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EFFECT OF FLY ASH ON WATER QUALITY AS INFLUENCED BY DISTANCE IN FOUR RADIANT DIRECTIONS FROM RAYALASEEMA THERMAL POWER PLANT (RTPP)

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ABSTRACT

Ground water samples were collected from four radiant directions (north, south, east and west) and from each direction five samples were collected from four distances at 1.0, 2.0, 4.0 and 8.0 km from Rayalaseema Thermal Power Plant (RTPP). The ground water had alkaline pH and electrical conductivity was within the permissible limit. The abundance of cations in four radiant directions and at four distances are in the order of Na^{+}> Ca^{+2}> Mg^{+2}> K^{+}. The order of anions observed as Cl^{-} > HCO_3^{-}> CO_3^{-}> SO_4^{-2}. The Sodium Adsorption Ratio (SAR) of ground water was within the permissible limit in all directions and distances. The Residual Sodium Carbonate (RSC) is < 1.25 m eq^{-1} in the ground water collected at four directions and distances thus becoming suitable for irrigation. The water samples at north, south, east and west direction arecategorized as very high saline low sodium water (C_3S_1) but in east direction at 8.0 km radius and at 1.0 km radius of west direction was classified as very high saline medium sodium water (C_3S_1)

KEY WORDS: Ground water, Rayalaseema Thermal Power Plant, Electrical Conductivity, Residual Sodium Carbonate (RSC), Sodium Adsorption Ratio (SAR)

INTRODUCTION

According to the World Energy Council the energy demand has astronomically increased in recent years and the energy demand is forecast to continue growing at an annual average rate of 1.6% between 2004 and 2030 (World Energy Council, 2007). This leads to consumption of fossil fuels, especially coal which expected largest demand, from 2772 Mt in 2004 to 4441 Mt in 2030. Approximately 79 per cent of the entire electricity is produced yearly by these coal fired power plants (Singh and Siddiqui, 2003). Most of industries are using pulverized coal as the fuel, producing enormous quantities of coal fly ash every year. Central Electricity Authority (CEA) of India reported that, on average 730 MT of coal consumed by the power plants to generate 210 MT of fly ash in the year 2018 – 2019 and may reach up to 437 MT by 2030. On an average for every one ton of coal consumption produces 29 % of fly ash.

Fly ash is the finest inorganic residue released as by product resulted from coal combustion in thermal power industries (Gitari *et al*., 2013). The nature of fly ash is mainly dependent on the type of coal that is burnt. When coal is burnt in pulverized coal boilers, the minerals dragged in the coal are thermally transformed into chemical species that become reactive or chemically activated. (Benitez *et al*., 2001).

Indian coal releases high ash into to the ambient medium than developed countries. Fly-ash is serious problem due to its physical characteristics and sheer volumes generated. Fly ash gets air borne very fast and pollutes the environment. Because of its fineness, it is very difficult to handle in dry state and disturbs the ecology through soil, air and water pollution. Various diseases like silicosis, fibrosis of lungs, bronchitis and pneumonitis were caused due to the long inhalation of fly-ash were also reported. This material though finds use in manufacture of cement, bricks and other civil construction materials, is not so popular on cost considerations.

Fly ash contains heavy metals like Pb, Ni, Fe, Cr, Mn and Zn at high concentrations along with some beneficial elements which help crop growth but may have deleterious effect on plant growth. Ground water is the most important source of water supply for drinking, irrigation and industrial purposes. It provides about 40 percent of the nation's public water supply. Due to industrialization and urbanization the ground water being polluted due to pollutants released in to surrounding environment. Fly ash carries huge amount of toxic heavy metals which on leaching pollutes ground water. Water quality around thermal power stations has to maintain within safer limits for ensuring minimum ash carriage to the surrounding areas. Thereby, there is a need to evaluate ground water quality in the surroundings of thermal power plants. Various research studies conducted but most of them were confined to laboratories or experimental farms but in-situ studies are scanty.

MATERIALS AND METHODS

Rayalaseema Thermal Power Plant (RTPP) was situated at latitude N 14º 41' 556'' and longitude of E 078º 28' 391''. In order to assess the water quality of the ground water around RTPP, water samples were collected in sterile polythene containers of one litre capacity in four radiant directions.

In each radiant direction, water samples were collected uniformly at four measured distances of 1.0 km, 2.0 km, 4.0 km and 8.0 km. At each distance, replicate samples were collected and presented their computed mean values.

The samples collected were brought to the laboratory at Agricultural Research Station, Utukur, Kadapa, Andhra Pradesh for detailed analysis. pH and EC were estimated by potentiometric and conductometric methods as proposed by Jackson (1967 & 1973). Sodium (Na^+) and potassium (K^+) were measured by flame photometry. Calcium and magnesium were determined with versanate method, Black (1965). Carbonates and bicarbonates were estimated by titration with H_2SO_4 (Tandon, 1998), chlorides by Mohr's method. Measurements were done in triplicate to ensure reliability and accuracy. Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), Residual Sodium Bicarbonate (RSBC), Potential Salinity (PS), Kelly's Ratio (KR), Magnesium Hazard (MH), Total Hardness (TH) and Permeability Index (PI) were computed, using the standard formulae.

a) Sodium Adsorption Ratio (Richards, 1968)

$$SAR: \frac{Na^{+2}}{\frac{\sqrt{Ca^{+2}+Mg^{+2}}}{2}}.$$

b) Residual Sodium Carbonate (Richards, 1968)
RSC: $(CO_3^{-2}+ HCO\text{-}_3^{-}) – (Ca^{+2}+ Mg^{+2})$

c) Residual Sodium Bicarbonate (Gupta and Gupta, 1987)

$$RSBC: (HCO_3^{-} - Ca^{+2})$$

d) Potential Salinity (Doneen, 1961)

$$PS: Cl^{-} + ½ SO_4^{-2}$$

e) Kelly's Ratio

$$KR: \frac{Na}{Ca+Mg}$$

f) Permeability Index (Doneen, 1964)

$$PI: \frac{Na^{+}+\sqrt{HCO_3^{-}}}{Ca^{+2}+Mg^{+2}+Na^{+}}$$

g) Sodium Percentage

$$SP: \frac{Na^{+}+K^{+}}{Ca^{+2}+Mg^{+2}+Na^{+}+K^{+}} \times 100$$

h) Magnesium Hazard (MH)

$$MH: \frac{Mg^{+2}}{Ca^{+2}+Mg^{+2}} \times 100$$

i) Total hardness
TH: $2.5 (Ca^{+2}) + 4.1 (Mg^{+2})$

RESULTS AND DISCUSSION

Chemical parameters analyzed were used to evaluate the quality of ground water were presented in Tables 1 to 4.

Soil Reaction (pH)

The pH of fly ash affected groundwater samples are slightly alkaline in nature further with distance the alkalinity was decreased and highest pH was found in south direction as 7.84. The pH of fly ash is alkaline in reaction and dissolution of the same can increase the pH of the surrounding ground water. The results were in line with the findings of Khan and Umar (2019) and Krechetov *et al*. (2019). The temperatures near RTPP ranges from 22 °C and 43°C which raises the alkalinity of water because at that temperature the solubility of CO_2 reduces. Similar reports were made by Kanchan *et al*. (2015).

Electrical Conductivity (EC)

The electrical conductivity of ground water is within the permissible limits in all directions and distances where highest electrical conductivity 1.16 dS m^{-1} was recorded in north direction. This higher electrical conductivity is due to downward percolation of ions of chlorides, sulphates and carbonates from ash ponds through soil strata. Further, the ionizable solids are directly proportional to the electrical conductivity of water. Similar reports were observed by Khan and Umar (2019), Pandey *et al*. (2019), Gosh and Tiwari (2021). None of the sample was found to be unsuitable for irrigation according to classification of Richards, (1968).

Cations (Ca^{+2}, Mg^{+2}, K^{+} and Na^{+})

The ground water collected at all four directions and distances contained lower concentrations of magnesium and potassium, while calcium and sodium recorded relatively higher concentration and found to be above critical limit. Further, among directions, ground water in east direction recorded maximum calcium and sodium. The higher calcium , sodium in east direction was due to wind ward direction and dissolution of minerals from lithological composition. Further, high calcium in the fly ash might have been leached down to the lower strata. The results were in line with the findings of Spielmeyer *et al*. (2017), Gosh and Tiwari (2021). The order of abundance of cations in four directions was $Na^{+} > Ca^{+2} > Mg^{+2} > K^{+}$. The high sodium in groundwater is due to its strong tendency to remain adsorbed on soil particles but can easily be exchanged, which increases its concentration in groundwater, Goyal (2006). The cation exchange through water-rock interaction in addition to human activities is the main reason of increase in sodium in ground water (Ramkumar *et al*., 2013).

Anions (Cl^{-}, CO_3^{-2}, HCO_3^{-} and SO_4^{-2})

The anion concentration of groundwater collected at four directions was within the permissible limit except for chlorine in north direction at 1.0 and 2.0

Table 1. Chemical properties of ground water collected in North direction at four distances from Rayalaseema Thermal Power Plant (RTPP)

Parameter	1.0 km	2.0 km	4.0 km	8.0 km
pH	7.58	7.08	7.40	7.28
EC (dS m^{-1})	1.42	0.78	1.39	1.06
Potassium (mg l^{-1})	8.76	4.37	5.63	5.63
Calcium (mg l^{-1})	152.00	77.33	74.00	73.30
Magnesium (mg l^{-1})	30.53	27.20	26.80	27.20
Sodium (mg l^{-1})	276.51	242.58	125.14	106.12
Carbonates (mg l^{-1})	20.00	22.00	30.00	18.00
Bicarbonates (mg l^{-1})	79.30	81.33	115.90	58.96
Chlorides (mg l^{-1})	273.36	222.46	121.88	113.60
Sulphates (mg l^{-1})	26.00	15.50	14.50	17.75

Table 2. Chemical properties of ground water collected in South direction at four distances from Rayalaseema Thermal Power Plant (RTPP)

Parameter	1.0 km	2.0 km	4.0 km	8.0 km
pH	7.84	7.70	7.43	7.50
EC (dS m^{-1})	1.31	1.01	1.02	1.27
Potassium (mg l^{-1})	7.88	6.25	7.51	5.63
Calcium (mg l^{-1})	66.00	46.66	40.00	62.66
Magnesium (mg l^{-1})	22.00	26.40	29.60	29.60
Sodium (mg l^{-1})	139.82	94.30	126.33	76.50
Carbonates (mg l^{-1})	32.00	32.00	16.00	24.00
Bicarbonates (mg l^{-1})	69.13	71.16	51.03	83.36
Chlorides (mg l^{-1})	53.25	63.90	73.36	82.83
Sulphates (mg l^{-1})	22.83	17.25	20.58	22.50

Table 3. Chemical properties of ground water collected in East direction at four distances from Rayalaseema Thermal Power Plant (RTPP)

Parameter	1.0 km	2.0 km	4.0 km	8.0 km
pH	7.47	7.45	7.37	7.49
EC (dS m^{-1})	1.39	1.47	1.66	1.66
Potassium (mg l^{-1})	7.51	8.76	11.25	10.64
Calcium (mg l^{-1})	75.20	85.33	52.00	75.33
Magnesium (mg l^{-1})	43.73	45.86	40.26	40.00
Sodium (mg l^{-1})	255.60	123.90	128.09	252.07
Carbonates (mg l^{-1})	24.00	16.00	16.00	32.00
Bicarbonates (mg l^{-1})	28.30	46.06	81.33	16.13
Chlorides (mg l^{-1})	213.00	184.60	99.40	196.43
Sulphates (mg l^{-1})	16.25	38.16	18.50	20.00

Table 4. Chemical properties of ground water collected in West direction at four distances from Rayalaseema Thermal Power Plant (RTPP)

Parameter	1.0 km	2.0 km	4.0 km	8.0 km
pH	7.47	7.60	7.70	7.46
EC (dS m^{-1})	1.66	1.21	1.07	1.88
Potassium (mg l^{-1})	1.64	7.51	6.25	8.12
Calcium (mg l^{-1})	75.33	57.86	50.66	65.33
Magnesium (mg l^{-1})	40.00	29.20	25.20	28.80
Sodium (mg l^{-1})	252.07	105.57	96.08	124.55
Carbonates (mg l^{-1})	32.00	24.00	16.00	28.00
Bicarbonates (mg l^{-1})	16.13	52.56	56.93	107.76
Chlorides (mg l^{-1})	196.43	101.76	60.35	148.13
Sulphates (mg l^{-1})	20.00	18.50	18.08	17.75

Table 5. Quality parameters of ground water collected in North direction at four distances from Rayalaseema Thermal power Plant (RTPP)

Parameter	1.0 km	2.0 km	4.0 km	8.0 km
SAR	5.37	5.96	3.19	2.78
RSC	-8.17	-4.06	-6.36	-4.36
RSBC	-6.30	-2.53	-1.80	-2.70
Potential Salinity	8.50	6.76	3.88	3.75
Kelly's Ratio	1.24	1.69	0.93	0.85
Permeability Index	60.33	61.00a	58.33	53.33
Sodium Percentage	54.69	63.47	48.48	44.51
Magnesium Hazard	25.08	36.95	37.64	38.21
Total Hardness	505.17	304.84	294.88	294.77

km radius. Chloride concentration in north direction ranged from 113.60 to 273.36 mg l^{-1}; from 82.83 to 53.25 mg l^{-1} in south; from 99.40 to 213mg l^{-1} in east and in west direction 16 to 32 mg l^{-1}. At 1.0 km radius in north direction the chloride concentration reached beyond the permissible limit of 250 mg l^{-1} (WHO, The order of 1993). The order of anions in groundwater samples were observed as $Cl^{-} > HCO_3^{-} > CO_3^{-2} > SO_4^{-2}$. These results are in line with the findings of Gosh and Tiwari (2021). Higher chloride concentration in ground water was deposition of fly ash on soil surface further, their leaching might be increased soluble salts in water. The second abundant anion, bicarbonate in groundwater compared to other anions is due to bicarbonates derive mainly from rhizospheric CO_2, dissolution of carbonates and reaction of silicates with carbonic acid (Pandey *et al*., 2019).

For classification and evaluation of groundwater quality, water quality indices such as SAR, RSC, Magnesium hazard, permeability index, Kelly's ratio and Sodium percentage were calculated from the basic data and presented in Table 9.

Sodium Adsorption Ratio (SAR)

The observed SAR values indicates that water samples in north and south direction were categorized as low sodium hazard water S_1 (<10). The water in east and west direction fall under the category of medium sodium hazard water S_2 (10-18) (Richards, 1968). According to USDA classification the water samples at north, south, east and west direction was categorized as very high saline low sodium water (C_3S_1) but in east direction at 8.0 km radius and west direction at 1.0 km radius water is very high saline medium sodium water (C_3S_2). Water with high salts and low to medium sodium can be used for irrigation in soils possessing good drainage, with little danger of sodium accumulation to harmful level. SAR indicates the degree to which irrigation water tends to enter into cation exchange reactions in soil. However, none of the samples were found unsuitable for irrigation in four radial directions.

Residual Sodium Carbonate (RSC)

The mean Residual Sodium Carbonate is < 1.25 meq l^{-1} in the groundwater collected at four directions and distances thus becoming suitable for irrigation as guidelines given by Richards (1968). The results coincide with the findings of Sudhakar and Narasimha (2013) and Reddy (2013).

Residual Sodium Bicarbonate (RSBC)

Groundwater in four directions and distances is suitable for irrigation according to Gupta and Gupta (1987) as RSBC values recorded as < 5.0 meq l^{-1}.

RSC: RSBC Ratio

RSC: RSBC ratios of the ground water is suitable for irrigation as the values in north direction recorded as low alkaline (2.5 meq l^{-1}); in south direction was low alkaline (2.5 meq l^{-1}) to medium alkaline (2.5 – 5.0 meq l^{-1}); in east direction medium alkaline (2.5 – 5.0 meq l^{-1}) to highly alkaline (5.0 - 10 meq l^{-1}) and in west direction was low alkaline (2.5 meq l^{-1}) to medium alkaline (2.5 – 5.0 meq l^{-1}).

Potential Salinity (PS)

Potential Salinity of ground water in four directions was ranged between 2.33 - 8.50 and was categorized under medium permeable soils. Relatively high salinity was observed in north direction because of high chlorides and sulphates in ground water. (Donnen, 1961).

Permeability Index (PI)

The permeability index of ground water in four directions fall under good category (25 - 75 %) as suggested by Donnen, (1964). Similar results were observed by Subramani *et al* (2005). Permeability is a crucial parameter for assessing the suitability of irrigation water. According to data recorded in four directions, water falls under the category of class II (25 – 75%) and categorized as good for irrigation. PI values in north direction ranged from 53.33 to 60.33%, in south 50.66 to 63.00%, in east 47 to 75 and in west direction 57.66 to 62.66 percent.

Kelly's Ratio (KR)

Water with Kelly's ratio < 1.0 considered as suitable for irrigation, while those having higher values are considered as unsuitable. KR values of ground water in north direction is 0.85 to 1.25; south direction 0.59 to 1.22; in east direction 0.7 to 2.8 while in west direction 0.86 to 1.45. In general, with distance the KR values were decreased except east direction. According to Kelly's ratio values ground water collected and analyzed at 1.0 and 2.0 km is unsuitable for irrigation.

Table 6. Quality parameters of ground water collected in South direction at four distances from Rayalaseema Thermal power Plant (RTPP)

Parameter	1.0 km	2.0 km	4.0 km	8.0 km
SAR	3.81	2.92	3.67	1.98
RSC	-2.93	-2.28	-3.10	-3.43
RSBC	-2.16	-3.58	-1.16	-1.90
Potential Salinity	2.20	2.33	2.70	3.03
Kelly's Ratio	1.20	1.07	1.22	0.59
Permeability Index	63.00	61.00	64.00	50.66
Sodium Percentage	45.02	51.55	43.99	61.73
Magnesium Hazard	35.71	48.53	55.22	44.05
Total Hardness	255.20	229.89	221.36	278.01

Table 7. Quality parameters of ground water collected in East direction at four Distances from Rayalaseema Thermal power Plant (RTPP)

Parameter	1.0 km	2.0 km	4.0 km	8.0 km
SAR	5.89	2.74	3.22	9.53
RSC	-6.19	-6.80	-4.06	-4.20
RSBC	-3.29	-3.79	-1.26	-1.53
Potential Salinity	6.50	6.38	3.37	3.29
Kelly's Ratio	1.56	0.70	0.93	2.80
Permeability Index	58.00	47.00	57.33	75.00
Sodium Percentage	60.42	40.96	49.58	48.23
Magnesium Hazard	49.21	47.25	56.33	46.94
Total Hardness	367.29	401.35	295.06	352.32

Table 8. Quality parameters of ground water collected in West direction at four distances from Rayalaseema Thermal power Plant (RTPP)

Parameter	1.0 km	2.0 km	4.0 km	8.0 km
SAR	5.65	2.81	2.86	3.15
RSC	-4.69	-2.99	-3.16	-2.96
RSBC	-2.43	-1.36	-1.60	-1.50
Potential Salinity	6.15	3.44	2.26	2.56
Kelly's Ratio	1.45	0.86	1.01	0.92
Permeability Index	62.66	57.66	60.33	60.00
Sodium Percentage	60.77	47.31	48.35	49.80
Magnesium Hazard	46.94	45.68	45.32	42.35
Total Hardness	352.32	264.37	229.97	281.40

Table 9. Classification of groundwater based on quality parameters

S No	Parameter	Range	Water class
1	pH	6.5 – 7.5	Suitable
		7.6 – 9.5	Moderately suitable
		>9.5	Unsuitable
2	Electrical Conductivity (dS m^{-1})	< 0.25	Excellent
		0.25 – 0.75	Good
		0.75 – 2.25	Permissible
		>2.25	Unsuitable
3	Chlorides (mg l^{-1})	< 142	No Problem
		142 - 355	Moderate
		>355	Severe
4	SAR	< 10	Excellent
		10 – 18	Good
		18 -26	Doughtful
		>26	Unsuitable
5	RSC (meq l^{-1})	< 1.25	Safe
		1.25 – 2.50	Permissible
		>2.50	Unsuitable
6	Magnesium Hazard (MH)	< 50	Suitable
		>50	Unsuitable
7	Permeability Index (PI)	< 25	Unsuitable (Class III)
		25 - 75	Good (Class II)
		>75	Excellent (Class I)
8	Kelly's Ratio (KR)	< 1.0	Suitable
		>1.0	Unsuitable

Sodium Percentage (SP)

The sodium per cent value less than 60 % in groundwater is suitable for irrigation purpose as per the classification given by Wilcox (1955). The sodium percent of the study area varies from 40.96 to 63.47 per cent. The sodium per cent in north at 2 km, south at 8 km, east and west at 1 km are more than 60 per cent and are not suitable for irrigation.

Magnesium Hazard (MH)

Magnesium hazard less than 50 % suitable for irrigation and more than 50 % not suitable for irrigation and making the soil more alkaline. The magnesium hazard in the given water samples are less than 50 % except in east at 4 km and are suitable for irrigation.

Total Hardness (TH)

The hardness of the water is generally caused by calcium and magnesium. However the total hardness is caused by temporary and permanent hardness. Temporary hardness can be removed by boiling water and permanent hardness cannot be removed by any means. The total hardness is the summation of temporary and permanent hardness. Sawyer and McCarty (1967) classified water as < 75 mg l^{-1} as soft, 75-150 mg l^{-1} as moderately hard, 150-300 mg l^{-1} as hard and > 300 mg l^{-1}as very hard. The total hardness of ground water samples varies from 221.36 to 505.17 mg l^{-1} shows that ground water samples fall under the category of very hard and are not suitable for irrigation.

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