

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!



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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.

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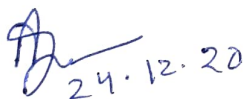
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(ASHWANI KUMAR SONKAR)

Table of Contents

Title	Page No.
<i>Certificate</i>	ii-iv
<i>Acknowledgement</i>	v
<i>Table of Contents</i>	vi- x
<i>List of Figures</i>	xi-xiii
<i>List of Tables</i>	xiv
<i>List of Abbreviation and Symbols</i>	xv- xvi
<i>Abstract</i>	xvii-xxiii
1. Introduction	1-17
1.1 An overview of the global water scenario	1
1.2 Groundwater scenario of India	3
1.3 Status of groundwater and surface water quality in Singrauli coalfield	6
1.4 Overview of the impacts of coal mining activities on environment and human health	8
1.4.1 Impact on topography & drainage	9
1.4.2 Impact on groundwater quality and quantity	9
1.4.3 Impact on aquifer system	10
1.4.4 Impact on surface water quality	10
1.4.5 Impact on air quality	11
1.4.6 Impact on soil properties	12
1.4.7 Impact on land use /land cover (LULC)	12
1.4.8 Impact of coal mining on human health	13
1.5 Application of remote sensing and GIS in water resources	14
1.6 Statement of the Problems	15
1.7 Organization of Thesis	16
1.8 Objective of the Study	17
2. Literature Review	18-47
2.1 Studies on assessment of groundwater level	18
2.2 Studies on delineation of groundwater potential zone	24
2.3 Studies on water quality assessment	30

2.4 Studies on land use / land cover changes	42
3. Study Area	48-63
3.1 Description of the study area	48
3.2 Topography of the study area	50
3.3 Geomorphology of the study area	51
3.4 Geology of the study area	52
3.4.1 Precambrian Basement	54
3.4.2 Talchir Formation	54
3.4.3 Barakar Formation	55
3.4.3.1 Kota Seam	55
3.4.3.2 Turra Seam	56
3.4.3.3 Purewa Seam	56
3.4.3.4 Khadia Seam	56
3.4.3.5 Pani Pahari Seam	56
3.4.4 Barren Measures	57
3.4.5 Raniganj Formation	57
3.5.6 Panchet Formation	57
3.4.7 Mahadeva Formation	58
3.5 Hydrogeology	58
3.6 Slope of the study area	59
3.7 Soil characteristics of the study area	60
3.8 Drainage pattern of the study area	61
3.9 Lineament feature of the study area	62
3.10 Flora and Fauna	63
4. Materials and Methods	64-81
4.1 Secondary data collection	64
4.2 Instrument and software used	64
4.3 Methodology adopted for assessment of groundwater level fluctuation	65
4.3.1 Preparation of various thematic maps	66
4.3.2 Groundwater level monitoring	66
4.4 Methods for computing groundwater potential zone	68
4.5 Sample collection, Preservation and Analysis	69
4.5.1 Groundwater sampling techniques	69

4.5.2	Preservation of groundwater samples	73
4.5.3	Labelling of groundwater samples	73
4.5.4	Separation of suspended sediments	74
4.5.5	Methods of analysis	74
4.6	GIS analysis for various water quality parameters	76
4.7	Calculation of CCME Water Quality Index	77
4.8	Statistical analysis	79
4.9	Methods adopted for analysis of land use/land cover changes	79
4.9.1	Data Source	79
4.9.2	Mapping	80
4.9.3	Change Analysis	80
4.9.3.1	Percent change estimation	81
4.9.3.2	Rate of LULC change	81
5.	Results and Discussion	82-159
5.1	Meteorological parameters of the study area	82
5.1.1	Climate	82
5.1.2	Annual rainfall patterns	82
5.1.3	Relative humidity	83
5.2	Assessment of groundwater level fluctuation of the study area	84
5.2.1	Groundwater level monitoring stations	84
5.2.2	Comparative analysis of WLF with various hydrogeological parameters using GIS	85
5.2.2.1	GIS analysis of WLF under different slope classes	86
5.2.2.2	GIS analysis of WLF under different elevation classes	87
5.2.2.3	GIS analysis of WLF under different geological formation	88
5.2.2.4	GIS analysis of WLF under drainage pattern	90
5.2.2.5	GIS analysis of WLF under different soil classes	91
5.2.3	Depth to groundwater level of pre-monsoon	93
5.2.4	Depth to groundwater level of post-monsoon	94
5.2.5	Water level fluctuation (WLF) of the study area	95
5.3	Delineation of groundwater potential zones using remote sensing, GIS and MIF techniques	99
5.3.1	Multi influencing factors (MIF) of groundwater potential zones	99

5.3.2 Assigning of weights	100
5.3.3 Weighted Overlay Method	103
5.3.4 Hydrologic Thematic Layers	104
5.3.4.1 Land use /land cover (LULC)	104
5.3.4.2 Lineament density	105
5.3.4.3 Drainage density	106
5.3.4.4 Slope	107
5.3.4.5 Geology	108
5.3.4.6 Soil	109
5.3.5 Ground water potential zone map of the study area	109
5.4 Qualitative Assessment of Groundwater	111
5.4.1 Characteristics of physicochemical parameters and heavy metals along with spatial distribution maps	113
5.4.1.1 pH and Electrical Conductivity (EC)	114
5.4.1.2 Total Dissolved Solids (TDS)	114
5.4.1.3 Bicarbonate (HCO_3^-)	114
5.4.1.4 Chloride (Cl^-)	115
5.4.1.5 Sulphate (SO_4^{2-})	116
5.4.1.6 Nitrate (NO_3^-)	117
5.4.1.7 Fluoride (F^-)	118
5.4.1.8 Calcium (Ca^{2+})	119
5.4.1.9 Magnesium (Mg^{2+})	120
5.4.1.10 Sodium (Na^+)	121
5.4.1.11 Potassium (K^+)	122
5.4.1.12 Total Hardness (TH)	123
5.4.1.13 Iron (Fe)	124
5.4.1.14 Copper (Cu)	125
5.4.1.15 Lead (Pb)	126
5.4.1.16 Cadmium (Cd)	127
5.4.1.17 Chromium (Cr)	128
5.4.1.18 Nickel (Ni)	129
5.4.1.19 Zinc (Zn)	130
5.4.2 Major Ions Chemistry	131

5.4.2.1 Anion Chemistry	131
5.4.2.2 Cation Chemistry	132
5.4.3 Correlation Analysis	133
5.4.4 CCME Water Quality Index of Groundwater	135
5.4.5 Hierarchical Cluster Analysis (HCA)	139
5.4.6 Geochemical classification and hydrogeochemical facies of the groundwater	141
5.4.6.1 Piper Trilinear Diagram	141
5.4.6.2 Gibb's Diagram	144
5.4.7 Suitability of groundwater for irrigational purposes	146
5.4.7.1 Sodium Absorption Ratio (SAR)	146
5.4.7.2 Sodium Percentage (%Na)	148
5.4.7.3 Kelly Ratio (KR)	150
5.4.7.4 Magnesium Hazard (MH)	151
5.5 Analysis of land use / land cover (LULC) changes from 1990 to 2019	153
5.5.1 Areal statistics of LULC	153
5.5.2 Percent change analysis of LULC	156
5.5.3 Rate of LULC changes	157
6. Effective Management of Groundwater	160-170
6.1 Augmentation of Groundwater Recharge Potential	160
6.1.1 Afforestation and Plantations	160
6.1.2 Rainwater Harvesting and Artificial Recharge	160
6.2 Water treatment Technology	169
6.3 Other Strategy	170
7. Conclusions and Future Suggestions	171-177
7.1 Conclusions	171
7.2 Suggestions for future work	177
8. References	178-201
Appendices	202-205
Appendix A.1	202
Appendix A.2	204
List of Publications and Papers Presented in Conferences	206

List of Figures

Figure No.	Caption	Page No.
1.1	Distribution of the Earth's water	2
1.2	Geographical distribution of various categories of assessment units	5
1.3	Impacts of coal mining on the environment and human health	8
3.1	False Colour Composite (FCC) of study area	49
3.2	Contour line map of the study area	51
3.3	Geomorphological map of the study area	52
3.4	Geological map of the study area	53
3.5	Slope map of the study area	59
3.6	Soil map of the study area	60
3.7	Drainage map of the study area	61
3.8	Lineament map of the study area	62
4.1	Methodology adopted for carrying out the objective	65
4.2	Sensor-based water level indicator	66
4.3	Photograph showing monitoring of groundwater level	67
4.4	Flowchart for delineating the groundwater potential zone	68
4.5	Flow chart of analytical methods	70
4.6 (a) & (b)	Field photograph showing sampling of groundwater	71-72
4.7	Photograph showing collected groundwater samples	73
4.8	Photograph showing analysis of water samples using Multi-parameter kit	75
4.9	Photograph showing analysis of water samples using Ion Chromatography	76
4.10	Photograph showing analysis of water samples using ICP-MS	76
5.1	Graph representing annual average rainfall	82
5.2	Location map of the monitoring dug-wells of the study area	85
5.3	Slope map of the study area	86
5.4	Elevation map of the study area	88
5.5	Geological map of the study area	89
5.6	Drainage map of the study area	91

5.7	Soil map of the study area	92
5.8	Groundwater level map during the pre-monsoon season	93
5.9	Groundwater level map during the post-monsoon season	94
5.10	Groundwater level fluctuation map of the study area	95
5.11	Graph showing WLF v/s Percentage of dug wells of the study area	96
5.12	Bar graph showing WLF of dug-wells in the study region	97
5.13	Interrelationship between the multi-influencing factors concerning the groundwater potential zone	100
5.14	GIS techniques used for groundwater potential zone	103
5.15	Land use/land cover (LULC) map of the study area	104
5.16	Lineament density map of the study area	106
5.17	Drainage density map of the study area	107
5.18	Groundwater potential zone map of the study area	110
5.19	Location map of groundwater sampling stations	111
5.20	Spatial distribution of Chloride in the study area	115
5.21	Spatial distribution of Sulphate in the study area	117
5.22	Spatial distribution of Nitrate in the study area	118
5.23	Spatial distribution of Fluoride in the study area	119
5.24	Spatial distribution of Calcium in the study area	120
5.25	Spatial distribution of Magnesium in the study area	121
5.26	Spatial distribution of Sodium in the study area	122
5.27	Spatial distribution of Potassium in the study area	123
5.28	Spatial distribution of Iron in the study area	124
5.29	Spatial distribution of Copper in the study area	125
5.30	Spatial distribution of Lead in the study area	126
5.31	Spatial distribution of Cadmium in the study area	127
5.32	Spatial distribution of Chromium in the study area	128
5.33	Spatial distribution of Nickel in the study area	129
5.34	Spatial distribution of Zinc in the study area	130
5.35	Percentage contributions of major anions	131
5.36	Box-whisker plot of major anions	131
5.37	Percentage contributions of major cations	132

5.38	Box-whisker plot of major cations	132
5.39	Graphical representation of water quality index	136
5.40	Spatial distribution of CCME WQI in the study area	137
5.41	Pie chart representing CCME WQI categories	137
5.42	Dendrogram of the HCA based on WQI of the sampling stations	140
5.43	Piper diagram for describing the hydro-geo-chemical facies variations	142
5.44	Modified Piper plot of the classification scheme for hydro-geo-chemical facies variations	143
5.45	Gibbs diagrams for groundwater samples	145
5.46	US Salinity diagram for the classification of irrigation water	147
5.47	Classification of irrigation water based on the Wilcox plot	149
5.48	Classify land use / land cover (LULC) maps of the study area	154
5.49	Bar showing LULC area distribution of the study area (1990–2019)	155
5.50	Bar showing change in LULC classes of the study area from 1990 to 2019	157
6.1	Diagram showing cross-section of the Storage tank	163
6.2	Components of rainwater harvesting and artificial recharge structure	164-167
6.3	Map shows the suggested locations of the rainwater harvesting structure	168
6.4	Flow chart of water quality management in coal mine	169

List of Tables

Table No.	Caption	Page No.
3.1	General stratigraphic succession of the Singrauli Coalfield	54
4.1	Analytical methods used for water quality analysis	74
4.2	Remote sensing data and their source used for the study	80
5.1	Annual rainfall data of the study area during 2009-2018 period	83
5.2	Effect of influencing factor, relative rates and score for each potential factor.	101
5.3	Weightage assigned to each factor based on their effect on the GWPZ	102
5.4	Details of sampling stations of the groundwater samples	112
5.5	Statistical summary of physicochemical parameters and heavy metals and its comparison with WHO (2011) Standards	113
5.6	Correlation coefficient matrix of water quality parameters	134
5.7	Classification of CCME WQI range and category of water	135
5.8	CCME Water Quality Index for groundwater of study region	138
5.9	Classification of water suitability for irrigation based on SAR	148
5.10	Classification of water suitability for irrigation based on Na%.	150
5.11	Classification of irrigation water based on Kelly's ratio	151
5.12	Computed values of SAR, Na%, KI and MH in the study area	152
5.13	Areal classification of LULC classes in the study area	155
5.14	Net change in areal extent of LULC classes	156
5.15	Rate of change in LULC classes of the study area	158

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 $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-} > \text{NO}_3^-$. 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 $\text{Ca}^{2+} > \text{Na}^+ > \text{Mg}^{2+} > \text{K}^+$. 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 (1990, 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.