Abstract

One of the global challenges before humanity is to ensure good water supply to meet its ever-growing demand due to the expanding world population and industrialization. Lakes, rivers, and reservoirs are some of the most substantial sources of freshwater. These water bodies cater to the needs for irrigation, drinking, domestic, industrial, and other uses. The locations of these water bodies are also ideal sites for coal mining, coal-based thermal power plants and many other associated industries. Deterioration of the water quality of these water bodies is a common phenomenon that happens due to natural and anthropogenic activities. It causes a significant risk on water quality and the health of living beings including human beings in and around the area of study. Due to adverse impact of coal mining and thermal power plants on water bodies, the issues of natural water adulteration and their mitigation require significant attention in the area under study.

In India, one of the major industrial activities which cause degradation of the environment is coal mining. It is also one of the eight core industries of India and plays a crucial role in the economic growth of the country. These large-scale coal mining activities pose both short-term and long-term adverse impacts on the environment in general and water quality in particular. The occurrence of coal and location of Govind Ballabh Pant reservoir in the area makes it an ideal site for power generation. Side by side, these industries are also the constant source of contamination of water. As water is the most vital natural resource and essential for human survival, hence this study focuses on assessment of water pollution of Govind Ballabh Pant reservoir due to coal mines and associated industries. An adequate amount of data has been collected from the representative sites in the study area. The water samples have been collected to discern the water quality and the risks associated with it. Along with this, other studies has also been conducted to assess the impact of mining on the volume of the reservoir (water retention capacity). This requires the implementation of efficient methodology for monitoring the annual changes and the deterioration taking place in the quality of water.

The increasing production of coal and power generation along with other industries near the Govind Ballabh Pant reservoir are posing the need for a thorough investigation of degradation in water quality. The Govind Ballabh Pant reservoir (study area) is located at the border of Madhya Pradesh (Singrauli district) and Uttar Pradesh (Sonbhadra district). The reservoir receives effluents from the nearby coal mines and the power plant.

The study area experiences tropical monsoon climate with the Koppen-Geiger climate classification of Cwa having an annual temperature range of 8.8^{0}C- 40.8^{0}C. The average annual temperature of the area is around 24.7^{0}C. The rainfall data acquired during 1967-2018 showed a decreasing trend which is also reflected by alterations in other climatic conditions. The average annual rainfall during this period of 61 years is 1167.53 mm with 80% rainfall falling during the monsoon.

The main objective of the study was to assess the impact of coal mining on the water quality of the Govind Ballabh Pant reservoir and to suggest management in order to protect the quality and volume of the water. To achieve the above objective, different methods and technologies were employed to comprehensively monitor and evaluate the water quality of the study area. Twenty-six physico-chemical parameters were identified to assess the impact of mining on the quality of water. For this, sixty sampling sites have been selected to monitor the quality of the water in pre and post monsoon seasons. Apart from this, statistical correlation between various water quality parameters was also done to manifest interrelations among various water pollutants. The analytical data of these 26 physico-chemical parameters were used for calculating the water quality index of 60 sampling sites during pre and post monsoon seasons of the study area. In addition, the statistical analysis of the data was conducted to investigate the correlation between these different parameters. Remote sensing and GIS technologies were also used to support the work done in the study area by preparing spatial distribution maps of various physico-chemical parameters along with the water quality index.

Besides the above studies, the assessment of Land Use/ Land Cover changes using multi-temporal Landsat data for the years 1988, 1996, 2005, 2016, and 2018 has also been done. The changes in Land Use/ Land Cover patterns due to mining and other activities were also determined using the Change Detection Map for the years 1988-2018.

The study also attempted to ascertain the change in volume of the Govind Ballabh Pant reservoir due to mining and other activities for the years 1998, 2013, 2016, and 2018 using Triangulated Irregular Network model. Finally, to mitigate the impact of mining and associated industries on the reservoir water quality, laboratory experimentation has been done to manifest the design and implementation of phytoremediation technology in addition to a sandstone filtration system.

On the basis of 26 physico-chemical parameters, the water quality during pre and post-monsoon season from 2016 to 2018 for 60 sampling locations had been analysed. The mean values of each season had been used to assess the quality of surface water for different purposes. The result of the analysis indicated that pH of most of the samples was more than 7, indicating the alkaline nature of water during both the seasons. The Total Dissolved Solids (TDS) and Total Suspended Solids (TSS) for all the samples were well within the permissible limit of 500 mg/L except for two samples during both the seasons. The EC of water samples ranged between 1148 μS/cm to 214 μS/cm with a mean value

of 477.4 µS/cm during pre-monsoon monsoon while it ranged from 1231 µS/cm to 354 µS/cm with a mean value of 573.6 µS/cm. However, most of the samples revealed moderately higher conductivity values than the permissible limit of 300 µS/cm as recommended by BIS/WHO but can be used for drinking purposes.

The cations like magnesium and sodium ranged from 37.9 mg/L to 10.1 mg/L and 49.9 mg/L to 11.9 mg/L respectively with a mean value of 19.2 mg/L and 27.1 mg/L respectively during pre-monsoon season. In post-monsoon season, it ranged from 33.5 mg/L to 8.1 mg/L and 59.2 mg/L to 20.9 mg/L with a mean value of 14.8 mg/L and 31.6 mg/L respectively. These values were well within the permissible limit of 50 mg/L and 50 mg/L respectively as suggested by BIS/WHO. However, the concentration of calcium and potassium in the region ranged from 95.2 mg/L to 11.1 mg/L and 26.2 mg/L to 10.6 mg/L with a mean value of 36.3 mg/L and 13.6 mg/L respectively during pre-monsoon season. Whereas in post-monsoon season, it ranged from 98.8 mg/L to 13.7 mg/L and 25.1 mg/L to 7.5 mg/L with a mean value of 41.6 mg/L and 12.0 mg/L respectively. These values were higher than the permissible limit of 75 mg/L and 15 mg/L respectively for most of the samples during both the seasons. The hardness of the surface water calculated from the cations analysed ranged from 206.4 mg/L to 82.2 mg/L and 202.3 mg/L to 95.4 mg/L respectively with a mean value of 123.6 mg/L and 128.3 mg/L respectively during pre and post-monsoon season respectively, depicting that it was well under the permissible limit of 500 mg/L as per BIS/WHO guidelines.

The heavy metals such as iron, copper, zinc, nickel, chromium, cadmium and lead were also analysed. These ranged from 2.1 mg/L to 0.1 mg/L, 1.8 mg/L to 1.0 mg/L, 5.8 mg/L to 1.4 mg/L, 0.29 mg/L to 0.01 mg/L, 0.08 mg/L to 0.01 mg/L, 0.26 mg/L to 0.01 mg/L and 0.48 mg/L to 0.01 mg/L respectively with a mean value of 0.8 mg/L, 1.1 mg/L, 2.5 mg/L, 0.07 mg/L, 0.02 mg/L, 0.05 mg/L and 0.12 mg/L respectively during pre-monsoon

season. However, during post-monsoon season, the heavy metals ranged from 2.1 mg/L to 0.1 mg/L, 1.8 mg/L to 1.0 mg/L, 5.8 mg/L to 1.4 mg/L, 0.26 mg/L to 0.01 mg/L, 0.07 mg/L to 0.01 mg/L, 0.23 mg/L to 0.01 mg/L and 0.45 mg/L to 0.01 mg/L respectively with a mean value of 0.7 mg/L, 1.1 mg/L, 2.4 mg/L, 0.07 mg/L, 0.01 mg/L, 0.04 mg/L and 0.09 mg/L respectively. These metals exceeded the permissible limit of 1.0 mg/L, 1.5 mg/L, 5.0 mg/L, 0.20 mg/L, 0.01 mg/L, 0.10 mg/L and 0.15 mg/L respectively as suggested by BIS/WHO in many samples for both the seasons.

During both the seasons, the important anions were also analysed. It has been observed that anions, such as chloride and phosphate ranged from 96.3 mg/L to 43.8 mg/L and 18.1 mg/L to 0.1mg/L respectively with a mean value of 60.8 mg/L and 1.8 mg/L respectively during pre-monsoon season. In post-monsoon season, it ranged from 91.0 mg/L to 31.6 mg/L and 16.8 mg/L to 0.1 mg/L respectively with a mean value of 51.1 mg/L and 1.5 mg/L respectively. These were well within the permissible limits of 250 mg/L and nil respectively as prescribed by BIS/WHO whereas fluoride, sulphate, nitrate and bicarbonate ranged from 1.7 mg/L to 0.6 mg/L, 735.5 mg/L to 60.5 mg/L, 97.2 mg/L to 10 mg/L and 362 mg/L to 122 mg/L respectively with a mean value of 1.3 mg/L, 115.7 mg/L, 19.3 mg/L, and 172.2 mg/L respectively during pre-monsoon season. However, during post-monsoon season, the anions ranged from 1.6 mg/L to 0.4 mg/L, 728.7 mg/L to 14.9 mg/L, 93.4 mg/L to 7.3 mg/L and 389 mg/L to 145 mg/L respectively with a mean value of 1.1 mg/L, 106.2 mg/L, 14.4 mg/L and 194.3 mg/L respectively. These exceeded the permissible limit of 1.5 mg/L, 150 mg/L, 45 mg/L and 200 mg/L respectively as recommended by BIS/WHO at few of the locations. Possibly, this is due to the discharge of industrial effluents into the surface water, making it unfit for human consumption.

To obtain a comprehensive summary of quality status of the water samples, water quality index has been determined. For this, 26 physico-chemical parameters were used to calculate the water quality index for the area collected during pre and post-monsoon seasons. The calculation of water quality index has been done by using the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) method. Evaluation of water quality parameters concluded that in the pre-monsoon season, 55% of the samples were under the good category, 26.67% under excellent, 13.33% under fair, 1.67% in marginal, and 3.33% in the poor category as per the classification. While during the post-monsoon season, 71.67% of water samples fell under the good category, 5% under the excellent category, 13.33% in the fair category, 3.33% in marginal, and 6.67% under the poor category for all the samples collected from the area under study. Few of the physicochemical parameters along with the Water Quality Index had also been depicted spatially in this thesis.

Apart from this, different statistical approaches for grouping water samples had also been utilized to prove its statistical optimization. For the statistical viability of the data, methods like Correlation Analysis, Box Plot, Hierarchical Cluster Analysis, and Piper Plot had been done for all water samples collected in both the seasons. During pre-monsoon, positive correlation was observed between TDS with EC (+0.997), K^+ with Hardness (+0.939) and Cd^{2+} with HCO_3^- (+0.864). While during post monsoon season, TDS with EC (+0.989), Na^+ with Hardness (+0.906) and Cd^{2+} with HCO_3^- (+0.875). The Box Plot analysis envisaged the quartiles distribution of various water quality parameters for estimating the water quality of the area. Hierarchical Cluster Analysis revealed that the water quality index was divided into 4 groups and 3 groups during pre and post monsoon seasons respectively. The hydro-geo-chemical facies analysis indicated Ca-Mg-Cl-SO_4 as the dominant type during pre and post-monsoon seasons.

The change in water quality was caused by many factors. The change in Land Use/ Land Cover pattern is important amongst them. The classification of the area was done by using

Landsat TM, ETM+, and OLI/TIRS images during 1988, 1996, 2005, 2016 and 2018 into six classes. This was apparent from the study that a decrease in the area of hills/forest (4.57%) and water body (3.06%). Further there is an increase in area covered by mining (2.54%), habitation (0.61%) and fallow/ barren land (5.29%) during a time span of 30 years was observed. Apart from it, Cropland exhibited a mixed trend showing an increase during 1996, decrease in 2005, again increasing up to 2016 followed by drastic decrease in 2018. This change in the area by the transformation of one land class into another was also manifested from the Change Detection map for the period of 1988-2018. Due to these changes in the land use/ land cover pattern, there was a possibility of addition of pollutants in the reservoir.

As a result of discharge and deposition of insoluble suspended solids and other fine particles into the reservoir, the water retaining capacity of the reservoir may be affected. To calculate this impact, the change in volume of the Govind Ballabh Pant reservoir during 1998-2018 was estimated using Triangulated Irregular Network model based on ASTERGDEM data. This study concluded that there had been an increasing trend in insoluble suspended solids in the reservoir thereby decreasing the volume of the reservoir from 1998 to 2018. It has been calculated that in 1998 the volume of reservoir was 30.72 km^3 and it is reduced to 25.12 km^3 in 2018. Possibly, this may be due to the increase in mining activities as exhibited by land use/ land cover maps of the area.

Apart from the assessment of water quality of the area affected due to mining and other activities in addition to change in Land Use/ Land Cover pattern, the management of water pollution caused due to coal mining activities had also been suggested in the study. This part of the thesis emphasized on the adoption of phytoremediation techniues in combination with a sandstone filtration system for the abatement of water pollution. For this study, an experimental setup was used to mitigate the water pollution discharged through Nalas. In the area, Balia Nala is a major stream carrying mine pollutants and entering directly into the reservoir. Therefore, Balia Nala was chosen as an example for the experiment at laboratory scale. The experimental setup includes aquatic wetland species such as *Eichhornia crassipes* and *Phragmites australis* for the removal of few contaminants.

It has been observed that within 15 days of treatment, there was a considerable decrease in a few of the contaminants such as TDS, TSS, magnesium, calcium, chromium and cadmium concentration. Hence, there was an overall improvement in the quality of water. This treated water can later be used for agricultural or industrial purposes while the remnant of these species can be used for composting, production of green fertilizers, and methane through anaerobic digestion. Therefore, the suggested method may be considered as an economical and sustainable solution for wastewater treatment of streams carrying mine pollutants and entering directly into the reservoir.