

CHAPTER 2

LITERATURE REVIEW

2.1 General Statement

Coal mining is providing several amenities to local populations along with raw materials for thermal power plants and coal based industries. On the other hand, the impact of mining on environment in general and water in particular is also significant. The large scale coal mining and its impact on water resources are getting importance both globally and nationally. Several researches has being done on water pollution caused by chemical, metallurgical industries, etc. There has been significant research work done related to the water pollution caused by coal mining in other parts of the world. However, very little work has been done in India to assess the impact of coal mining on water quality in general and on reservoir in particular. All these major research works done abroad and in India have been critically studied and the relevant findings and their contributions are summarized in subsequent paragraph.

2.2 Studies on water pollution caused by coal mining

Powell (1988) studied the degradation of water quality due to coal mining in eastern and western part of USA. Water parameters like pH, dissolved sulphate, iron and manganese indicated the deteriorating effect of coal mining on water quality due to disturbance of coal strata as revealed by data obtained through various mines under study. Here, comparative analysis of degradation in water quality caused by coal mine drainage in both the parts of USA.

Jamal et al (1991) in Gorbi mine of Singrauli, studied the neutralising capacity of the coal-overburden rock mass (Dhar et al 1986) of Barakar rock formations on acidic mine water. It revealed that the pH was raised from 5.5 to 7.44 when water flows over the overburden rock through a distance of 1km, 2.5 to 3.14 for a distance of 1.5km and 3.14

to 3.21 for a distance of 3km. This laboratory experiment showed that on increasing distance the acid neutralising capacity decreases.

Rösner (1998) determined the impact of abandoned mines on surface water and groundwater in the districts of the Cerbat Mountains, Arizona. Elevated arsenic, cadmium, and iron concentrations were detected in most surface-water samples due to presence of ore processing industries. While lead, copper, and zinc contamination differed from region to region, depending on the ore mined. Groundwater samples were polluted by high concentrations of these parameters. The reason may be due to immobilization of the heavy metals, dilution due to the rain or the presence of different groundwater systems.

Carlos et al (2011) assessed the impact of abandoned coal mines on water quality of three artificial lakes in Treviso, Santa Catarina State, Brazil. Sampling were carried out during the month of February and July. Results showcased that the lakes experienced high concentrations of SO_4^{2-} , Mg, Fe, Al, Ca, Ba, Si, Zn, Ni, Na, K, Sr, B, Cd, Cr, Pb and Cu due to coal mining activity and waste disposal practices adopted by the mining companies. This has drastically affected the water quality of the lakes and made them inappropriate for human consumption.

Arkoc et al (2016) studied the impact of coal mining on surface and ground water quality of Tozaklı coal field in Turkey. The water samples were analysed for chemical, trace metal and microbiological quality, and compared with EPA and WHO guidelines. The values of major cation and anion and trace element concentrations were below admissible limits of both EPA and WHO, except for SO_4^{2-} and NO_3^- . All the mine ponds and tap water were contaminated with *Enterococcus spp.* The results revealed that the surface and ground waters of the study area were not polluted by the coal mining operations.

Dutta et al (2020) determined the seasonal variability, cytotoxicity and remediation of AMD caused by Ledo opencast coal mining. AMD generated from mines was highly acidic in monsoon season, having pH as low as 3.3, high conductivity (1.30-2.49 mscm⁻¹) with high total dissolved solids (1068-1339 ppm). The cytotoxicity study depicts more toxicity in HepG2 followed by A549, MIAPaCa2, and L6 cell lines at higher concentrations. The remediation experiment reveals that limestone nano-particles are potential sorbent for hazardous elemental contaminants and PAHs from mine water.

Year of Publication	Name of Author	Major Contribution
1988	Powell	In USA, studied the effect of coal mining on water quality due to acid mine drainage caused by disturbance in coal strata.
1991	Jamal et al	In Singrauli, studied the effect of neutralising capacity of overburden on acid mine water of Gorbi.
1998	Rösner	Determined the impact of abandoned mines on water quality in Cerbat Mountains, Arizona.
2011	Carlos et al	Assessed the impact of coal mining on water quality of three artificial lakes of Brazil.
2016	Arkoc et al	In Turkey, studied the impact of mining on water quality of surface and groundwater. Results showed that water was not polluted by mining activities.
2020	Dutta et al	Determined the seasonal variability, cytotoxicity and remediation of AMD caused by Ledo opencast coal mining. AMD generated was highly acidic in nature.

Table 2.1 Tabular Representation of Summary of Literature Review

After going through exhaustive literature survey, it has been observed that the existing mines in different parts of the world are major cause of environmental degradation in general and water pollution in particular.

2.3 Studies on assessment of the water quality

Prasad et al (1999) estimated the value of 7 heavy metals at 20 groundwater sampling locations at Dhanbad town during three seasons of year. Except iron and manganese, the concentrations of rest of the heavy metals were below the permissible limits. In addition to it, Heavy Metal Pollution Index (HPI) employing weighted arithmetic quality mean

method was also evaluated. The HPI was less than the 100 depicting that the groundwater was not contaminated with heavy metals in spite of expansion in mining and other related industrial activities.

Sarkar et al (2006) in Jharia Coalfield, India, the geo-environmental quality was assessed utilizing modeling techniques of GIS and multivariate statistics. For each sampling location, the water quality index was computed for determining the acceptability of water for regular use. It also disseminate that the quality of surface water vary from good to very good while that of mine water ranged from poor to very poor. From the cluster analysis it was concluded that there were two types of mine water. The spatial distribution map revealed that the water was of poor quality in most of the area under study.

Rai (2010) analysed the temporal variations in pollution assessing seasonal changes in surface water quality of Govind Ballabh Pant Sagar reservoir. Here, a total of 24 physicochemical parameters were selected during the year 2004-05. Four sampling sites of the reservoir were selected for collection of samples. Statistical methods such as variance analysis, Pearson correlation, factor analysis and principal component analysis were utilized for computation. It was concluded that Belwadah has the highest concentration of metal pollution thereby making it unsuitable for drinking, domestic and irrigation purposes.

Agrawal et al (2011) in Singrauli district, the influence of Anpara and Renusgar coal-based thermal power plants was assessed on sources of drinking water. The ground water samples were assessed for As, Cd, Pb and Ni during pre and post monsoon season. It was concluded from the results that the exceeding limit of these metals were due emission of fly ash from thermal power palnts as well as due to dumping of it into the soil of the area thereby contaminating the ground water.

Singh et al (2012) using 35 parameters for 92 mine water samples in Jharia coalfields, the water quality was assessed. It was found that these samples possessed high TDS, Hardness and SO_4^{2-} . Trace metals such as Fe, Mn, Ni, Pb were well above the permissible limit suggested for drinking water. The water quality varied from good to fair making it suitable for irrigation purpose. Though few samples showcased higher residual sodium carbonate, salinity and Mg-ratio making it unsuitable for irrigation. Ca–Mg– SO_4 and Ca–Mg– HCO_3 were the dominant hydro-geo-chemical facies. The mine water chemistry showed dominance of Mg^{2+} and Ca^{2+} amongst the cations and SO_4^{2-} and HCO_3^- in anions. It was concluded that the quality of samples ranged from good to fair and can be used for irrigation after proper treatment at few locations.

Khan et al (2013) in Singrauli the water quality of 27 water samples using 16 physico-chemical parameters were assessed. Land use/land cover map along with Base map, and drainage map were computed from satellite data of 4th May 2010 of IRS P6 LISS III and Survey of India toposheet no. 63L/12 at 1:50000 scale. Land use areas were classified into 15 categories out of which open forest covers 20.33 %, uncultivated land 20.25 %, cultivated land 12.60 %, dense forest 11.00 %, and other categories cover 35.82 %. The physico-chemical analysis revealed that the alkalinity, TDS exceeds the permissible limit of WHO. The water chemistry showed that ions like calcium and magnesium were within desirable limits and sulfate and potassium exceed the limit at few locations, while sodium and chloride had higher values. The heavy metals such as copper and zinc exhibited the values well within the desirable limits while iron, cobalt and chromium had values higher than the desirable limits indicating the degradation in the water quality.

Manoj et al (2013) In Birbhum district of West Bengal, India, for classification of surface water chemistry of ponds multivariate technique was employed. To evaluate this, 16 parameters of the samples were used along with Piper Diagram, agglomerative

hierarchical cluster analysis (AHCA) and discriminant analysis (DA). All the water samples fell into 'Ca²⁺-Na⁺-HCO₃⁻ Type'. It was concluded that the most significant pollutant was PO₄³⁻ with the organic wastes. On the basis of anthropogenic influence, the sampling locations were divided into 3 groups while DA showed BOD, pH, Cl⁻ and total hardness as the main parameters within these groups.

Brindha et al (2014) selected 10 parameters for analysis of water quality of ground water and surface water of Adyar River in Chennai. In these Na-Cl and Mg-Cl were the main water types. EC of groundwater increased towards the east following the general groundwater flow direction. A homogeneous trend was observed between the ions of groundwater and surface water samples. The main reason for the contamination of water is untreated domestic sewage as well as it's into the soil.

Jayalakshmi et al (2015) in St. Thomas Mount Block of Kancheepuram District of Tamil Nadu, spatial distribution map along with computation of Ground water quality was performed. On the basis of Land Use changes, the WQI of the area was calculated using 10500:1993(BIS) and (ICMR) standards for nine water-quality parameters. According to spatial interpolation technique the WQI varied from poor to moderate. It was seen from the map that around 76.5% of the area was not suitable for drinking.

Saha et al (2018) identified the alterations in water bodies due to heavy metal contamination, the study used multivariate statistical technique in the industrial region of Bangladesh. Correlation matrix was used to find out association between various heavy metals. It was observed that the on increasing the distance from source the concentration of metals decreased. Apart from it, Principal Component Analysis and Hierarchical Cluster Analysis was also employed to detect the source of pollution such as industrial effluent, municipal waste, and burning of fossil fuel. The above mentioned sources were

accountable for 79.97% of the total variance. On the basis of Hierarchical Cluster Analysis, nine sampling locations were divided into three clusters.

Rakotondrabe et al (2018) twenty two samples of groundwater and surface water were collected for evaluation of water quality in the Mari catchment of Bétaré-Oya (East Cameroon). Apart from estimating the physico-chemical parameters multivariate statistical technique in addition to computation of heavy metal pollution index was done. Except nitrate, all the major elements were well within the permissible limit as prescribed by WHO at few locations. The water was categorized into Ca-Mg-HCO₃ type and Na-HCO₃-K type. In surface water, the concentration of Pb, Cd, Mn, Cr and Fe were higher than the permissible limit as suggested by WHO making it unsuitable for drinking. The main cause of it are the hydrolysis of silicate minerals of plutonic-metamorphic rocks, composing the geological basement of the area, vegetation, soil leaching and mining activities. The value of TSS and trace elements exceeded the permissible limit due to the presence of gold mining activities in the area. The multivariate statistics helped in recognizing the highly polluted areas associated with physical and chemical pollutants.

Kumar et al (2019) evaluated 54 samples using 15 parameters for calculating the groundwater quality of Singrauli district during pre and post monsoon seasons. Ca-Mg-HCO₃ was the main water type. Gibbs ratios designated that weathering of rock is the primary cause for evaluating the groundwater chemistry. Ca²⁺, Mg²⁺, Na⁺, K⁺, HCO₃⁻, Cl⁻, SO₄²⁻ concentrations in the groundwater were well within the permissible limits as recommended by WHO for drinking water. During post and pre monsoon season 35% and 44% respectively of the samples had F⁻ concentrations while for NO₃⁻ 22% and 26% respectively of the samples were well above the permissible limit. The main reason for fluoride concentration is contamination from leaching from ash ponds whereas high NO₃⁻ is due to formation of nitrogen oxides due to coal combustion, their deposition and

leaching into the groundwater. Most of the samples exceeded concentration of Fe and Cr of WHO permissible limits, making it unfit for drinking purpose. The study also suggested that majority of groundwater samples were suitable for irrigation purpose. The USSL plot represented that majority of groundwater belonged to C_3S_1 class exhibiting high salinity hazard and low alkali hazards essential for proper drainage.

Bhardwaj et al (2020) analyzed 48 water samples (27 groundwater and 21 surface water) for evaluating the contamination of heavy metals in Singrauli industrial belt area. Eighty-eight percent of groundwater and 90% of surface water samples were contaminated with Hg, Pb and Cd along with As were well above the WHO permissible limit. Apart from it, 95% of the samples had HPI value greater than 100 while CD value of 89% of the samples exhibited contamination with heavy metals (As, Hg, Cd, Pb). Spatial distribution map represented that many of the contaminated samples lie near thermal power plants, ash ponds and coal mines. LULC (land use/land cover) study showed a considerable decrease in water bodies by (108 km²), agricultural land by (54 km²) and barren/fallow land by (51 km²) from 2000 to 2016. A fourfold increase in overburden, a threefold increase in dumping yards, a 2.5 times increase in urban areas, and a twofold increase in mining areas was observed.

Year of Publication	Name of Author	Major Contribution
1999	Prasad et al	The groundwater of Dhanbad town was evaluated using 7 heavy metals at 20 stations using HPI. The value of it was below 100 indicating groundwater was not polluted with heavy metals.
2006	Sarkar et al	WQI of surface water of Jharia coalfield along with multivariate statistics and spatial distribution was computed. The dendrogram obtained was divided into 2 clusters however the WQI falls under poor category.
2010	Rai	Surface water quality of Govind Ballabh Pant Sagar reservoir was evaluated using 9 metals and 15 physico-chemical parameters for 2004-05. The quality was not suitable for drinking, irrigation, bathing, etc purposes.

2011	Agarwal et al	In Singrauli district, the impact of Renusagar and Anpara thermal power plant in ground water samples using 4 heavy metals. These metals were above the permissible limit as suggested by WHO.
2012	Singh et al	In Jharia coalfields, 92 mine water samples were evaluated using 35 parameters. The quality ranged from good to permissible for irrigation.
2013	Khan et al	In Singrauli, 16 parameters for 27 water samples was evaluated along with Land Use/ Land Cover of the study area in 2010. The water quality of the area was not suitable for domestic purposes.
2013	Manoj et al	In Birbhum, West Bengal, the surface water quality was calculated using 16 parameters. Along with it, multivariate statistics was used. Organic wastes was the most important pollutant.
2014	Brindha et al	In Chennai, surface and ground water quality using 10 parameters was evaluated. A wide variation between quality of surface and ground water was found out.
2015	Jayalakshmi et al	In Kancheepuram district of Tamil Nadu, water quality index along with spatial distribution map of ground water was computed. 76.5% of total area was unfit for drinking ranging from poor to moderate.
2018	Saha et al	In Bangladesh, statistical methods were used for detection of heavy metals contamination in water bodies. Anthropogenic sources were the major cause of pollution.
2018	Rakotondrabe et al	In Bétaré-Oya, the influence of gold mining on surface and ground water quality was evaluated at 22 sites. It helps in identifying highly polluted areas.
2019	Kumar et al	In Singrauli, 54 ground water samples for 15 parameters were evaluated. The samples were unfit for drinking purposes.
2020	Bhardwaj et al	In Singrauli, 48 ground and surface water were used for calculation of water quality using 4 parameters. 88% of ground water samples and 90% of surface water samples was contaminated with mercury.

Table 2.2 Tabular Representation of Summary of Literature Review

To summarize this section, previous work that has happened on assessment of the water quality using various physico-chemical parameters has been studied. The work done by various researchers for assessing the impact caused by mining has not given much emphasis on water quality, quantity of stagnant water bodies like lakes, ponds, reservoirs

located in the vicinity of the coal mines. The literature survey also revealed that there is further need to research in depth the concentration of various pollutants deciding the quality of water in stagnant water bodies.

2.4 Studies on analysis of land use/land cover

Alexander et al (1973) employed ERTS-I MSS data for digital processing of stripped areas of west branch of the Susquehanna River using ERTS imagery. Under-flight data and ground-based data were utilized for ground truth assessment and sub-categorizations of stripped areas illustrating the presence of acid mine drainage. Seasonal alterations in categorization was also done in association with demonstrative effects on vegetation. Conclusive results showed that ERTS data can be utilized for monitoring the extent of stripping in study areas as well as efficacy of reclamation and pollution mitigation.

Mamula et al (1978) confirmed that in opencast coal mine of southern Montana, remote sensing was one of the most viable and beneficial tool for collecting environmental and land-use data on seasonal, spatial, dynamic basis for analyzing the large-scale surface mines in the northern great plains of the area. The Western Energy Co.'s Rosebud mine near Colstrip, Mont., was chosen as a sample site since it represents surface mining activities in the Powder River basin of Montana having large plain area in the northern Great Plains. The study utilized Landsat image in band 5 possessing black-and-white tone in combination with Colored infrared and black-and-white aerial photographs. These all were employed for recognizing high wall and bench areas, ungraded spoils, graded and recontoured areas, revegetated recontoured areas, natural and impounded surface water, and miscellaneous areas. The cultural and natural processes and cumulative environmental effects during the expectancy of a substantial surface mine can be observed by keeping an eye on the direct relationship between the enhanced satellite imagery, infrared and black-and-white aerial photography, standard large-scale

topographic maps such as U.S. Geological Survey 7¹/₂ minute quadrangle maps and data obtained by an onsite inspection of mining and reclamation by Federal or State agencies. Ghosh et al (1993) in Jharia coalfield, the level of groundwater was analyzed which was primarily dependent on the topography, geomorphic features such as abandoned channels, confluence of channels, losing streams and human-induced recharge conditions of the area. These features are indicated by the presence of soil moisture content and vegetative cover. The groundwater map of Jharia coalfield was prepared from the aerial photographs using the grey tone and vegetation cover as the criteria. The obtained results are assisted with field observation as well as the data was used for the preparation of groundwater map. Hence, the ground-water map obtained through the present analysis will help in obtaining details about sites of near-surface aquifers in combination with countering severe drought during summer endured by many portions of the coalfield.

Venkataraman et al (1997) used remote sensing data along with limited ground-based information with the help of the Leopold matrix method, factor analysis and cluster analysis techniques investigated the environmental consequences of opencast iron ore mines of Goa, India. It was concluded the study, it was noticed that on increasing the mining activities there was a decrease in vegetation and land degradation in the study area. Apart from it, turbid zones of surface water were also delineated. From the factor analysis and cluster analysis, the soil samples were divided into, four zones on the basis of analysis of soil chemical data and the impact of mine overburden wash-off on the quality of soil was exhibited. The marginal impact of mining on quality of groundwater was concluded from the primary results of the oxygen isotope study.

Wu et al (2008) analyzed TM images of 1995 and 2001 in Liaoning province of China to obtain a set of information about the coal mining area. Using supervised classification of ERDAS the coal mining area was classified into five classes viz water body, agricultural

land, construction land, coal mining area and other lands. The land use change matrix depicted that during a timespan of six years from 1995 to 2001, the alteration in the land utilization was high. There was an increase in area occupied by water bodies, agricultural land, and coal mining land while the area occupied by construction and other land had decreased. The percentage speed of the construction land is the highest at -1.08%. The primary reason for it was the conversion of agricultural land and construction area into coal mining land. During reclamation the coal mining land was converted into agricultural land.

Khan et al (2012) studied the land use/land cover of Singrauli coalfield using multispectral/multi-temporal data of 8th May 2001 and 4th May 2010 from Indian Remote Sensing Satellite (IRS) geocoded False Colour Composite (FCC). For the base map, Survey of India toposheet no. 63L/12 on scale 1: 50,000 was used which was overlapped on the FCC for deriving land use/land cover map of the study area through visual interpretation method. Interpretation of satellite data resulted in formation of 14 land use/land cover classes such as dense forest, open forest, open scrub, cultivated land, uncultivated land, mining pit, overburden dumps, wasteland, and settlement. For verifying it, Ground truth verification was done in major areas. The assessment of land use/land cover data during 2001 and 2010 showed that there was loss of dense forest area which can be due to increase in coal mining activity. The area occupied by open scrub had increased from 29.82 km² in 2001 to 42.45 km² in 2010 due to the plantation activities in the area. Area of overburden dumps had increased from 30.4 km² in 2001 to 39.44 km² in 2010 due to increase in coal mining areas. There was also an increase in settlement area from 39.72 km² in 2001 to 44.82 km² in 2010, whereas the area under cultivated land had decreased from 104.54 km² in 2001 to 92.61 km² in 2010. The main reason for change

in land use/land cover was mainly due to coal mining activities and industrial expansion, making it one of the leading industrial zones in northern India.

Areendran et al (2013) presented the change in Singrauli district of Madhya Pradesh in terms of land use/land cover (LU/LC) for monitoring land management. These changes were mapped using a remotely-sensed multi-date satellite data using Geographic Information System (GIS) for spatial and temporal changes in the land use/land cover using Landscape metrics. Apart from this, the Markov transition matrix and change rate were also computed for each class of the LU/LC. These changes from one class to the other were delineated by employing change matrices. The study analyzed that there was a decrease in vegetation cover while an increase was observed in the rate of deforestation. However, built-up and mining areas have showed a positive increase in area. This study might help in planning, management and utilization of land and other natural resources and related future impacts of mining.

Li et al (2015) studied the eco-fragile region of Mu Us Sandy Land (MUSL) region of northern China which is a home to approximately one-third of the coal reserves of China. On implementation of western development policy in China in 2000, there was an explanation in mining activity increasing rapidly in the MUSL region thus strongly influencing the endurable socio-economic development. On the basis of the Landsat TM, ETM and OLI images from 2000, 2005, 2010 and 2013 the expansion of coal mining activities had been systematically monitored using the changes of the land cover type as an indicator for the expansion of mining activity in the MUSL region. Based on this data, a database of mining activities was developed by establishing a classification system of mining region and used it for spatial and temporal evolution trends of mining activity. It was concluded that the two main dominant types of land cover were vegetation and sparse vegetation, mainly accredited to the alteration in mining regions in the study area.

Rai et al (2016) analyzed Land use land cover (LU/LC) pattern of 25 years using remote sensing and GIS in Sonbhadra district of Uttar Pradesh and Singaruli region of Madhya Pradesh as a result of natural and socio-economic factors. However, the study area was located in the proximity of Govind Ballabh Pant Sagar reservoir. Land use and land cover patterns of 1991, 2000 and 2014 were assessed and comparative analysis was done using hybrid method of classification in ERDAS. Data for computing LU/LC was obtained from TM of 1991 and ETM+ of 2000 and 2014 of LANDSAT from remote sensing satellite imageries and Survey of India (SOI) topographic sheets on a 1:50000 scale. After this the Landsat data was analyzed and processed in ArcGIS version 10.3. In this analysis, the change in statistics of area such as agriculture, barren land and forest cover which was controlled by change in geology and existing structural anomaly were computed. It was noted that there existed an intense relationship between decrease in forest cover and increase in mining areas. The confusion matrix had exhibited that there was a conversion small amount of forestland into scrubland, agricultural land and barren land. The study also concluded that the forested areas was most prone to conversion and continuous increase of human pressure on forests makes them prone to deforestation activities in the study area.

Ahmad et al (2017) in Singrauli district the spatial and temporal expansion of mines were evaluated using satellite remote sensing data since 1976. The datasets used for the present study were obtained from Landsat satellite during 1976, 2002, 2010 and 2015. It was seen that there was an annual increase in area of mines, which was 4.25 times higher when compared with the period (2010-2015) to (1976-2002). A Continuous decrease in the annual area of forest cover was observed due to increase in the mining activity between the study periods (1976-2015). The study also concluded that these satellite data were successful in studying the spatial and temporal changes in LU/LC classification related

to mining activities as well as it proved to be very helpful in monitoring these changes at regular intervals, so that the adverse impacts are scrutinized.

Rwanga et al (2017) analyzed Landsat 8 OLI/TIRS during 2015 for computing Land Use/Land Cover analysis in Limpopo province of South Africa. This objective of classification was achieved using remote sensing and Geospatial Information System (GIS) techniques. The research was divided into two sections (1) Landuse/Landcover (LU/LC) classification and (2) accuracy assessment. The study utilized supervised classification for performing Non Parametric Rule. The LU/LC was categorized into agriculture (65.0%), water body (4.0%), and built up areas (18.3%), mixed forest (5.2%), shrubs (7.0%), and Barren/bare land (0.5%). It was concluded there had been an overall classification accuracy of 81.7% and kappa coefficient (K) of 0.722. The kappa coefficient was rated as substantial and hence the classified image were found to be fit for further research. Hence, this study can be treated as an important source of decision making which can be used by planners and decision makers for sustainable planning to protect the environment.

Garai et al (2018) discussed the change in land use/land cover patterns, the impact of coal mining on the land use/land cover changes as well as its regional environmental impact. The various land use categories mainly comprises of water body, mining area, forest cover, built-up area, barren land and agriculture land in Godavari coalfield area of southern India. The land use/land cover changes were assessed during a period of 24 years in the Godavari coalfield area i.e., from the year 1990 to 2014. These alterations were monitored on an interval of 5 year time using Landsat-5 TM, Landsat-8 OLI and TIRS satellite images as well as the human impact on the landscape were determined. Apart from it, quantification of spatial-temporal dynamics and change detection of land use/land cover patterns were also analyzed. It was concluded from the study that there

was an increase in water body from 2.77% in 1990 to 3.29% in 2014 while the mining area increased from 0.04% in 1990 to 0.23% in 2014. Besides this, forest cover has decreased from 36.38% in 1990 to 31.67% in 2014 though built-up area and barren land showed an increase of 0.34% to 0.89% and 1% to 1.69% in 1990 and 2014 respectively. There was steady increase in agricultural land from 59.46% in 1990 to 62.22% in 2014. Hence, the trend of major changes in the land use/land cover classes in the study areas from 1990 to 2014 was also exhibited in this study. It was also revealed that there was a direct impact of mining on forest cover along with other factors. Therefore, it can be helpful in decision making for land reclamation and land management in the Godavari coalfield of India.

He et al (2019) analyzed the groundwater quality as well as monitored change in LU/LC of Xi'an City in Guanzhong Basin for a period of ten years, from 2005 to 2015. The study also established relationship between groundwater quality and LU/LC patterns. For scrutinizing the hydrogeochemistry and groundwater quality techniques such as Piper diagram, Gibbs diagram and self-organizing map (SOM) were employed. Remote sensing image data generated by Landsat 5 and Landsat 8 satellites in 2005, 2010 and 2015 were used for computing the LU/LC patterns of Xi'an City in those three years. The data obtained were further used for conversion of LU/LC between 2005 and 2010 and between 2010 and 2015. Entropy weighted water quality index (EWQI), curved streamline searchlight model (CS-SLM), and multiple linear regression analysis were used for relating groundwater quality to the LU/LC patterns of Xi'an City during these three years. The Piper diagram showed that groundwater in Xi'an City was primarily of $\text{HCO}_3\text{-Na}$ type and/or $\text{HCO}_3\text{-Ca-Mg}$ type. Whilst the Gibbs diagram showcased that the main progression of hydrogeochemistry was through rock weathering and water-rock interactions. SOM characterized the groundwater into eight groups, and displayed various

spatiotemporal patterns of water quality parameters. The LU/LC classification revealed that the urban land in Xi'an City has increased by more than 160%, while forest and agricultural land areas had decreased by 52.54% and 83.08% respectively, from 2005 to 2015. The coefficient of multiple linear regression of EWQI and the percentages of LU/LC types in CS-SLM for the wells, urban land, agricultural land, and industrial land indicated that these had negative effects on groundwater quality while the area covered by forest had positive impact on the groundwater quality during the period.

Orimoloye et al (2020) utilized geographic information system and remote sensing techniques for computing land-use and land-cover dynamics in the gold mining area of South Africa using the data retrieved from Landsat 5 for years 1984, 1994, 2004 and Landsat 8 for 2014 and 2019 acquired from the United States Geological Survey and Remote Pixel Databases using ArcGIS 10.4 and R programming. It was concluded the study that tailings dam and built-up areas showed positive change from 90.5 to 172.9 km² between the year 1984 and 2019 along with mine effluent and water bodies which also increased from 14.7 to 18.8 km² during the same period. There was also an increase in vegetation from 342.5 to 371.1 km² suggesting that the area had observed revegetation during these years. It was further revealed that the study related to vegetation health in the area employed vegetation indices such as the Global Environmental Monitoring Index, Normalised Difference Impervious Surface Index and Normalised Difference Moisture Index. It was finally concluded that the areas possessing low index values were more vulnerable to the effect of mining and other anthropogenic activities whereas high-index areas indicated restricted or no impact.

Year of Publication	Name of Author	Major Contribution
1973	Alexander et al	Stripped areas of Susquehanna river were studied using ERTS-IMSS data. Results showed that it was effective in monitoring stripped data as well as in reclamation and pollution abatement.
1985	Mamula et al	The changes in the surface coal mines of southern Montana has been evaluated by Landsat MSS and Colour infrared aerial photographs which showed that the surface mining is extensively disturbing the other resources present in the vicinity of the mines.
1993	Ghosh et al	A land use map of Jharia coalfield for 1987 has been prepared using Landsat satellite imagery data. This gives a glimpse of conditions prevailing in 1987 to monitor the damages to land use caused by mining when compared with the land use condition of 1974.
1997	Venkataraman et al	Environmental impact of opencast iron ore mines in Goa, India was studied using remote sensing data and limited ground based information with the help of Leopold matrix method, factor analysis and cluster analysis methods.
2008	Wu et al	The coal mine of Liaoning province, China was classified using supervised classification on the basis of two temporal TM images of 1995 and 2001. The result showed that in the six years of 1995 to 2001, the area of water body, agricultural land and coal mining land had continually increased, on the contrary, construction area and other decreased.
2012	Khan et al	The present study utilizes MSS data of IRS geocoded FCC of 8th May 2001 and 4th May 2010 for land use/land cover mapping of Singrauli Coalfield. The comparative analysis of land use/land cover data shows that loss of dense forest area are due to the expansion of coal mining activity.
2013	Areendran et al	In Singrauli, LU/LC was mapped. The results showed that vegetation cover had decreased while deforestation, built-up and mining areas had increased in the study area.
2015	Li et al	In Mu Us Sandy Land region of China LU/LC during 2000-2013 was evaluated. The data obtained from Landsat TM, ETM and OLI images for classifying spatial and temporal evolution trends of mining activities.
2016	Rai et al	LU/LC changes over 25 years has been studied in Singrauli region during a time span of 1991-2014. Landsat data was used to depict a strong

		relationship between loss of forest cover and growth in mining industries.
2017	Ahmad et al	Evaluated the spatial and temporal expansion of coal mines near Singrauli district since 1976. Continuous losses in the annual forest cover due to increase in the mining area between the study periods (1976-2015) was observed in order to take necessary steps to mitigate it.
2017	Rwanga et al	LU/LC in Limpopo province of south Africa was studied using Landsat 8 OLI/TIRS during 2015. The study was classified into 6 classes with overall classification accuracy of 81.7%.
2018	Garai et al	The land use/land cover changes in Godavari coal field area of southern India was studied for a period of 24 years i.e., from the year 1990 to 2014. It was observed that there is a direct impact of mining on forest cover along with other factors.
2019	He et al	In Xi'an City of Guanzhong basin, ground water quality and LU/LC Conversion was studied during 2005-2015. Results showed that urban land had increased by 160% while forest and agricultural land reduced by 52.54% and 83.08% respectively.
2020	Orimoloye et al	The study showed LU/LC in South Africa during 1984-2019. Results showed that built-up areas, water bodies, vegetation had increased.

Table 2.3 Tabular Representation of Summary of Literature Review

The various factors contributing in pollution of water has also been studied and found that besides mining activities, land use/ land cover change pattern also plays an important role in affecting the water quality and quantity of the reservoir. To summarize this section, most of the past researchers have utilized the land use/ land cover data from different sources like historical archives, ground truth and satellite imagery to spatially and temporally analyze the change in land use/ land cover using different GIS technologies. These work mostly focused on analyzing the impact of industrialization on forest cover and agricultural land and future planning without any specific focus on the impact of mining on water quality. This thesis focused on the impact on water quality due to change in land use/land cover pattern. The time period of 30 years for the analysis is also significant and larger than most of the previous studies.

2.5 Studies on estimation of reservoir volume

Sharma et al (2013) evaluated the volume of Ujjani and Govind Ballabh Pant Sagar reservoirs in India using radar altimetry data and optical satellite imagery (such as Landsat). The volume estimated was contrasted with the published data. Quantum GIS plugin was also developed for monitoring change in volume of the reservoirs. However, the limitation of the methodology was that the reservoir volume can be estimated only up to the deepest radar altimetry data available for the reservoirs of interest. The study also showcased the commercial and the scientific potential of this technology, particularly in Indian reference. This technique can be effectively used in many disaster management programs, including floods since India is prone to natural disasters, therefore, Radar altimetry data have the potential to be used in such cases. High-resolution and precise hydrography created by Radar altimetry are most appropriate for further validation of scientific understanding of natural phenomena such as floods and the coastal environment. Thus, it was concluded that by using satellite images with higher spatial resolution, the surface area of the reservoirs could be more accurately evaluated and hence the volume calculated.

Ouma (2016) utilized Real-Time Kinematic Global Positioning System (RTK-GPS) DEM in comparison with ASTER and contour-derived DEM for evaluating the capacity of the reservoir. The results exhibited that the RTK-GPS DEM produced best results for estimation of the reservoir capacity-area curve, designated by a convex slope with an exponential deterministic relationship given by $V = 0.09 \times A^{1.435}$. In addition to it, there is presence of an empirical relationship between the reservoir volume and the GPS point density d_i as $V_e = c \times d_i^p$. This relationship depends on the reservoir terrain, slope and surface area. The confirmation of results with in situ data exhibited that there was a difference of less than +10% between the simulated and observed storage volumes of the

reservoir. While the Nash-Sutcliffe coefficient showed an average efficiency of +0.7 of on the basis of monthly observed and simulated reservoir storage volume. In a prevailing reservoir having design data, this technique can be utilized for comparing and automating the monitoring and redesigning of the reservoir. Hence, this can be considered as a better method for conventional lake or reservoir monitoring and redesigning of reservoir.

Fuska et al (2017) worked for the verification of historic data of historical man-made water reservoir at Ottergrund in Banská Štiavnica district, a UNESCO world heritage site. The primary objective was the preparation of area-storage capacity curve. On paper format, there was a presence of historic map showing contours of reservoir bottom as well as the area-storage capacity curve. This historic data was examined and collated with the results of the computed area-storage capacity curve obtained from a new tool termed as “ASC_Curve”, based on a Python script. This tool used ArcPy site package and works in association with the TIN model for observing the bottom of water reservoir. In this study, using TIN model, historic bottom of the reservoir was observed by putting historic contour as input data for the creation of TIN model. It was concluded from the study, that the storage capacity computed with the use ASC_Curve tool was 97% of the volume of the reservoir as shown in the historic map. There were minor mathematical errors in the historic contour plan for the calculations using data for area-storage capacity. The siltation of reservoir strongly affect the morphology of the water reservoir through erosion and transportation from reservoir watershed hence this tool can be used to answer the amount of the material eroded and transported through surface runoff into the water reservoir. Therefore, it can be helpful for the assessment of current storage capacity of water reservoirs if used in combination with echo-sounding equipment for surveying the data for producing TIN model for the bottom of the water reservoir.

Khaba et al (2017) reservoir storage capacity loss of the Muela Reservoir in northern Lesotho was analyzed between 1985 and 2015 due to deposition of sediment by the Bathymetry records obtained from the Lesotho Highlands Development Authority (LHDA). For identifying this, eight surveys data between 1985 and January 2015 were assessed for quantifying the bathymetric change during each survey. For this, four interpolation methods such as Kriging, natural neighbor, spline and inversed instance weighting methods were used for generation of digital terrain models during each survey. Apart from this, triangulated irregular network (TIN) surface was also prepared using each data-set. On the basis of Krigging, between 1985 and early 2015, 15,400m³/year of storage capacity loss was ascertained on an average for the whole 30 years of time period. However, the results stipulates presence of high inter-annual irregularity in the rate of reduction of reservoir capacity, contemplating errors during the survey as well as for volumetric calculation of reservoir proposing that rates of reduction in volume of reservoir varied between 11,400m³/year to 18,200m³/year.

Khasanov (2020) studied Kyzylsay and Tashtepa water reservoirs in Tashkent region, Uzbekistan. In this study, for the construction of the Kyzylsay and Tashtepa water reservoirs in Tashkent region, Uzbekistan, the vertical accuracy of the Shuttle Radar Topography Mission (SRTM DEM) was compared with the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER DEM). Vertical differences between SRTM and ASTER products were calculated on the basis of root mean squared error (RMSE) when compared to GPS data. It was concluded that SRTM based measurements of ground control points (GCPs) exhibited RMSE of 4.262 m while ASTER DEM based measurements exhibited RMSE of 3.693 m for the Toshtepa Reservoir situated on the plain whilst for the Kyzylsay reservoir situated in the mountains, the results showed that RMSE of 12.82 m for SRTM and 15.77 m for ASTER.

On the basis of it, SRTM DEM outperforms ASTER DEM for distinguishing vertical accuracy. This again stipulated that ASTER DEM was better than SRTM DEM in identifying the vertical accuracy for plane and SRTM DEM is recommended over ASTER DEM in mountainous region. The longitudinal profiles of dams (Kyzylsay and Tashtepa) of all DEMs are compared with the geodetic data of the design institute - UzGIP. The area and volume of the reservoir were identified using the digital model compared with the data of the design institute - UzGIP using a geodetic tablet.

Year of Publication	Name of Author	Major Contribution
2013	Sharma et al	In India, 2 reservoirs (Ujjaini and Govind Ballabh Pant Sagar) were selected for volume estimation and monitoring using radar altimetry data. These data were used for generation of accurate hydrographs for monitoring frequent floods and coastal environment.
2016	Ouma	The reservoir storage capacity was evaluated using (RTK-GPS) DEM with comparison to ASTER and DEM. The results obtained through RTK-GPS DEM were the best amongst them.
2017	Fuska et al	In Banská Štiavnica district for Ottergrund reservoir, the area storage capacity curve was plotted using TIN model. It was found that the capacity of it was reduced due to siltation from watershed of the reservoir.
2017	Khaba et al	Muela Reservoir in northern Lesotho was analyzed for capacity loss due to sediment deposition, between 1985 and 2015. Four interpolation methods (inversed instance weighting, Kriging, natural neighbor, and spline) were used. TIN surface was created from each data-set. The results indicated high inter-annual variability in the rate of reservoir capacity reduction and reservoir volumetric calculation methods suggested that rates of reservoir volume reduction can vary between 11,400m ³ /year and 18,200m ³ /year.
2020	Khasanov	In Uzbekistan, Kyzylsay and Tashtepa reservoirs were analysed. Here, SRTMDEM and ASTERDEM are compared amongst themselves and with the GPS data. SRTMDEM was found to be more accurate amongst the two for calculating area and volume of the reservoir.

Table 2.4 Tabular Representation of Summary of Literature Review

Further, a detailed literature survey has also been conducted to find out available technique for estimation of volume of water with time. Overall, very little work has been performed on using remote sensing in estimating volume of very large reservoirs across a long period of time and its correlation with the water quality, coal mining activities and vice-versa. This thesis used Triangulated Irregular Network model based on ASTERGDEM data for analyzing the change in volume of the Govind Ballabh Pant reservoir during 1998-2018 due to the mining activities.

From sections 2.2 to 2.5, it has been concluded that little previous work has been done in the areas specifically targeted in this thesis and this had presented newer findings on the impact of coal mining on water quality, land use/ land cover and volume estimation of the reservoir. Most of the researchers had either focused on analyzing a group of parameters like heavy metals or ions but very few have used both. In this thesis, 26 physico-chemical parameters including both ions and heavy metals had been analyzed for all the water samples. In addition to it, statistical analysis of the data was also done to establish relationship between the various parameters. The detailed analysis of LU/LC has also been conducted for a period of 30 years to assess its impact on water quality. Further, the volume of the reservoir was also estimated for a period of 20 years to determine the effect of mining on volume of the reservoir. Apart from it, an attempt has also been made through literature survey to establish technique for treatment of mine effluent before disposing off into the reservoir. This research had presented new findings on the impact of phytoremediation in combination with a sandstone filtration system on improving the water quality at one of the major source (i.e. Balia Nala) entering directly into the reservoir.

Research Gap

After going through exhaustive literature survey, the following research gap has been found out:

- 1) There was little work done on assessment of water quality in and around the study area. Further, seasonal variations in water quality has not been studied properly. Hence, there is a need to conduct thorough water quality assessment with seasonal variation particularly during pre and post monsoons.
- 2) There were sufficient work done on assessing the pollution level due to coal mines and mining activities in India. However, the water pollution due to coal mining on stagnant water bodies (lakes, reservoir, etc.) is the need of hour in the study area.
- 3) The use of remote sensing data was widely applied for water quality assessment as well as for Land Use/ Land Cover of the area in developed countries. However, a little work was found for estimating the volume of the reservoir through remote sensing technique in our country. Hence, there is a need to estimate whether the reservoir water retaining capacity is decreasing or not.
- 4) There were many papers on water quality management by different techniques including physical and chemical methods for small quantity of water. Phytoremediation technique is an emerging technique which find a little attention in our country. Hence, there is a need for treatment of large volume of water by phytoremediation technique.

For doing the above work Singrauli Coalfield of Singrauli, Madhya Pradesh was identified for above investigation. A brief discussion about the study area has been described in the next chapters.