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An Evaluation Over The Methodological Efficiency In Groundwater Contamination Studies: A Case Study From Wardha Valley Coalfields.

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Abstract
The coalfields are very usual with the groundwater contaminations and a proficient methodology is always sought by the researchers. The present article deals with the evaluation of methodology adopted in the heavy metals contamination studies in the Wardha valley coalfields, Maharashtra. On evaluating the methodology with the respective outcomes and other related works, it is suggestive to inflate the heavy metal contamination analysis by including the hydro-geochemical approach, which ultimately contributes an understanding of accountability for the contamination. The hydro-geochemical parameters not only disclose the groundwater chemistry but also illustrate the geological influence. The statistical approach like of Principal Component Analysis (PCA) augmented with an interpolation technique executed by the ArcGIS is evident to be a competent tool to approximate the source of contamination spatially. The interpolation of factor loadings generated from the PCA on the study area maps aids in sorting spatial contamination hotspots. The petrography and mineral chemistry study of the rock taken from spatially located contamination points validates the source. The cumulative effect of all such versatile methods could be apparently reflected in the designing of the mitigation policy. The study evidently supports the adopted methodology for the fruitful groundwater contamination studies but also suggests the flexibility.

Keywords – Groundwater contamination, Wardha valley coalfields, Geographical Information System, Principal Component Analysis.

1. Introduction

The Wardha valley coalfields are the active and one of the most coal producing belts in the central India. Since the inception of the coal exploration after its report in 1831 near the Kumbhari village; the Wardha valley coalfields has gain a certain significance in impending years (Raja Rao 1982). The unceasing mining activity in the Wardha valley coalfields has not only altered its geomorphology but has also shaped a realm of contaminations in all domains and the groundwater contamination is one of them. The groundwater contamination is much common and intensely studied aspect in and around coalfields, where heavy metals and other hydro-geochemical parameters are commonly acts as contaminants. The disturbed of hydrology, pollution of water bodies and descending of groundwater level are the major quantifiable effects of mining activity on the water realm (Pulles *et al.,* 1995; Younger *et al.,* 2002). The contaminated groundwater's quality cannot be reinstated by ceasing the pollutants; hence its regular monitoring to device ways and means to protect it is must (Mufid al-hadithi, 2012). The present article deals with the evaluation of methodology adopted for the groundwater contamination studies done in the Wardha valley coalfields. This article will reveal the probable pros and cons of the approach adopted.

2. Methodology

To evaluate the methodology in the groundwater contamination study in the Wardha valley coalfield, it has been coordinated with the respective objectives attainments. The convergence of results and interpretations into a fruitful outcome has also been conducted and the respective outcomes were verified with the similar works to validate the methodology. The approach has also been corresponded with a bunch of articles that deals with the similar kind of problem. The evaluation of the adopted approach has been finally done to derive the gist from all above correlations.

3. Depiction of adopted approach

A vigorous literature review has been done from all the probable relevant articles to sort the line of approach for the groundwater contamination study in the Wardha valley coalfield. Accordingly the line of action was proposed to achieve the pre-determined objectives viz., heavy metal contamination extent in groundwater, its source approximation and probable remediation.

3.1 Literature Survey: A detailed literature survey has been done to develop a comprehensive vision for the groundwater contamination studies. A special preference has been given to the studies done on the various Indian coalfields like those of; Raja Rao (1982), Singh *et al.,* (1983), Singh (1987; 1990; 1994), Choubey and Sankaranarayana (1990), Choubey (1991), Pathak and Banerjee (1992), Soman and Kale (1992), Tiwary and Dhar (1994), Gupta (1999) and Prasad and Jaiprakas (1999) as pioneering workers; whereas, Tiwary (2001), Khan *et al.,* (2005), Tiwary and Sinha (2006), Warhate *et al.,* (2007), Satapathy *et al.,* (2009), Singh *et al.,* (2010), Tripathy (2010), Murkute and Badhan (2011), Singh *et al.,* (2011), Kale and Soman (2012), Khan *et al.,* (2013), Chandra and Jain (2013), Singh *et al.,* (2013), Adhikari *et al.,* (2013), Murkute (2014), Tiwari *et al.,* (2014), Singh *et al.,* (2015), Saini and others (2016), Mahato *et al.,* (2016), Kumar and Singh (2016), Neogi *et al.,* (2017), Singh *et al.,* (2017), Mahato *et al.,* (2017), Tiwari *et al.,* (2017), Neogi *et al.,* (2018) and Shylla *et al.,* (2020) as the exceptional workers. On vigorous review of above cited articles, the objective and methodology to attain them was sorted out.

3.2 Field and GIS Procedures: The detailed observation was done by multiple field visits. These observations not only help to delineate the study area but also gave a deep understanding of it. The toposheet no. 55L/16, 55 P/4, 55 P/8, 56 I/13, 56 M/1 and 56 M/5 were used to trace and review the study area (Figure 1). With the help of field observation and outputs from ArcGIS software, the sampling locations of groundwater were selected to generate a uniform representation of the study area.

3.2.1 Groundwater sampling: To represent the groundwater situation of the study area 45 groundwater sample locations were selected by area sampling (sub-type of cluster sampling) with specially consideration to the mining sites, urban settlements and agricultural lands. To achieve the maximum precision in terms of the sampling hygiene and sampling techniques, the procedures suggested by the American Public Health Association (APHA) were adopted. The non-stagnant samples were collected in pre-washed narrow mouth polyethylene bottles, which were thoroughly rinsed by sample water before final sealing (Plate 1) for pre- and post-monsoon seasons of 2019 and 2020. As the objective includes heavy metals/trace metals, being very fragile to changed chemical environment, they were made stable by acidification to as low as pH of 2 by Conc. HNO_3 (Plate 1). The immediate preservation in the cold storage (4^0C) was done after systematic labelling.

3.2.2 Rock sampling: To develop a sound representation of the groundwater chemistry of any area, the study of the respective aquifers is requisite. The stratigraphic sequence depicted in the work of Raja Rao (1982) and the base map of the GSI was kept in consideration before picking the rock sampling locations. The intention behind rock sampling is the petrography and mineral chemistry and hence, the samples were taken so. The samples of fresh and non-weathered outcrop with an approximate size of 12 cm X 12 cm were taken by grab sampling method from pre-selected locations (Plate 2). The rock samples were then labelled in accordance with the locations. The initial results of the groundwater analysis also narrowed the rock sampling locations to certain contaminated zones.

3.3 Analytical Procedure: The analytical part has been done in two steps viz., groundwater and rock sample analysis. The rock sampling analysis is somewhat motivated from the opening groundwater results too.

3.3.1 Groundwater analysis: The analytical part of groundwater was executed into two parts viz., spot and laboratory. The collected samples were then immediately subjected to the spot analysis which includes pH, EC and TDS measurement by digital meters. The laboratory analytical part includes the determination of major cations, anions and trace metals with respective methods (Table 1).

3.3.2 Rock sample analysis: On classification of the collected rock samples by megascopic approach, they were sorted for the petrographic study. The samples near to groundwater contamination zones were prioritized and dressed accordingly. The standard procedure for thin section preparation was followed. On thin sectional studies, some samples were selected for mineral chemistry and hence, polished and prepared accordingly as per Electron Probe Micro-analyser (EPMA) requirements (Plate 3).

3.4 Statistical and GIS Analysis: To deduce multifaceted outputs from the data, the statistical analysis was performed. The software named XLSTAT was used to perform various statistical analyses including the Principal Component Analysis (PCA). To enhance the representation of the outcomes, the ArcGIS software was used for the preparation of ordinary kriging interpolation maps and respective prediction standard error maps.

4. Discussion

The above methodology adopted in the groundwater contamination study of the Wardha valley coalfield had direct implication over the quality and rationality of outcomes. Let us observe some of them;

4.1 Precision in results: The caution in sample selections may it be location wise or the collection wise, the utmost accuracy was achieved. The standard procedure followed in the study imbibes a confidence in the consequential analysis. The results so derived can be put in a high confidence frame irrespective to the agreement or disagreement with the hypothesis. Hence, the standard procedures like suggested by APHA must be adopted with due consideration.

4.2 Inclusive groundwater sympathetic: Though the present groundwater contamination study was focused over the heavy metal contaminations, the evaluation of hydro-geochemical parameters generates a comprehensive depiction of the groundwater chemistry. Such depiction has not only revealed the groundwater facies but has also aided in understanding the process responsible for the heavy metal contamination (Ganvir and Guhey, 2022). The facies analysis done on behalf of hydro-geochemical results, disclosed the dominance of the strong acids (SO_4^{2-}-Cl^-- NO_3^-) over weak acids (HCO_3^-), which implies towards the role of acidic environment in the groundwater. As the study area is a coalfield, the existence of acid mine drainage cannot be denied (Ganvir and Guhey, 2020). In such manner the cationic-anionic determination aids in source approximation.

4.3 Effectual data manifestation: The PCA is an efficient method to determine the contamination sources (Facchinelli *et al.,* 2001). The trace metal data generated in the present study was subjected to the PCA and as a result, a comprehensive correlation has been obtained for the assessed trace metals. These correlations disclosed the various close associations among the trace metals, which implies towards the common source. In the present study the metals Cd, Fe, Ni and Pb were found to be closely associated (Ganvir and Guhey, 2020). Apart from them, multiple weak-moderate associations were also derived among trace metals which help in understanding the co-existence. The factor loadings derived from the PCA has been used in ArcGIS software for further source approximation.

4.4 Spatial source approximation: The ordinary kriging interpolation is not only meant for the unsampled regions, but also is useful for the probabilistic simulations of vagueness about the anonymous by estimated predicted values (Deutsch and Journel, 1998). The trace metal data generated from the groundwater analysis has been subjected to the ordinary kriging interpolation done by ArcGIS. This has developed a map for each and every assessed metal representing the spatial dispersal of it on the study area map. The map clearly manifests contamination zones which directly sorts the contamination source. The factor loadings for observation derived from the PCA were also subjected to the interpolation and has shown agreement with the contamination sources manifested in individual contaminated metal maps.

4.5 Geological source approximation: Once the source approximation was done, the sampled rocks from the source region was analysed with due precision. As a consequence, the white and grey sandstone belonging to the Barakar formation disclosed the presence of Pyrite (FeS_2) in thin section and was confirmed in the EPMA study (Ganvir and Guhey 2021). Similarly, the other sampled rock like carbonaceous shale has also indicated the presence of considerable sulphur content in mineral chemistry analysis. This sulphur presence ultimately supports the role of acid mine drainage, which was also manifested in hydro-geochemical facies analysis. On a similar line of action, the presence of high iron content in the Kamthi sandstone was confirmed. In contrast to this, the EPMA is very useful in mantle petrography and sometimes may not be much fruitful in case of sedimentary rocks.

5. Conclusion

The evaluation of the methodology adopted during the contamination study in the Wardha valley coalfield clearly indicates the efficiency of it. The augmentation of heavy metal contamination study by the hydro-geochemistry assists in understanding the process accountable for the contamination. The statistical tools resolve the chaos in the data to an evident representation. The PCA amplified with GIS tools has proved to be one of the most efficient tools to approximate the source of contamination spatially. The petrography and mineral chemistry study (especially from contamination zones) adds robust evidence to the source approximation. Hence, to perform a fruitful groundwater contamination studies, the above methodology is suggestive, but may vary as per situatedness.

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TABLES

Table 1: Methodology adopted for groundwater analysis.

Parameter	Method	Instrument	Remark
Ca^{2+}	Titrimetric	-	EDTA with P & R indicator
Total Hardness	Titrimetric	-	EDTA with Eriochrome Black-T indicator
Mg^{2+}	Calculation	-	Subtracted Ca^{2+} from TH
Na^+	Photometric	flame photometer	589 nm
K^+	Photometric	flame photometer	766 nm
HCO_3^-	Acid Titrimetric	-	Methyl red and bromocresol green
SO_4^{2-}	Spectrophotometric	UV-Vis spectrophotometer	By barium chloride-gelatin reagent/420 nm

NO_3^-	Spectrophotometric	UV-Vis spectrophotometer	220 nm
Cl^-	Titrimetric	-	Potassium chromate indicator
Trace metals (Al, Cd, Cr, Cu, Fe, Ni, Pb and Zn)	Spectrophotometric	Atomic Absorption Spectrophotometer	Respective Std. wavelengths

FIGURES

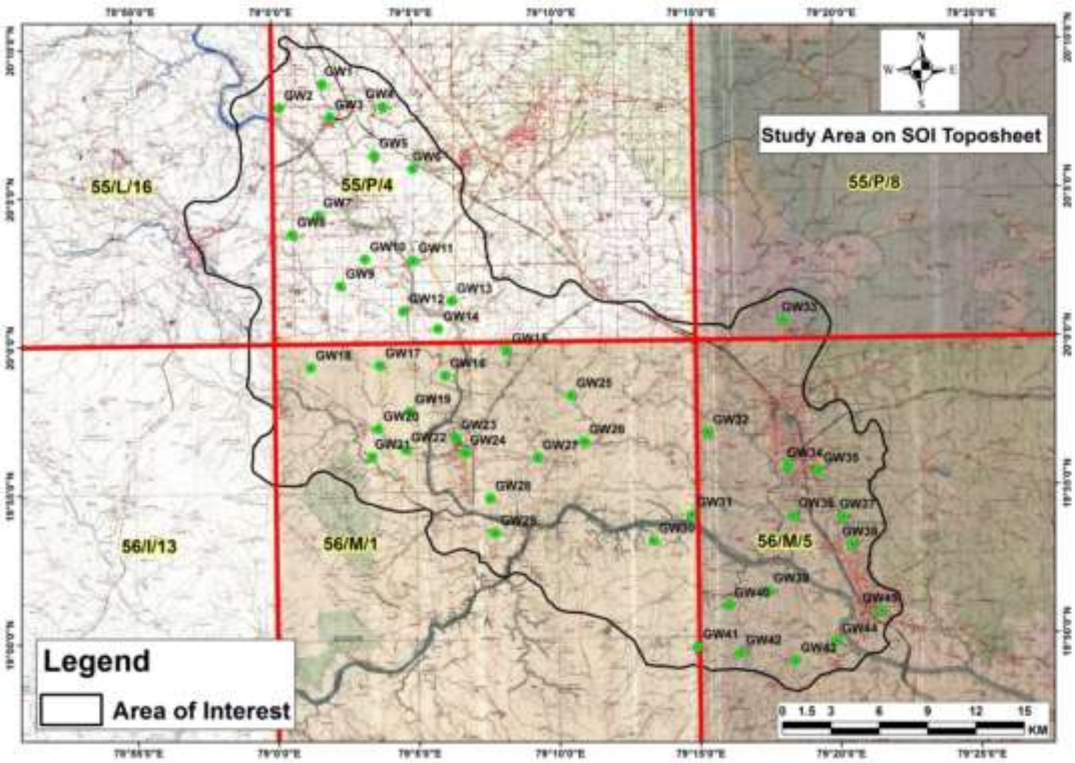

Figure 1: Map with toposheets coverage and groundwater sampling locations in the study area.

PLATES

Plate 1: Photograph indicating groundwater sampling procedures.

Plate 2: Photograph indicating rock sampling locations.

Plate 3: Photograph indicating petrographic and EPMA analysis.