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Seasonal Variation of Air Quality and CAQI at Tummalapalle Uranium Mining Site and Surrounding Villages

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Authors' contributions

This work was carried out by author AMB as part his Research work leading to PhD and as part of BRNS project. Field work was done by the authors AMB and NY. The locations, experimental work and protocols are prepared by all the authors. Manuscript is finalized by authors SVS and AVK with the consent of other authors.

Original Research Article

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ABSTRACT

The air quality levels of Tummalapalle Uranium mining site is studied using Combined Air Quality Index (CAQI) and Z – score. Samples of PM_{10}, TSP, SO_x and NO_x were collected by installing high volume samplers at Ten locations of Tummalapalle Uranium Mining site and its surrounding villages. The locations are selected based on the wind roses and these are classified as core zone, buffer zone – 1 and buffer zone – 2, based on radial distance from the mining site. The samples were collected twice a month during November - 2010 to February – 2012, of all the seasons i.e., winter, summer and monsoon. The CAQI has been estimated to assess the air pollution in ten selected sampling locations using concentrations of four common pollutants (PM_{10}, TSP, SO_x and NO_x). The spatial concentration distributions of pollutants were standardized by means of Z - scores to avoid any effects of unity scale on the distance measurements. These Z – scores are used to assess the air quality in three spatial zones (core zone, buffer zone – 1

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and buffer zone – 2). The evaluated CAQI values for all the three seasons are varying in the range of 20–50 at all the sampling locations. The CAQI values indicate moderate air pollution at the locations of UCIL–Mining site and Tummalapalle during winter and summer seasons. This is also supported by the high Z–scores obtained for the core zone containing these two locations.

Keywords: Combined Air Quality Index (CAQI); Z – scores; air pollution; uranium mining.

1. INTRODUCTION

Economical generation of large scale electrical energy is a major challenge at the global scale, particularly in developing countries like India. Nuclear energy is predominantly showing a great potential towards economic production of electricity. In this context, Government of India (UCIL-Uranium Corporation of India Limited) started the Uranium mining from its ore at Tummalapalle, Pulivendula, Andhra Pradesh.

Uranium mining may discharge particulates (PM_{10}, TSP) and gaseous pollutants (CO, SO_x, NO_x, etc.) into the atmosphere through the usage of machinery, burning of fuel, ore transportation, chemicals usage, constructional works, etc. This causes the degradation and drastic changes in the environment through air pollution [1]. Hong-di et al., reported that the particulate concentration were high at heavily traffic area [2].The presence of these pollutants in high concentration can cause health and respiratory problems to the human [3]. In order to study the relative risk of the increased concentrations, various researchers [1,3-10] have developed different air quality indexes (AQI). Sicard et al., has been used an improved, next generation, sanitary index allowing to assess air quality [11]. Combined Air Quality Index (CAQI) and Z–scores are important indicators to understand the variation of the air quality. Further, it assists in data interpretation for decision making processes related to pollution mitigation measures and air quality management [3]. CAQI is a tool, which calculates the overall air quality with respect to the criteria pollutants PM_{10}, TSP, SO_x and NO_x and the measurements are converted into non dimensionless number using Indian National Ambient Air Quality Standards (INAAQS).The Z–scores provides the zonal air quality in the study area. The CAQI is exclusively designed based on Indian climatic conditions and concentration ranges of pollutants**.**

Estimation of air quality indices for this particular region has not been reported so far, and therefore, the objective of current study is to estimate the air quality at Tummalapalle Uranium mining site and its surrounding Villages within 30 km radial distance from the mine using CAQI and Z – scores. The CAQI and Z – scores are calculated using the concentration of pollutants PM_{10},TSP, SO_x and NO_x.

2. STUDY AREA

The study area, an uranium underground mining site is located in Tummalapalle village, YSR District, Andhra Pradesh, India. The mining site is located in between latitudes 14°18'36” N and 14°20'20” N and longitudes 78°15'16” E and 78°18' 03.3” E. The study area is confined in the tropical region where the climate is characterised by very hot summers, mild winters and monsoon rains and it lies at southwest monsoon which runs from June to September in southern India. In summer season, the temperature ranges from a minimum of

15°C at night to a maximum at 46°C during daytime. In winter maximum temperature during day goes up to 40°C and minimum temperature at night reaches as low as 10°C [12].

The air sampling was carried out at ten locations, which are in the radius of 30 km from the Uranium mining site. The sampling locations and its latitude and longitude were measured through GPS locator values are given in the Table–1.The sampling locations were fixed on e basis of wind roses and locations were distributed according to the radial distances from the site. 5 locations were within 5 km, considered as Core Zone; 3 locations were in between 5-10km, considered as Buffer Zone-1 and 2 locations were between in 10-30 km, considered as Buffer Zone–2. The geographical distributions of the sampling locations are shown in Fig. 1.

Table 1. Location names, Latitudes/Longitudes and Distances from the mining site

S. No	Location	Zones	Distance from the site (km)	Latitude/ Longitude	Site Characteristics
1	UCIL-Mining site	Core Zone	0.53	14°19'09.25"N/78°16'08.22"E	a
2	Tummalapalle		1.17	14°19'37.61"N/78°15'20.28"E	a, b
3	Rachakuntapalle		3.74	14°18'24.12"N/78°17'46.38"E	a, b
4	Bhumaiagaripalle		3.93	14°19'50.64"N/78°18'05.94"E	a, b
5	Velpula		4.55	14°21'52.14"N/78°16'11.76"E	a, b
6	Bestuvaripalle	Buffer Zone-1	6.64	14°22'56.58"N/78°15'11.94"E	b, c, d
7	Vemula		7.85	14°22'14.46"N/78°19'13.26"E	b, c, d
8	V. Kottapalle		9.90	14°22'10.44"N/78°21'29.46"E	b, c
9	JNTUACE Pulivendula	Buffer Zone-2	14.28	14°26'55.74"N/78°14'04.50"E	c
10	Pandulakunta		17.70	14°10'49.68"N/78°11'30.06"E	b

Note: a – Located near mining site; b – Village habitation; c – Located near Road side; d – Located near stone crushing

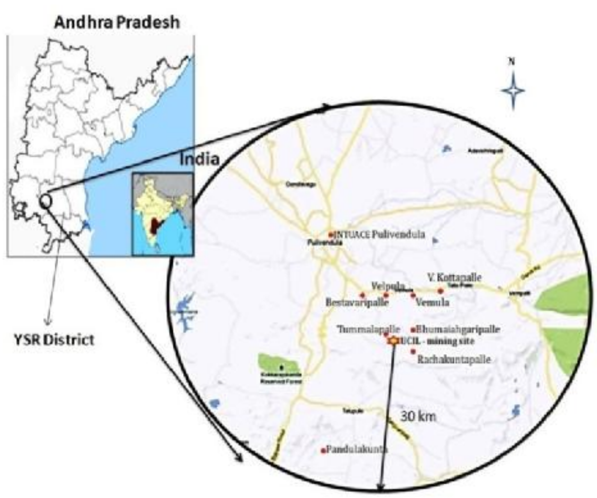

Fig. 1. Geographical distribution of the sampling locations

3. MATERIALS AND METHODS

3.1 Materials

All reagents used for the analysis were of analytical grade. Milli–Q water is used for all dilutions. All the glass wares were cleaned by soaking in dilute nitric acid and were rinsed with distilled water prior to use.

3.2 Sample Collection and Analysis

The samples of PM_{10}, TSP, SO_x and NO_x were collected twice a month (once in a 15 days) from November - 2010 to February – 2012 in all the ten selected locations, covering all the seasons i.e., winter, summer and monsoon. High Volume air sampler Model APM 460 BL of Envirotech with a Gaseous attachment Model APM 411 was used to collect the samples by running the equipment for a period of 24 hours at an average flow rate of 1.3 LPM (lit/min). For the collection of gaseous pollutants SO_x and NO_x, the gaseous attachment of high volume air sampler, having impingers (bubbler trains) in series was used.

3.2.1 Estimation of PM_{10} and TSP

The high volume air sampler consist of a cyclone separator which fractionates the dust present in the air into two fractions based on particle size i.e., 1) PM_{10} – with an aerodynamic diameter less than 10 µm and 2) PM>10 - particulate matter with aerodynamic diameter greater than 10 µm. PM_{10}were collected by passing air on pre-weighed glass fiber/EPM 2000 filter paper (20.3 cmX25.4 cm). PM>10 were collected in a cup which is attached to cyclone. The PM_{10} and PM>10 were weighed accurately using 0.01 mg sensitive electronic balance (Make: Sartorius and Model: CP225D).Total Suspended Particulate (TSP) is calculated by adding both PM_{10} and PM>10.

3.2.2 Estimation of NO_x and SO_x

Ambient air sample collected in ‘gaseous attachment of high volume sampler’ is passed through known concentration of Sodium Arsenite solution for the collection of NO_X. The concentration of absorbed nitrite ion produced during sampling is determined colorimetrically. Phosphoric acid, sulfanilamide, and N-(1-naphthyl)-ethylenediamine di-hydrochloride (NEDA) is added to the nitrate ion absorbed in arsenite solutionto form coloured azo-dye complex. The absorbance of the highly coloured azo-dye was determined at 540 nm by spectrophotometrically (Modified Jacobs & Hochheiser Method) [13].

SO_x from air is made to absorb in a solution of potassium tetrachloro - mercurate (TCM). Upon the absorption, a dichlorosulphitomercurate complex, which resists oxidation by the oxygen in the air, is formed. The formed complex is stable to strong oxidants such as ozone and oxides of nitrogen. The complex is made to react with para-rosaniline and formaldehyde to form the intensely coloured pararosaniline methylsulphonic acid. The absorbance of the solution is measured by means of spectrophotometer at the wavelength of 560 nm (Modified West & Gaeke Method) [13].

3.3 Quality Control

The filter papers and cyclonic cups used for particulate samples (PM_{10} and PM>10) were pre – conditioned by keeping in a desiccator for 24hrs and were pre – weighed. After collection of particulate matter both filter paper and cyclonic cups were reconditioned for another 24 h by keeping in the desiccator. Then these reweighed for estimation of PM_{10} and TSP. The absorbing solutions for gaseous samples (SO_x and NO_x) were prepared as per standard analytical procedure. The gaseous samples were collected using impingers with 0.5 LPM (lit/min) flow rate for the duration of 8 h. This was repeated for 3 times a day to give 24 h average concentration. After the collection of the gaseous samples, these are transferred into the HDEP bottle and preserved in the refrigerator. The samples were analyzed immediately after the collection of batch samples. All the procedures during collection of samples were strictly followed as per the guidelines of CPCB, India [13,14].

3.4 Combined Air Quality Index (CAQI)

CAQI is a tool, which calculates the overall air quality with respect to the pollutants PM_{10}, TSP, SO_x and NO_x and the measurements are converted into dimensionless number using Indian National Ambient Air Quality Standards (INAAQS) [14].The CAQI is exclusively designed based on Indian climatic conditions and concentration ranges of pollutants. CAQI gives a meaningful assessment of pollution in a generic way. CAQI formula is designed as per Oak Ridge Air Quality Index [15,16] which is a non linear equation and may include one to five pollutants based on the available standards for pollutants. CAQI is calculated on daily basis of each sampling time and the seasonal CAQI were calculated by simple arithmetic mean.The category and descriptions of CAQI are given in Table 2. The CAQI formula is as follows:

$$\text{CAQI} = \left[\left(\frac{100}{4}\right)\left(\sum_{i=1}^{4} P_i \Big/ P_{si}\right)\right] \quad \text{--------------------------- (1)}$$

Where P_i = Concentration of Pollutant *i* (PM_{10}, TSP, SO_x and NO_x)
P_{si} = Standard value for prescribed pollutant *i* (as per INAAQS)

Table 2. Category and Description of CAQI

CAQI value	Description	Description Color	Health effects
0-40	Clean Air	Green	No health effects
41-100	Moderate Air Pollution	Yellow	Unhealthy for sensitive groups
101-200	Heavy Air Pollution	Orange	Unhealthy
>200	Severe Air Pollution	Red	Very unhealthy – alert

3.5 Z – Score

The pollutant variables (Concentrations of PM_{10}, TSP, SO_x and NO_x) are standardized by means of Z – scores of the pollutants to avoid any effects of unit scale on the distance measurements by applying the following equation [17].

$$Z_{ji} = \frac{C_{ji} - \mu_i}{SD_i} \text{ – – – – – – – – – – – – – – – – } (2)$$

Where, Z_{ji} – standardized Z – score value of pollutant *i*in the zone of j
C_{ji} – the average concentration of pollutant i in the zone of j
μ_i – the average value of pollutant i for all the zones
SD_i– standard deviation of pollutant p

As per the above equation: if Z_{ji}> 0, the pollution level is higher than the average value of all regions (μ_i); if Z_{ji}< 0, which infers the pollution level is comparatively low and if Z_{ji} = 0, infers the pollution is at average level.

4. RESULTS AND DISCUSSION

The objective of the present work is estimate the air quality around the Tummalapalle uranium mining site. In this regard, the concentration of pollutants measured and CAQI is estimated for all the three seasons namely winter, summer and monsoon. The obtained values are reported in Table 3.

The data from Table 3, indicates that PM_{10} vary from 25.7 – 64.4 µg m^{-3}; TSP ranges from 57.3 – 126.1 µg m^{-3}; SO_x ranges from 2.2 – 5.2 µg $m^{-3}$and NO_x vary from 17.0 – 50.1 µg m^{-3}. Indian air quality standards are also reported in the Table 3. It may be noted all the observed pollutant concentrations are much below the standard values. Further, it may be observed that all the pollutant concentrations at locations 1 (UCIL-mining site) and 2 (Tummalapalle) are in higher concentration compared to other locations. It may also be observed that during summer, highest seasonal average for PM_{10} and TSP were observed at Tummalapalle, Vemula, respectively, whereas highest SO_x and NO_x were observed at Tummalapalle during winter season. The observed high levels of particulate matter at UCIL – Mining site is due to the construction and mining activity. The high concentration of particulates at the industrial area may be attributed due to resuspension of road dust, soil dust, automobile traffic and nearby industrial emission [2,18]. High concentration of gaseous pollutants at Tummalapalle is noticed which may be due to vehicular transportation, burning of wood, enhanced combustion activities [1,3] as most of the labourers working at the site are residing at Tummalapalle. However, still measured SO_x and NO_x concentrations were below the Indian NAAQS.

Table 3. Seasonal Average Pollutant Concentration (µg m^{-3}) and CAQI

S. No	Location	Distance	Winter (n^* = 7)						Summer (n^* = 6)						Monsoon (n^* = 6)					
			PM_{10}	TSP	SO_x	NO_x	CAQI	Description	PM_{10}	TSP	SO_x	NO_x	CAQI	Description	PM_{10}	TSP	SO_x	NO_x	CAQI	Description
1	UCIL - Mining site	0.53	49.8	98.4	5.0	46.2	40.8	MAP	60.0	126.1	4.8	49.5	47.7	MAP	51.8	110.0	3.6	25.2	35.7	CA
2	Tummalapalle	1.17	46.9	92.2	5.2	50.1	40.5	MAP	64.4	118.3	3.8	49.1	47.4	MAP	51.3	92.9	4.9	27.1	34.4	CA
3	Rachakuntapalle	3.74	37.0	74.9	3.9	44.4	33.7	CA	46.0	105.8	2.9	39.1	37.9	CA	32.4	60.9	4.0	16.4	22.1	CA
4	Bhumaiagaripalle	3.93	40.1	85.9	2.5	38.7	33.6	CA	37.2	93.0	3.2	32.9	32.2	CA	52.9	98.7	4.8	21.4	33.8	CA
5	Velpula	4.55	48.7	87.8	4.8	37.2	36.3	CA	29.5	73.4	2.5	47.3	32.1	CA	50.0	94.8	5.0	23.4	33.2	CA
6	Bestuvaripalle	6.64	50.5	73.6	4.9	48.8	38.6	CA	43.4	87.1	2.6	47.4	37.4	CA	54.4	94.7	4.7	20.1	33.2	CA
7	Vemula	7.85	48.4	87.9	4.2	41.9	37.5	CA	57.1	145.8	2.8	47.2	48.1	MAP	54.9	80.3	4.1	20.1	31.3	CA
8	V. Kottapalle	9.90	34.2	84.7	3.2	45.3	34.3	CA	40.5	86.9	4.0	37.5	34.0	CA	39.2	67.0	3.2	29.0	28.2	CA
9	JNTUACE Pulivendula	14.28	42.5	64.7	4.1	50.1	35.7	CA	52.1	96.0	3.4	32.2	36.2	CA	35.4	57.3	4.2	21.6	24.1	CA
10	Pandulakunta	17.70	29.3	66.1	2.2	24.1	23.8	CA	28.9	66.2	2.3	17.0	21.5	CA	25.7	64.9	2.3	19.8	21.4	CA
11	INAAQS		100	200	80	80			100	200	80	80			100	200	80	80		

*Note: MAP – Moderate Air Pollution; CA – Clean Air; *: n= number of samplings in a given season*

4.1 Seasonal variation of Air quality and CAQI

Seasonal variation of CAQI for all the ten sampling locations is shown in Fig. 2. On the basis of CAQI values, it can be inferred that in general the better air quality may be observed in the following order monsoon>winter>summer. The similar seasonal pattern was also observed at Beijing [19]. The values of CAQI at UCIL– Mining site (location 1), Tummalapalle (location 2) and Vemula (location 7) are greater than 40, therefore, the air quality at these locations may be categorized as moderate pollution (See Table 2). Whereas the CAQI below 40 throughout the year for all the remaining sampling locations. Therefore, the air quality at these locations may consider as clean air (Table 2).

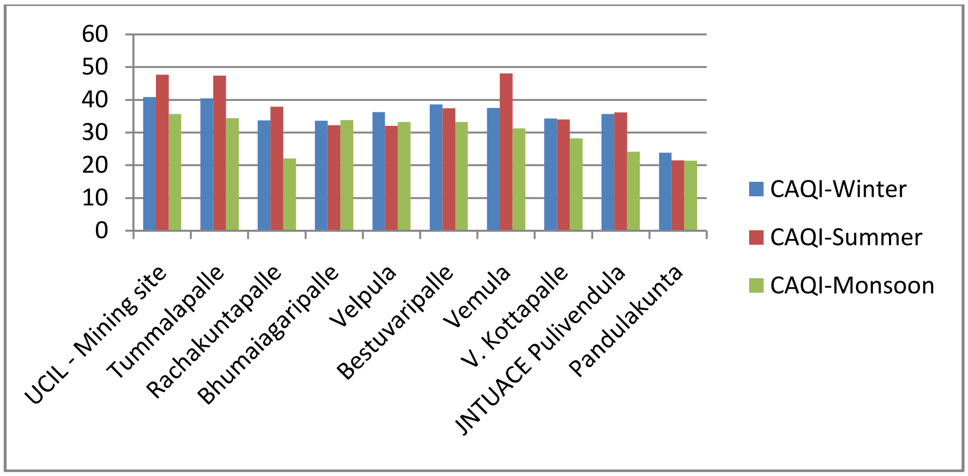

Fig. 2. Seasonal Variation of CAQI

The UCIL–Mining site and Tummalapalle are situated in core zone having the radial distance of 0.53 and 1.17 km, respectively. The higher pollution generation at these locations is due to movement of tipper Lorries carrying ore, operating machineries, fuel combustion, combustion activities of villagers and labourers staying in nearby areas. In addition to these activities, vehicles for local public transportation may be the reason for the elevated values of CAQI for the above two locations. The location Vemula is located in buffer zone – 1 at radial distance of 7.85 km and the sampling location is located on Pulivendula - Kadapa highway, catering to huge vehicular movement. In addition to the above, the existing stone crushing mills near the location adding extra pollution load. Further, it is also observed from Fig 2 that the CAQI at the Pandulakunta sampling location was lowest in all the seasons. This may be mainly due to the situation of this location. This location is being far away from the mining site as well as road side activity and it is situated at one side of hill.

4.1.1 Winter

The CAQI values in winter were found to show decreasing pattern with increase in distance of the locations from the mining site up to 4^{th} (Bhumaiagaripalle) location. As per study area description, these locations are in core zone and the pollution is expected mainly from mining construction activities, local activities of the villagers. From 5^{th}–10^{th} locations, no particular trend was observed. The evaluated data of CAQI indicates Moderate air pollution at UCIL – mining site as well as at Tummalapalle, whereas clean air at remaining 8 sampling locations.

4.1.2 Summer

It is found that the same trend is also observed in summer season in line with winter season, except the concentration values are observed to be higher. The CAQI is inversely proportional with the distance from the mining site up to 5th (Velpula) location. These are located in core zone as per the description of study area and therefore, primary cause of this pollution is expected to be from constructional activities at mining, house hold activities of the villagers, etc. From 6th –10th locations, no particular trend was observed. This is because of the locations are far away from the mining site and the pollution is probably expected from other combination of sources like vehicular transportation, stone crushing, fuel combustion, crop cultivation activities, etc. The CAQI value at Vemula is highest during summer. The reason may be its location being near to road side and the stone crusher was running continuously during sampling time. In addition to this, road construction activities are taking place during this period.

4.1.3 Monsoon

In monsoon, the observed CAQI values shows different pattern when compared to winter and summer. The CAQI is showing decreasing trend with increasing distance of the locations from the mining site for all the locations except the 3rd location. The value of CAQI indicates clean air for all the ten sampling locations. During monsoon, the pollution may be expected to be low, since the mining activity, vehicular transportation is reduced due to rain. Further the particulate matter cannot transport large distance during rainy season.

4.5 Pollution Levels and its characteristics – Zonal distribution

The air pollution characteristics indicated by Z – score test for the three zones namely core zone, buffer zone – 1 and buffer zone – 2 are given in Table 4.

Table 4. Z – Scores of three zones

Zones	Z – Scores			
	PM_{10}	TSP	SO_x	NO_x
Core Zone	0.23	0.42	0.50	0.17
Buffer Zone – 1	0.24	0.18	0.27	0.22
Buffer Zone – 2	-0.49	-0.72	-1.33	-0.40

It is observed that, the core zone is showing higher Z – scores when compared to buffer zone -1 and buffer zone – 2. In case of core zone, the pollution levels of all the 4 pollutants are greater than 0, Further, Z scores of TSP (Z_{ji} = 0.42) and SO_x (Z_{ji} = 0.50) are higher when compared with PM_{10} and NO_x. Hence, core zone may be characterized as high TSP/SO_x pollution zone. In buffer zone - 1, the Z_{ji} values of PM_{10} (0.24) and NO_x (0.22) are observed high in comparison with other two zones. Hence, buffer zone-1 may be characterized as high PM_{10}/NO_x pollution zone. Buffer zone - 2 has the smallest Z_{ji} values for all the pollutants PM_{10} (-0.49), TSP (-0.72), SO_x (-1.33) and NOx (-0.40) in comparison with other two zones and even less than zero. The air pollution for this group may be characterized as low PM_{10}/TSP/SO_x/NO_x.

5. CONCLUSIONS

The present study is focused on variation of seasonal air quality in and around the Tummalapalle Uranium mining site by estimating the combined air quality index (CAQI) and Z–scores. The CAQI and Z–scores are estimated using the concentration of the four common air pollutants (PM_{10},TSP, SO_x and NO_x).The observed air pollution at all the locations is below the Indian air quality standards. The seasonal air quality founds to be better in the order of monsoon>winter>summer. The CAQI at the Pandulakunta sampling location was lowest in all the seasons. The quality of air comes under 'clean air' during monsoon at all the sampling locations. Moderate air pollution is observed at UCIL – Mining site and Tummalapalle during winter and summer seasons. Core zone and Buffer zone - 1 are showing high Z – scores (i.e., positive) for all the pollutants indicating higher air pollution where as Buffer Zone - 2 is showing low values (i.e., negative) revealing pollution free zone.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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