ABSTRACT

Water is vital to the existence of all forms of life as well as the livelihood of the human beings. Water trapped within ice caps, glaciers, and lakes releases fresh water for life to exist on Earth; thus, groundwater among them, presented as fresh water, is the source of supply for almost all regions. Water shortages due to population growth and industrialization are a recent global issue. A few of the most significant sources of freshwater are ponds, canal, rivers, and reservoirs and these water bodies satisfy needs for drinking, domestic, irrigation, industrial, and other purposes. This water is also ideal for a variety of other sectors, including coal mining and coal-fired power plants. These water bodies frequently experience depletion in their quality as a result of anthropogenic and natural activities which poses a serious threat to the water quality and the wellbeing of all living things, including people, in and around the study area. The study area must pay close attention to the issues of water quality deterioration and their mitigation because of coal mining operation and thermal power plants.

The present study has been carried out in Korba coalfield region situated in central India under South Eastern Coalfields Limited (SECL). Korba coalfield (KCF) has been divided into three active mega projects, including Gevra OCP (47 MTPA), Dipka OCP (33 MTPA), and Kushmunda OCP (24 MTPA). The thermal power plants which use coal in the Korba district includes Korba Super Thermal Power Plant, Dr. Shyam Prasad Mukharjee Thermal Power Station (Korba East), Hasdeo Thermal Power Station (Korba West), the captive power plant of BALCO (BCPP), and numerous others. These plants have an effect on surface water and groundwater resources by consistently causing an increase of pollution through the disposal of different materials in the nearby environment.

The primary objective of this study is to evaluate the possible impact of coal mining operations on local surface and groundwater quality, land use and land cover changes, and land surface temperature (LST), normalized difference vegetation index (NDVI), normalized difference water index (NDWI) along with their correlations in the area.

The present study of the potential impacts of coal mining operations on both groundwater and surface water is being carried out in the Korba coalfield region. A total of eighty-six (86) groundwater samples from multiple locations in the area during both the pre (March 2022) monsoon season and the post (November 2022) monsoon season were collected and examined for thirteen different important physicochemical parameters, including pH, EC, TDS, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Total Hardness, F^{-}, Cl^{-}, NO_3^{-}, SO_4^{2-}, and HNO_3^{-}. The obtained groundwater samples were examined to assess their hydrogeochemical facies and their suitability for drinking and irrigational purposes. The analytical results indicate that the groundwater is slightly acidic to alkaline in nature during both pre and post monsoon season.

The results of the physicochemical analysis showed that major cations were most abundant in the following order: $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$ in the pre-monsoon season and $Na^{+} > Ca^{2+} > Mg^{2+} > K^{+}$ in the post-monsoon season. The order of mean abundance of major anions are as follow: $HCO_3^{-} > Cl^{-} > SO_4^{2-} > NO_3^{-} > F^{-}$ in both seasons respectively. Based on correlation analysis, the significantly strong positive correlation were observed between pair of parameters such as EC and TDS ($r = 0.999$), EC and HCO_3^{-} ($r = 0.898$), TDS and HCO_3^{-} ($r = 0.866$), TH and Mg^{2+} ($r = 0.821$), TH and Na^{+} ($r = 0.968$), TH and Cl^{-} ($r = 0.861$), Na^{+} and Cl^{-} ($r = 0.872$) in pre monsoon season, while EC and TDS ($r = 0.997$), EC and HCO_3^{-} ($r = 0.908$), TDS and HCO_3^{-} ($r = 0.910$), TH and Mg^{2+} ($r = 0.885$) during post monsoon season.

The CCME WQI of groundwater samples ranged from 48.63 to 100 during the pre-monsoon season. According to the results of the CCME WQI analysis, 27 (62.79%) samples were categorised as excellent, 13 (30.23%) samples as good, 2 (4.65%) samples as fair, rest 1 (2.3%) samples as marginal and no sample was assigned to the poor class of CCME WQI during the pre-monsoon season. Whereas, CCME WQI ranged from 72.79 to 100 during the post-monsoon season and consequently 28 (65.12%) samples were excellent, 14 (32.56%) samples as good, rest 1 (2.33%) samples were fair and no samples were assigned to marginal to poor category.

The dendrogram shows that total 43 sampling sites based on WQI value were divided into three Clusters, with Cluster I having the most 27 (62.79%) sampling sites, Cluster II is of 15 (34.88%) sampling sites and Cluster III only one GW-10 (2.33%) in pre-monsoon season. Whereas, Cluster I having 28 (65.12%) sample sites, Cluster II consists of 14 (32.56%) sampling sites and only GW-16 (2.33%) was included in Cluster III in post-monsoon season. The piper trilinear diagram is a graphical representation of the major ions that can be used to quickly determine the hydrogeochemical facies of groundwater in the studied area. The diamond-shaped section from Piper diagram shows that 27.91% samples (pre-monsoon) and 16.28% samples (post-monsoon) of the samples fall into the CaMg-HCO3 group, showing the percolation and dissolution of minerals like calcite and dolomite, which are prominent in the geology of the area. Similarly, around 72.09% samples (pre-monsoon) and 74.42% samples (post-monsoon) of samples fall into the Ca-Mg-Cl-SO4 category, indicating the existence of anthropogenic activities such as ongoing mining operations and the presence of thermal power plants in the study region. Whereas, the remaining 9.30% samples (post-monsoon) fall under the NaCl-SO4 category, which shows the process of small minerals dissolving in the area.

As per the Gibbs diagram, the majority of the groundwater samples from both seasons fall within the rock water dominance and evaporation crystallisation field concerning for both cation and anion, indicating that the rock dominance and evaporation crystallisation is having an impact on groundwater quality in the area.

The majority of groundwater samples were determined to be suitable for irrigation based on the irrigation groundwater categories such as Sodium absorption ratio (SAR), Sodium percentage (%Na), Kelly’s index (KI), Permeability index (PI), and Magnesium hazard (MH) respectively. Based on SAR value the majority of groundwater samples (97.7% in pre monsoon and 90.7% in post monsoon) fall under excellent category while rest (2.3% in pre monsoon and 9.3% in post monsoon) comes under medium class of SAR which is suitable for irrigation. According to the Wilcox plot, (93.02% in pre monsoon and 88.37% in post monsoon) groundwater samples are excellent to good class and the rest (6.97% in pre monsoon and 11.63% in post monsoon) groundwater samples belong to good to permissible class, which can be used for irrigation.

The Kelly's index (KI) indicates that (approximately 93.02% in pre monsoon and 74.40% in post monsoon) groundwater samples fall into the suitable class and the rest (6.98% in pre monsoon and 25.60% in post monsoon) samples fall into the unsuitable class. Permeability index (PI) represents that (6.98% in pre monsoon and 6.98% in post monsoon) the samples belong to Class I, (81.4% in pre monsoon and 79.1% in post monsoon) samples belong to Class II, showing that all groundwater sampling locations were suitable for irrigation usage and the rest (11.6% in pre monsoon and 14% in post monsoon) samples belong to Class III is not suitable for irrigation. The Magnesium Hazard values indicates that (95.3% in pre monsoon and 74.4% in post monsoon) the samples belong to excellent category ($MH < 50$), rest (4.7% in pre monsoon and 25.6%

in post monsoon) samples belong to unsuitable class (MH > 50), which is not suitable for irrigation.

In order to evaluate the quality of the surface water, a total of 34 surface water samples from different locations were collected and examined for same physicochemical parameters as groundwater analysis. Based on pH measurements, surface water is slightly acidic to alkaline during both seasons.

The order of mean abundance of major cations are $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$ in both pre and post monsoon season whereas the order of mean abundance of major anions are as follow: $HCO_3^{-} > SO_4^{2-} > Cl^{-} > NO_3^{-} > F^{-}$ in both seasons respectively. The significant strong positive correlations were observed between different parameters such as EC and TDS (r = 0.998), EC and TH (r = 0.852), EC and HCO_3^{-} (r = 0.862), TDS and TH (r = 0.846), TH and Mg^{2+} (r = 0.828), Mg^{2+} and SO_4^{2-} (r = 0.801) in the pre monsoon season, while EC and TDS (r = 0.991), EC and SO_4^{2-} (0.873), TDS and SO_4^{2-} (r = 0.873), Na^{+} and Cl^{-} (r = 0.910), during post-monsoon season.

The CCME WQI of surface water samples ranged from 80.79 to 100 during pre-monsoon season while 86.87 to 100 during the post-monsoon season. As per CCME WQI analysis, 3 (17.65%) samples during pre-monsoon and 4 (23.53%) samples in post monsoon season were categorized as excellent. The remaining 14 (82.35% in pre monsoon) samples and 13 (76.47% in post monsoon) samples as good category.

SAR calculation indicates that all the surface water samples (100% in pre & post monsoon) fall into the low category which is suitable for irrigation purpose. Based on Wilcox plot, (94.12% in pre monsoon and 100% in post monsoon) surface water samples are excellent to good category. Rest 5.88% of samples in pre monsoon season was good to permitted, allowing them to be used for irrigation. According to Kelly's ratio classification, (approximately 94.10% in pre monsoon and 74.40% in post monsoon) surface water samples fall into the acceptable class, which is suitable for irrigation, and the rest (5.9% in pre monsoon and 25.60% in post monsoon) samples fall into the unsuitable class.

The assessment of groundwater in terms of heavy metals has been done by collecting seventy samples from different site in the Korba Coalfield region (bore well = 46, hand pump = 18, and dug well = 6) in the pre monsoon and post monsoon season of 2022. Ten heavy metals, including aluminium (Al), barium (Ba), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), lead (Pb), nickel (Ni), and zinc (Zn), have been analysed by using an ICP-MS equipment. A few elements, including Al, Fe, Mn, Ni, and Zn, exceeded their recommended required limits, while the other elements held within those standard limits as per the BIS and WHO.

HPI value of the groundwater samples ranged from 0.79 to 53.59 in pre monsoon and 0.79 to 31.72 in post monsoon season from which 30 (85.71% in pre monsoon and post monsoon season) samples were classified as low HPI and 5 (14.28% in pre monsoon) samples and 1 (2.86% in post monsoon) samples as high category of pollution. The remaining 4 samples (11.45% in post monsoon) was medium category of HPI.

HEI values ranged from 0.53 to 20.25 during the pre and from 0.41 to 5.87 during post monsoon season. Total 16 (45.71% in pre monsoon) samples and 25 (71.43% in post monsoon) samples fall into the low category, 14 (40.0% in pre monsoon) samples and 8 (22.85% in post monsoon) samples fall into the medium category, and the remaining 5 (14.29% in pre monsoon) samples and 2 (5.71% in post monsoon) samples fall into the high HEI category.

MI of groundwater samples varied from 0.26 to 15.52 in pre monsoon and 0.195 to 4.04 in post monsoon season. Overall, 31 (88.57% in pre monsoon) samples and 35 (100% in post monsoon) samples belong to very pure to slightly affected, making them safe to drink. The remaining samples (11.42% in pre monsoon) and (2.86% in post monsoon) classified as the moderately to seriously affected class are unsafe to consume.

Scatter plot has yielded better results in the identification of strong correlation between different indices such as HPI, HEI and MI. According to the scatter plot, HEI and MI have a strong correlation ($R^2 = 0.9348$) in pre monsoon and ($R^2 = 0.8128$) in post monsoon seasons. Additionally, PCA analysis revealed that the groundwater quality in the study area was governed by large loading with an absolute value ≥ 0.40, which included the water quality parameters under PC1, PC2, and PC3. It has a total variance of 37.71%, 14.98%, 12.69% in the pre monsoon as well as 25.71%, 18.18%, 13.26% during the post-monsoon. The three factors with eigenvalues (3.772, 1.498, 1.269 in pre monsoon season) and (2.569, 1.818 1.326 in post monsoon season) were extracted from principal factor matrix after varimax rotation.

The remote sensing & GIS application has been applied to analyse land use/land cover changes in the study area which affects majorly to both water quality and vegetation cover in the area. In this study, a total of six LULC classes (Forest, Habitation, Water bodies/river, Mining Area, Crop land/vegetation and Fallow land) were determined based on Landsat TM, ETM+ and OLI/TIRS images during 2001, 2011 and 2021 respectively. The findings revealed a pattern of significant changes in the land use/land cover classifications between 2001 and 2021. Forest area was declined from 16.033 Km^2 (7.08%) in 2001 to 14.848 Km^2 (6.55%) in 2021. Mining area increased from 12.737 Km^2 (5.62%) in 2001 to 30.348 Km2 (13.39%) in 2021. The habitation was found to be increased from 10.902 Km^2 (4.81%) in 2001 to 19.131 Km^2 (8.44%) in 2021 whereas water bodies/rivers has also declined from 11.570 Km^2 in 2001 and 8.580 Km^2 in 2021 respectively. The majority of the water body has been harmed by the expansion of mining blocks in the area. The crop land/vegetation area has declined from 89.220 Km^2 (39.37%) in 2001 to 68.874 Km^2 (30.39%) in 2021. The fallow land shows a mixed trend, first decreased from an area of 86.142 Km^2 (38.01%) in 2001 to 80.634 Km^2 (35.58%) in 2011, and then increased from an area of 80.634 Km^2 (35.58%) in 2011 to 84.823 Km^2 (37.43%) in 2021 respectively. The accuracy of the prepared LULC map for the years 2001, 2011, and 2021 have also been performed which reveals that overall accuracy values of 90.5%, 92.1%, and 94.5% as well as the Kappa coefficient accuracy values of 88.2%, 90.5%, and 93.3%. It indicates that the LULC analysis was very precise. This change in the area caused by the transformation of one land class into another was also noticeable on the change detection map for the period 2001-2021.

To investigate the trends of the spatiotemporal relationship of LST with NDVI and NDWI using five different cloud-free Landsat TM, ETM+ and OLI/TIRS data sets for 2001, 2006, 2011, 2016 and 2021 have been used. An exponential increase in surface temperature over the past 20 years is evidence of dynamic coal mining operations in the Korba region. The temperature increase within the area was found to be 9.87℃ between 2001 and 2021 via LST monitoring. The continuous rise in surface temperature causes decline in water bodies (-034) as well as vegetation cover (-0.06) throughout the study region. The linear regression results revealed that a low to very low negative correlation between LST with NDVI and NDWI which indicates that LST is inversely correlated with both NDVI and NDWI for this region.