Mine Water: Isotopic Evidence of Origin of Seepage and Hydrodynamic Behaviour

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ABSTRACT

For designing new mines or further development of existing mines, it is vital to know the source and origin of mine water and the hydrodynamic behaviour of groundwater. Environmental isotopes, both radioactive and stable, are very powerful tracer tools in tackling problems associated with mine water. Ever since these techniques were developed, their hydrological applications have been amply demonstrated, whereas their mine water applications are scarce.

This paper demonstrates the usefulness of isotope techniques in elucidating the origin of mine seepage in underground coal mines, in the Jharia coal field, the source of which could have been river, abandoned mines or groundwater. Tritium, carbon-14 and oxygen-18 measurements were carried out on mine, surface pond and groundwaters during 1984 and 1986. Seepage waters of 1984 collection were devoid of tritium, whereas in 1986, 300 and 400 m horizons showed relatively higher tritium close to that of abandoned mines, thereby facilitating identification of seepage to be that of an admixture of groundwater and water from abandoned mines. Non-contribution from river was inferred from high carbon -14 ages, low tritium values and relatively positive oxygen-18 contents.

In another study, environmental tritium and carbon-14 measurements provided information about the main catchment area feeding the confined aquifers, which have been undergoing depressurisation for mining of lignite. Further, study of spatio-temporal variation of groundwater characteristics assumes greater significance because of the proximity of the aquifer to the coast. Effect of large scale withdrawal of groundwater from a lignite mine area on the regional groundwater flow regime is studied in light of periodical carbon-14 and hydrochemical data. A significant increase in apparent radiocarbon ages of groundwater is observed and this change is fairly correlated with decreasing piezometric levels. Increased values of chloride and groundwater ages are suggestive of a rapidly changing hydrologic regime, which is influenced by mine pumpage and rapidly growing industrialisation.

In conclusion, the isotope techniques facilitate in proper management of water associated with mining activity.

INTRODUCTION

Mineral deposits are generally associated with groundwater. Presence of excessive (beyond certain limits) amounts of waters in mines is a natural hazard, both from safety as well as economy aspects. Further, any mining activity is expected to alter the status of a groundwater regime. As a result of mining, at times, surfacewater/groundwater influx may lead to mine flooding, mine collapse etc. Therefore, for development of new mines or further development of mining activity, it is vital not only to know source and origin of mine water, but also to ascertain whether the source is stagnant or dynamic; and further in case of depressurisation of the aquifer, underlying the mine, how the hydrological regime is likely to behave with time. For all such and many more questions, environmental isotope techniques provide valuable information. Isotope techniques have been very extensively employed for groundwater studies but their applications to mine hydrology are limited. The reason for this could be the sampling problems associated with great depths, especially where a large volume of water sample has to be treated, and further non- familiarisation of available isotope techniques to mining personnel. Environmental radioisotopes, such as tritium (half life 12.43 yrs) and radiocarbon (half life 5730 yrs) with widely different half lives provide a dimension of time (age of water and flow rate) for groundwater movement and hydrological processes. Further presence of thermonuclear tritium/radiocarbon provides a unique evidence of very young waters.

Stable isotope concentration, as that of oxygen-18 and/or deuterium, in water is a function of environmental factors, such as altitude, latitude, climatic conditions, evaporative process etc. Thus their measurements greatly aid in establishing the linkage between different types of water. For example, from deuterium and tritium measurements on samples of the Lubin Coal Basin, Poland (Rozkowski and Prezewlocki, 1974), it was concluded that precipitation was infiltrating at a higher rate in the mines. In the South African iron mines, Verhagen et al., (1979) have provided the information that the Kalahari beds provided limited contribution, whereas dolomite outcrops constitute the main recharge area. In an another study, Zuber et al., (1979) determined leakages originating from the surrounding formations in the Wapno salt mines.

In this paper we demonstrate the usefulness of isotope techniques in elucidating the origin of seepage in Sudamdih mine at Jharia Coal Field, Bihar, India; and in another study the isotope measurements provided information about the main catchment area feeding the confined aquifers, which were undergoing depressurisation for mining of lignite, wherein study of spatio-temporal variations of groundwater characteristics assume greater significance in view of the proximity of aquifer to the coast. Effect of large scale withdrawal of groundwater from a lignite mine area on the regional groundwater flow regime is studied in light of C-14 and hydrochemical data. Temporally increased values of chloride and groundwater ages are indicating rapidly changing hydrologic regime due to mine pumpage and industrialisation.

ISOTOPIC EVIDENCE OF SOURCE OF MINE SEEPAGE

Mine location, geology and environmental conditions

The study was carried out in the Sudamdih mine area, situated in the south-eastern part of the Jharia Coal field, about 25 km from Dhanbad town in Bihar State of India (Fig. 1).

The Jharia Coal field has an elliptical shape with an area of 450 sq.km, and contains 18 coal seams. Sudamdih is one of the most difficult mines in the coal field. The area is bordered by the great Patherdih horst in the north and lies close to a great fault running south of Damodar River. The mining area extends about 1 km from the northern bank of the Damodar River. The mining area is pitted with many old workings which were water logged at the time of investigation. Among many mineable coal seams in several horizons there is a persistent problem of water percolation. At certain places the percolation is noted to be seasonal. The investigation was carried out with the objective of determining the source of heavy percolation from among different possibilities such as the Damodar River, groundwater, water logged mines, surface pond etc.

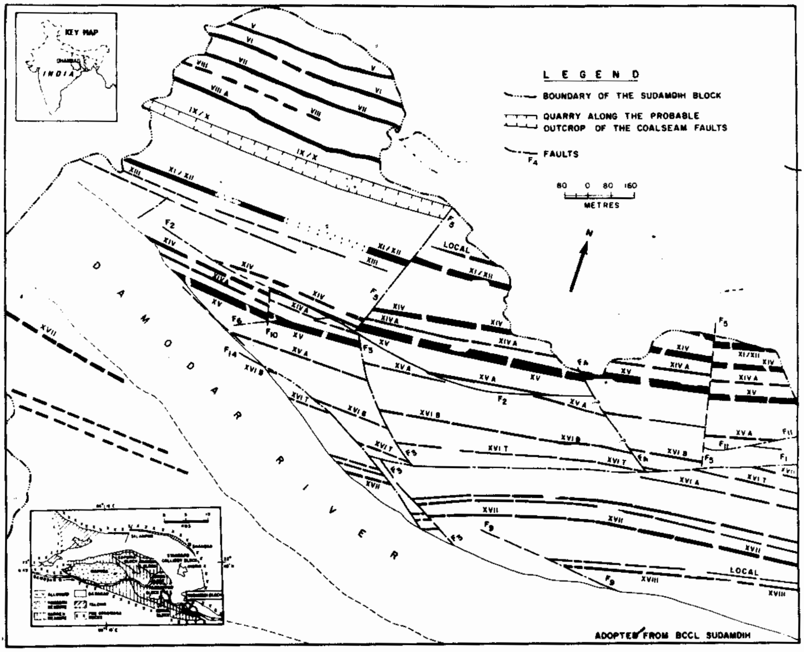

Fig. 1. Plan showing probable outcrops of coal seams and faults at Sudamdih area, Jharia Coalfield.

The Jharia coal field consists of two predominant rock types; the basement Archaean gneisses and Permo-carboniferous and lower Mesozoic sediments, comprising the Gondwana system. There is a great stratigraphic unconformity between them. The study area is underlain by the Damodar series and Barakar stage. The post Gondwana earth movements are manifested in the field by the presence of large number of vertical, sub-vertical and cross faults.

The study includes coal seams V - XVIII, and at the time of investigation the coal was being extracted from VIII A, IX/X and XI/XII coal seams from horizons at 200, 300 and 400 m depth.

Groundwater in this area occurs under unconfined conditions in weathered, jointed and fracture zones. The depth to water table varies between 1.3 and 20 m. The streams which are perennial are effluent.

The problem in the Sudamdih active mine area was heavy percolation of water in the VIII A and XI / XII seams. The rate of percolation in VII A - 300 m horizon was noted to be 2.5 cu.m/min, whereas in 400 m horizon the seepage was 5.5 cu.m/min. The objective of this investigation was to determine the source of seepage out of various possibilities.

Methodology

The methodology is based on the fact that the surface water e.g. river and pond waters are characterised by different isotopic composition than that of groundwater and water in the abandoned mines. In the case of river water, the stable isotopic composition is more negative than that in surface pond water where evaporation is the predominant process. Deep groundwater contribution, being devoid of tritium and higher C-14 ages, can easily be differentiated. Contrarily abandoned mine contribution can be identified on the basis of the higher tritium content of recent water stored in the mines.

The methodology of identifying the source of seepage necessitated collection of water samples from the seepage at different horizons as well as those from the possible sources and then linking them isotopically. Isotope measurements consisted of tritium, C-14 and oxygen-18 contents of natural waters. Tritium and C-14 were measured in low background gas proportional counters using methane as counting gas, synthesised and purified from water samples (15 ml) and dead carbon-di-oxide (in case of tritium); and in case of C-14 it is synthesised from tritium free hydrogen, and sample carbon- dioxide evolved by acidifying bi-carbonates/carbonates precipitated from about 60-100 litres of water samples (Sukhija et al., 1990) by barium hydroxide and barium chloride in the field itself.

Results and discussions

From Sudamdih mine mainly two sets of samples were collected during 1984 and 1986 and the results are shown in Fig. 2. For the 1984 collection (Table 1), samples no., 2 and 4 from old mines, pond sample (no. 5) and river water sample (no. 6) had bomb tritium (15-50 TU); whereas the mine seepage water samples (nos, 9 to 20) from the active mines of VIII A, IX/X and XI/XII at different horizons, did not have bomb tritium, thus indicating absence of fast connection with surface sources. The oxygen-18 concentration (expressed as % deviation from standard mean ocean water) in the abandoned mines water samples cluster around -7.5 to -7.8% originating from the mixture of rain waters having varying concentration of oxygen-18. The active mines have relatively more positive O-18 content indicating mixtures of groundwater and abandoned mine contribution, the major proportion arising out of groundwater.

However, for 1986 collection tritium values were found to vary considerably from those of 1984, particularly values from the seams of VIII-A, 400 m and 300 m horizons east lateral (30 - 50 T.U), which were found close to the 1984 levels of XV horizon. In the west, higher radiocarbon ages (23,430 yrs), low tritium and relatively positive O-18 (sample no.12, 17, 18) indicate predominance of groundwater and no contribution from river or abandoned mines, whereas eastern samples indicate admixture of groundwater and water from abandoned mines, whereby reduction in C-14 ages and presence of tritium is noticed.

Thus the environmental isotope measurements aided in understanding the mechanism of the source of seepage.

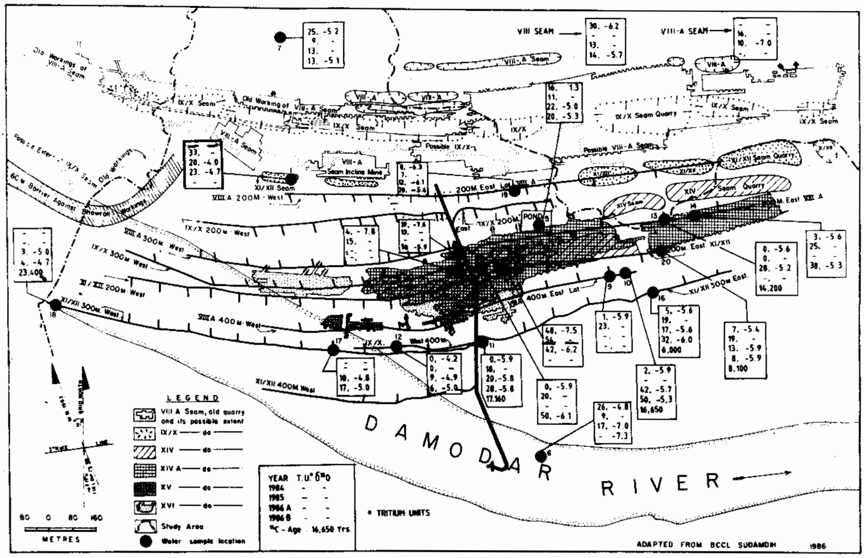

Fig. 2. Sample location map for environmental isotope study in Sudamdih Shaft mine area.

TABLE 1. Tritium, oxygen-18 and carbon-14 data for different collections of water samples

S.no	Location	1984		1986*			1986**	
		^3H	^{18}O	^3H	^{14}C	^{18}O	^3H	^{18}O
1.	XI/XII old seam	-	-	20±3	-	-4.0	23±3	-4.7
2.	XIV old seam	19±3	-7.6	-	-	-	50±3	-5.9
3.	XIV-A old seam	4±3	-7.8	-	-	-	-	-
4.	XV old seam	48±3	-7.5	-	-	-	42±3	-6.2
5.	Pond water	16±3	+1.3	22±3	-	-5.0	20±3	-5.3
6.	Damodar river water	26±3	-4.8	17±3	-	-7.0	-	-7.3
7.	A shallow well	25±3	-5.2	13±3	-	-	13±3	-5.1
8.	A deep well	-	-	9±3	-	-5.3	-	-
9.	400 m VIII-A E 5th rise	1±3	-5.9	-	-	-	-	-
10.	400 m VIII-A E	2±3	-5.9	42±4	16650± 500	-5.7	50±3	-5.3
11.	400 m IX/X E	0±3	-5.9	20±3	17160± 600	-5.8	28±3	-5.8
12.	400 m IX/X W	0±3	-4.2	9±3	-	-4.9	6±3	-5.0
13.	300 m VIII-A E 8th rise	0±3	-5.6	28±3	14200± 500	-5.2	-	-
14.	300 m VIII-A E lateral	3±3	-5.6	-	-	-	38±3	-5.3
15.	300 m IX/X E stopping	0±3	-5.9	-	-	-	50±3	-6.1
16.	300 m XI/XII E 5th rise	5±3	-5.6	17±3	5900± 300	-5.6	32±3	-6.0
17.	300 m XI/XII W 4th rise	-	-	10±3	-	-4.8	17±4	-5.0
18.	300 m XI/XII W phase	-	-	13±3	23430±1380	-5.0	4±3	-4.7
19.	200 m VIII-A E 2 nd dip	0±3	-6.3	12±3	-	-6.1	20±3	-5.4
20.	200 m XI/XII E lateral	7±3	-5.4	13±3	8100± 300	-5.9	8±3	-5.9

* January collection ** August collection

HYDRODYNAMIC BEHAVIOUR OF GROUNDWATER REGIME IN NEYVELI LIGNITE MINE.

Lignite deposits of about 3300 million tons, in an area of 480 sq.km, are found to be present around Neyveli situated about 200 km away from Madras, towards southern coast. These deposits sit on top of a powerful artesian aquifer comprising of Cuddalore sandstone. As the water pressure head stood about 50 m above the lignite bed at the time of initial mining, therefore lignite excavation invariably necessitated depressurisation of the underlying aquifer by means of 25-30 pumps with draft of about 8000 Cu.m/hr, thus leading, in due course of time, many artesian wells either stopped flowing or reduced flow. Therefore the problem of the source area of recharge to the confined aquifer and changing hydrologic regime attracted paramount attention, and Neyveli Lignite Corportion sponsored a project for isotope studies and groundwater modeling (Sukhija et al., 1987 and '93; Gupta et al., 1986 and '92; Rangarajan et al., 1987 and '89).

Here we present the results of isotope measurements consisting of tritium and C-14; chloride and piezometric levels of groundwater regime in the study area to understand the changing hydrologic regime.

Geology of the study area

The geology of the study area is shown in Fig. 3 (Subramanyam, 1969). Towards the west, the bluish grey granite gneiss outcrop, followed by the Cretaceous and Tertiary sediments towards the east. Fairly wide spread and thick Cuddalore sediments of upper Miocene consists mainly of sandstones, sands and also extensive clay beds with thick lignite deposits, occupy the middle of the study area, striking NE-SW and dipping SE. A large part of the study area is covered by 50 m thick recent alluvium. The important formation from groundwater point, is the Cuddalore sandstone, in which groundwater occurs under phreatic, semi-confined and confined conditions. The two aquifers in the confined condition below the lignite are physically separated by an extensive clay, but, perhaps, hydraulically they are a single unit (Subramanyam, 1969) as the piezometric surface of the lower and upper aquifers stood at the same level initially.

Selection of sites for isotope measurements

More than 100 deep wells (>50m) were selected for piezometric level data, and water samples for environmental tritium, C-14, oxygen-18 (a few wells) and chloride measurements. A few measurements were carried out in 1966-68, '77 and '81 but during 1985 - 1991 about sixty samples were repeated.

Results and discussions

Catchment area for Neyveli Aquifer

In order to prepare a realistic groundwater budget and model, in case of confined aquifer, it is most important to know not only the recharge rate but also the catchment area for the confined aquifers. Our methodology is based on environmental isotope tracers viz., tritium and C-14, which we have measured in a large number of samples for a considerable time. No measurable tritium was detectable till 1977 in most of the wells. There after, during 1977 to 1987, a number of samples showed the presence of bomb tritium. Later on extensive C-14 measurements resulted in the delineation of catchment area for the confined aquifers, wherein radiocarbon levels were those of "Modern" age (Fig. 4).

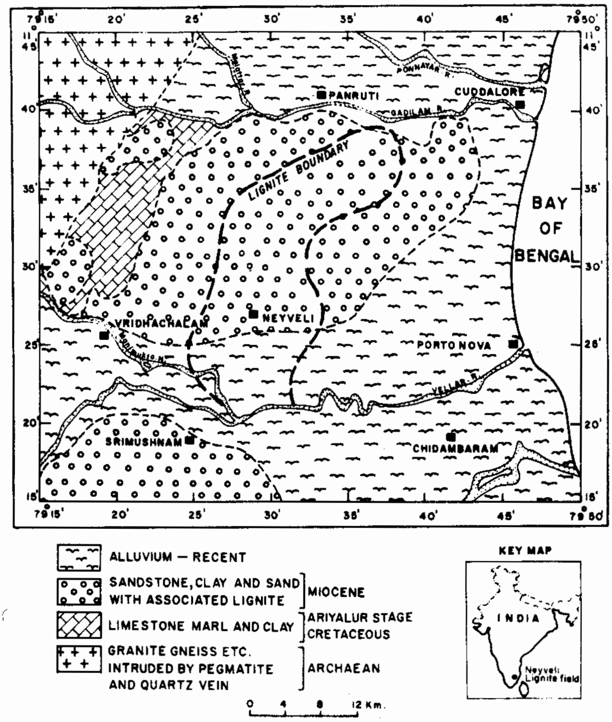

Fig. 3. Geological Map of Neyveli Area

Another characteristic, which we utilised, was to ensure the groundwater movement from unconfined to confined aquifers by way of increasing age. The area thus delineated, measured more than 600 sq.km, and can provide at least 110 MCM/yr by way of direct recharge from precipitation.

We have observed during 1977 and 1987, presence of tritium in some of the deep wells of confined aquifers, located in the mine area but close to the recharge area. The presence of tritium pulse close to the recharge area reflects the enhanced groundwater flow rate close to the recharge area, as a consequence of mine pumpage. Since such a phenomenon is observable mostly in wells close to recharge area, this suggests the dominance of lateral flow over vertical flow. In the case of vertical flow dominance, one should see the tritium pulse all over in a confined aquifer of the mining area.

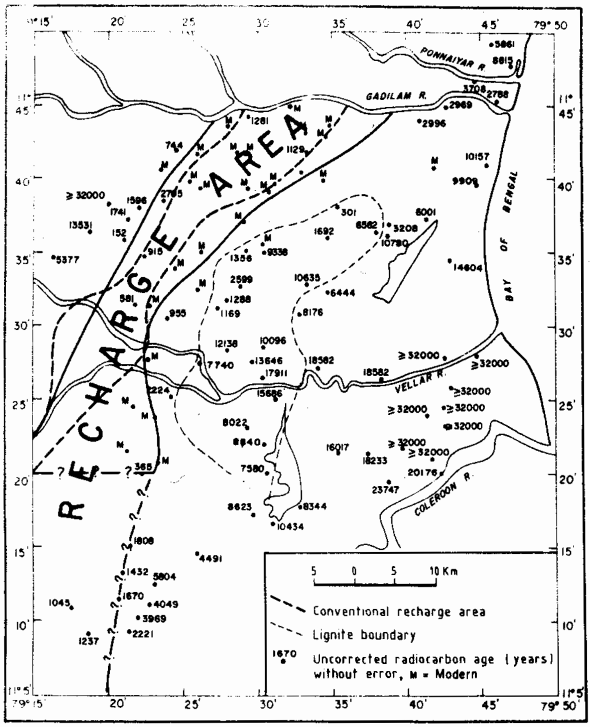

Fig. 4. Delineation of principal recharge area for Neyveli Groundwater aquifer based on Isotopic data (^{14}C ages).

Groundwater age variation with time

The ages of deep groundwaters have been estimated by taking 100 percent modern carbon as the initial C-14 activity in the recharge zone. This is justified in view of the fact that 75 to 80% samples have shown C-14 concentration to be 100 pMC or more in the recharge area (no corrections were applied). Here we compare the groundwater age data as measured in 1985 and in 1991. The hydroisochrones of 1985 and 1991 are shown in Figs. 5 and 6 respectively. As can be seen from the Fig. 5, the contours are evenly spaced with increasing ages towards SSE direction, i.e., in the direction of groundwater flow. When we compare both the hydroisochrones (Figs. 5 and 6), for 1991 samples we find that contours of the same ages are pushed westward and the contours are quite crowded in the recharge and mine area. This is because of ever increasing cone of depression, which facilitates movement of very young waters closer to the older water as a result of depressurisation. Apart from the disposition of contours, the symmetry of placement of C-14 ages as observed during 1985, is apparenly lost during 1991. These isochrones and their temporal changes are manifestation of the magnitude of groundwater withdrawal, which in turn exhibit the changing hydrodynamic character of the pumped aquifer.

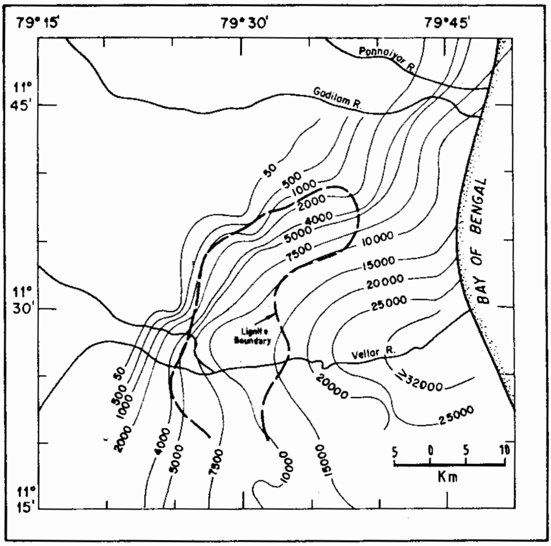

Fig. 5 Isochrones based on uncorrected radiocarbon ages of deep groundwater samples (1985 collection).

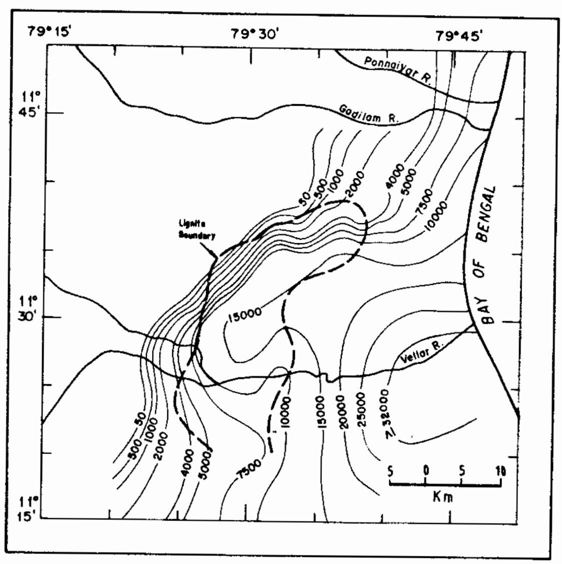

Fig. 6 Isochrones based on uncorrected radiocarbon ages of the deep groundwater samples (1991 collection)

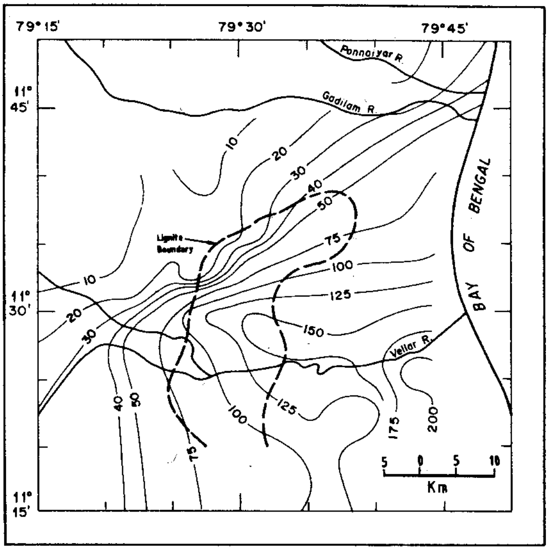

Fig. 7 Isochlors based on chloride conc. (ppm) of deep groundwater (1985 collections)

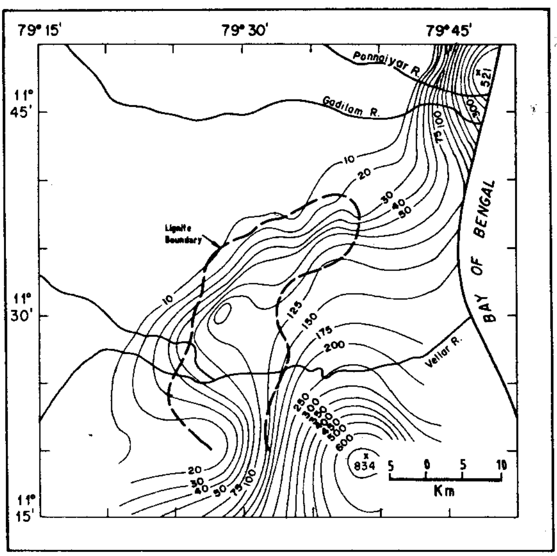

Fig. 8 Isochlors based on chloride conc. (ppm) of deep groundwater (1991 collection)

We also attempted to correlate the apparent changes in groundwater ages during 1985-1991, and the change in piezometric levels. Maximum changes in apparent groundwater ages were 6000 - 8000 yrs, as observed in the mining area and in northeast (where industrialisation is more), and maximum changes in piezometric levels were also localised more or less in the same area.

Chloride - temporal variation

As the aquifer is located close to coast, and there are large stresses on it, it is natural to look for a change in chloride concentration with time. In general, we find there is very good correspondence between the chloride and radiocarbon data. Isochlors drawn for 1985 and 1991 data are shown in Figs. 7 and 8 respectively. During 1985, there is a similarity between chloride contours (Fig.7) and radiocarbon contours (Fig. 5). We observe that chloride concentration is low (15-20 ppm) in the recharge area, slowly increasing in the flow direction and high in the discharge area (~200 ppm). However, in the central region, where there is heavy withdrawal of groundwater because of mining activity, the contours are closely spaced indicating greater change in chloride concentration with in this region.

Isochlors of 1991 data have become more cramped when compared to isochlors of 1985. There is distinctly high chloride concentration (~800 ppm) in south-eastern region. This is possibly due to heavy pumpage locally, there by bringing in more mineralised water from the discharge area into the pumped wells in the south-east region. There also appears a change in hydrologic regime in SSW region, which, however, needs to be further examined in view of sparse data, and such a displacement of isochrones and isochlors as well provides a clue to the lateral movement of groundwater towards the region of cone of depression.

CONCLUSIONS

In this paper, attempt has been made to demonstrate the usefulness of isotope techniques in two mine hydrology problems in different environmental conditions; one in the coal mining and the other in lignite mining. The mine seepage could be linked to its source because of characteristic isotope concentration of different types of waters. The changing hydrologic regime could be better appreciated and studied with the aid of isotope techniques which provided the insight to the hydrodynamics of mine water in space as well in time.

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REFERENCES

1. Gupta, C.P.,Thangarajan, M., Gurunadha Rao, V.V.S., Sarma, M.R.K., Ramachandra, Y.M., Singh, V.S. and Sankaran, S. Regional Groundwater modelling studies in Neyveli Basin, Tamil Nadu. NGRI Tech. Report, Hyderabad (1986).

2. Gupta, C.P., Thangarajan, M., Sarma, M.R.K., Singh, V.S. Ahmed, S. and Rao, V.V.S.G. Modelling of Neyveli Aquifer System. NGRI Technical Report (1992).

3. Rangarajan, R., Muralidharan, D., Deshmukh, S.D., Hodlur, G.K., Murthy, N.N. and Gangadhara Rao, T. Estimation of recharge in Neyveli Groundwater Basin by injected tritium method for 1985 monsoon. NGRI Tech. rep. no. NGRI-87-ENVIRON-20 (1987).

4. Rangarajan, R., Deshmukh, S.D., Muralidharan, D., and Gangadhara Rao, T. Recharge estimation in Neyveli Groundwater Basin by tritium tagging method. NGRI Tech. Rep. no. NGRI-89-ENVIRON-65. (1989).

5. Rozkowski, A. and Prezewlocki, K. Application of stable environmental isotopes in mine hydrology taking Polish coal basins as an example. Proc. of sym. "Isotope techniques in groundwater hydrology" IAEA, Vienna (1974).

6. Subramanyam, V. Geology and groundwater aspects of the Neyveli Lignite Field, South Arcot dist. Madras state. Memo. of the Geological Survey of India, v. 94 (1969).

7. Sukhija, B.S., Reddy D.V., and Bhattacharya, S.K. Source of seepage in the Sudamdih mine area using environmental Isotopes, Bihar, India. J. of Hydrology, v. 93 (1987). pp. 191 - 197.

8. Sukhija, B.S., Mehrotra, V.K., Nagabhushanam, P., Giri, V.Y. and Syed Hussain. Low level tritium laboratory with online data acquisition system at NGRI, Hyderabad, India. Bull. of Radiation Protection v. 13/1 (1990).

9. Sukhija, B.S., Reddy, D.V., Nagabhushanam, P., Syed Hussain, Giri, V.Y. and Patil, D.J. Isotope studies of Neyveli Groundwater Basin. NGRI Tech Report no. NGRI-93-GW-149, (1993).

10. Verhagen, B.Th., Smith, P.E., Dziembowski, Z. and Oosthuizen, J.H. An environmental isotope study of major dewatering operation at Sishen mine, Northern Cape Province. "Isotope Hydrol. 1978" v. I, (1979) pp 65 - 81.

11. Zuber, A., Grabczak, J. and Kolonko, M. Environmental and artificial tracers for investigating leakage into salt mines. Proc. of sym. IAEA, "Isotope Hydrology 1978" v. I (1979). pp 45 - 63.