Journal of Mines, Metals and Fuels, *73(2): 487-497; 2025. DOI: 10.18311/jmmf/2025/47447*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.co.in/index.php/jmmf*

Seasonal Variations and Distribution of Major Ions in the Aerosol Around a Coal-Fired Thermal Power Plant

Minal Gune[1,2]*, K. Balakrishna[2], B. R. Manjunatha[3], Saurabh Joshi[1], Vidula Swami[4] and M. A. Mohammed Aslam[5]

[1]Department of Civil and Environmental Engineering, Kolhapur Institute of Technology's College of Engineering (Empowered Autonomous), R.S. No. 199B/1-3, Gokul - Shirgoan, Kolhapur - 416234, Maharashtra, India; minugune@gmail.com

[2]Department of Civil Engineering, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal - 576104, Karnataka, India

[3]Department of Civil Engineering, Dayananda Sagar College of Engineering, Shavige Malleshwara, Hills, Kumaraswamy Layout, Bangalore – 560111, Karnataka, India

[4]Department of Civil Engineering, Kolhapur Institute of Technology's College of Engineering (Empowered Autonomous), R.S. No. 199B/1-3, Gokul – Shirgoan, Kolhapur - 416234, Maharashtra, India

[5]Department of Geology, School of Earth Sciences, Central University of Karnataka, Kadaganchi - 585367, Karnataka India

Abstract

The seasonal changes of major ions in the aerosols around a coal-fired thermal power plant in southwestern India, is the primary objective of this study. Data collected during one-year period shows that both natural and anthropogenic sources have an impact on the samples. Sea salts from the Arabian Sea and the weathering of silicate rock, or mineral dust, have major impact on aerosol samples from natural sources, whereas contributions from fly ash, vehicular emission are anthropogenic. Principal component analysis and thematic maps support this finding. The distance-wise distribution of major ions and wind backward trajectory analysis indicated that anthropogenic activities have a significant impact on the pre-monsoon and post-monsoon samples than on the monsoon and early-monsoon seasons.

***Major Findings:** 1. In the study area, major ions shows more temporal variations than spatial; the distance wise distribution of major ions, thematic maps and PCA analysis reflects that the samples are influenced by both natural and anthropogenic sources. 2. In monsoon season, the major ions show low concentration compared to pre-, early-, and post-monsoon seasons. This could be due to the impact of heavy rains resulting in the dilution in the concentrations.*

Keywords: *Principal Component Analysis, Seasonal Variations of Major Ion Concentration, Thematic Maps*

1.0 Introduction

The demand for electricity has increased over the last 20 years, resulting in rising industrialization, urbanization, and infrastructure expansion. As a result, it has an adverse effect on environment and degrades the quality of the water, land, air, etc. Therefore, it is very important to study their pollution on environment. This study investigates the effects of aerosol particles in the air around a coal-fired thermal power plant in Udupi,

**Author for correspondence*

southwest coast of India. Small suspended particles, known as aerosols, are found around the environment. It is present in the atmosphere in the form of mist, vapour, smoke, and airborne dust particles. Aerosols are small suspended particles that are seen in the surrounding. It can be found in the atmosphere as airborne dust particles, vapour, smoke, or mist. The diameter of these suspended particles varies from a few nanometers to hundreds of micrometres[1,2]. Aerosols have a major impact on the climate and atmosphere's chemistry. It participates in several chemical processes which help in the formation of cloud droplets. These aerosols are formed by natural processes including volcanic eruptions, mineral dust, and sea salts, which have the potential to significantly impact the earth's climate[3-6]. It comes from natural and anthropogenic sources, such as burning fossil fuels, industries, cars, home heating, etc. The characteristics of atmospheric aerosols are influenced by their origins. The sizes of particles in the aerosols range from submicrometer to micrometre. These aerosol particles consist of a variety of inorganic and organic materials. These species are classified into four classes: sulphates, dust, carbonaceous aerosols, and sea salt[5-7]. Fine aerosols, heavy metals, sulphate, nitrate, persistent organic pollutants, and carbonaceous species have all increased significantly during the past 20 years as a result of rapid industrialization and other major anthropogenic activities[8,9].

Acid deposition has grown to be a major worldwide environmental concern within the past 20 years. The increased emissions of sulphur and nitrogen oxides caused by anthropogenic activity intensified the acid fallout, causing damage to historical sites, plants, and soils. These particles produce a cloud of dust that reflects sunlight back into space and cools the surface of the earth[10-12]. This cooling impact could mitigate global warming, but it can have negative impacts on terrestrial and aquatic ecosystem around industrial areas by increasing aerosol particle acidity, cloud formation, and precipitation. The main causes of acidification are oxides of sulphur, carbon, nitrogen, and ammonium. Heavy metals and other chemicals with a high molecular weight can travel long distances as aerosol particles. These particles get deposited in the soil. Moreover, low molecular weight molecules like sulphur and nitrogen can evaporate into the atmosphere as gaseous particles. Their concentration can therefore vary depending on a number of factors, including the source's location, anthropogenic factors, natural factors, and wind directions. Therefore, the chemistry of aerosols and their sources must be understood[12]. The hydrological cycle is primarily influenced by aerosol deposition in the atmosphere. The surface solar radiation balance is lowered by aerosols, which lowers ocean water evaporation and affects the water cycle and global patterns of rainfall[13].

The major path through which atmospheric aerosol particles are transferred from the atmosphere to the soil and natural water (surface and ground water) is through rainfall. Determining pollution from local, regional, and global sources could therefore help from a study of the chemical compositions of rainwater and their geographical and geographic variations. Acidic gases like SO_2, NO_x (x = 2, 3), and CO_2 contribute to the rainfall that is influenced by human activity. Basic gases such as NH_3 can occasionally cause acid neutralisation. The formation of sulfuric acid, nitric acid, carbonic acid, and ammonium hydroxide bases occurs when these acidic gases dissolve in clouds[3].

The objective of this research is to understand the distribution of major ions in aerosol within 8-kilometer radius around the coal-fired thermal power plant , Udupi Power Corporation Limited (UPCL). Agriculture land on NH 66, SH 67, and SH 1 surrounds the study region. The study aims to understand the seasonal variations in air pollution caused by vehicle exhaust, fly ash, biomass burning, and diesel emissions from thermal power plants. India's coal-based thermal power plants generate cost effective electricity[14]. However; the negative aspects of using coal to generate energy are its lower calorific value and with high–ash content.

2.0 Methodology

2.1 Passive Air Sampling (Aerosol)

The study area (Figure 1) lies between longitudes 74°45' E and 75°0' E and latitudes 13°0' N and 13°15' N. It is approximately 300 square kilometres in area. The Arabian Sea lies to the west of the study area, Nandikur town lies to the north, Surathkal borders it on the south, and Karkala borders it on the east. It covers an area of about 300 square kilometres.

Rocks from the archean age are found in the study area. The research area has been divided into two regions: the centre region has patches of amphibolite, while the northern region comprises Peninsular Gneiss and Kanara Granite[15]. Red lateritic soil with sand grains covers the chemically weathered rocks. The study area experiences four distinct seasons: April to June is the early monsoon; October to December is the post-monsoon; January to March is the pre-monsoon; and July to September is the monsoon. The study region has a tropical environment with around 4000 mm of annual rainfall and an average annual temperature of 26.5°C. There's approximately 1466 mm of evapotranspiration and 61–91% humidity. The wind speed is 0.5 to 2.5 m/s. Early summer winds come from the west-southwest, while late winter winds come from the east-northeast[16-18].

Twelve surficial soil samples (a total of 48 samples) were taken for each season's pre-monsoon (March), early-monsoon (June), monsoon (September), and post-monsoon (December) at 2 km, 4 km, 6 km, and 8 km radial distances from the power plant. The central location for the study area is Nandikur (UPCL, thermal power plant), as well as National and State Highways 67, 66, and 1.

In the study region, the two polypropylene bowls of the Passive Air Sampler (PAS) were positioned at 12 different points at radial distances of 2, 4, 6, and 8 kilometres from the TPP (Figure 1). The mat, which had a diameter of 15 cm, was stored inside the bowl and was composed of nitrile polymer, which is naturally adhesive. Dust sample collection was done using these polypropylene bowls and mat. The collected dust from the bowl (height 0.22 m, 0.15 m, and total volume of 0.03051 m^3) is dissolved by sprinkling one litre of ultrapure water in the bowl and mat. Later, the samples were placed into a previously cleaned 1-liter polypropylene (PP) bottle. The one-liter PP bottles that had been previously cleaned and filled with the samples were then used to collect water samples. The samples were subjected to simultaneous measurements of pH, temperature, Electrical Conductivity (EC µS cm-1) and Total Dissolved Solids (TDS, mg/l). The multi-parameter hach manufactured equipment that was pre-calibrated was used to measure these parameters. To prevent diluting and contaminating the PP bottles, the samples were rinsed. After being placed within a polythene bag and sealed, the bottles were brought into the laboratory for additional extraction and processing. Water samples were collected and then passed through cellulose acetate filter paper with a 0.22 µm pore size, measuring 47 mm in diameter. On the same day, samples were passed through a filtering device made by Sartorius in a laminar flow bench with a hand vacuum pump (Mityvac). Samples for geochemical analysis were measured, processed, and preserved using similar methods to those used for ground water and was stored at 4°C until examination[19-21].

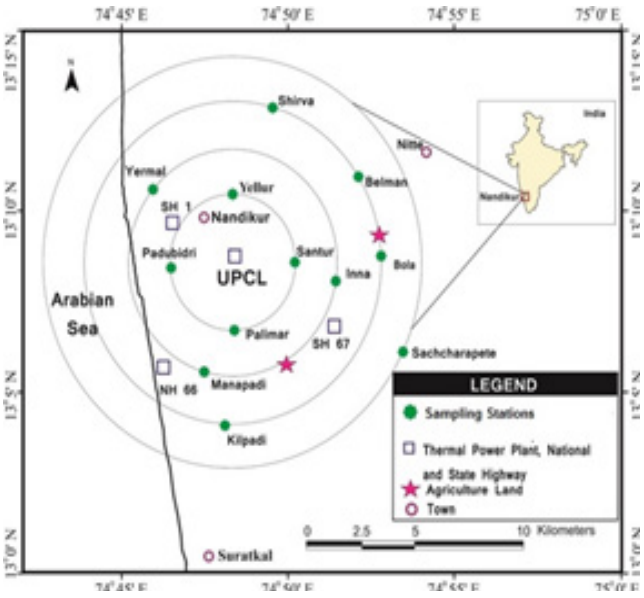


Figure 1. The locations of the sample stations and UPCL. The distance between the concentric circle are two kilometres.

2.2 Major Ions

The DIONEX-1100 Ion Chromatography (IC) with auto sampler, which is available at the Central Instrumentation Facility (CIF) of MIT, was used for analysing the filtered water samples for major ions. The analysis's details are listed below. An aliquot of 5 millilitres of the sample was taken and put into a poly vial with a filter tip cap on it.

When samples are prepared for analysis, they are placed into the auto sampler that is attached to the IC. Major cations such as Na^+, K^+, Ca^{2+}, and Mg^{2+} as well as anions Cl^-, NO_3^- and SO_4^{2-} were all simultaneously analysed using ion chromatography. Each system had its own columns and suppressors. Prior to analysis,

Table 1. Standard methods referred for sample analysis to measure major ions

Parameters	Methods	Reference
Onsite analysis		
pH, Temp, Conductivity	Hach multi-parameter Probes	Methods for chemical analysis of water and waste water, EPA
Laboratory Analysis		
Titration		
Major Ions Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, NO_3^- and SO_4^{2}	Ion Chromatography DIONEX -1100	Methods for chemical analysis of water and waste water, EPA

the equipment was calibrated using Merck cation and anion standards. Eluents were made with concentrations of 20 mM Methanesulfonic Acid (MSA) for cations and 8 mM $NaCO_3$ and 1 mM $NaHCO_3$ for anions. To ensure analytical accuracy, check standards in the form of Merck's cation and anion standards were employed as shown in Table 1. All of the cations and anions were found to be below the detection limits when the procedure blanks were run at the start, middle, and end of the analyses[19,20]. Table 1 depicts the standard methods referred for sample analysis to measure major ions.

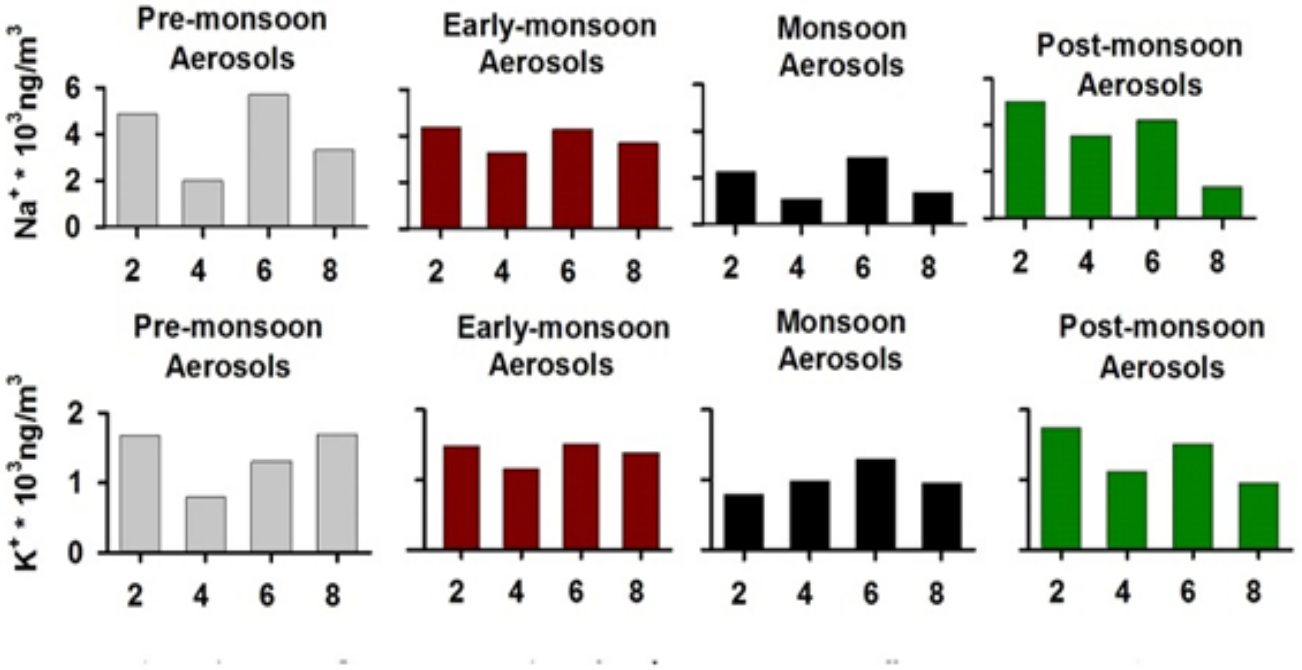
3.0 Results and Discussion

3.1 Physico-Chemical Parameters of Air (Aerosol)

The average pH in all seasons was found to be mildly acidic in aerosol (6.12). In pre-monsoon (6.46), early-monsoon (6.16) and post-monsoon (6.08) seasons a higher pH value compared to monsoon (5.81) seasons. In pre-monsoon season the electical conductivity (EC) in aerosol was found to be higher in pre-monsoon (86.52 µs/cm), early-monsoon (82.01 µs/cm) and post-monsoon (86.86 µs/cm) season compared to monsoon (55.32 µs/cm) season. This may be due to dilution in concentration due to haevy rain. The temperature ranges from 25 to 27^0 C during the wet season and from 28 to 30^0 C during the dry season[22] as shown in Table 2.

3.2 Seasonal Variation of Major Ions in Air (Aerosol)

The data of seasonal variations of major ions in aerosol are shown in Figure 2. The elements measured in



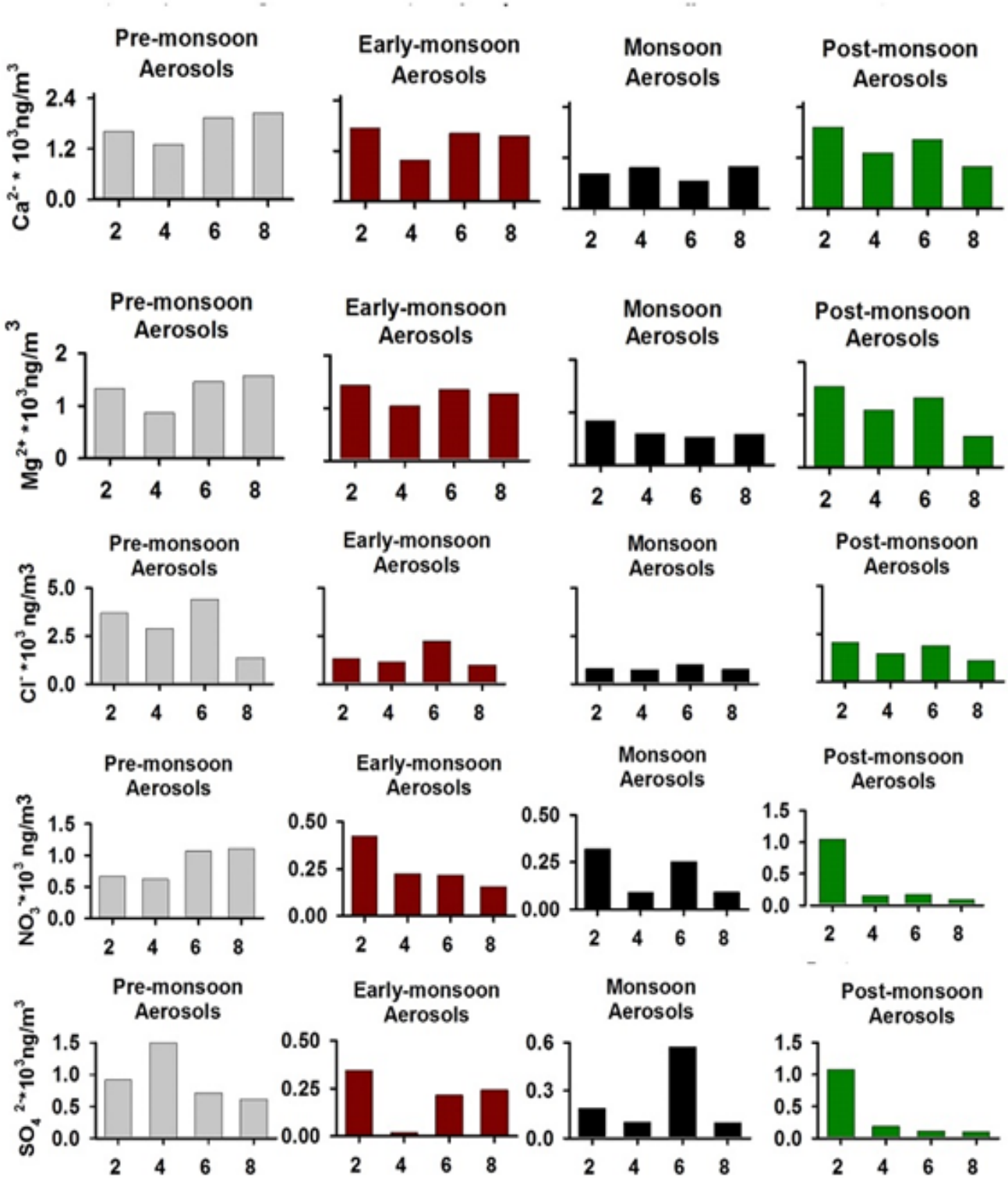


Figure 2. Seasonal variation of average major ion concentration of aerosol within 8-km radius of UPCL.

Table 2. Physico-chemical characteristics of aerosol within 8-km radius of UPCL around the coal-fired thermal power plant.

Note: Temperature is in ^{0}C and Conductivity (EC) in µs/cm.

Pre-monsoon (Aerosols)				Early-monsoon (Aerosols)		
Sampling Location	**pH**	**EC**	**Temp**	**pH**	**EC**	**Temp**
Santur	6.2	91	27.8	6.1	129	26
Palimar	6.7	105	28.7	5.7	72	26
Yellur	6.9	81.3	28.1	7	68	27
Padubidri	6	85.3	27	6	88.2	26.8
Inna	6.4	31	29.3	6.7	69.2	26.3
Yermal	6.7	89	27	6	42	28
Manapadi	6.9	52	28	6.3	81	27
Shirva	5.8	113	27.9	5.8	86	27
Kilpadi	6.3	87.3	27	6.3	82.2	27.5
Belman	6.9	112.3	28	6	92	26.9
Bola	6.2	95	28	6.3	82	28
Sachcharapete	6.6	96	29	6.0	93.0	27.5
Monsoon (Aerosols)				**Post-monsoon (Aerosols)**		
Sampling Location	**pH**	**EC**	**Temp**	**pH**	**EC**	**Temp**
Santur	6	64.1	26.9	6	73.1	27
Palimar	5.6	30.6	26.9	5.7	100	26.7
Yellur	6.5	85.3	27	6.3	126.3	27.6
Padubidri	5.7	50.6	29.4	6	130	27.2
Inna	5.8	40.1	28	6.5	95	27.2
Yermal	6.6	50.1	26.9	6.2	70.2	27.5
Manapadi	6.5	56.6	26.9	7	62.4	28.1
Shirva	5.7	55.3	28	5.8	91	28
Kilpadi	5.5	59.3	26.4	5.7	84	26
Belman	5.2	66.3	26.1	6.3	88	27
Bola	5.5	50.1	26.8	6	58.4	27
Sachcharapete	5.3	55.2	26	5.6	60.4	27

decreasing order are Na^+ followed by, Cl^-, Ca^{2+}, K^+, Mg^{2+}, NO_3^- and SO_4^{2-}. The average Na^+, Cl^- and Ca^{2+} shows a higher concentration in all four seasons within 2 km (pre-monsoon 4.85, 3.68, 1.62, early-monsoon 4.37, 1.31, 1.74, monsoon 2.26, 0.81, 0.82, post-monsoon 5.02, 2.06, $1.93*10^3$ng/m^3) and 6 km (pre-monsoon 5.71, 4.42, 1.94 early-monsoon 4.28, 2.25, 1.62, monsoon 2.88, 1.01, 0.57, post-monsoon 4.22, 1.90, $1.63*10^3$ng/m^3) radius

in aerosol compared to 4 km (pre-monsoon 1.99, 2.87, 1.31, early-monsoon 3.27, 1.16, 0.98, monsoon 1.08, 0.75, 0.97, post-monsoon 3.55, 1.50, 1.31*10^3ng/m^3) and 8 km (pre-monsoon 3.30, 1.35, 2.05, early-monsoon 3.71, 0.99, 1.57, monsoon 1.36, 0.76, 0.98, post-monsoon 1.36, 1, 1*10^3ng/m^3) radius from the thermal power plant.

Figure 2 illustrates the significant distance wise seasonal variations in aerosol concentration of K^+ Mg^{2+}, NO_3^- and SO_4^{2-}. The sea salt from the Arabian Sea is mainly the reason for the high content of Na^+ and Cl^- in the aerosol samples[23]. The high concentrations of K^+, Mg^{2+}, Ca^{2+}, NO_3^-, and SO_4^{2-} in the aerosol during the pre- monsoon season suggest that the aerosol samples are affected by both natural and anthropogenic activity, including the weathering of silicate rock (granite and amphibolite), fly ash emissions from thermal power plants, vehicle emissions, and burning of biomass (agricultural activities)[3]. The high aerosol concentration during the pre- and post-monsoon seasons may be resulting from changes in wind direction, as indicated by the backward trajectory analysis. The wind direction changes during the pre-monsoon season from northeast to west-southwest and during the post-monsoon season from west-southwest to east-northeast (Figure 2), (Klemm *et al.*,[24] from the Indian government's meteorological department, http://www.imd.gov.in). These air masses absorb ion concentrations. The northern Indian Ocean is the source of these air masses, especially during the southwest monsoon[25].

3.3 Thematic Mapping

A thematic diagram is generated by interpolating and plotting the spatial distributions of the average major ion concentration in aerosols. Using the Inverse Distance Weighing (IDW) system, ArcGIS 10.2.1 is used to plot the thematic diagram. Figures.3 and Table 3 highlights the average concentration of major ions at different sampling points throughout the study area. The aerosol NO_3^- shows a higher concentration at santur (1.14*10^3/m^3), Inna (0.58*10^3/m^3), yellur (0.55*10^3/m^3) compared to other stations. Compared to other stations, SO_4^{2-} shows high concentration at Santur (1.14*10^3/m^3), Manapadi (1.13*10^3/m^3) and Yellur (0.57*10^3/m^3). It indicates the fall out of ions from aerosol to the soil due to

Table 3. The average NO_3^-, SO_4^{2-} concentration of aerosol around 8 km radius from UPCL around a coal-fired thermal power plant

Note: The average NO_3^-, SO_4^{2-} concentration represented by Thematic Maps as shown in Figure 3.

Sampling Station	NO_3^-*10^3ng/m^3	Sampling Station	SO_4^{2-}*10^3ng/m^3
Manapadi	0.114	Yermal	0.069
Yermal	0.129	Inna	0.166
Sachcharapete	0.302	Sachcharapete	0.255
Palimar	0.370	Bola	0.269
Belman	0.379	Palimar	0.315
Padubidri	0.406	Belman	0.338
Bola	0.418	Shirva	0.369
Shirva	0.451	Kilpadi	0.501
Kilpadi	0.454	Padubidri	0.503
Yellur	0.552	Yellur	0.569
Inna	0.576	Manapadi	1.124
Satur	1.135	Satur	1.137

gravity and heavy rainfall[26]. Due to the presence of strong wind there is dispersion of major ions, resulting in high concentration. This shows that the anthropogenic activity has a minimal impact on the aerosol samples compared to the natural sources.

According to Ramachandra and Aithal (2012 a, b[27,28], in the 7-8 years after the UPCL thermal power plant was established in 2003, the growth of vegetation decreased from 8.1% to 4.2%. In order to observe changes in the area's land cover and land use after the power plant, they collected multi-frequency remote sensing imagery.

3.4 Source Analysis: Principal Component Analysis (PCA)

In SPSS V 21, R-mode factor analysis is used to interpret the major ions in the study area. To determine the elements or sources of the major ions signature in the samples, major ions with factor loading values greater than 0.6 are taken into consideration[5]. Since the loading value (>0.6) is statistically significant and significantly increases the variance of the dataset, it is used. Table 4 depicts a rotated component matrix along with the factor scores.

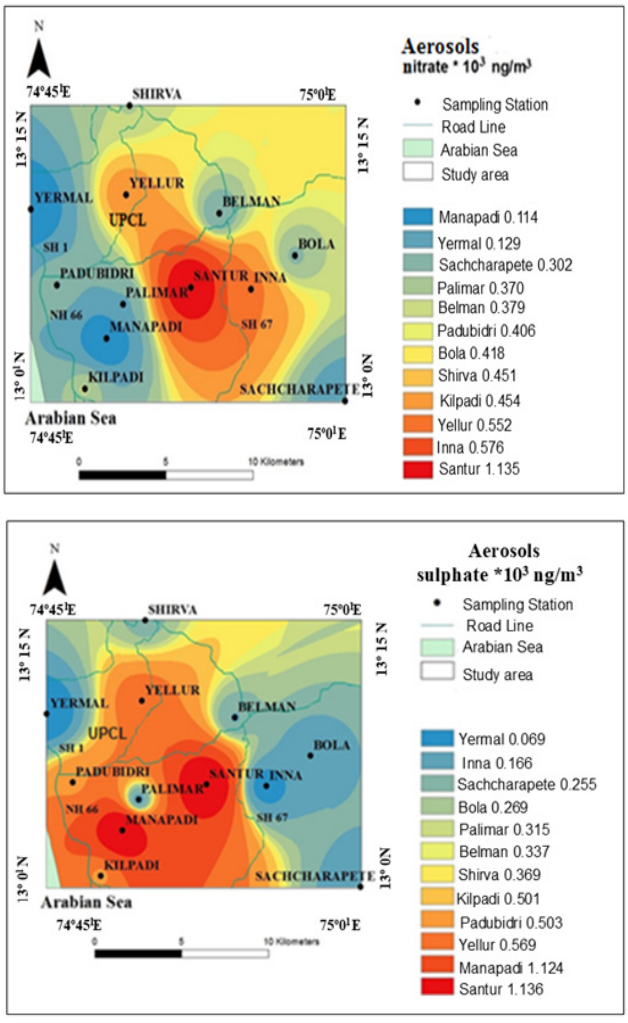


Figure 3. Thematic map representing average NO_3^-, SO_4^{2-} concentration in aerosol.

The aerosol samples showed two factors. Factor 1 has a moderate positive loading for pH (0.151), Cl^- (0.217), NO_3^- (0.191), negative loading for SO_4^{2-} (-0.032), positive loading for Na^+ (0.772), K^+ (0.768), Mg^{2+} (0.907), Ca^{2+} (0.863), and EC (0.915). Mineral dust from weathering of silicate rock and sea salts from the Arabian Sea are significantly contributed to the factor 1. Therefore, it may be concluded that the significant variables of factor 1 are from natural sources. This is supported by % variance (41.07) and cumulative % (25.16). The variables belonging to factor 2 are Cl^- (0.793), NO_3^- (0.687), SO_4^{2-} (0.874) and moderate positive loading for Na^+ (0.315), Mg^{2+} (0.148), Ca^{2+} (0.214), pH (0.376),

Table 4. Principal component analysis of major ion ($*10^3$ ng/m^3) of aerosols sample around the coal-fired thermal power plant

Major ions	Factor 1	Factor 2
Na^+	**0.772**	0.315
K^+	**0.768**	-0.004
Mg^{2+}	**0.907**	0.148
Ca^{2+}	**0.863**	0.214
Cl^-	0.217	**0.793**
NO_3^-	0.191	**0.687**
SO_4^{2-}	-0.032	**0.874**
pH	0.151	0.376
EC	**0.915**	0.305
% of Variance	41.074	25.159
Cumulative %	41.074	66.234

Extraction method: Principal component analysis
Rotation Method: Varimax with Kaiser Normalization

Table 5. Interspecies correlation of major ion concentrations (*10^3 ng/m^3) in aerosol samples around the coal-fired thermal power plant

Correlations									
	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	NO_3	SO_4^{2-}	pH	EC
Na^+	1								
K^+	0.447**	1							
Mg^{2+}	0.674**	0.610**	1						
Ca^{2+}	0.620**	0.560**	0.837**	1					
Cl^-	0.605**	0.033	0.282	0.337*	1				
NO_3^-	0.278	0.238	0.258	0.281	0.347*	1			
SO_4^{2-}	0.118	0.125	0.116	0.197	0.573**	0.523**	1		
pH	0.113	0.098	0.280	0.212	0.218	0.141	0.228	1	
EC	0.833**	0.678**	0.829**	0.829**	0.431**	0.398**	0.235	0.198	1

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

EC (0.305), and negative loading of K^+ (-0.004), suggesting the influence of anthropogenic activity. It is confirmed by % of variance (25.16) and cumulative % (66.23). The major ion inter correlation analysis (r=0.99, p <0.01), as presented in Table 4, confirms this interpretation.

Na^+ shows positive correlation with Mg^{2+} (0.674), K^+ shows positive correlation with Mg^{2+} (0.610), Na^+ shows positive correlation with Ca^{2+}(0.620), Mg^{2+} shows positive correlation with Ca^{2+} (0.837), Na^+ shows high correlation with Cl^- (0.605), and moderate correlation of Cl^- with SO_4^{2-} (0.573) and NO_3^- with SO_4^{2-} (0.523) and K^+ with Ca^{2+} (0.560). The pH shows a low correlation with all major ions whereas Cl^- shows a weak correlation with K^+ (0.033), Mg^{2+} (0.282) and Ca^{2+} (0.337). The NO_3^- and SO_4^{2-} shows weak correlation with Na^+ (0.278, 0.118), K^+ (0.238, 0.125), Mg^{2+} (0.256, 0.116), Ca^{2+} (0.28, 0.197) (Table 5). This indicates that, the study area is primarily influenced by natural sources, with negligible anthropogenic activity. EC shows strong positive correlations with Na^+ (0.833) K^+ (0.678), Mg^{2+} (0.829) whereas Ca^{2+} (0.829) and EC shows weak correlation with Cl^- (0.431), NO_3^-. (0.398), SO_4^{2-} (0.235), pH (0.198).

4.0 Conclusions

In comparison to spatial variability, the study area exhibits more temporal variations in the chemical composition. Both natural and anthropogenic sources have an impact on the study area: fly ash and diesel emission from thermal power plants; automobile emissions from the surrounding highways; sea salt from the Arabian Sea; and mineral dust from weathering of silicate rocks.

Principal component analysis, thematic maps, and the distance-wise distribution of major ions all indicate the above conclusion. Major ion concentrations in monsoon samples are lower than in pre-, early-, and post-monsoon seasons; this variation could be due to dilution by heavy precipitation. The results of the wind back trajectory analysis support this finding.

5.0 References

1. Schleicher NJ, Norra S, Chai F, Chen Y, Wang S, Cen K, *et al.* Temporal variability of trace metal mobility of urban particulate matter from Beijing: A contribution to health impact assessments of aerosols.

Atmos Environ. 2011; 12; 45:7248-65. https://doi.org/10.1016/j.atmosenv.2011.08.067
2. Yadav S, Satsangi GP. Characterization of particulate matter and its related metal toxicity in an urban location in South West India. Environ Monit Assess. 2013; 185:7365-79. https://doi.org/10.1007/s10661-013-3106-6
3. Rastogi N, Sarin MM. Long-term characterization of ionic species in aerosols from urban and high-altitude sites in western India: Role of mineral dust and anthropogenic sources. Atmos Environ. 2005; 39:5541-54. https://doi.org/10.1016/j.atmosenv
4. Bagalwa S, Majaliwa JGM, Karume K, Kansiime AK. Major ions in atmospheric deposition in Lake Kivu Basin. J Environ Prot Sci. 2023; 14:3. https://doi.org/10.4236/jep
5. Hegde P, Sudheer AK, Sarin MM, Manjunatha BR. Chemical characteristics of atmospheric aerosol over the southwest coast of India. Atmos Environ. 2007; 41:7751-66. https://doi.org/10.1016/j.atmosenv
6. Hegde P. Major ionic composition of aerosol, rainwater and its impact on surface and subsurface waters in and around Mangalore, west coast of India. Environ Monit Assess. 2007; 133:119-25. https://doi.org/10.1007/s10661-006-9565-2
7. Kothai P, Saradhi IV, Pandit GG, Markwitz A, Puranik VD. Chemical characterization and source identification of particulate matter at an urban site of Navi Mumbai, India. Aerosol Air Qual Res. 2011; 11:560-9. https://doi.org/10.4209/aaqr
8. Lynda M, Erick O, Kiptoo J, Gabriel M. Analysis of the levels of phosphates, nitrates, and sulphates in the Wheat Growing Area of Ntulele in Narok County, Kenya. J Environ Earth Sci. 2015;5(4).
9. Jiang H, Li Z, Wang F, Zhou X, Wang F, Ma S, *et al*. Water-soluble ions in atmospheric aerosol measured in a semi-arid and chemical-industrialized city, Northwest China. Atmosphere. 2021; 12(4). https://doi.org/10.3390/atmos12040456
10. Bhattacharya U. Studies on trace element contents of coal and coal-bearing sediments in Raniganj coal field and its impact on geo-environmental degeneration of the coal basins. GSI. 1993; Report. 1987-1989.
11. Sushil S, Batra VS. Analysis of fly ash heavy metal content and disposal in three thermal power plants in India. Fuel. 2006; 85:2676-9. https://doi.org/10.1016/j.fuel
12. Shamshad A, Fulekar MH, Pathak B. Impact of coal-based thermal power plant on environment and its mitigation measures. Int J Environ Sci. 2012; 1(4): 60-4.
13. Ramanathan V, Crutzen PJ, Kiehl JT, Rosenfeld D. Aerosols, climate, and the hydrological cycle. Science. 2001; 294:2119-24. https://doi.org/10.1126/science
14. Mishra UC. Environmental impact of coal industry and thermal power plants in India. J Environ Radioact. 2004; 72:35-40. https://doi.org/10.1016/S0265-931X(03)00183-8
15. Balasubrahmanyan MN. Geochronology and geochemistry of Archean tonalitic gneisses and granites of South Kanara district, Karnataka, India. In: Windley BF, Naqvi SM, editors. The origin and evolution of Archean geochemistry. Developments in Precambrian Geology. Amsterdam: Elsevier; 1978. p. 59-77. https://doi.org/10.1016/S0166-2635(08)70092-6
16. Stein AF, Draxler RR, Rolph GD, Stunder BJB, Cohen MD, Nagan F. NOAA's HYSPLIT atmospheric transport and dispersion modeling system. BAMS. 2021; 96:12. https://doi.org/10.1175/BAMS-D-14-00110.1
17. Ravindra BM, Ranganathan N. Geo Karnataka. Karnataka Assistant Geologists Association, MGD Centenary Volume; 1994. p. 388-95.
18. Awasthi SK, Krishnamurthy KV. Geology of parts of Puttur and Sullia taluks, South Kanara district, Karnataka. Progress report for the field season 1978-1979. GSI, Karnataka (South) Circle; 1979. p. 1-11.
19. Gurumurthy GP, Balakrishna K, Tripti M, Riotte J, Audry S, Braun JJ, *et al*. Sources of major ions (trace elements) and processes affecting the geochemical and isotopic signatures of subsurface waters along a tropical river, Southwestern India. Environ Earth Sci. 2015; 73:333-46. https://doi.org/10.1007/s12665-014-3428-x
20. Tripti M, Gurumurthy GP, Balakrishna K, Chadaga MD. Dissolved trace element biogeochemistry of a tropical river, Southwestern India. Environ Sci Pollut Res. 2012; 20(6):4067-77. https://doi.org/10.1007/s11356-012-1341-y
21. Gune M, Harshavardhana BG, Balakrishna K, Udayashankar HN, Shankar R, Manjunatha BR. Rock magnetic fingerprinting of fly ash in soils around a coal-fired thermal power plant. Environ Monit Assess. 2016; 188:272. https://doi.org/10.1007/s10661-016-5279-2
22. Gune M, Balakrishna K, Udayashankar HN, Manjunatha BR. Distribution of major ions in groundwater, river water, and estimation of

groundwater recharge in Mulki River basin, southwest coast of India. IJEE. 2016; 9(5):1952-9.
23. Keene WC, Pszenny AAP, Galloway JN, Hartley ME. Sea-salt corrections and interpretation of constituent ratios in marine precipitation. J Geophys Res. 1986; 91:6647-58. https://doi.org/10.1029/JD091iD06p06647
24. Klemm O, Bachmeier AS, Talbot RW, Klemm KI. Fog chemistry at the New England coast: Influence of air mass history. Atmos Environ. 1994; 28:1181-8. https://doi.org/10.1016/1352-2310(94)90295-X
25. Siefert RL, Johnsen AM, Hoffmann MR. Chemical characterization of ambient aerosol collected during the southwest monsoon and inter-monsoon seasons over the Arabian Sea: Labile-Fe (II) and other trace metals. J Geophys Res Atmos. 1999; 104:3511-26. https://doi.org/10.1029/1998JD100067
26. Gune M, Harshawardha BG, Ma WL, Balakrishna K, Zhang Z, Li YF, *et al*. Occurrence of heavy metals in soil surrounding a coal-fired thermal power plant in the south-west coast of India. Bull Environ Contam Toxicol. 2020; 104:602-8. https://doi.org/10.1007/s00128-020-02831-y
27. Ramachandra TV, Aithal BH. Land use dynamics at Padubidri, Udupi district with the implementation of a large-scale thermal power project. Int J Earth Sci. 2012; 5:405-17.
28. Ramachandra TV, Aithal BH, Mahapatra DM, Krishnadas G. Impact of indiscriminate disposal of untreated effluents from a thermal power plant on water resources. Indian J Environ Prot. 2012; 32(9):705-18.