at a few locations. The maximum positive water level fluctuation indicates that the area is acting as a recharge area whereas negative values indicate that the area is acting as a discharge area. Based on the comparative analysis between WLF map and thematic maps of various hydrogeological factors, it has been found that WLF in south-western and some portion of the north-eastern portion showed moderate to higher value, This may be due to most of the non-hilly areas come under the gentle to moderate slope category with lower elevation in the area forms the perfect hydrogeological condition for recharging of groundwater. It has been observed that north-west, south-east and central part of the study area showed lower WLF which may be due to the presence of overburden dump, presence of higher elevation and steep slope. Thus, the combined effect of slope, elevation, geology, drainage and mining activities are on the groundwater level fluctuation in the study area is maximum.

The present research was carried out also to delineation of groundwater potential zones in the study area utilizing the combined application of remote sensing, GIS and multi influencing factor techniques. Six thematic layers such as lineament, land-use, geology, drainage, slope, and soil has been used to delineation of the groundwater potential zones. These thematic maps are digitized and transformed into raster data using the feature to raster converter tool in ArcGIS tools. The raster maps of these factors are assigned a fixed score and weight calculated from multi influencing factor (MIF) technique. Moreover, each weighted thematic layer was statistically computed to get the groundwater potential zones. The obtained groundwater potential zones has been divided into four classes namely very good, good, very poor and poor zones. The groundwater potential zone map have been indicated that very good to good groundwater potential found in the plains as it includes cropland, gentle to moderate slope, Talchir and Barakar formation and pediplains. The poor to very poor groundwater potential was found in and around the mining area, forest/hilly area with a steep slope, metamorphic terrain and built-up area. A comparative analysis was done by comparing the groundwater level fluctuation map with the groundwater potential zone map. After comparing it was found that the maximum water level fluctuation area shows very good groundwater potential zone whereas the lowest water level fluctuation area shows poor groundwater potential zone.

This study was also carried out in the Singrauli coalfield area to investigate the possible environmental impacts of coal mining activities on groundwater quality. A total of forty-six (46) groundwater samples around different mining projects (NCL) were collected from hand pumps during the summer month of May-2018 and analyzed for major physicochemical parameters (pH, EC, TDS, total hardness, bicarbonate, Cl^-, F^-, NO_3^-, SO_4^{2-}, Ca^{2+}, Na^+, Mg^{2+}, K^+) and important heavy metals (Fe, Cu, Pb, Cd, Cr, Ni, Zn). The collected groundwater samples were analyzed to identify the hydrogeochemical facies and the suitability assessment for domestic and irrigation purposes. The analytical results indicate the slightly acidic to slightly alkaline nature of the groundwater in the study region. Bicarbonate and chloride were the dominant anions and representing on average 43% and 28% of the total anions. Nitrate is the least dominant anion of the total anions. The order of mean abundance of major anions was $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^-$. Calcium and sodium was dominant ion among all the cations and representing on average 40% and 38% of the total cations, respectively. The Potassium was the least dominant cations, representing 4% of the total cations. The order of mean abundance of major cations is $Ca^{2+} > Na^+ > Mg^{2+} > K^+$. In correlation analysis, Out of 210 correlation coefficients (r), 76 negatives and 134 positive correlation coefficients were observed.

The strong positive correlation coefficients were observed between TDS and EC (r=0.999), SO_4^{2-} and EC (r=0.872), SO_4^{2-} and TDS (r=0.871), SO_4^{2-} and Cl^-(r=0.817), TH and Ca^{+2} (r=0.807), while strong negative correlation coefficients were observed between K^+ and F^-(r=-0.316), Fe^{2+} and pH (r=0.311).The CCME water quality index (WQI) of groundwater samples was found in the range of 64.90 to 96.52. Almost 56% of the total water samples were found in the range of good category, 35% were found in fair category, 7 % were found in excellent category and 2 % were found in the marginal category, respectively. The central and few portions of the northern and southern regions of the study area indicated lower CCME WQI values, whereas the eastern and western regions of the study area showed higher CCME WQI values. The sampling locations have been clustered based on WQI similarity in samples collected from various sites in the study area. The dendrogram indicates that the sampling stations have mainly grouped into three clusters: Cluster I, II and cluster III. Cluster I consist of 26 sampling stations whereas cluster II consist of 17 sampling stations. Cluster III consists of only three sampling stations (GW-3, GW-46, GW-44) which are differed from Cluster I and Cluster II. The Piper trilinear diagram is a graphical presentation of the major ions to quickly determine the hydrochemical facies of groundwater in the study area. The diamond-shaped part of the plot reveals that nearly 48% of the groundwater samples laid under the Ca-Mg-HCO_3 category indicating the percolation and dissolution of minerals. However, approximately the same percentage of samples i.e. 46% of the samples fall under the Ca-Mg-Cl-SO_4 group representing the presence of anthropogenic activities. Apart from this, only 4% and 2% of the groundwater samples appeared under NaCl-SO_4 and NaK-HCO_3 groups respectively and showing the process of dissolution of minor minerals present in the area. The Gibbs diagram indicated that the majority of the water samples fall under the rock water dominance field for both ratios (cations & anions) and only few samples were placed under the evaporation dominance zone.

Suitability of the groundwater for the irrigation purposes was also examined using Sodium adsorption ratio (SAR), Sodium percentage, Kelly’s ratio (KR) and Magnesium hazard (MH). The computed SAR values of the groundwater in the study area ranged from 0.40 and 7.20 meq/l with an average value of 1.36 meq/l. Majority of water samples fall under the C2-S1 (medium salinity and low alkali) and C3-S1 (higher salinity and low alkali) category, which can be used for irrigation purposes. The soluble sodium percentage of the analyzed groundwater samples of the study region varies from 10.31% to 78.24% with an average value of 32.27 %. Based on Wilcox classification, about 76.08% of the water samples come under very good to good and 19.56 % of the samples come under good to permissible class, which may be used for irrigation purposes, whereas the rest of water samples (GW-15, 16) fall under the range of good to permissible range. Kelly's ratio ranges from 0.11 to 3.40. Based on Kelly’s classification, about 91.30% of water samples were suitable and 8.70% of water samples are unsuitable for irrigation purposes. The magnesium hazard (MH) values ranged from 10.97 to 82.84 meq/l with the mean value of 41.33 meq/l. Based on MH classification, approx. 23.91% of the groundwater samples were not appropriate for irrigation purposes.

The opencast coal mining activities have influence on land use/land cover. The land use/land cover changes have an influence on both groundwater quality and quantity. The land use/land cover changes in the study region were examined for a period of 29 years i.e., from the year 1990 to 2019. The land use/land cover changes were identified on the two-time interval (9 or 10-year) using time-series Landsat imagery (1900, 2000, 2009 and 2019). The various land use/land cover classes viz. built-up area, mining area, forest/hilly area, cropland, waterbody/river and fallow land in the study region are identified. The result of the classified images indicated that the built-up area increased from 0.71% in 1990 to 2.07% in 2019. The mining area increased from 4.39% in 1990 to 19.88% in 2019. Whereas, forest/hilly area has decreased from 25.75% in 1990 to 16.13% in 2019. The cropland area and water body/river slightly increased from 30.34% to 33.66% and 0.92% to 1.79% in 1990 and 2019 respectively. Between 1990 and 2019, fallow land decreased from 37.86% in 1990 to 26.43% in 2019. This decrease could be possible due to the expansion of coal mining activities. The rapid expansion of coal mining and industrial activities had been responsible for drastic changes in the land use/land cover change in the last 3 decades in the study region.