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Ground Water Quality Criteria Index for Mine Sectors.

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Abstract: Data on water quality for coal, dolomite, limestone, manganese, iron, bauxite , stone quarry and a diamond-prospecting mining sectors distributed over different parts of India was collated and was used to find "overall mine water quality index for (OMWQI" domestic and irrigation uses for each sector. Indices were calculated by Horton's and weighted Arithmetic Index methodsIndices, as per Horton's approach for coal, limestone, dolomite, iron, diamond, manganese, rock phosphate stone quarry, and bauxite by Horton's method were respectively 16,50, 85, ,298,79, 81,1,47 and 434. Lower the index, the better is the water quality. Respective indices by weighted Arithmetic method were38,50,31,271,82,61,1,68, &116 . Water from all the sectors except iron and bauxite deposit areas is suitable for both drinking and irrigation. Higher values in iron and bauxiteore -bearing areas were higher due iron beyond permissible limits.

I. INTRODUCTION

Enviro Techno Consult Private Ltd., (ETCPL) based at Nagpur, is recognised as "in house R & D unit" by D.S.I.R, Dept. Of Science & Technology, Govt. of India and has been accredited by NABET since 2010 as a consultant organization for environmental impact assessment of mining projects. ETCPL have conducted baseline -environmental - quality surveysfor a number of mining projects for their environmental clearances. Aquatic environment survey being a part of environment , examination of surface and ground water quality in buffer area (10 km radius) was a part of EIA(environmental impact assessment) report. These mining projects include coal, manganese, iron, limestone, dolomite, rock phosphate mining and also a perspective diamond mine project which is now abandoned. These projects are located in different pats of India. Aquatic environment of project includes both surface and ground water. Ground water for mining projects includes both shallow and deeper aquifers because both are vulnerable to mining activities. Therefore, substantial water quality analyses data is available.

II. PURPOSE

Underground water in mining areas can be considered as water sources for its uses viz. drinking, agriculture and industrial, if this water meets desired standards for these uses. UNEP has published a report entitled "Global Drinking Water Quality Index Development and sensitivity Analysis Report" [1]. Surjeet Singh[2] et.al have published a paper "Development of an Overall Water Quality Index (OWQI) for surface water In Indian Context".Aim of WQI is to give a single value to water quality from mine areas after reducing a number of parameters into a simple expression to interpret water quality data. In this paper, this OWQI - concept has been applied to ground water quality in different mine areas for its agriculture or domestic uses. This index would be called "overall mine area ground water index" (OMWQI). Same index was applied to water accumulated in abandoned mine pits in these sectors. This water is either which is rain water or ground water or both. OMWQI if applied this water will indicate ifmine-pit waters in these areas can be used for either drinking or agriculture or both.Water quality index would give full information to concerned policy makers as it gives influence of seven chosen parameters(TDS, hardness, chloride, sulphate, fluoride, iron and nitrate during water quality management.

III. APPROACH

Ground water quality data collected during impact assessment surveys was grouped under individual mining sectors viz. coal, manganese, iron, bauxite, lime stone, dolomite and stone metal quarry. Average sector-wise ground water quality was examined for water use drinking, agriculture and need basedindustrial use. Quality criteria differs with water use e.g. drinking water is defined by IS 10500, agriculture-use depends on sodium adsorption ratio (SAR) and its criteria for industrial use is industry- specific.Water sample collection, preservation and analyses for sources wereas per MOEF & CC prescribed methods. Hence uniformity in analytical methods for water quality was assured. Water samples were collected from wells/bore wells located in the buffer zone (area within 10 km radius) as per Standard methods for Examination of water &Wastewater (AWWA)[3], Her Majesty's publication

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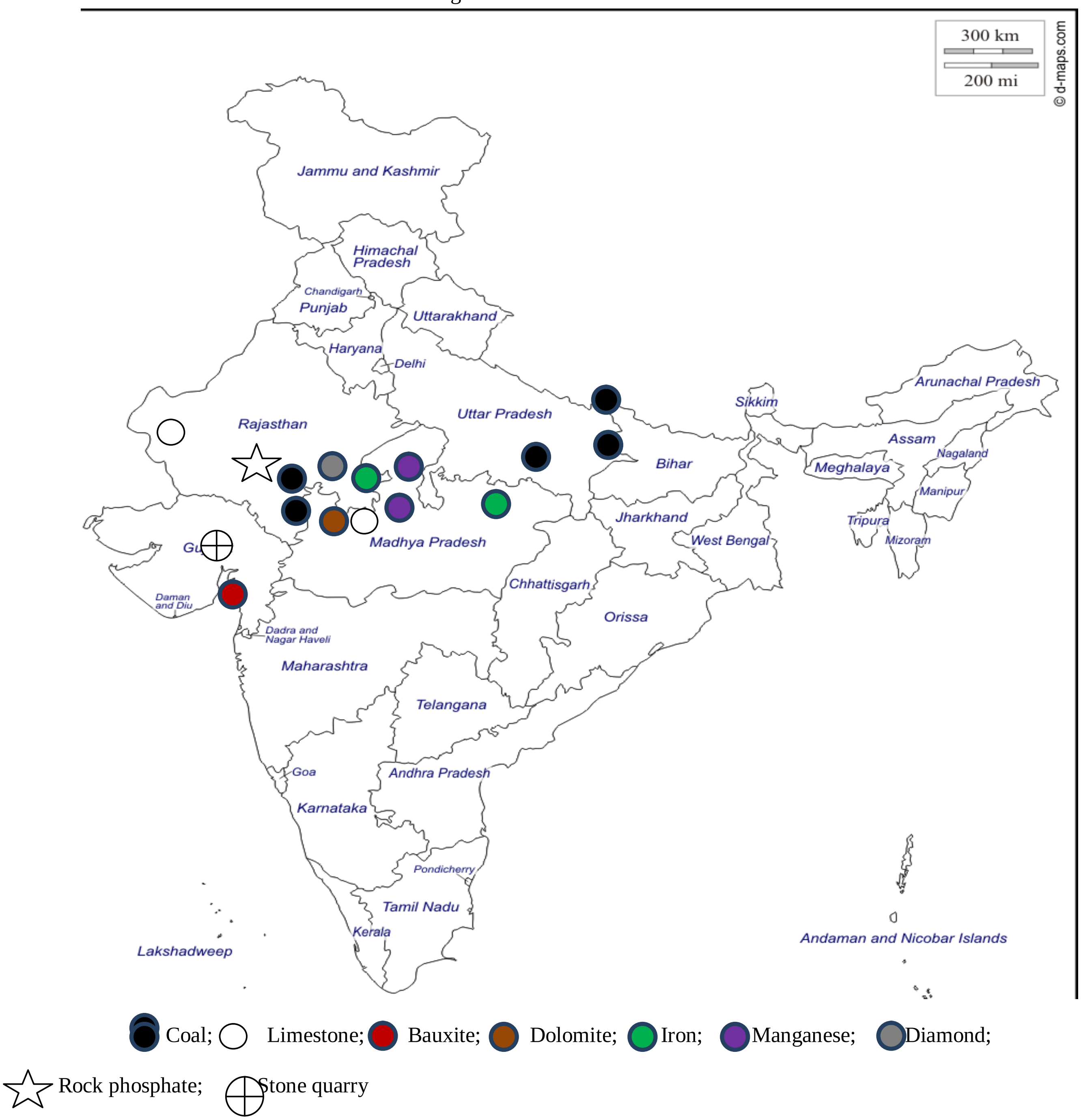
entitled Water &Wastewater manual-[4], GEMS/Water Operational Guide[5]. Variable parameters like pH, temperature, dissolved gases e.g. CO_2, DO were estimated at sites. Samples were preserved for estimation of trace metals. Samples were analysed for water quality parameters as per references cited above. Concentrations of total dissolved solids, calcium, magnesium, sodium, chloride, bicarbonates, silica, pH etc. were tabulated separately for coal, manganese, limestone, dolomite, iron, stone–metal mining sectorshas been compared with regard to dissolved ions' concentrations, relative ionic strengths, probable composition of residues during water use.

IV. STUDY AREAS

Locations of these ore/minerals deposits are distributed in Jharkhand, Bihar, M.P. Chhattisgarh, Maharashtra and Gujarat states(Figure 1).

Figure 1 Location of mine sectors



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V. RESULTS

Number of samples examined for different mines-premises are given in Table 1.

Table1. Sector wise number of samples

Mining sector	Number of samples	Tables
Coal	19	1-3
Limestone	27	4-8
Dolomite	16	9-10
Iron	7	11
Manganese	6	12
Rock phosphate	3	13
Stone	5	14
Bauxite	1	15
Diamond	8	16
Averages of mining sectors	--	17

Sector-wise water analyses data is available in respective impact assessment reports. Conclusions about water quality would be judicious if they were based on averages of soluble salts in ground water samples in each mining sector and averages are included in Table 2.Figure 2 indicates averages of dominant dissolved ions. Figure 3 shows ionic strengths of ground water in all the sectors.

Table 2 :Mining –sectorwise average water quality:

Parameters	Coal	Iron	Limestone	Manganese	Dolomite	Diamond	Rock phosphate	Stone quarry	Bauxite
pH	6.5-8	7.4-8.1	7.3-8.6	7.2-8.2	6.7-7.9	7.4-7.7	6.8-7.8	7.5	7.5
Conductivity, µS	1151	555	1016	382	818	622	848	615	325
TDS,mg/L	886	297	948	421	613	411	482	362	182
Total alkalinity as $CaCO_3$, mg/L	273	161	239	343	310	350	175	191	72
P alkalinity as $CaCO_3$, mg/L	0	0	0	0	0	0	0	233	0
MO alkalinity as $CaCO_3$, mg/L	273	161	239	343	310	350	175	0	72
Bicarbonates (alk.x 1.22) mg/L as $CaCO_3$	330	197	283	418	390	334	213	233	88
T. Hardness as $CaCO_3$, mg/L	364	190	310	325	391	365	211	189	100
Ca Hardness as $CaCO_3$, mg/L	173	133	186	178	241	230	146	143	78
Mg Hardness as $CaCO_3$, mg/L	233	57	112	165	161	110	65	46	22
Calcium as Ca^{++}, mg/L	69	53	80	71	91	92	58	57	31
Magnesium as Mg^{++}, mg/L	54	13	34	40	43	28	16	11	5
Chloride as Cl^-, mg/L	19	36	104	51	76	84	57	36	27
Sulphates as SO_4^{--}, mg/L	91	9	51	13	46	15	33	14	6
Total Iron as Fe, mg/L	0.5	1.0	0.12	0.2	0.1	0.4	-	0.15	1.5
Reactive silica as SiO_3, mg/L	6.0	7	-	-	-	-	-	-	-
Fluoride, mg/L	1.0	0.3	0.5	0.2	1.0	0.7	-	0.8	1.7
Nitrate as NO_3, mg/L	20	10	-	2.3	1.5	4.7	39	-	1.1
Manganese, mg/L	-	-	-	0.14	-	-	-	-	-

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Ionic strength	12.4	7.1	11.3	10.7	12.8	13.9	7.1	6.2	3.1
Carbon dioxide as $CaCO_3$,mg/L		16.2							5

Figure 2 : Dissolved ions in ground water

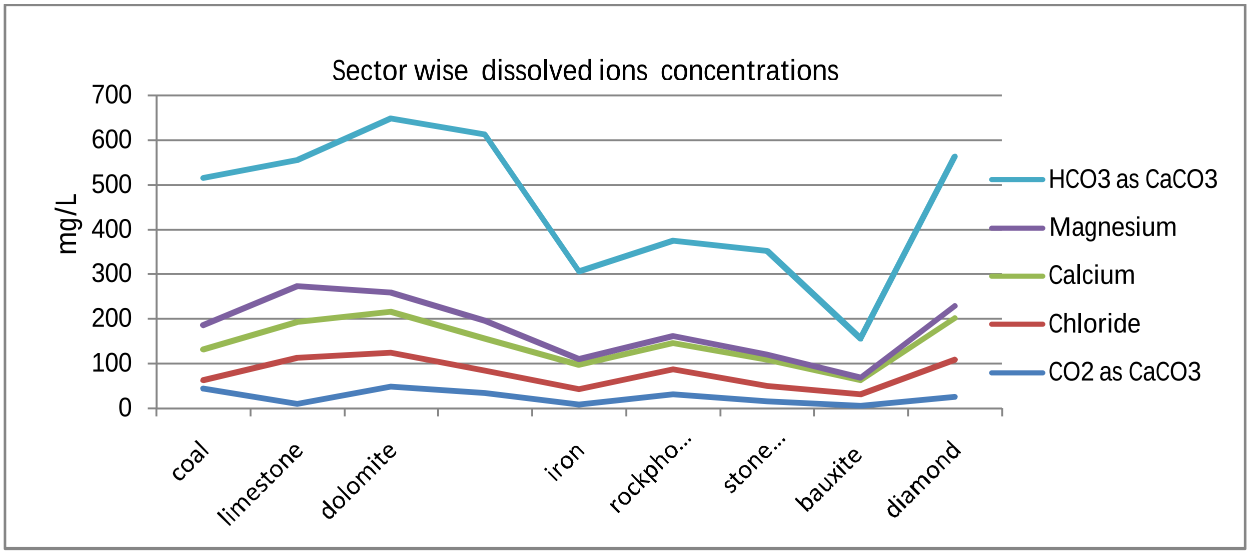
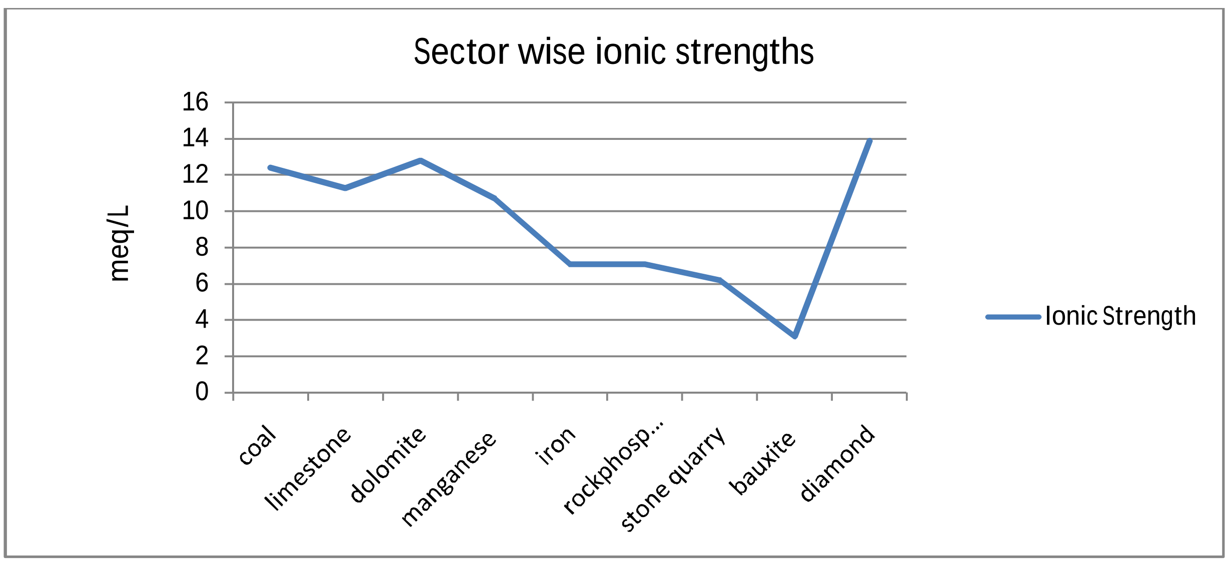


Figure 3 : Ground water-Ionic strengths



VI. DISCUSSION

Ultimate sources of dissolved ions in ground water are mineral contents in rocks near respective mine area. Purity and sizes of minerals in rock texture, porosity, regional structure, degree of fissures, residence time of water in the rocks, temperatures, life forms in area etc. will govern concentrations of dissolved ions. There is correlation between local geology and routine water quality. Water analyses included dissolved ionic species viz. calcium, magnesium, iron, manganese, chromium, sodium, bicarbonates(HCO_3^-), chloride, sulphate, nitrate etc. Chemically, resulting mine water is “dilute solutions” of these ions. It can be assumed that there is chemical equilibrium between solute(soluble salts) and solvent water.Water quality is defined in physical, chemical and biological forms and water quality parameters are selected on basis of its intended use.

In this paper OMWQI has been worked out in terms of their i) total dissolved solids concentrations, ii) ionic strengths, iii) the residues likely to be deposited during its uses and iv) sodium adsorption ratio.

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Volume 5 Issue X, October 2017- Available at www.ijraset.com

Water forms a residue during or after its use in the order of least -solubility of resulting salts e.g. $CaCO_3$will precipitate first, followed by $CaSO_4$, $MgCO_3$,$MgSO_4$ and so on. Probable compositionsof residuesand their quantities (mg/L)of likely deposits during use of these ground waters are included in Figure 3.

Utility of water for agriculture depends on a computed parameter called "sodium adsorption ratio (SAR)". SAR for these waters are plotted in Figure 4.

Figure 4 : Probable composition of residues

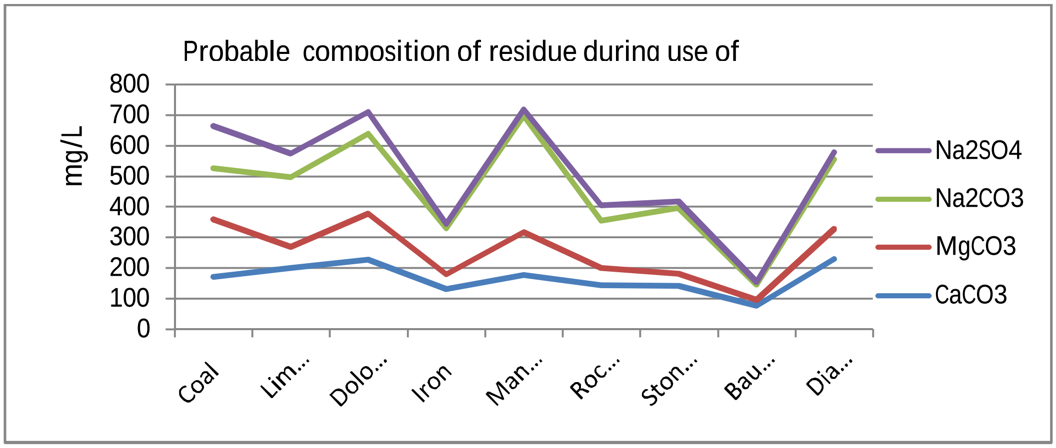
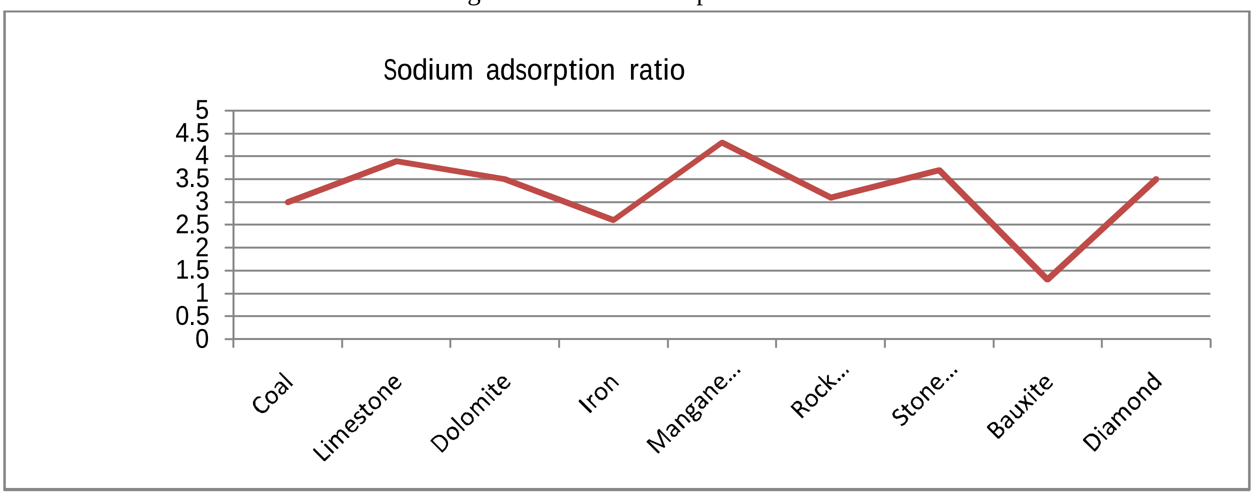


Figure 5: Sodium adsorption ratio



Water quality index: Horton's method was used to develop OMWQI for drinking and irrigation purposes. This method requires **a)** parameter selection, b) quality rating(q_n) calculated by using equation $q_n = \{(V_n-V_{id}) / (S_n - V_{id})\}$ x100. $V_n$where estimated value of n^{th}water quality parameter in a sector; V_{id} = ideal value of for n^{th} parameter in pure water(V_{id} for pH is 7 & 0 for other parameters) and S_n is standard permissible value of n^{th} parameter and c) unit weight (W_n) which was calculated using relation W_n= k/S_n in which S_n is standard permissible value ofn^{th}water quality parameter and k is proportionality constant determined by using equation k = [Σ1/Sn=1,2,3,…n)] .Selected parameters mentioned in IS10500[6]for domestic use of ground water were pH, total hardness, chloride, fluoride, nitrate, iron, sulphate chromium, zinc and arsenic. Calculated WQI for different sectors are given in Table 3.

Another method for calculation of overall ground water quality index reported by Dhakad[7]et.al. is "weighted Arithmetic Index" was also used to find OMWQC. In this method, i) unit weight for a parameter is calculated by taking its 'inverse value' as per drinking water standard BIS 10500[6] and ii) the quality rating or sub-index (Qi) corresponding to i^{th} parameter Pi is a number reflecting the related value of this parameter. Qi is calculated using relation Qi=Σ[{ M_i(-)Ii/(S_i-I_i}] x 100 in which Mi are the measured values of selected parameters; I_i is ideal value of i th parameter and Si is the standard value of the i^{th} parameter. Negative sign shows numerical difference between the two values and not the algebraic sign. Ideal value for pH is 7 and is 1 for

fluoride. There are two standards in IS10500 viz. desirable and permissible. OMWQI has been calculated with regard to TDS, total hardness, chloride, sulphate, iron, fluoride and nitrate.
Calculated water quality criteria indices by both these methods are included inTable 3.

Table 3: Sector wise WQ indices

Sector	OMWQI $\Sigma q_n W_n / \Sigma W_n$ Horton	OMWQI Weighted Arithmetic mean
Coal	16	38
Limestone	50	50
Dolomite	85	31
Iron	298	271
Diamond	79	82
Manganese	81	61
Rock phosphate	1	1
Stone quarry	47	68
Bauxite	434	116

N.B. values rounded to nearest decimal.

Higher values OMWQI in bauxite and iron ore mines are due to higher concentrations (1 to1.5 mg/L) of iron which is not a health related parameter and is aesthetically unwanted.
Ranges of WQI and water quality status along with its possible uses are given in Table 4.

Table 4 : Water uses & corresponding OMWQI

Possible uses	OMWQI	Status
Drinking, Irrigation and Industrial	0-25	Excellent
Domestic, Irrigation and Industrial	25-50	Good
Irrigation and Industrial	51-75	Fair
Irrigation	76-100	Poor
Restricted use for Irrigation	101-150	Very poor
Proper treatment required before use.	Above 150	Unfit for drinking

A. Water quality index for irrigation use:

Use of ground water from various mine-sectors and its suitability for irrigation is based on criteria included in a text book entitled "Wastewater Engineering, Treatment & Reuse[7]. Water quality problemscan be a) salinity due to conductivity and TDS affecting water availability to crop, b) effect on water infiltration rate due to SAR and conductivity and c) toxicity of specific ion like sodium, chloride , boron, nitrate, bicarbonate and pH . Ground water quality classification for irrigation is shown in Table 5.

Table 5 : Ground water classification for irrigation*

Sr.	Parameter	Excellent	Good	Poor
1	TDS/salinity	<450	450-2000	>2000
2	adj. R_{Na} SAR infiltration rate increases with water salinity	<0.7	0.7-3.0	>3.0
3	Conductivity, dS/m	0.7	0.7-3	>3.0
4	Chloride-m mol /L Surface irrigation Sprinkler irrigation	 <4 <3	 4-10 >3	 >10.0
5	Nitrogen (NO_3-N),mg/L	<5	5-30	>30.0

6	Bicarbonate ($HCO3^-$) overhead sprinkling only, mmol/L	1.5	1.5-8.5	>8.5
6	pH	--------- 6.5-8.4--------------		

*"Wastewater Engineering, Treatment & Reuse[8]
Parameters at serial no 1-6 in Table 5 for mines areas were worked out for ground waters under study and were used to calculate water quality criteria in mines. These are given in Table 6.

Table 6 : Sector wise water quality parameters for irrigation

Parameter	Mine sector								
	Coal	L.S.	Dolomite	Fe	Diamond	Mn	Stone quarry	Rock phosphate	Bauxite
TDS/salinity	886	948	613	297	411	421	362	482	182
SAR & Conductivity	3.5	4.4	5.2	3.3	4.9	8.1	4.7	4.2	1.8
Conductivity, dS/m	0.1	0.1	0.8	0.6	0.6	0.4	0.6	0.8	0.3
Chloride-mmol/L	0.5	2.9	2.1	1.0	2.3	1.4	1.0	1.6	0.8
Nitrogen (NO_3-N),mg/L	20	-	1.5	10	4.7	2.3	-	39	1.1
Bicarbonate (HCO_3) mmol/L	5.4	4.6	6.3	3.2	5.5	6.8	3.8	3.5	1.4
pH	--------------6.5-8.6---------------								

Resulting values for OMWQI for these sectors are given Table7.

Table 7: OMWQI for sectors

Mines	OMWQI
Coal	128
Limestone	113
Dolomite	178
Iron	121
Diamond	158
Manganese	197
Stone Quarry	130
Rock Phosphate	233
Bauxite	55

If water quality index based on TDS,SAR, conductivity, chloride, nitrate and bicarbonate for a ground water sample exceeds the calculated values then that source may not be suitable for agricultural use.
It has been suggested by Eaton[8]that 'residual sodium carbonate (RSC)' is a good index for sodicity-hazard of irrigation waters. Water with RSC exceeding 2.5 m mol (+)/1, would unsuitable for irrigation; RSC between 1.25 & 2.5 m mol(+) /L would be marginally suitable and water with RSC less than 1.25 m mol(+) /L would be safe. RSC for all sector-waters was calculated using

the formula RSC=(CO_3 + HCO_3)–(Ca^{++} +Mg^{++}), where ion concentrations are expressed as mmol/L. They are given in **Table8**and it can be concluded that ground waters from all the sectors are suitable for irrigation.

Table 8: Residual sodium carbonate

Coal	Lime stone	Dolomite	Iron	Diamond	Manganese	Stone quarry	Rock phosphate	Bauxite
1.4	1.2	2.2	1.4	1.9	3.3	1.9	1.9	0.4

Utility of water in abandoned coal mine pits in Chandrapur, Kanhan and in SECL coal field areas for domestic purposes was verified by calculating indices by Horton and Weighted Arithmetic Index methods and for irrigation by calculating 'residual sodium carbonate'. Results are given below.
They are given below :

Area	WQI by Horton'smethod	WQI by Weighted Arithmetic Index	Residual sodium carbonate for irrigation RSC, mmol/L
OMWQI for coal	16	38	1.4
Chandrapur coal fields	21	18	2.0
Kanhan coal mine	63	62	-0.6
SECL coal fields	16	22	-0.7

VII. CONCLUSIONS

A. Overall mine water quality indices indicate that ground water in all the sectors except iron and bauxite can be safely used for both irrigation and domestic purposes. Water from iron and bauxite deposit areas can be treated for removal of iron before use.

B. During base-line-environmental quality surveys of mining projects it was observed that there are a number of abandoned mine pits in which water(rain and ground/sub soil) is accumulated and is stored.

C. These water bodies are not being officially used for any purpose. It is suggested that representative samples from these pits be analysed for OMWQI parameters be worked before they are used. One such application showed that coal mine pit water can be utilised. Other water quality criteria parameters can be included depending on their importance.If ground water from mines is to be used in industries, industry will have to decide on intended uses viz, cooling process etc. It will be advisable that industry should calculate "the criteria index" for selected source.

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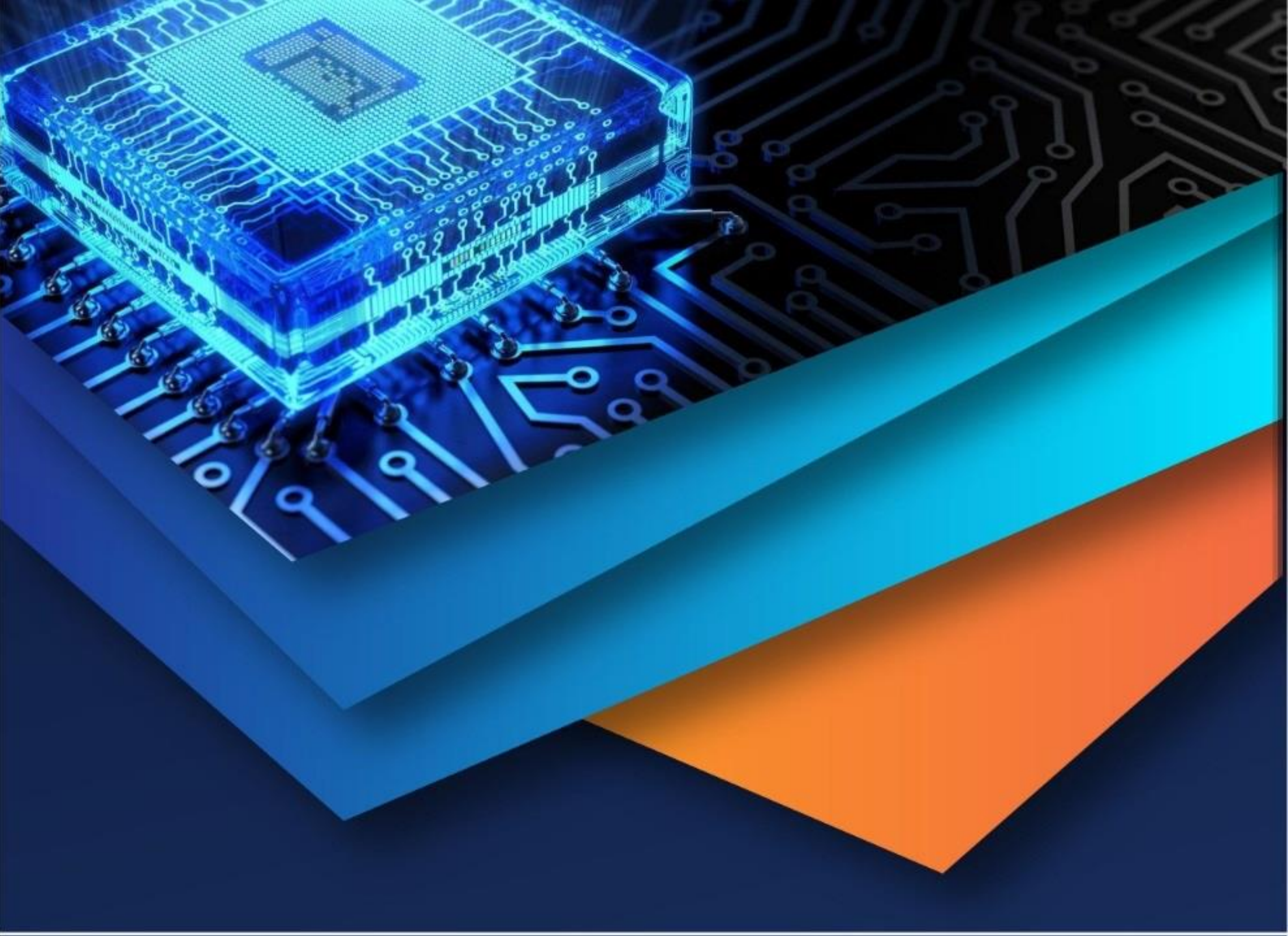

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