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Impact of Indiscriminate Disposal of Untreated Effluents From Thermal Power Plant on Water Resources

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Effluents of thermal power plants contain trace elements and heavy metals, needs remediation before discharging to the environment. Heavy metals tend to bioaccumulate in a biological organism, such as fish and thus enter the human food chain. Present study has been carried out to assess the contamination of water sources in Yellur and surrounding villages closer to a thermal power plant in Udupi district, Karnataka State. Water samples from 6 km buffer zone were collected and analyzed for physico-chemical parameters and the core zone (within 2 km) samples were analyzed for heavy and trace metals (Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn) contamination. This study indicates that the well, stream and pond water within the core zone is contaminated with heavy metals and the levels were higher than the maximum acceptable limits of the stipulated drinking water guidelines. Physico-chemical analysis showed DO, turbidity, TDS, chlorides, sodium, potassium and hardness of samples of core zone were exceeding the maximum permissible limits of WHO drinking water guidelines.

KEYWORD

Udupi, Thermal Power Plant, Water pollution, Heavy metals.

INTRODUCTION

In recent years the global energy demand has increased with the advances in industrialization and this has been largely met by fossil fuels. Coal meets 29.6% of global primary energy needs and its share in the world's electricity generation is about 42% (World Coal Association, 2011). India with an installed electricity generating capacity of 190 Gw caters to a population of 1.21 billion. Coal combustion from thermal power plants contributes to 55.32% of the total electricity generation in India (Ministry of Power, 2012). Apart from dwindling stock indigenous coal resources are unable to supplement the increasing energy demands. Conventional generation of electricity from fossil fuel based sources, like coal results in serious environmental problems (pollution of air, water and land) with far reaching local and global implications (global warming and changes in the climate regime). Major pollutants due to coal based power generation include sulphur dioxide, carbon and nitrogen compounds, non-combustible hydrocarbons, heavy metals and flyash.

Major environmental problems associated with the use of coal as fuel in thermal power plants are the likely contamination of air, water and land environment affecting the livelihood of the local people. The disposal of flyash from coal-fired power generation and its possible impacts on the environment, has been a serious environmental problem. The flyash is disposed of either by dry methods of disposal in landfills or by wet methods of disposal where the ash is mixed with water and removed as slurry for settlement in ponds. The supernatants are discharged into a receiving system and the final effluents discharged into a natural aquatic drainage system, like a river. Both these methods of flyash disposal result in metal contamination of surface and groundwater resources and hence can transfer these contaminants into the food chain (Mehra *et al.*, 1998). The major part of flyash is disposed off in unmanaged landfills or lagoons, leads to environmental pollution in the area through flyash erosion and leachate generation (Gupta *et al.*, 2002). Heavy metals, like arsenic, lead, nickel, cobalt, chromium, boron and antimony found in flyash are hazardous for living organisms. These elements released to the soil, surface water and groundwater by leaching processes affects the biota in an ecosystem.

The leaching potential of ash ponds is higher due to diurnal and seasonal variations in temperature, moisture and other parameters (Praharaj *et al.*, 2002). Leaching of soluble ions from ash ponds into the ground water was reported near Vijayawada Thermal Power Station (Suresh *et al.*, 1998). Leachability of metals, such as cadmium, chromium, zinc, lead, mercury and silver (cations) increases with decreasing pH or under acidic conditions (Dwivedi *et al.*, 2008). Al, Fe, Mn and Pb are the major contaminants contributed from the ash pond effluent to the river water in Orissa and their enrichment with respect to the respective prescribed limits confirmed that the river water is contaminated to varying degrees and, therefore, not potable (Tripathy *et al.*, 2002). Bioaccumulation of heavy metals in plants lead to increased elemental composition that eventually enters the food chain. An investigation of flyash contaminated areas in Uttar Pradesh showed the bioaccumulation of heavy metals, like Fe, Zn, Cu, Mo, B, Si, Al, Cr, Pb, Cd, Hg and As in native aquatic, terrestrial and algal species in the vicinity (Rajarshi *et al.*, 2009).

The effluents discharged by thermal power plants (TPP) require treatment, before they are discharged into the fresh water streams. Effluents from thermal power plants include thermal discharges, wastewater effluents (for example cooling tower blow down; ash handling wastewater; wet FGD system discharges; material storage runoff; metal cleaning wastewater and low-volume wastewater) and sanitary wastewater. There is also the release of ash pond decant into the local water bodies from the coal-based industries. Such release of ash pond decant tends to deposit ash all along its path thereby causing fugitive dust nuisance when it dries up. Also when such water mixes with a water body, it increases the turbidity of the water body thereby decreasing the primary productivity. This is harmful to the fisheries and other aquatic biota in the water body. The effect of Tuticorin Thermal Power Plant effluents on Tuticorin coastal water reveal an elevated temperature of coolant water resulted in suppression of phytoplankton, zooplankton, fishes and shell fishes (Selvin *et al.*, 2010). The effect of Tuticorin Power Plant on the Tuticorin Bay is evident from the enhanced water temperature upto 2 km from discharging point apart from the decline of depth of Bay and increased ash layer and turbidity due to sustained discharge of ash slurry (Selvaraj *et al.*, 2000) leading to eutrophication with higher biological oxygen demand (BOD) and reduced levels of dissolved oxygen (DO). The physical (pH, TDS, TS and TSS) and chemical (BOD, DO, CO_2, Cl_2, H_2S, SO_4 and PO_4, etc.) constituents of a water body help to understand the extent of water pollution (Dwivedi and Pandey, 2002). These constituents decide the biotic assemblages and distribution pattern in any water body. In recent years cases related to surface and ground water pollution have increased due to the inadequate environmental protection measures in coal mining and related industries as well as the presence of active and abandoned coal mines, waste dumps, coal washeries, coking coal plants, thermal power plants, steel fertilizer and cement plants (Amita Kiran and Jha, 2011). Overexploitation of ground water has resulted in drying up of wells, salt intrusion in coastal areas and depletion of water resources.

A coal-based thermal power project (with the installed capacity of 1200 Mw) is setup in Udupi District, Karnataka State in the coastal region of India (Figure 1). The region is sandwiched by Western Ghats in the

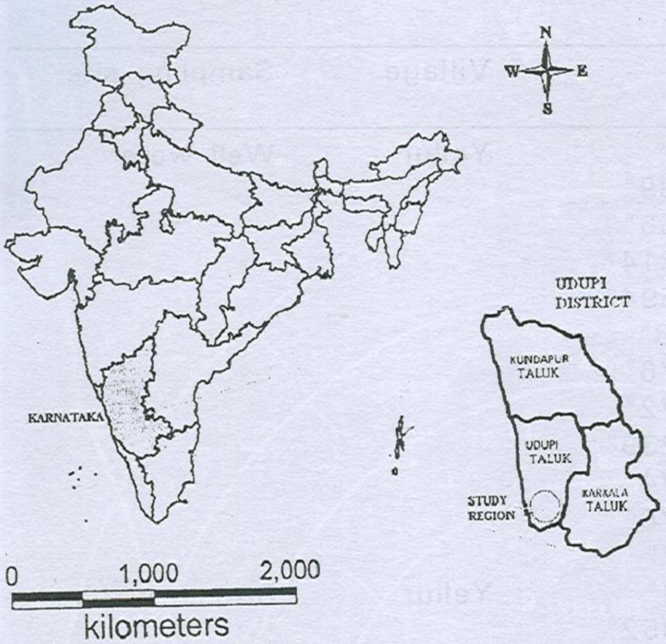

Figure 1. *Study region*

east and Arabian Sea in the west. The river Shambhavi, a tributary to river Mulki flows nearly 4 km south of the Yellur village. The phase 1 of this power plant (600 Mw) achieved commercial operation from June 2010. The water for condenser cooling water system is pumped from Arabian Sea at a distance of 6 km. A re-circulating type natural draft cooling tower has been installed and the sea water is returned after cooling in the cooling towers. The liquid effluents from the Thermal Power Plant are being released to nearby streams. The objective of this study is to analyze the environmental impacts of effluent discharge on the surrounding environment focusing on the surface and ground water quality in the vicinity of thermal power plant.

MATERIAL AND METHOD

Study region : Location - geography, climate, vegetation

A 600 Mw Thermal Power Plant (13.158°N, 74.797°E) located at Yellur panchayath has been operational since June 2010 and supplying electricity to the power distribution company, MESCOM. Field investigations were carried out in a buffer zone of 6 km of TTP (Figure 1) in Yellur as well as surrounding villages of Padebetu, Nadsal (Tenka Yermal), Nandikur, Santhoor, Karnire, Bada and Palimar (and parts of other villages) located in Udupi taluk, Udupi district, Karnataka. Water and soil samples were collected from location marked in figure 2, mainly in the core zone of 2 km around Yellur village. An ash pond is also situated nearly 3.5 km from the TPP in Santhur village (Figure 2). The region has 4 distinct seasons: (1) Rainy season (June-September), (2) warm and damp post-monsoon season (October-November), (3) winter season (December-February) and (4) summer season (March-May). It has a maritime climate with temperatures ranging from 22°C to 36°C, annual average rainfall of 4035 mm and humidity ranging from 61 to 91 % (India Water Portal, http:// www. indiawaterportal.org).

The vegetation in the region is tropical semi-wet with evergreen and deciduous type. Some of the terrestrial flora includes *Acacia sp., Albizziar sp.,* etc. Paddy is the major crop of the region. Pulses, like black gram, green gram, horse gram, cow pea; fruits, like mango, banana, pineapple, jackfruit, sapota; vegetables, like pumpkin, gourd, sweet potato, bean, brinjal, lady's finger, tomato, onion, garlic and horticultural crops, like coconut, arecanut, pepper are grown in the region (Bhat, 2003). There is no any major irrigation scheme in Udupi district. The minor irrigation schemes include both surface water and ground water schemes. The ground water schemes consists of dug wells, shallow and deep tubewells, while surface water schemes includes mainly lift irrigation schemes and surface flow (tanks, anicuts, pickups, barrages). Udupi is one of the 3 coastal districts of Karnataka. Nearly 20% of the work forces are cultivators and 15% are agricultural labourers. About 14% of rural people are involved in household industries. Agriculture is the predominant activity and the net sown area is highest in the taluk (37%). Low cropping intensity is reported due to lack of irrigation facilities. The area under cropping is in decline also due to high cost of cultivations and labour scarcity. Well organized and mechanized marine fishing is a

Table 1. *Sampling locations in the study region.*

Sampling Code	Latitude	Longitude	Village	Sampling site
1	13°15'68"	74°80'746"	Yellur	Well water
2	13°9'25.46"	74°48'27.89"		
3	13°9'9.0354"	74°47'43.55"		
4	13°9'9.0354"	74°47'5.1314"		
5	13°9'10.476"	74°47'1.4594"		
6	13°9'13.09"	74°48"1.28"		
7	13°9'11.56'	74°48'14.76"		
8	13°9'11.844"	74°48'4.572"		
9	13°10'18.1554"	74°47'18.239"		
10	13°10'14.2674"	74°48'34.74"		
11	13°11'21.552"	74°47'6.576"		
12	13°9'57.6354"	74°48'5.22"		
13	13°9'38.73"	74°47'43.4"	Yellur	Stream water
14	13°9'10.5114"	74°47'41.352"		
15	13°9'4.79"	74°47'46.78"		
16	13°9'38.95"	74°47'44.18"		
17	13°9'8.69"	74°47'45.03"	Yellur	Pond water
18	13°9'38.7354"	74°47'43.403"		
19	13°9'41.9"	74°48'42.74"	Santhur	Well water
20	13°947.63"	74°49'45.12"		
21	13°8'51.072"	74°49'56.1"		
22	13°9'27.4674"	74°47'1.248"	Padebetu	Well water
23	13°9'36.8994"	74°46'54.804"		
24	13°8'47.652"	74°48'1.332"	Nandikur	Well water
25	13°8'12.9114"	74°48'21.636"		
26	13°10'54.4434"	74°48'7.8514"	Kathyar	Well water
27	13°10'31.044"	74°52'5.7794"	Belman	Well water
28	13°7'14.8434"	74°48'0.7594"	Karnire	Well water
29	13°8'52.73"	74°45'35.54"	Nadsal	Well water

major source of income for the coastal inhabitants. Large and medium scale industries in the region include cashew-nut processing, rice mills, coconut powder units, fish canning and processing, fish meals and fish oil units, fish net manufacturing, printing units, granite units, readymade garments, auto parts, etc., (Udupi District, Human Development Report, 2008). The study region is part of Padubidri Industrial Area as recognized by the Karnataka Industrial Areas Development Board (KIADB).

Method

Water samples were collected depending upon accessibility and availability from open wells, bore wells, ponds, streams, etc., within a 2 km core zone as well as 6 km buffer zone around the TPP site during August 2011. These sampling locations were assigned codes (ranging from I to 29) and spatially mapped over the study region (Figure 2). Two villages beyond the buffer zone were also visited for sampling to understand the impact (if any) beyond the study region. Table 1 lists the sampling locations alongwith villages collected during field visits. Water samples were collected in 1L disinfected (acid washed) polythene bottles. Water quality parameters were analyzed as per the standard protocol (APHA, 1995). Water samples from the core zone were ana-

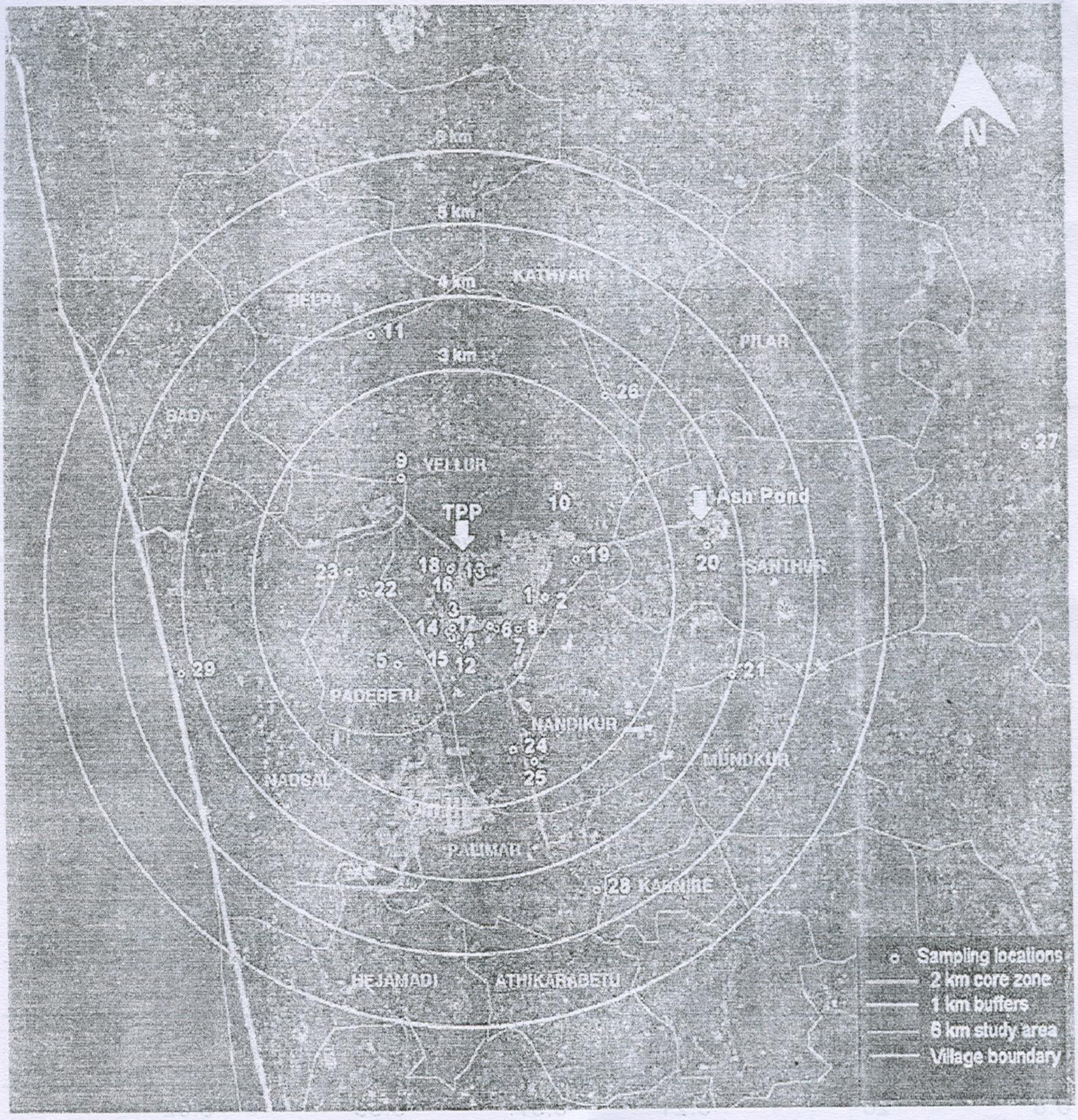

Figure 2. *Sampling locations in the study region with village boundries; concentric circles 1 km apart depict the different strategic sampling zones*

lyzed for heavy metals, like cadmium, chromium, copper, iron, manganese, nickel, lead and zinc. The quantitative estimation of heavy metals was done with the help of ICP- OES (Thermo-iCAP 6000 Series) to know the concentrations of heavy metals in water.

RESULT AND DISCUSSION

Physico-chemical analysis

Table 2 lists the physico-chemical parameters of water samples and table 3 gives the maximum permissible limits (MPL) and the samples which deviate from MPL.

Table 2. *Physico-chemical analysis of collected water samples, in ppm*

Sampling code	DO	Water temp., °C	pH	Turbidity, NTU	TDS	Chloride (Cl^-)	Sodium (Na^+)	Potassium (K^+)
1	1.73	28.7	4.5	1.65	51	19.9	13.1	1.3
2	1.06	28.6	4.4	0.72	465	258	169	7
3	5.01	27	3.8	2.2	1200	593	542	4
4	3.24	28.4	4.1	3.61	947	557	26	6
5	3.04	28.3	4.6	1.26	78	36.9	31.6	1.2
6	1.18	29.8	4.9	2.49	167	90.9	60.4	1.7
7	2.96	28.5	4.7	0.89	142	73.8	47.5	1.7
8	2.68	27.4	5.1	4.69	197	105	64.2	1.4
9	5.38	27.1	5.4	0.65	96	28.4	27.8	1.4
10	7.4	27	5.7	21.4	56	11.4	7.7	1.7
11	3.93	28	4.3	0.46	43	5.68	2.8	0.4
12	3.9	28	5.4	104	454	1385	595	10
13	3.3	27.7	5.6	9.81	352	193	96	3
14	0.74	29.6	6.1	176	2304	1747	1755	32.5
15	7.6	26.7	5.4	36.2	4928	3862	915	30
16	4.34	28.6	4.1	3.44	540	483	299	2
17	7.9	27.6	2.9	43	8976	4672	380	30
18	5.88	27.6	3.6	26	4120	3238	300	25
19	3.71	28	5.8	4.79	116	36.9	35.1	6.4
20	2.94	28.4	6.6	65.6	156	5.68	25	0
21	3.42	28 8	4.1	1.45	81	11.4	7.6	0.9
22	8.81	26.1	5.7	22	118	28.4	27.2	18.1
23	3.4	27.6	5.3	0.65	78	17	25.7	1.5
24	4.24	28.6	4.8	2.74	53	14.2	7.2	1
25	2.37	30.6	4.8	0.52	41	17	7.2	1.7
26	2.83	28.5	3.9	0.35	63	14.2	9.5	1.1
27	4.8	28	4.9	0 77	37	8.52	2.2	0.9
28	3.73	27.7	5.9	135	145	28.4	14.8	4.8
29	4.2	27.9	6.8	4.3	289	93.7	1 3.4	12.9

Table 2. *Continue*

Alkalinity	Total hardness	Ca	Mg	Nitrate	Phosphate
0.8	20	3.21	0.97	0.09	0.02
0.4	80	14.4	10.7	0.06	0.03
0.8	168	40.08	16.57	0.11	0.13
0.4	132	19.24	20.47	0.1	0.01
0.8	32	3.21	5.85	0.05	0.01
0.8	44	12.83	2.92	0.11	0.02
0.8	36	8.02	3.9	0.14	0.01
1.2	44	9.62	4.87	0.11	0.02
0.8	12	3.21	0.97	0.22	0.01
0.8	16	4.81	0.97	0.22	0.04
0.8	24	1.6	4.87	0.15	0.01

0.8	516	59.3	89.7	0.1	0.03
0.8	76	4.81	15.6	0.07	0.21
2	636	81.76	105.3	0.13	0.02
0.04	580	72.14	97.46	5.8	2.37
0.5	86	15.23	11.69	0.2	1.77
0	1520	160.3	282.6	9.3	1.18
0.07	580	88.18	141.3	7	1.69
0.5	60	23.25	0.49	4.5	1.7
3.2	88	3.21	19.49	0.26	0.02
0.8	16	3.21	1.95	0.15	0.14
1.6	40	14.43	0.97	0.13	0.03
1.2	44	8.02	5.85	0.16	0.02
0.8	16	4.81	0.97	0.18	0.07
1.2	20	6.41	0.97	0.14	0.02
0.4	12	3.21	0.97	0.15	0.01
0.6	20	6.41	0.97	0.15	0.01
1.6	60	19.24	2.92	0.14	0.04
1.8	68	20.04	5.36	0.3	2.3

Dissolved oxygen : The amount of dissolved oxygen (DO) in an aquatic system is an indicator of its health as DO helps in the respiration. The presence of organic wastes imposes a very high oxygen demand on the receiving water leading to oxygen depletion with severe impacts on the water ecosystem. The effluents also constitute heavy metals, organic toxins, oils, volatile organics, nutrients and solids. TPP effluents cause temperature difference in the water and reduce the available oxygen. The DO of the analyzed water samples varied between 0.74 to 8.81 ppm. Only 7 samples had DO more than 5 ppm. It decreased with increasing temperature similar to earlier reports (Selvin *et al.*, 2010). Lower DO values are indicative of fast oxidizing chemicals in the immediate vicinity. DO in the surface waters were substantially low compared to the ground water systems, due to effluents discharge. Reduced aquatic biodiversity in the nearby streams and ponds further corroborates of lower DO, similar to Bholakpur (Rasheed *et al.*, 2011).

Turbidity : Turbidity in water is caused by suspended and colloidal matter, such as clay, silts, finely divided organic and inorganic matter, plankton and other microscopic organisms, waste discharge and sediments from erosion. Turbidity values of the collected samples ranged from 0.35 to 176 NTU beyond permissible limit. Among the collected samples, 8 samples mostly found in the immediate vicinity of the TPP were above the acceptable range. The stream water (sample no. 8) showed extremely high turbidity (I76 NTU) due to direct disposal of black coal mix effluent. Sample 15 was observed to be a finely suspended red colour solution with turbidity values of 26 NTU while the nearby stream was having a turbidity value of 36 NTU. This is due to the direct discharge of effluents to streams and subsequent leaching to ground water resources. Turbidity decreased with increasing distance from the power plant. The turbidity of well water sample (sample no. 20) near to the ash pond was about 65 due to leaching of ions from ash pond and sediments from erosion caused due to improper lining of ash pond.

Total dissolved solid (TDS) : TDS affect the water quality in myriad of ways impacting the domestic water usage for cleaning, bathing, etc., as well as drinking purposes

Table 3. *Various parameters analyzed and range of their values in the collected water samples of study region, in ppm*

Parameter	Range	Maximum permissible limits as per WHO	No. of samples within permissible limit	No. of samples above permissible limit
DO	0.74 to 8.81	>5	22 (75.9%)	7 (24.1%)
pH	2.9 to 6.8	6.5-9	2 (6.9%)	27 (93.1%)
Turbidity, NTU	0.35 to 176	10	21 (72.4%)	8 (27.6%)
TDS	37 to 8976	1500	25 (86.2%)	4 (13.8%)
Chloride	5 to 4672	1000	24 (82.8%)	5 (17.2%)
Sodium	2.2 to 1755	200	22 (75.9%)	7 (24.1%)
Potassium	0 to 32.5	10	23 (79.3%)	6 (20.7%)
Alkalinity	0 to 3.2	600	29 (100%)	0
Total hardness	12 to 1520	600	27 (93.1%)	2 (6.9%)
Calcium-Ca	1.6 to 160	200	29 (100%)	0
Magnesium-Mg	0.49 to 282	100	26 (89.7%)	3 (10.3%)
COD	2 to 78	10	23 (79.3%)	6 (20.7%)
Nitrate	0.05 to 9.3	45	29 (100%)	0
Phosphate	0.01 to 2.4	5	29 (100%)	0

Table 4. *Heavy metal analysis of water samples collected from the study region, in mg/L*

Sample	14	18	15	17	2	Range	Maximum permissible limit as per WHO	No. of samples within permissible limit	No. of samples above permissible limit
Cd	0.00	0.68	1.00	5.02	0.03	0-5.02	0.003	1(20%)	4(80%)
Co	0.01	0.02	0.06	0.09	0.00	0-0.09	0.01	2 (40%)	3 (60%)
Cr	0.08	0.09	0.19	0.28	0.09	0.08-0.28	0.05	0	5 (100%)
Cu	0.15	0.03	0.12	0.12	0.19	0.03-0.19	0.05	1(20%)	4 (80%)
Fe	4.39	11.86	14.85	94.14	1.22	1.22-94.14	0.3	0	5(100%)
Mn	0.27	3.53	3.73	8.49	0.20	0.2-8.49	0.5	0	5(100%)
Ni	0.01	0.13	0.14	0.01	0.01	0.01-0.14	0.02	3(60%)	2(40%)
Pb	0.07	0.06	0.10	0.16	0.83	0.1-0.83	0.01	0	5(100%)
Zn	7.42	0.37	0.26	0.15	4.27	0.15-7.42	3	4(80%)	1(20%)

(APHA, 1995). Surface as well as groundwater with high dissolved solids are of inferior flavour and induce an unfavourable physiological reaction to the dependent population. The TDS values in the samples analysed, ranged from 37 to 8970 ppm across all locations. Among them, 4 samples were above the desirable limit. The water samples 17 and 18 (well and pond) which is in core region has maximum values ranging from 4120 - 8976 ppm. The stream water sample (15) had high TDS of 4928 ppm due to effluents rich surface run off as well as salt deposits. This would eventually result in higher build up of total solids in surface and ground water making it more unpalatable and hard to be used for domestic purposes. The results are comparable to ground water samples from 13 stations around a distance of 10 km and closer to ash pond at Vijayawada Thermal Power Station, Andhra Pradesh (Suresh *et el.*, 1998).

Chloride : Chlorides are essentially potential anionic radical that imparts chlorosity to the waters and considered as a pollution indicator (Zafar, 1964; Kumar 1995). An excess of chlorides leads to the formation of potentially carcinogenic and chloro-organic compounds like chloroform, etc. Chloride values in samples ranged from 5 to 4670 ppm. Among the collected samples, 5 samples exceeded the permissible limits. Samples from well (12), pond (17, 18) and streams (14, 15) from Yellur village (within 2 m from TPP) showed very high chloride values due to the discharge of hyper concentrated salt solutions and effluents from the TPP. High chloride content has deleterious effect on metallic pipes and agricultural crops. Certain areas within the core zone are affected by chloride contamination due to the discharge of effluents. Similar results were reported in Satpura reservoir due to the effluents discharged from Thermal Power Plant at Sarni, Madhya Pradesh (Sanhitha *et al.,* 1997) and within 10 m of Vijayawada Thermal Power Station (Suresh *et al.,* 1998). Chloride values showed decreasing trend as moved away from TPP.

Sodium : Sodium (Na) is one of the essential cations that stimulate various physiological processes and functioning of nervous system, excretory system and membrane transport in animals and humans. Increase of sodium ions has a negative impact on blood circulation, nervous coordination, thence affecting the hygiene and health of the nearby localities. According to WHO guidelines the maximum admissible limit is 200 ppm. In this study the concentration of sodium ranged from 2.2 - 1755 ppm (sample 14). Water samples of wells (3 and 12) were exceeding permissible limits.

Potassium : Potassium (K) is an essential element for both plant and animal nutrition and occurs in ground waters as a result of mineral dissolution, decomposing of plant materials and also from agricultural runoff. Potassium ions in the plant root systems helps in the cation exchange capacity to transfer essential cations, like Ca and Mg from the soil systems into the vascular systems in the plants in replacement with the potassium ions. Incidence of higher potassium levels in soil system affects the solute transfer (active and passive) through the vascular conducting elements to the different parts of the plants. The potassium content in the water samples ranges between 0-32.5 ppm and about 6 samples were above the permissible limits.

Alkalinity : Alkalinity is a measure of the buffering capacity of water contributed by the dynamic equilibrium between carbonic acid, bicarbonates and carbonates in water. Sometimes excess of hydroxyl ions, phosphate and organic acids in water causes alkalinity. High alkalinity imparts bitter taste. The acceptable limit of alkalinity is 600 ppm. The water samples analyzed were having lower alkalinities because of acidic environment in the soil systems.

Total hardness : Hardness is the measure of dissolved minerals that decides the utility of water for domestic purposes. Hardness is mainly due to the presence of carbonates and bicarbonates. It is also caused by variety of dissolved polyvalent metallic ions predominantly calcium and magnesium cation although other cations, like barium, iron, manganese, strontium and zinc also contribute. In the present study, the total hardness ranged between 12 to 1520 ppm. Throughout the analysis in the due course of the study, 2 samples were observed to have exceeded the permissible limits of 600 ppm. The pond water sample (17) and nearby stream (8) consistently showed higher values. Earlier studies also report of increased total hardness values (Suresh *et al.,* 1998; Sanhitha *et al.,* 1997).

Calcium : Calcium (Ca) is one amongst the major macro nutrients which are needed for the growth, development and reproduction in case of both plants and animals. The presence of Ca in water is mainly due to its passage through deposits of limestone, dolomite, gypsum and other gypsiferous materials (Manivasakam, 1989). Ca concentration in all samples analyzed periodically

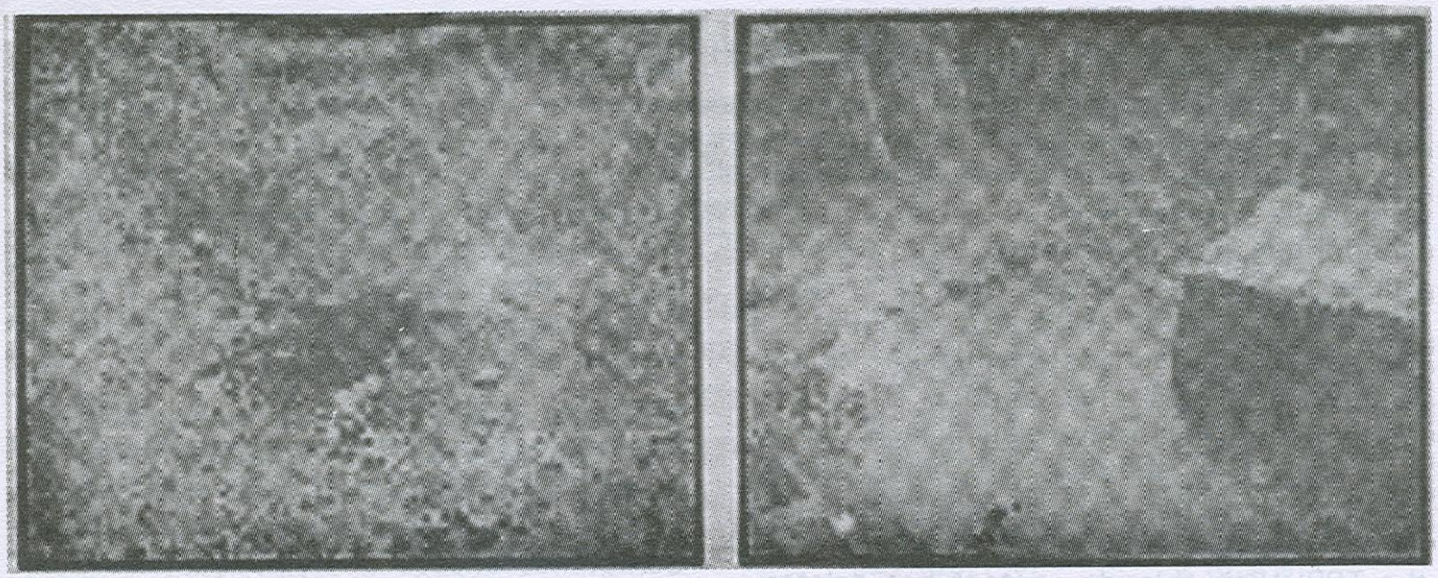

Figure 3. *Effuents from thermal power plant mixing with stream water*

ranged between 1.6 to 160 ppm.

Magnesium : Magnesium (Mg) in one of the most essential macro nutrients that helps as a cofactor in the enzyme systems and in the central metal ions that constitutes the chlorophyll molecule essential for plant photosynthesis. In this study the concentration of magnesium ranged from 0.97-282 ppm. Total 3 samples were above the maximum permissible limits of 50 ppm and are comparable to earlier reports in similar environment (Suresh *et al.,* 1998; Sanhitha *et al.,* 1997). This indicated Mg accumulation in the water systems resulting in the increase in overall hardness of water making it unpalatable and unsuitable for any domestic applications.

Nutrient (nitrate and phosphate) : Nutrients essentially comprise of various forms of N and P which readily dissolve in solutions that are uptaken by microbes and plant root systems in the form of inorganic mineral ions. Accumulation of N as nitrates and P as inorganic P in aquatic ecosystems causes significant water quality problems due to higher net productivity. Together with phosphorus, nitrates in excess amounts in streams and other surface waters can accelerate aquatic plant growth causing rapid oxygen depletion or eutrophication in the water. Nitrates at high concentrations (10 mg/L or higher) in surface and groundwater used for human consumption are particularly toxic to young children affecting the oxygen carrying capacity of blood cells (RBC) causing cyanosis (methemoglobin-emia). In the present study, nitrate values ranged from 0.05 to 9.3 ppm and phosphate values ranged between 0.01 to 2.4 ppm.

Trace and heavy metal analysis

Table 4 gives the account of heavy metals of water samples analyzed from core region and the samples exceeding the maximum permissible limits.

Cadmium: Concentrations of cadmium ranged from 0 to 5.02 mg/L and are above maximum permissible limits in most samples. Sample 17 (pond water) showed the maximum amount of cadmium (5.02 mg/mL). These results are comparable to the earlier reports (Baba *et al.,* 2003; Prashant *et al.,* 2011; Ahmet *et al.,* 2004). Cadmium is extremely toxic and accumulates in the kidneys and liver, with prolonged intake at low levels sometimes leading to disfunction of the kidneys (APHA, 1995).

Cobalt : Concentration of cobalt ranged from 0 to 0.09 mg/L and the sample 17 (pond water) showed high value of 0.09 mg/L. Cobalt occurs only sparingly in ores usually as the sulphide or the arsenide. It is widely used in alloys of various steels in electro-

Figure 4. *Contaminated open well water*

plating in fertilizers and in porcelain and glass. Toxic effect of Co includes loss of body weight and depressed appetite.

Chromium : Chromium is used in alloys in electroplating and in pigments. Chromate compounds frequently are added to cooling water for corrosion control. Hexavalent chromium compounds have been shown to be carcinogenic by inhalation and are corrosive to tissue (APHA, 1995).Thc concentration of chromium was between 0.08 and 0.28 mg/L exceeding the permissible limits illustrate contamination due to the direct discharge of effluents.

Copper : Copper salts are used in water supply systems to control biological growths ill reservoirs and distribution pipes. In this study the concentration of copper ranged between 0.03 and 0.19 mg/L exceeding permissible limits.

Iron : The concentration of Fe ranges from 1.22 to 94.14 mg/L exceeding the perrnissible limits. Iron may be present in drinking water as a result of the use of iron coagulants or the corrosion of steel and cast iron pipes during water distribution. Acute Fe toxicity causes vomiting, gastroenteritis. haemorrhage, cardiac depression, metabolic acidosis. Fe ingestion in large quantities results in a condition known as heamochromatosis (normal regulatory mechanism do not operate effectively), where in tissue damage results from iron accumulation (WHO, 2011).

Manganese : It is a trace element. On exposure to air, groundwater containing Mn will precipitate black MnO_2. The presence of manganese in drinking-water, like that of iron, may lead to the accumulation of deposits in the distribution system. At levels exceeding 0.1 mg/L, manganese in water supplies causes an undesirable taste in beverages and stains sanitary ware and laundry (WHO, 2011). The concentration of Mn exceeded the permissible limits in all the samples due to effluent discharge from TPP. Ahmet *et al.* (2004) reported higher Mn concentrations in ground waters near Yatagan TPP, Turkey.

Nickel : The concentration of Ni ranged between 0.01 and 14 mg/L and about 40% samples showed high nickel. Possible sources of nickel contamination in surface water include anthropogenic sources, combustion of fossil fuels, battery wastes, components of steel (Puttaih *et al.*, 2008; Prashant *et al.*, 2011).

Lead : Lead in a water supply may come from industrial mine and smelter discharges or from the dissolution of plumbing and plumbing fixtures. It is toxic by ingestion and cumulative poison. The concentration of Pb ranged from 0.1 to 0.83 mg/L, exceeding permissible limits as reported earlier in well water samples near Yatagan Power Plant (Baba *et al.*, 2003) and drinking water resources near Anpara and Renusagar Thermal Power Plants (Prashant *et al.*, 2011).

Zinc : Zinc commonly enters domestic water from deterioration of galvanized iron, disinfection of brass and also from industrial pollution (APHA, 1995). The concentration of zinc varied from 0.15 to 7.42 mg/L. 20% of samples was above the permissible limits.

Analysis of water samples collected from the core region (2 km from TPP) illustrate the contamination of water resources in the surrounding villages Yellur, Nandikur and

Padebetu, Santhur and Nadisal due to mismanagement of TPP effluents. The effluents containing heavy metals and trace metals are being released by Thermal Power Plant to the nearby streams, which leach contaminating the ground water resources. The leaching of heavy metals is very high near thermal power plants (Prashanth *et al.,* 2010, Sivakumar and Dutta, 1996; Querol *et al.,* 1993). Field investigations also revealed stunted growth of saplings (very evident in the TPP's green belt), drying of leaves, corrosion of metals and resultant damage to tin roofs, dish antennas, transmission lines, railway tracks, fencing of TPP boundary, enhanced respiratory diseases, nonpalatable grasses (livestock refrain from feeding on grasses), etc. This is due to deposition of supersaturated saline mist on soil and foliage. The saline mist gets released from the cooling towers, which is locally dispersed by the wind to the nearby localities even upto 2 km. The altitudinal gradient of the location has also enhanced the dispersion. Salt deposition on: (1) Foliage has resulted in 'leaf burn' as leaf tissue is damaged due to contact with highly ionized salts, (2) crops, has attenuated the yield due to phyto-toxicity, (3) metal fixtures and accessories leading to corrosion due to the formation of metal oxides.

CONCLUSION

Physico-chemical and heavy metal analysis of 29 water samples collected in core region (within 2 km of TPP) show of lower DO and higher values of TDS, turbidity, chlorides, sodium, potassium, magnesium and total hardness levels. Water samples collected from Yellur, Padebetu, Nandikur and Santhur villages which were within 2-4 km from TPP exceeded the permissible limits. All samples within the core zone reveal heavy metals and trace elements contamination exceeding the permissible limits. Mismanagement is evident from the coal washed water draining to the nearby streams, which has enhanced the ionic concentrations. Apart from these, due to deposition of supersaturated saline mist on soil and foliage has resulted in the stunted growth of saplings (very evident in the TPP's green belt), drying of leaves, corrosion of metals and resultant damage to tin roofs, dish antennas, transmission lines, railway tracks, fencing of TPP boundary, enhanced respiratory diseases, non-palatable grasses (livestock refrain from feeding on grasses), etc. The saline mist gets released from the cooling towers, which is locally dispersed by the wind to the nearby localities even upto 2 km. Heavy metals being leached out from the plant contaminated the water resources nearby and has affected the health and livelihood of local people.

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