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Determination of surface water quality around thermal power plant based on water quality index and physicochemical characteristics

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Abstract
Coal fires thermal power plants in India are the major sources of power required for the development of the nation. In spite of availability of pollution control technologies in India, the thermal power plants in many states are polluting the air, water and soil, and also leading to loss of property and lives. Khaparkheda thermal power plant in Nagpur District of Maharashtra showed repeated fly ash pond breaches and pollution of Kanhan River, groundwater, air and farm lands. There is a Stream flowing by the side of fly ash pond which receives the fly ash through the overflow of fly ash pond or by accidental breach of fly ash pond. This Stream carries the fly ash to the Kanhan River polluting it. Apart from this, there are other sources of pollution such as wastewater from villages and upstream industries. The present study was undertaken to study the sources of fly ash pollution and the status of pollution of Kanhan River and Stream. The observations have shown the higher turbidity, higher COD and BOD values and presence of some toxic metals in Kanhan River and Stream. The estimated Water Quality Index (WQI) indicated that the upstream part of Kanhan River was excellent for drinking and domestic purpose while the downstream part of Kanhan River was not suitable for drinking purpose. The WQI of Stream showed that the stream water was not suitable for drinking and domestic purpose.

Keywords: thermal power plant, khaparkheda, kanhan river, stream, fly ash, water quality index

Introduction

The major source of energy in India is the coal fired thermal power plant (cTPP) which is required for the development of the nation. cTPP is one of the oldest methods of energy production. More attention has been given to improving the technology to increase the efficiency of thermal power plants. Increase in efficiency results in more energy to the unit mass of coal and thus lesser emission of pollutants like particulate matter, and greenhouse gases like SO2 and NO2 and fly ash. Old and new plants are responsible for emission of greenhouse gases SO2, NO2, CO, and PM10, PM2.5 and wastewater. Various technologies are available.to minimise the emission of these pollutants. Government regulations and policies are also available to control the emission of pollutants from power plants. It is the mandatory for cTPPs to keep the emission below the stipulated standards. In spite of all these mandatory restrictions, there are increasing incidences of air, water and land pollution affecting surrounding ecology and the exposure of people to ill effects of pollutants (The Times of India, July 9, 2021, Nawaz, 2013; Ramya et al., 2013; Nalawade et al., 2012; Singh et al., 2010) [25, 13, 17, 12, 21]. There has been loss of ecology, biodiversity, crop production, deterioration of water resources, soil resources and public health (Yashwant Shailendra, July 27, 2020) [28] leading to miserable life and deterioration of socioeconomic conditions. When the water resources, villages and farms were covered by fly ash after fly ash pond breach, the power plants did not bother to remove the fly ash and remediate the polluted area (Yashwant, July 27, 2020) [28]. The states in India having largest number of cTPPs and having largest number of fly ash pond breaches are Bihar, Jharkhand, Madhya Pradesh, Maharashtra and Uttar Pradesh (Times of India, July 9, 2021) [25]. Times of India (July 9, 2021) [25] reported the repeated fly ash breaches from fly ash ponds of Khaparkheda and Koradi power plants resulting in pollution of Kanhan River in the last three years and affecting the livelihood of local people. Therefore, this study aims at studying the sources of fly ash pollution from Khapar kheda thermal power station (KTPS) and pollution status of Kanhan River and Stream in KTPS area.

Materials and methods

The KTPS of the Maharashtra State Power Generation Company (MAHAGENCO) is the oldest thermal power plant in Nagpur District established in 1989. It is situated on the bank of the Kanhan River near Khaparkheda Town in Nagpur District. The total capacity of KTPS is 1340 MW. It has 4 units of 210 MW capacity and one unit of 500 MW capacity. Coal mines at Saoner and Dumri and some nearby mines supply coal to KTPS and Koradi thermal power plant which are around 6 km away from each other on the bank of Kanhan River on upstream and downstream areas respectively. They are 15 km away from Nagpur City and provide electric power to eight districts of

Vidarbha region. Kanhan River flows by the side of Koradi thermal power plant in upstream area and by the side of KTPS in downstream area. There is one small stream flowing by the side of fly ash pond of KTPs and then meets the Kanhan River. This unnamed stream is referred here as Kanhan Strem or k-Stream for the sake of convenience. The methodology for sample collection and preservation techniques was as per the *Standard Methods for the Examination of Water and Wastewater* (APHA, AWWA, and WPCF, 2012) [2]. Grab water samples were collected from Kanhan River and k-Stream that flows by the side of the fly ash pond of KTPS. The parameters such as temperature, electric conductivity, pH, colour, odour and taste were recorded at the time of collection. Dissolved oxygen (DO) was fixed at the site and brought to laboratory for analysis. For remaining parameters, water samples were collected, preserved and brought to laboratory for analysis. Water Quality Index (WQI) was determined following the procedure adopted by Ravi kumar et al. (24 January 2013) [19]. The value of WQI is useful in deciding the suitability or non-suitability of water body for drinking purpose and domestic use.

Results and Discussion

Study area

The area around the KTPS is undulating to plain area. The area has broad valley of Kanhan River with its tributary Pench River and small streams and ponds. The highest elevation is at Suradevi hills with 384 m amsl the lowest elevation is at Kanhan River bed with 260 m amsl. The slope of land is towards the Kanhan River bed. The Kanhan River flows from North-West (NW) to South-East (SE) and Pench River from North (N) to South (S) and meets with Kanhan on South of study area. The Kanhan River flows from Koradi thermal power station (Koradi TPP) to KTPS.

Climate and rainfall

The climate of Khaparkheda area is tropical climate with very hot summer and moderate winter. Thus, the temperature remains high throughout the year. The winter months are December, January and February, while the summer season is of long duration from March to September. The rainy season starts from June to September. The post monsoon season is from October to November. The average annual rainfall is about 1170 mm. The best climatic conditions are from January to April, June and August to December. The highest average temperature is 40^0C in May and lowest is 27^0C in January. Khaparkheda area has the tropical savannah climate.

Hydrogeology of the area

The shallower groundwater in the area is present under unconfined pockets and deep groundwater is present under phreatic condition. The precambrian crystalline rocks are hard and compact and they have secondary porosity like jointing and fracturing (Rathod et al, 2014) [18]. The capacity of these rocks to store, transmit and yield groundwater depends on weathering and intensity of joints and fracturing of the formation (Subramanian et al., 1996) [23]. The section of land in wells as well as cutting of roads at some places indicates that the zone of weathering extends to the depth of 10-15 m below the ground level. The rocks shows the presence of minerals like plagioclase and oligoclase feldspar and and other minerals like muscovite and biotite, hornblende and augite. The feldspars contain sodium, potassium, calcium, aluminium, silicon and oxygen. Fluoride is also reported from these rocks (Duraiswami and Patankar, 2011; Pujari & Deshpande, 2005; Pujari et al., 2011) [8, 15, 14]. The sandstone present in Kamptee area is a good aquifer due to their porous and permeable nature (Rathod et al, 2014) [18].

Sources of water pollution in study area

The wastewater and fly ash disposal by KTPS is responsible for water pollution. The wastewater sources are cooling tower blow down, boiler blow down, de-mineralization (DM) plant effluent, coal handling plant, dust suppression, ash handling, leachate of fly ash pond containing heavy metals, effluent from oil handling and transformer areas, power house and turbine area effluent, and domestic waste water contaminate surface water bodies around the KTPS.

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The KTPS produces 2.5 MMT fly ash per year as per MAHAGENCO's notification dated March 2018 for inviting Expression of Interest (EOL) applications for reuse of fly ash to manufacture products. Very small fly ash is reused and large quantity of fly ash is disposed of in ash pond by collecting it in the form of wet slurry (Singh et al., 2010) [21].

Sampling sites

The Study area and the sampling points are shown in Figure 1 and Table 1.

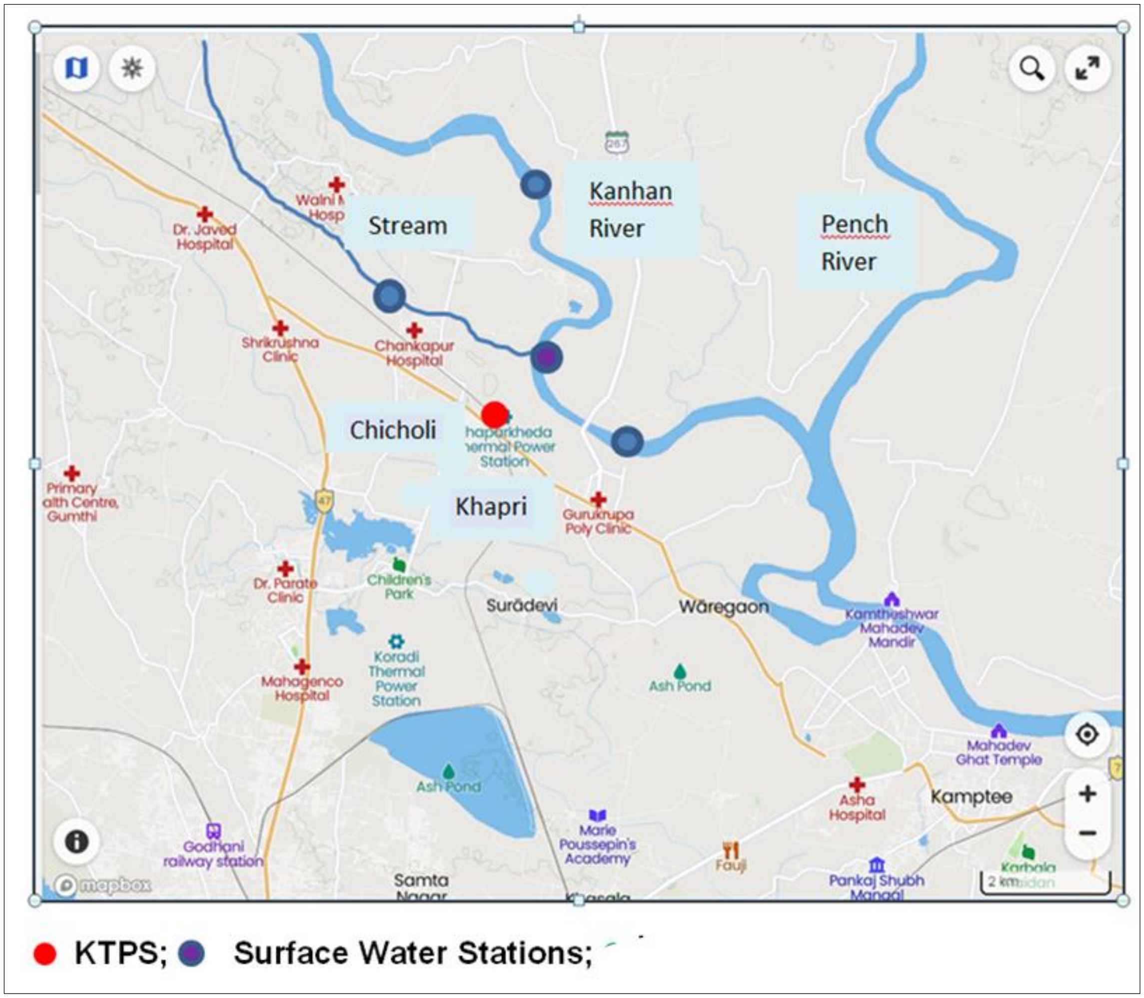

Fig 1: Surface water and groundwater sampling stations around KTPS

Table 1: Water sampling points on Kanhan River and k-Stream

Sampling Station	Sampling Site	Distance from Confluence of k-Stream with Kanhan river
SW1	Kanhan River	3 km upstream of confluence of Kanhan River with k-Stream
SW2	Kanhan River	Confluence point of k-Stream and Kanhan River
SW3	Kanhan River	1.5 km downstream to confluence point
SW4	k-Stream downstream to fly ash pond overflow	k-Stream receiving overflow from fly ash pond

The analytical data of surface water samples were compared with Drinking Water Quality Standard (IS 20500:2012) (BIS 2012) [4] and parameters having values higher than the standard were considered as pollutants with reference to drinking/domestic water quality. These observations were used to evaluate the environmental performance of the ferroalloys industry. Water Quality Index (WQI) was determined to indicate the suitability/non-suitability of water quality for drinking and domestic purpose.

The surface water samples from different stations were compared with Irrigation Water Quality Standard (CPCB, 2001, BIS 1986) [6, 5] to evaluate its suitability for agricultural irrigation because the study area is dominated by agricultural fields.

Physicochemical characteristics of Kanhan River

The physicochemical characteristics of Kanhan River are shown in Table 2.

Table 2: Physicochemical characteristics of Kanhan River and k-Stream Water

S.N.	Water Quality Parameter	Unit	Kanhan River	Confluence	Kanhan D/s Confluence	k-Stream
			SW1	SW2	SW3	SW4
1.	pH	--	7.8	7.9	8.1	8.2
2.	Temperature	^0C	29.0	30.0	29	30.2
3.	Colour		Slightly turbid	Slightly milky	Slightly milky	Milky white
4.	Turbidity	NTU	8	84	78	286
5.	Dissolved Oxygen (DO)	mg/L	6.6	5.9	6.2	4.5

6.	Electrical Conductivity	µS/cm	785	1465	986	2446
7.	Total Dissolved Solids (TDS)	mg/L	432	870	614	1663
8.	Chemical Oxygen Demand (COD)	mg/L	42	107	47	158
9.	Biochemical Oxygen Demand (BOD)	mg/L	19	58	28	56
10.	Alkalinity as Caco3	mg/L	173	237	194	276
11.	Hardness as CaCO3	mg/L	199	258	226	354
12.	Nitrate as NO3	mg/L	8.7	19.32	10.80	12.85
13.	Phosphate as PO4	mg/L	0.8	1.69	1.67	1.7
14.	Calcium as CaCO3	mg/L	125	132	128	212
15.	Magnesium as CaCO3	mg/L	79	98	95	127
16.	Calcium, Ca2+	mg/L	57	53	48	87
17.	Magnesium, Mg2+	mg/L	26	28	25	31
18.	Chloride as Cl^{1-}	mg/L	86	212	442	605
19.	Sulphate, SO_4^-	mg/L	49	85	67	132
20.	Fluoride, F^{1-}	mg/L	1.0	1.03	1.10	1.13
21.	Silica	mg/L	9.2	7.57	8.31	6.4
22.	Iron, Fe^{3+}	mg/L	0.37	2.8	1.9	1.8
23.	Manganese, Mn^{2+}	mg/L	0.003	0.7	0.56	BDL
24.	Copper, Cu^{2+}	mg/L	0.002	0.003	0.003	0.04
25.	Molybdenum as Mo	Mg/L	0.03	0.08	0.4	0.09
26.	Cadmium, Cd^{2+}	mg/L	BDL	BDL	0.3	0.7
27.	Zinc, Zn^{2+}	mg/L	0.007	0.007	0.003	0.13
28.	Boron as B	mg/L	0.7	1.0	0.8	1.1
29.	Lead, Pb^{2+}	mg/L	BDL	BDL	0.03	0.05
30.	Mercury, Hg^{2+}	mg/L	BDL	BDL	BDL	BDL
31.	Arsenic, As^{3+}	mg/L	BDL	BDL	0.6	0.9

Kanhan River water showed slight turbidity at SW1 station indicating the impact of fly ash pollution from Koradi thermal power plant. The temperature varied from 29 to 30^{0}C and pH from 7.8 to 8.1 showing alkaline water. The turbidity was 8 NTU at SW1 station but very high ranging from 78 to 84 NTU at SW 2 and SW3 stations. The dissolved oxygen (DO) ranged from 5.9 to 6.6 mg/L showing medium self-purification capacity of the river. The conductivity varied from 785 µS/cm at upstream station and 1465 µS/cm at confluence of k-stream and Kanhan River, while it decreased at downstream station to 986 µS/cm. Total dissolved solids (TDS) were recorded as 432 mg/L at SW1 station and 870 mg/l at confluence point (SW2) and slightly lower that is 614 mg/L at downstream station (SW#). The conductivity and total dissolved solids were reduced by 31.3% and 29.4% respectively at downstream station with respect to confluence point due to self-purification capacity of Kanhan River. The COD and BOD levels at SW1 station were 42 mg/L and 19 mg/L respectively, while at confluent station were 107 and 58 mg/L respectively and decreased at downstream station (SW3) 47 and 28 mg/L respectively. These values indicated organic pollution in Kanhan River. The BOD/COD ratio at SW1 to SW3 stations varied from 0.45 to 0.60 and being more than 0.4 indicate easily biodegradable organic pollution in Kanhan River. The contents of silica and chlorides which ranged from 7.57-9.2 mg/L and 86-442 mg/L respectively indicating organic pollution due to wastewater discharges in the Kanhan River. The concentrations of nutrient minerals such as calcium, magnesium, iron, copper, and zinc were 48-57, 25-28, 0.37-2.8, 0.002-0.003, 0.003-0.007 mg/L respectively were sufficient for biological life. The fluoride concentration varied from 1.0-1.1 mg/L which was suitable for dental health of people. The toxic metals such as lead and arsenic were present at concentrations 0.03 mg/L lead at SW3 station and 0, 6 mg/L arsenic in SW3 station. The presence of metals and silica in Kanhan River may be due to leaching of fly ash. Mercury was .not detected in the Kanhan River water. The nitrates (8.7-19.32 mg/L) and phosphates (0.8-1.69 mg/L) in Kanhan River were found to be higher than the normal freshwater bodies. The high content of nitrate-nitrogen indicates the excessive use of chemical fertilizers in the agricultural farms along the river course as well as the discharge of domestic wastewater or industrial wastewater in the river.

Physicochemical characteristics of k-Stream water

The physicochemical characteristics of k-Stream water are shown in Table 2. The colour of the water was milky white and showed the presence of fly ash in water and on the bottom of k-Stream. The overflow of fly ash pond to the k-Stream was observed.

The pH was 8.2 showing alkaline water. The temperature was 30.2^{0}C. The electrical conductivity was 2248 µS/cm which was slightly higher than freshwater streams and indicated higher mineral content in the k-Stream. The turbidity was very high 286 NTU due to particulate matter in suspension. The dissolved oxygen (DO) was 4.5 mg/L Total dissolved solids (TDS) was 1763 mg/L. The COD and BOD values were high namely 105 mg/l and 25 mg/L respectively. The values of COD above 30 mg/L and BOD above 14 mg/L indicate polysaprobic zone or grossly polluted zone of k-Stream. The BOD/COD ratio was 0.24 indicating slowly biodegradable pollutants in the k-Stream water. The k-Stream may be receiving, apart from fly ash from fly ash pond, industrial waste and municipal wastewater from the surrounding areas. The total hardness was 322 mg/L indicating very hard water (Table 3). Total alkalinity was 267 mg/L and indicated the good buffering capacity of water that may be due to wastewater pollution. The nitrate and phosphate concentrations were very high being 0.85 mg/L and 1.7 mg/L respectively, indicating pollution by municipal wastewater. The concentrations of nutrient minerals such as calcium, magnesium, iron, copper, zinc were sufficient for biological life being 87, 24.6, 1.4, 0.02 and 0.13 mg/L respectively.

Table 3: Total hardness and water quality classification

S.N.	Classification of water	Range of total hardness
1.	Soft	0 - 75
2.	Medium hard	75 - 150
3.	Hard	150 - -300
4.	Very hard	>300

The sulphate concentration was 103 mg/L and its low content indicated the absence of putrescible organic zone in the k-Stream water. The concentrations of chlorides and silica were 605 and 6.4 mg/L indicating pollution of the k-Stream water with domestic wastewater. The toxic metals such as cadmium, lead, and arsenic were present at concentrations of 0.07, 0.05 and 0.9 mg/L respectively. The mercury was not detected in water. The fluoride content was 1.13 mg/L being optimum suitable for dental health of people. There was possibility that silica and the metals might have been leached from the fly ash pollution.

Comparison of water samples with irrigation water standard

Table 4 indicate the standard of CPCB and BIS for irrigation water as well as corresponding concentrations of parameters in Kanhan River and k-Stream. Kanhan River water at all the stations showed parameters suitable for irrigation. However, k-Sstream water was not suitable as irrigation water due to chlorides and pH higher than the standard.

Table 4: Comparison of surface water samples with irrigation water standard*

Parameter	Standard	Kanhan River			k-Stream
		SW1	SW2	SW3	SW4
TDS (mg/l)	2100	432	870	614	1663
Chlorides as chlorine (mg/l)	500	86	212	442	605
Boron (mg/l)	2	0.7	1.0	0.8	1.1
Sulphates (mg/l)	1000	49	85	67	132
Conductivity at 25^0C (µs/cm)	3000	785	1465	986	2446
pH	6.0 – 8.0	7.8	7.9	8.1	8.2

*(CPCB, 2001, BIS 1986) [6, 5]

Pollution status of Kanhan River and k-Stream water

The pollution status of Kanahn River and k-Stream as compared to Desirable limit of drinking water standard (IS 10500:2012) [4], which is considered here as normal fresh water, is depicted In Table 5.

Table 5: The percentage increase in water quality parameters above drinking water quality standard as unsuitability for drinking purpose

S.N.	Water Quality Parameter	% increase in k-Stream Water	% increase in Kanhan River
1.	EC	22.3	--
2.	TDS	66.3	--
3.	Total Alkalinity	38.0	18.5 at SW2
4.	Total Hardness	18.0	--
5.	Calcium	16.0	--
6.	Magnesium	3.33	--
7.	Chloride	142.0	76.8 at SW3
8.	Fluoride	13.0	3- 10 at SW2 & SW3
9.	Iron	500.0	23.3-833.3
10.	Cadmium	23233.0	9900 at SW3
11.	Lead	400.0	200 at SW3
12.	Arsenic	8900.0	5900 at SW3
13.	Molybdenum	28.57	14.3 at SW2
14.	Boron	120.0	40-100

The k-Stream is seen to have most of the parameters above the Desirable limit of the standard. The increase in parameters at serial number 1 to 7 ranged from 3.33% to 142%. Above standard. In case of Kanhan River, the most of the parameters are not above the standard except total alkalinity at SW2, chlorides at SW3, and metals. The major observation is that the fluoride and the metal elements are at higher concentrations in both the k-Stream and Kanhan River (especially at SW2 and SW3 stations). This indicates that apart from wastewater source, the natural leaching of metals from fly ash is the main source of these metals to the Kanhan River and the k-Stream. Out of these metals, the metals such as cadmium. Lead, arsenic and molybdenum are highly toxic to public health (Jaishankar et al. 2014) [10], therefore the k-Stream water and Kanhan River water were not suitable for drinking. Tchounwou et al. (2012) [25] reported that due to their high toxicity, arsenic, cadmium, chromium, lead, and mercury are classified under the priority metals that are of public health importance. US EPA also classified them as human carcinogens. The present observation is also supported by the media reports and research articles about the fly ash pollution in KTPS and Koradi thermal power plant area. In December 2020, the fly ash from the fly ash ponds of KTPS was flown into Kanhan River polluting the river water which is used as a source of water supply to Nagpur City (Behl, 2021) [3]. Due to this incident, the soil in agricultural farms using Kanhan River water for irrigation were affected and public health of people was also affected due to consumption of polluted Kanhan River water. Times of India (July 9, 2021) [26] gave reference of *A Status Report of Neglect of Coal Ash Accidents in India in May 2019-May 2021* (by ASAR Social Impact Advisors, Centre for Research on Energy and Clean Air (CREA) and Manthan Adhyayan Kendra) for recurring fly ash breaches from fly ash ponds of Khaparkheda and Koradi Power Plants in Nagpur District polluting the Kanhan River water in the last three years and impacting the livelihood of residents by the side of the river. In KTPS, low grade coal is used which contains large part of quartz and glass particles including soil material. This on burning in power plant forms ferro-aluminosilicates with high content of silica, aluminium and iron. The silica (SiO_2) forms the major part of fly ash, followed by aluminium and iron. The fly ash contains organic matter ranging from 1.9 to 4.5 mg/kg. The total aluminium content ranges from 20.6 to 27.5 percent. The iron content in fly ash ranges from 4.3 to 8.7 percent, the amount of sodium, potassium, calcium, magnesium, and titanium ranges from 0.38-0.66%, 0.31-0.65%, 0.57-1.88%, 0.53-1.32% and 0.98-1.52% respectively. Apart from these elements, some trace elements such as boron, molybdenum, copper, zinc and manganese are present in traces being 165-250 mg/L, 0.76-1.2 mg/L, 40-109 mg/L, 47-136 mg/L, and 100-700 mg/L respectively. These elements leach out from fly ash and pollute the surface water as well as groundwater (Dubey et al., 1999) [7]. Spadoni et al. (2014) [22] also observed that groundwater locally exceeds the concentration limits recommended by the Bureau of Indian Standards (BIS, 2005) [5] and by the World Health Organization (WHO, 2008) [28] for Mg (2+), Ca (2+), NO3 (-), SO4 (2-), total dissolved solids (TDS) and for some minor elements like As, Mo, V and U. Environmental problems are also common in case of many other thermal power plants in India. Adarsh (6 May 2021) [1] reported fly ash pollution of Kosasthalaiyar River near Ennore, which was the source of irrigation water. Fly ash slurry in sea water covered large area of salt pans and crop land and groundwater became salty due to fly ash discharge from NCTPS power plant, 25 km north of Chennai. In Singrauli of Madhya Pradesh, Reliance thermal power plant's fly ash pond breach resulted in flooding of fly ash slurry destroying the houses in villages and farm lands and resulted in deaths of a few villagers (Dutta, April 29, 2020) [10]. Yashwant (July 27, 2020) [30] quoted a recently released report *Coal Ash in India – A Compendium of Disasters, Environmental and Health Risks* which gave details of 76 major coal ash accidents occurred between 2010 and June 2020 which caused extensive pollution of water, air and soil leading to deaths and loss of property in surrounding villages. In October 2019, fly ash dyke breach occurred in case of NTPC's Vindhyachal thermal power plant in Madhya Pradesh and around 3.5 million tonnes of fly ash entered into the Govind Vallabh Pant Sagar also called as Rihand reservoir, the only source of water for Singrauli District in M.P. and Sonbhadra District in U.P. Yashwant (July 27, 2020) [30] reported that fly ash pollution in Ennore River led to reduction in fishery potential and livelihood of fishermen and biomagnificaiton of heavy metals in the fish, prawn and oysters from Ennore River. Severe contamination of groundwater from Seppakkam village near Chennai with cadmium, mercury and chromium was observed as the fly ash pond lacked impervious lining and salt water and heavy metals from fly ash seeped to groundwater (Yashwant, July 27, 2020) [30]. Mehta et al. (1998) [12] reported that the water hyacinth population in Yamuna River showed marked reduction during 1987-1995 due to huge amount of regular disposal of fly ash by Indraprastha Power Station (IPP Stn) and Rajghat Power House (RPH), owned by Delhi Electric Supply Undertaking. Regular monitoring of the quality of surface water around TPPs and mitigation of pollution are important from public health point of view, because more than 90% population in India is dependent on groundwater / surface water for drinking purpose (Yadav et al., 2012; Ramachandraiah, 2004; Tank and Singh, 2010) [29, 17, 25].

Determination of Water Quality Index (WQI)

Water Quality Index (WQI) is a tool to analyse the impact of pollution on surface water and groundwater and it gives a composite rating of impacts of different water quality parameters on water quality (Sahu and Sikdar, 2008) [21]. Water quality index gives the evaluation of surface water quality or groundwater for human consumption. A total of 19 parameters were used to calculate the WQI of surface water quality. Suitable weight (wi) was given to each of 19 select water quality parameters based on their importance in drinking quality of water, highest weight 5 was given to a parameter having highest impact on water quality and the value 2 was given to a parameter with no impact on water quality. Relative weight (Wi) of each parameter was calculated using formula [$Wi = \frac{wi}{\Sigma wi}$] (Table 6).

Table 6: The water quality parameters and their weight and relative weight for determination of WQI for surface water samples

S.N.	Parameter	(IS 10500:2012) Desirable Limit	Weight (wi)	Relative Weight (Wi)
1.	pH	8.5	3	0.0423
2.	EC	2000	3	0.0423
3.	TDS	1000	5	0.0685
4.	Total Alkalinity	200	2	0.0281
5.	Total Hardness	300	3	0.0423
6.	Calcium	75	2	0.0281
7.	Magnesium	30	2	0.0281
8.	Chloride	250	3	0.0423
9.	Sulphate	200	3	0.0423
10.	Nitrate	45	5	0.0704
11.	Fluoride	1.0	3	0.0423
12.	Iron	0.3	4	0.0563
13.	Cadmium	0.003	5	0.0685
14.	Copper	0.05	5	0.0704

15.	Lead	0.01	5	0.0704
16.	Arsenic	0.01	5	0.0704
17.	Molybdenum	0.07	5	0.0704
18.	Boron	0.5	5	0.0704
19.	Zinc	5	5	0.0704
			Σwi = 71	ΣWi = 1.024

Quality rating scale (qi) was calculated by formula [qi = $(\frac{Ci}{Si})\ 100$] where Ci is concentration of each parameter, except pH and conductivity, and Si is standard (Table 7).

Table 7: Calculation of Quality Rating (qi) of each surface water quality parameter

S.N.	Parame-ter	Desira-ble Limit	Concentration in water sample				Quality Rating (qi) qi = $(\frac{Ci}{Si})\ 100$			
			SW1	SW2	SW3	SW4	SW1	SW2	SW3	SW4
1.	pH	8.5	7.8	7.9	8.1	8.2	91.7	92.9	95.3	96.5
2.	EC	2000	785	1465	986	2446	39.3	73.3	49.3	122.3
3.	TDS	1000	432	870	614	1663	43.2	87.0	61.4	166.3
4.	Total Alkalinity	200	173	237	194	276	86.5	118.5	97	138
5.	Total Hardness	300	199	258	226	354	66.3	86	75.3	118
6.	Calcium	75	57	53	48	87	76	70.7	64	116
7.	Magnesium	30	26	28	25	31	86.7	93.3	83.3	103.3
8.	Chloride	250	86	212	442	605	34.4	84.8	176.8	242
9.	Sulphate	200	49	85	67	132	24.5	42.5	33.5	66
10.	Nitrate	45	8.7	19.32	10.80	12.85	19.3	42.9	24	28.6
11.	Fluoride	1.0	1.0	1.03	1.10	1.13	100	103	110	113
12.	Iron	0.3	0.37	2.8	1.9	1.8	123.3	933.3	633.3	600
13.	Cadmium	0.003	0	0	0.3	0.7	0	0	100	23333.3
14.	Copper	0.05	0.002	0.003	0.003	0.04	4	6	6	80
15.	Lead	0.01	0	0	0.03	0.05	0	0	300	500
16.	Arsenic	0.01	0	0	0.6	0.9	0	0	6000	9000
17.	Molybdenum	0.07	0.03	0.08	0.4	0.09	42.9	114.3	571.4	128.6
18.	Boron	0.5	0.7	1.0	0.8	1.1	140	200	160	220
19.	Zinc	5	0.007	0.007	0.003	0.13	0.14	0.14	0.06	2.6

The sub index SI was calculated by formula [SI = Wi x qi]. Finally, water quality Index (WQI) was calculated by formula [WQI = ΣSI] (Table 8).

Table 8: Calculation of sub index (SI) for each surface water parameter

Parameter	Wi	SI = Wiqi			
		SW1	SW2	SW3	SW4
pH	0.0423	3.879	3.93	4.031	4.082
EC	0.0423	1.662	3.101	2.085	5.173
TDS	0.0685	2.959	5.96	4.206	11.392
Total Alkalinity	0.0281	2.431	3.33	2.726	3.878
Total Hardness	0.0423	2.805	3.638	3.185	4.991
Calcium	0.0281	2.136	1.987	1.798	3.260
Magnesium	0.0281	2.436	2.622	2.341	2.903
Chloride	0.0423	1.455	3.587	7.479	10.237
Sulphate	0.0423	1.036	1.798	1.417	2.792
Nitrate	0.0704	1.359	3.020	1.690	2.013
Fluoride	0.0423	4.23	4.357	4.653	4.780
Iron	0.0563	6.942	52.545	35.655	33.78
Cadmium	0.0685	0	0	6.85	1598.331
Copper	0.0704	0.282	0.422	0.422	5.632
Lead	0.0704	0	0	21.12	35.2
Arsenic	0.0704	0	0	422.4	633.6
Molybdenum	0.0704	3.020	8.047	40.227	9.053
Boron	0.0704	9.856	14.08	11.264	15.488
Zinc	0.0704	0.010	0.010	0.004	0.183
	WQI	46.498	112.434	573.553	2386.768

The WQI values are classified into five types namely, excellent water (WQI < 50), good water (50 > WQI < 100), poor water (100>WQI< 200), very poor water (200>WQI<300) and water unsuitable for drinking (WQI >300).

Estimated WQI values indicate that SW1 Kanhan River water quality was excellent, SW2 Kanhan River water at confluence was poor, SW3 Kanhan River water quality at downstream to confluence point and k-Stream water quality were unsuitable for drinking and domestic use.

Conclusion on surface water quality

Determination of the quality of surface water and groundwater is important to evaluate the impact of thermal power plants and urbanisation and the suitability of water for domestic, agricultural or industrial purpose. Fly ash from Koradi and Khaperkheda thermal power plants is disposed of in fly ash pond adjacent to many small villages which use groundwater for drinking and domestic purposes and river water for irrigation. Fly ash and fly ash leachates containing minerals and toxic metals were observed to be one of the reasons to pollute the surface water with minerals and toxic metals.

The physicochemical data and water quality index (WQI) determination indicate that the Kanhan River water at confluence and downstream station and k-Stream water were not suitable for drinking use or for irrigation use.

There is lack of thermal power plant's will towards transparency, accountability, compliance and a governance system with law enforcement, penalization and monitoring as well as towards reuse and recycle of fly ash. Thermal power plants in India need to improve their efforts for environmental management.

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