Multivariate Statistical Interpretation of Physico-Chemical and Radiological Parameters of Tapi River Water Due to the Operation of Kakrapar Atomic Power Station

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Abstract- **Eleven physico-chemical and three radiological parameters were studied in eight different sampling locations from upstream and downstream of Tapi river water due to the operation of the Pressurised Heavy Water Reactor (PHWR) located at Kakrapar. Different multivariate statistical techniques such as Cluster Analysis (CA), Factor Analysis (FA)/ Principal Component Analysis (PCA) were applied for evaluation of temporal/spatial variations of water quality data obtained during 2007-2009. The PCA of the four data sets evolved three PCs each for all the regions with eigen value > 1, explaining 57.4, 62.5, 55.7 and 70.0% of the total variance in respective water quality data sets. CA of grouping all the eight sampling locations on the aquatic system into three statistically significant clusters at (D_{link}/D_{max}) x 100 < 70. CA technique was found to be useful in offering a reliable classification of the surface water. No significant seasonal variations were observed except temperature. The results of physico-chemical parameters were well within the Central Pollution Control Board (CPCB), India prescribed limits. The radioactivity levels of ^{137}Cs, ^{90}Sr and ^{3}H activity were also well within the prescribed technical specification limit by Atomic Energy Regulatory Board (AERB), India. The present study demonstrated the insignificant impact on aquatic environment due to operation of Kakrapar Atomic Power Station.**

Keywords- KAPS; Physico-Chemical Parameters; Radiological Parameters; Tapi River

I. INTRODUCTION

The quality of surface water is a very sensitive issue. Anthropogenic influences (urban, industrial and agricultural activities, increasing consumption of water resources) as well as natural processes (changes in precipitation inputs, erosion and weathering of crustal materials) degrade surface water and impair their use for drinking, industrial, agricultural, recreational or other purposes [1]. The ecosystem services of watercourses such as rivers and lakes directly or indirectly contribute to both human welfare and aquatic ecosystem [2]. Rivers are highly vulnerable to pollution. Therefore it is important to control water pollution, monitor water quality in rivers [3] and interprete the temporal and spatial variations in water quality [4-5]. The origin of Tapi River is Mount Vindhya of Satpura range in Maharashtra. It has a total length of 702 km and occupies an area of 65,300 square km. It has got catchment area of 48.14 km^2.

The requirement of Kakrapar Atomic Power Station (KAPS) for the process of cooling and raw water system is met from the Moticher Lake which is a balancing reservoir between the Kakrapar weir (left bank canal) and the Ratania regulator. KAPS draws 2.77 m^3 sec^{-1} of water from Moticher Lake and after utilization in the plant system, it discharges 2.08 m^3 sec^{-1} of water through the discharge point (Blow-down) into the Moticher Lake.

Radioactive liquid waste is generated during the operation and maintenance of Pressurised Heavy Water Reactors (PHWRs). The liquid waste mainly contains ^{3}H, $^{134+137}$Cs, ^{90}Sr, ^{60}Co, ^{65}Zn, ^{54}Mn etc. Among these radionuclides, the major activity is due to ^{3}H. Barring the ^{3}H activity, the other important radionuclides which contribute to the activity of the liquid waste are $^{134+137}$Cs, ^{90}Sr and ^{60}Co. Generally low-level liquid waste is diluted and then discharged into the nearby water-body through blowdown water discharge line as per the standard waste management practice. The Moticher lake water is partly mixed with Tapi River through the Koliwada regulator (1.38 m^3 sec^{-1}). The objective of this study is to characterize and assess the physico-chemical and radiological parameters of Tapi River due to the operations of KAPS.

II. MATERIAL AND METHODS

A. Study Area

This study was carried out at Kakrapar, Gujarat, India as shown in Fig. 1. Kakrapar is situated on the southern bank of Moticher Lake, which is about 85 km by road from Surat city, in the southern region of Gujarat State (Latitude-21o 14' N and longitude-73^{o}22' E). This study was also carried out upto Kamrej (75 km from Kakrapar near Surat city).

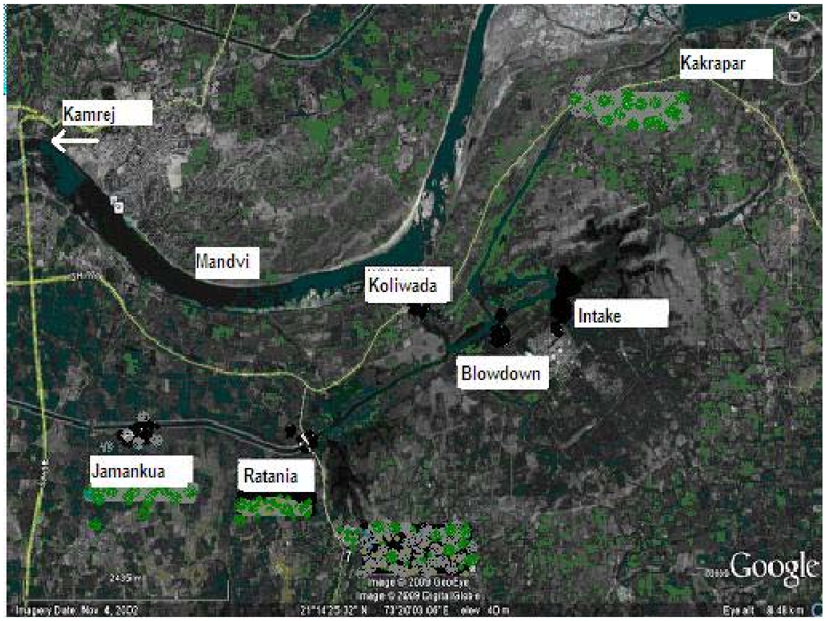

Fig. 1 Sampling Location

B. Sample Collection and Analytical Methods

The water samples were collected from eight different sampling locations (Upstream: Kakrapar, Intake point; discharge point of KAPS: Blowdown; downstream: Ratania, Koliwada and Jamankua; Tapi river: Mandvi and Kamrej). The Physico-chemical parameters (Temperature, Conductivity, pH, Chloride, Total Solid (TS), Total Dissolved Solid (TDS), Total Suspended Solid (TSS), Oil & grease, Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), Biological Oxygen Demand (BOD)) and radiological parameters (137Cs , 90Sr , 3H) were measured in water samples on a monthly basis.

The samples were radio-chemically analysed for 137Cs and 90Sr as per the standard method [6] and counted using gas flow low background beta counter. For 3H analysis, 4 ml of the sample was mixed with 15 ml scintillator cocktail (consisting of 7.0 g PPO, 0.12 g POPOP and 100 g Naphthalene in one liter of 1-4 Dioxane solvent) and counted using Ultra-low-level Liquid Scintillation Spectrometer (LSS) system, Model: TRICARB-3170 TR/SL). The counting system was calibrated with a 3H standard supplied by Amersham International. The system background count rate was 1-2 counts per minute and the counting efficiency of the LSS system for detection of 3H was about 25%. Water quality parameters, their units and standard methods of analysis [7] are summarized in Table I.

TABLE I WATER QUALITY PARAMETERS ASSOCIATED WITH THEIR ABBREVIATIONS, UNITS AND ANALYTICAL METHODS USED

Parameters	Abbreviations	Unit	Analytical Methods
Temperature	Temp	^{0}C	Thermometer
pH	pH	PH unit	PH meter
Electrical conductivity	EC	µS cm^{-1}	Electrometric
Chloride	Cl^{-}	mg l^{-1}	Tritimetric
Dissolved Oxygen	DO	mg l^{-1}	Prob method
Chemical Oxygen Demand	COD	mg l^{-1}	Dichromate Method
Biological oxygen demand	BOD	mg l^{-1}	Winkler azide method
Total solids	TS	mg l^{-1}	Gravimetric
Total dissolved solids	TDS	mg l^{-1}	Gravimetric
Total suspended solids	TDS	mg l^{-1}	Gravimetric
Oil & grease	Oil & grease	mg l^{-1}	Gravimetric
Radio Caesium	^{137}Cs	mBq l^{-1}	Ion exchange
Radio Strontium	^{90}Sr	mBq l^{-1}	Precipitation
Tritium	^{3}H	Bq l^{-1}	Scintillation

C. Data Treatment by Statistical Method

All mathematical and statistical computations were performed using Excel 2003 (Microsoft Office) and

STATISTICA 1999 (StatSoft Inc.). Multivariate analysis of the Tapi River water quality data set was performed through principal component and cluster analysis techniques [8-10].

III. RESULTS AND DISCUSSION

A. Physico-Chemical Parameters

The basic statistics of 11 water quality parameters based on 198 water samples collected during 2007-2009 are summarised in Table II. In most cases, pH measurements were found to be in the GPCB/CPCB permissible limit i.e 6.5-8.5. Out of 198 cases, only in 4 cases (samples collected on 6th March 2008, 6th February 2009, 3rd October 2009 and 5th February 2010), pH was found to be above 8.5. The maximum pH was found to be 8.8 sampled on 3rd October 2009. The parameters such as conductivity, temp., COD, BOD, DO, TSS, Oil & grease and Cl- are observed to be well within the CPCB permissible limit [11]. The sample collected on 1st July 2008 from Mandvi showed the maximum TS (615 mg l-1) and TDS (590 mg l-1) respectively.

TABLE II SUMMARY OF BASIC STATISTICS OF WATER QUALITY PARAMETERS OF SURFACE WATER SAMPLES COLLECTED AROUND KAKRAPAR

Parameter	No. of Samples	Minimum	Maximum	Mean	Std.Dev.	Median	Skewness	Kurtosis	GPCB/ CPCB Permissible Limit (1986)
pH	198	7.1	8.8	8.1	0.3	8.1	-0.6	0.0	6.5-8.5
Cond. (µS cm^{-1})	198	235.0	1001.0	313.9	68.1	305.0	5.6	52.4	2250
Temp. (^{0}C)	198	17.5	40.0	27.7	4.0	28.0	-0.1	0.4	40
COD (mg l^{-1})	198	3.2	33.6	8.8	3.0	8.8	5.1	38.4	250
BOD (mg l^{-1})	198	0.7	5.8	3.3	1.1	3.3	-0.1	-0.1	$BOD_3$20
DO (mg l^{-1})	198	1.3	7.7	5.8	0.9	5.9	-0.8	2.8	>4.0
TS (mg l^{-1})	198	150.0	615.0	204.8	41.5	197.5	5.5	48.7	600
TDS (mg l^{-1})	198	128.0	590.0	185.1	40.9	178.5	5.5	49.3	500
TSS (mg l^{-1})	198	4.0	42.0	21.6	5.8	22.0	0.8	5.9	100
Oil & Grease (mg l^{-1})	198	1.1	5.5	2.7	0.9	2.5	0.8	0.2	14
Cl$^-$(mg l^{-1})	198	16.0	170.0	24.7	12.7	22.0	8.8	92.7	250

Location-wise variation of water quality parameters are represented in Fig. 2. The parameters such as conductivity, TS, TDS, TSS, BOD, COD and Cl- were observed to be more at Mandvi and Kamrej. The reasons for the higher concentration of these parameters may be due to factors such as washing and bathing activity by the public, sewage disposal etc. The maximum temperature was observed to be at the discharge point of KAPS. However it is well within the limit of CPCB: 40 0C [12]. Seasonal variation of water quality parameters are represented through the Box & Whisker plot, as shown in Fig. 3. Significant variation in most water quality parameters are not observed in different seasons, except for the variation in temperature. The variation of temperature shows a distinct seasonal effect. Elmanama et al., 2006 studied the seasonal and spatial variation in the monitoring parameters of Gaza beach during 2002-2003[13].

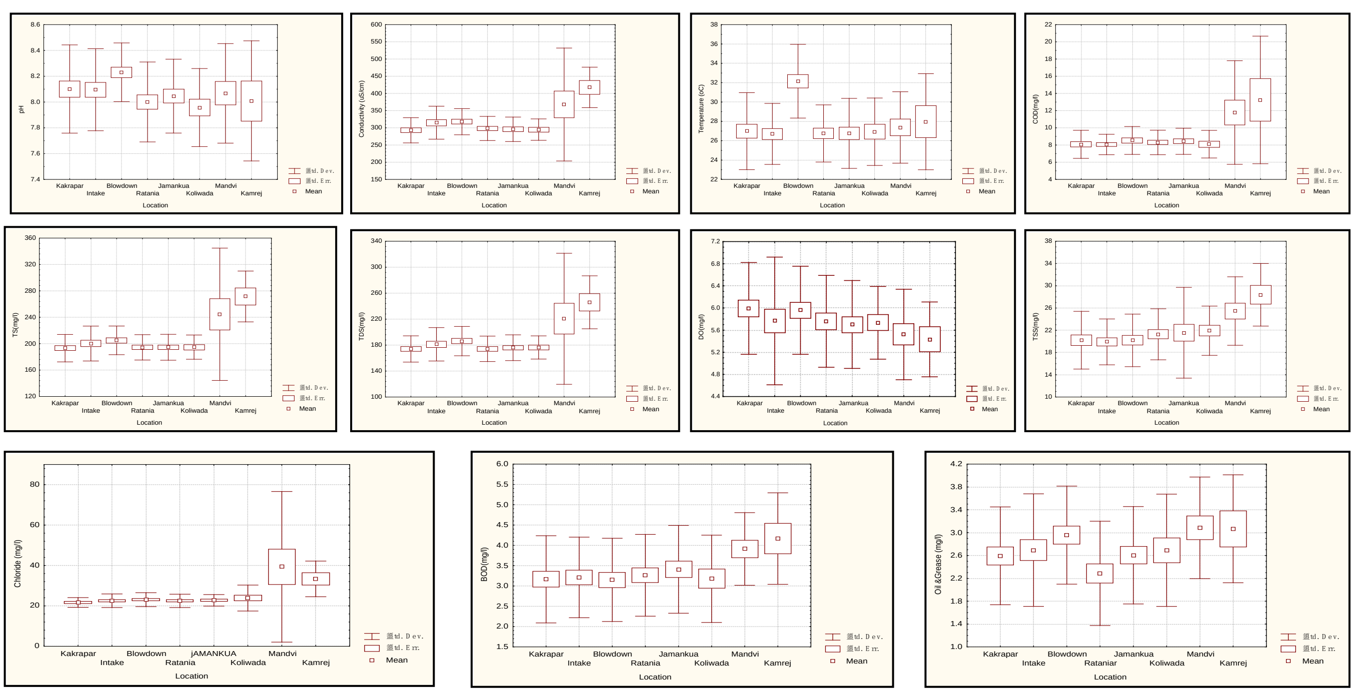

Fig. 2 Location-wise variation of water quality parameters

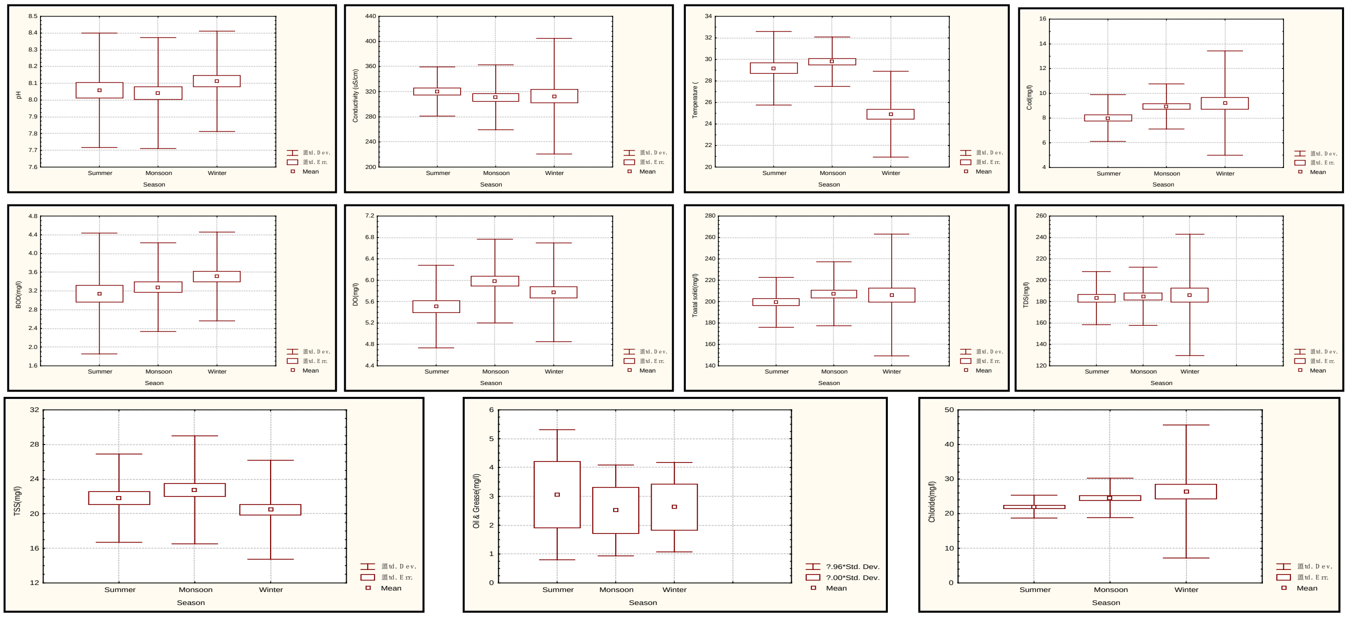

Fig. 3 Seasonal variation of water quality parameters

Pearson Product moment correlation ($p < 0.05$) was used to study the linear correlation between different water quality parameters and the different significant levels that are shown in Table III. It is observed that conductivity was significantly and positively correlated with TS, TDS, Cl- and the magnitude of correlation was 0.91, 0.9 and 0.71 respectively. The other correlation coefficients between the variables are observed to be less than 0.7.

TABLE III PEARSON PRODUCT MOMENT CORRELATION (MARKED CORRELATIONS ARE SIGNIFICANT AT $P < 0.05$)

Parameters	**pH**	**Cond. (µS cm^{-1})**	**Temp. (^{0}C)**	**COD (mg l^{-1})**	**BOD (mg l^{-1})**	**DO (mg l^{-1})**	**TS (mg l^{-1})**	**TDS (mg l^{-1})**	**TSS (mg l^{-1})**	**Oil & Grease (mg l^{-1})**	**Cl$^-$ (mg l^{-1})**
pH	1.00										
Cond. (µS cm^{-1})	0.03	1.00									
Temp. (^{0}C)	0.02	**0.17**	1.00								
COD (mg l^{-1})	0.04	**0.56**	-0.10	1.00							
BOD (mg l^{-1})	-0.02	0.08	-0.01	**0.31**	1.00						
DO (mg l^{-1})	-0.05	-0.12	**-0.24**	-0.09	-0.10	1.00					
TS (mg l^{-1})	0.05	**0.91**	0.12	**0.59**	0.14	-0.10	1.00				
TDS (mg l^{-1})	0.04	**0.90**	0.13	**0.54**	0.10	-0.08	**0.97**	1.00			
TSS (mg l^{-1})	-0.11	**0.19**	0.08	**0.20**	0.01	-0.06	**0.16**	0.03	1.00		
	-0.25	-0.01	0.05	-0.08	0.00	0.12	-0.06	-0.02	0.03	1.00	
Cl$^-$(mg l^{-1})	-0.06	**0.71**	-0.06	**0.59**	**0.14**	0.13	**0.69**	**0.68**	**0.15**	0.01	1.00

Note: Significant values are bold faced.

B. Factor Analysis/Principal Component Analysis (Fa/Pca)

The principal component analysis/factor analysis was applied to the data sets (11 variables) separated for the four different spatial regions viz. Upstream dataset (Intake-Kakrapar), Discharge point dataset (Blowdown point), Downstream (Ratania, Koliwada, Jamankua) dataset and Downstream (Mandvi and Kamrej in Tapi river) dataset as delineated by CA technique, to compare the compositional patterns between the analysed water samples and to identify the factors that influence each one. The input data matrices (variables X cases) for PCA/FA were [11 x 60] for the Upstream region (Intake-Kakrapar), [11 x 30] for Discharge point region (Blowdown point), [11 x 81] for Downstream (Ratania, Koliwada, Jamankua) region and [11 x 27] for Downstream (Mandvi and Kamrej in Tapi river) region respectively. The PCA of the four data sets evolved three PCs each for all the regions with eigen value > 1, explaining 57.4%, 62.5%, 55.7% and 70.0% of the total variance in respective water quality data sets. Equal numbers of VFs were obtained for the four regions through FA performed on the PCs. Corresponding VFs, variable loadings and variances are presented in Table IV. For the data set pertaining to Upstream region (Intake-Kakrapar), among the three VFs, VF1 explaining 29.4% of total variance has strong positive loadings (>0.70) on Conductivity, TS and TDS. VF2 explaining 16.2% of the total variance has positive loading on temperature. VF3 explaining 11.9% of the total variance has positive loadings on BOD and negative loading on oil & grease.

TABLE IV FACTOR LOADINGS OF EXPERIMENTAL VARIABLES (11) ON SIGNIFICANT PRINCIPAL COMPONENTS FOR (A) UPSTREAM DATASET, (B) DISCHARGE POINT DATASET, (C) DOWNSTREAM (RATANIA, KOLIWADA, JAMANKUA) DATASET, (D) DOWNSTREAM (TAPI RIVER) DATASET

Variables	**VF-1**	**VF-2**	**VF-3**
Upstream dataset (Intake-Kakrapar)			
pH	0.164	-0.652	0.080
Cond. (µS cm^{-1})	**0.909**	-0.031	-0.017
Temp.(^{0}C)	0.415	**0.702**	0.048
COD(mg l^{-1})	0.063	-0.542	0.443
BOD(mg l^{-1})	-0.201	0.333	**0.725**
DO(mg l^{-1})	-0.157	0.286	0.089
TS(mg l^{-1})	**0.942**	-0.026	0.103
TDS(mg l^{-1})	**0.911**	0.081	0.002
TSS(mg l^{-1})	0.288	-0.354	-0.066
Oil&Grease(mg l^{-1})	-0.224	0.270	**-0.772**
Cl^-(mg l^{-1})	0.432	-0.203	0.429
Eigen value	3.231	1.776	1.309
% total variance	29.370	16.150	11.903
Cumulative % variance	29.370	45.519	57.422
Discharge Point Dataset (Blowdown Point)			
pH	0.203	0.135	0.077
Cond. (µS cm^{-1})	**0.862**	0.021	-0.126
Temp.(^{0}C)	0.385	-0.607	0.010
COD(mg l^{-1})	-0.087	**0.812**	0.260
BOD(mg l^{-1})	0.070	0.035	**0.880**
DO(mg l^{-1})	-0.333	-0.233	0.316
TS(mg l^{-1})	**0.960**	0.081	0.029
TDS(mg l^{-1})	**0.938**	-0.131	0.118
TSS(mg l^{-1})	-0.015	0.170	**-0.755**
Oil&Grease(mg l^{-1})	-0.030	**-0.813**	0.241
Cl^-(mg l^{-1})	0.237	0.684	-0.267
Eigen value	2.920	2.443	1.514
% total variance	26.548	22.210	13.759
Cumulative % variance	26.548	48.758	62.518
Downstream (Ratania, Koliwada, Jamankua) Dataset			
pH	0.298	0.659	-0.155
Cond. (µS cm^{-1})	**0.887**	-0.078	0.098
Temp.(^{0}C)	0.431	-0.073	0.573
COD(mg l^{-1})	-0.099	0.657	-0.115
BOD(mg l^{-1})	-0.273	0.396	-0.115
DO(mg l^{-1})	-0.350	0.412	**-0.084**
TS(mg l^{-1})	**0.902**	0.168	0.033
TDS(mg l^{-1})	**0.923**	0.074	-0.181
TSS(mg l^{-1})	-0.178	-0.005	0.849
Oil&Grease(mg l^{-1})	-0.231	-0.637	-0.227
Cl^-(mg l^{-1})	0.210	0.433	0.184
Eigen value	3.119	1.812	1.199
% total variance	28.351	16.473	10.900
Cumulative % variance	28.351	44.824	55.724
Downstream (Mandavi and Kamrej in Tapi River) Dataset			
pH	-0.191	**-0.718**	0.191
Cond. (µS cm^{-1})	**0.970**	0.030	-0.021
Temp.(^{0}C)	-0.074	0.141	-0.384
COD(mg l^{-1})	**0.727**	0.085	0.507
BOD(mg l^{-1})	0.231	0.204	**0.724**
DO(mg l^{-1})	0.202	-0.020	**-0.801**
TS(mg l^{-1})	**0.965**	-0.060	0.020
TDS(mg l^{-1})	**0.957**	-0.109	-0.037
TSS(mg l^{-1})	-0.077	**0.794**	0.131
Oil&Grease(mg l^{-1})	-0.144	**0.768**	0.221
Cl^-(mg l^{-1})	**0.852**	0.087	-0.039
Eigen value	4.229	2.039	1.438
% total variance	38.449	18.532	13.076
Cumulative % variance	38.449	56.982	70.057

Note: Significant factor loadings are bold faced.

For the data set pertaining to the discharge point region (Blowdown), among the three VFs, VF1 explaining 26.5% of total variance has strong positive loadings (>0.70) on Conductivity, TS and TDS. VF2 explaining 22.2% of the total variance has strong positive loading on COD and negative loading on oil & grease. VF3 explaining 13.8% of the total variance has strong positive loadings on BOD and negative loading on TSS.

For the data set pertaining to the downstream region (Ratania, Koliwada, Jamankua), among the three VFs, VF1 explaining 28.4% of total variance has strong positive loadings (>0.70) on Conductivity, TS and TDS.

For the data set pertaining to the downstream region (Mandvi and Kamrej in Tapi river), among the three VFs, VF1 explaining 38.4% of total variance has strong positive loadings (>0.70) on Conductivity, COD, TS, TDS and Cl-. VF2 explaining 18.5% of the total variance has positive loading on TSS, oil & grease and negative loading on pH. VF3 explaining 13.1% of the total variance has positive loading on BOD and negative loading on DO.

C. Spatial Similarity and Site Grouping

Cluster analysis was applied to detect spatial similarity for grouping of sites under the monitoring network. It rendered a dendogram (Fig. 4), grouping all the eight sampling locations on the aquatic system into three statistically significant clusters at (Dlink/Dmax) x 100 < 70. The clustering procedure generated three groups of sites in a very convincing way, as the locations in these groups have similar characteristic features and natural background source types: Cluster-1 (Intake, Blowdown, Kakrapar, Jamankua and Ratania), Cluster-2 (Mandvi and Koliwada) and Cluster-3 (Kamrej) respectively. It implies that for rapid assessment of water quality, just one site in each cluster may be as good in spatial assessment of the water quality as the whole network. It is evident that the CA technique is useful in offering a reliable classification of the surface water in the whole region and will make it possible to design a future spatial sampling strategy in an optimal manner. Thus, the number of sampling locations in the monitoring network will be reduced, hence the cost without any loss in the significance of the outcome.

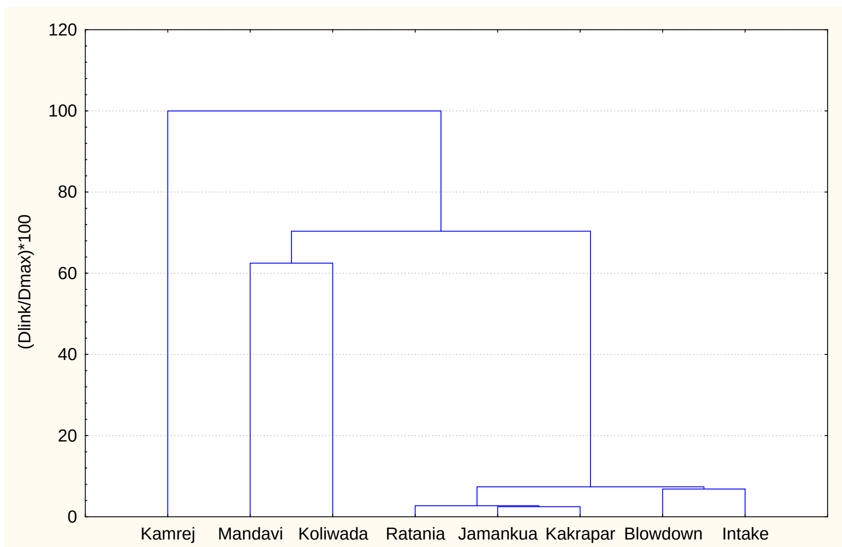

Fig. 4 Dendogram showing clustering of sampling sites

D. Variation of Temperature in Two Different Scenarios

Moticher Lake is a recipient of liquid waste from KAPS. The water required for the two units of PHWRs is drawn from Moticher Lake through Intake Structure. The condenser cooling water which is at a slightly elevated temperature is released into Moticher Lake at Blowdown Point. Since the thermal effluent is discharged into Moticher Lake, an attempt was made to assess the impact of thermal effluent discharged into Moticher Lake at KAPS (as tabulated in Table V). The temperature of water from different locations was measured in two different scenarios. Two water flow scenarios were studied. In the first scenario, there was less inflow of 263 cusecs and an outflow of 840 cusecs of water into Moticher Lake. In the second scenario, there was more inflow of 2856 cusecs and outflow of 2854 cusecs. In both the scenarios temperature of inflow water through the Kakrapar left bank canal and outflow through Ratania Regulator in Moticher Lake was found to be 30°C. The temperature of thermal effluent discharged at Blowdown point in both the scenarios was 37°C which is below Gujarat Pollution Control Board (GPCB) limit i.e. 40°C. In the first scenario, the higher temperature of thermal effluent (37°C) discharged at Blowdown point remained constant upto a radius of 200 m (both upstream and downstream) in Moticher Lake. In the second scenario, the temperature of thermal effluent discharged at Blowdown point attained the normal inflow temperature i.e. 30°C within 200 m distance in the downstream and no elevated temperature was noticed in the upstream. However the dilution available (100 times) in Moticher Lake is reducing the temperature of the effluent within the lake. This is also further confirmed by the results obtained during regular study. During the study, apart from temperature measurement, related parameters such as dissolved oxygen and pH were also measured (as reported in Table V). The study reveals that the impact of thermal effluent discharged into Moticher Lake is insignificant.

TABLE V TEMPERATURE AND OTHER RELATED PARAMETERS WITHIN THE LAKE IN TWO DIFFERENT SCENARIOS

Location	First Scenario			Second Scenario		
	Temp. (°C)	DO (mg l^{-1})	pH	Temp. (°C)	DO (mg l^{-1})	pH
Kakrapar	30	7.5	7.9	30	6.9	7.7
Intake point	30.5	7	7.8	30	6.7	7.9
Blowdown Point	37	6.1	8.3	37	6.2	8.2
Koliwada Regulator	34	6.8	8.1	31	6.7	8
Ratania Regulator	30	6.5	7.9	30	6.3	7.8

E. Radiological Parameters

Water samples were analysed for radiological parameters (137Cs, 90Sr and 3H) and tabulated in Table VI. The water samples collected from upstream (Intake, Kakrapar) and extreme downstream (Mandvi and Kamrej) locations showed Below Detectable Level of 137Cs (≤1.5 mBq l-1) and 3H (≤10 Bq l-1) respectively. The 90Sr activity in all the water samples was Below Detectable Level (≤1.5 mBq l -1). The 137Cs and 3H activity in water samples collected from liquid effluent discharge point (Blowdown) were found to be in the range of ≤1.5-74.0 mBq l-1 and≤10 -4875 Bq l-1 respectively. The water samples collected from Ratania, Koliwada and Jamankua showed Below Detectable Level of 137Cs (≤1.5 mBq l-1) and 3H (≤10 Bq l-1) respectively in most cases.

TABLE VI 137CS, 90SR AND 3H ACTIVITY IN SURFACE WATER SAMPLES COLLECTED AROUND KAKRAPAR

Location	Radionuclides	No. of Samples	No. of BDL	Range	GM	GSD
Kakrapar	^{137}Cs (mBq l^{-1})	30	30	≤1.5	-	-
	^{90}Sr (mBq l^{-1})	30	30	≤1.5	-	-
	^{3}H (Bq l^{-1})	30	30	≤10	-	-
Intake	^{137}Cs (mBq l^{-1})	30	30	≤1.5	-	-
	^{90}Sr (mBq l^{-1})	30	30	≤1.5	-	-
	^{3}H (Bq l^{-1})	30	30	≤10	-	-
Blowdown	^{137}Cs (mBq l^{-1})	30	12	≤1.5 -74	5.9	3.6
	^{90}Sr (mBq l^{-1})	30	30	≤1.5	-	-
	^{3}H (Bq l^{-1})	30	10	≤10-4875	94	11
Ratania	^{137}Cs (mBq l^{-1})	30	25	≤1.5 -20.0	2.1	2.1
	^{90}Sr (mBq l^{-1})	30	30	≤1.5	-	-
	^{3}H (Bq l^{-1})	30	29	≤10-21	10.2	1.4
Jamankua	^{137}Cs (mBq l^{-1})	30	26	≤1.5 -21.6	1.9	1.9
	^{90}Sr (mBq l^{-1})	30	30	≤1.5	-	-
	^{3}H (Bq l^{-1})	30	30	≤10	-	-
Koliwada	^{137}Cs (mBq l^{-1})	23	18	≤1.5 -17.9	2.3	2.3
	^{90}Sr (mBq l^{-1})	23	23	≤1.5	-	-
	^{3}H (Bq l^{-1})	23	19	BDL-43	11.6	1.4
Mandavi	^{137}Cs (mBq l^{-1})	16	16	≤1.5	-	-
	^{90}Sr (mBq l^{-1})	16	16	≤1.5	-	-
	^{3}H (Bq l^{-1})	16	16	≤10	-	-
Kamrej	^{137}Cs (mBq l^{-1})	10	10	≤1.5	-	-
	^{90}Sr (mBq l^{-1})	10	10	≤1.5	-	-
	^{3}H (Bq l^{-1})	10	10	≤10	-	-

The 137Cs, 90Sr and 3H activity in all the analysed samples is well within the technical specification limit prescribed by AERB [14]. The decrease in activity levels in Ratania, Koliwada and Jamankua with reference to liquid effluent discharge point (Blowdown) is due to the sufficient dilution available at Moticher Lake. It is reported that dilution to the tune of 100 times is available in Moticher Lake [15].

IV. CONCLUSIONS

The Physico-chemical and radiological parameters were studied in water samples collected from eight different sampling locations of Tapi River. Different multivariate statistical techniques such as Cluster Analysis (CA), Factor Analysis (FA)/ Principal Component Analysis (PCA) were applied for evaluation of temporal /spatial variations and interpretation of water quality data obtained during 2007-2009. Significant variation in most of the water quality parameters was not observed in different seasons except for variation in temperature. The impact of thermal effluent in Moticher Lake was insignificant. The 137Cs, 90Sr and 3H activity in most water samples was below detectable level. The physico-chemical parameters and radioactivity levels were well within the CPCB prescribed limit and the technical specification limit prescribed by AERB. The study reveals that the Nuclear Power Station situated at Kakrapar is not affecting the water quality of Tapi River with respect to radiological and physico-chemical parameters.

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