International Journal of Environment and Climate Change

Volume 14, Issue 4, Page 692-707, 2024; Article no.IJECC.116205
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Ambient Air Quality Assessment through Air Quality Index and Air Quality Health Index for Eastern Coastal Region, Gandhidham, Gujarat, India

Pratik D. Sengani [a,b,c*], Rachna Chandra [b,d] and Gaurav Agarwal [e]

[a] School of Science, RK University, Bhavnagar Highway, Kasturbadham, Rajkot, Gujarat -360020, India.
[b] Environmental Impact Assessment Division, Gujarat Institute of Desert Ecology (GUIDE), P.O Box No. #83, Opp. Changleshwar Temple Mundra Road, Bhuj-Kachchh, Gujarat -370001, India.
[c] Present Address: ClimaCrew Pvt Ltd. Sakar III, Ahmedabad- 380014, India.
[d] Faculty of Agriculture, Sri Sri University, Cuttack -754005, Odisha, India.
[e] Faculty of Engineering and Technology, Parul University, Vadodara -391760, India.

Authors' contributions

This work was carried out in collaboration among all authors. Author PDS collected the samples, analyzed them and drafted the MS. Author RC supervised the team during data collection, sample analysis and MS writing. Authors GA did the supervised and corrected the initial MS draft. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2024/v14i44151

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/116205

Original Research Article

Received: 25/02/2024
Accepted: 29/04/2024
Published: 02/05/2024

**Corresponding author: E-mail: pratik21292@gmail.com;*

ABSTRACT

The impact of coastal developmental projects such as ports on regional air quality has been a matter of concern, as they are known to induce rapid industrialization and urbanization as collateral development on a long-term basis. Gandhidham-Kachchh, Gujarat, India is hub for industrialization, thus various developmental activities and port activities may release toxic gases into the environment. Thus, an attempt was made to assess the present ambient air quality in and around eastern coastal region of Gandhidham, Gujarat using Air Quality Index (AQI) and Air Quality Health Index (AQHI). The primary focus was on respirable particulate matter (PM_{10}) and fine particulate matter ($PM_{2.5}$) along with other gaseous pollutants. In total 134 samples were collected from 11 stations during January to December 2018. Sampling was carried out 24 hourly on a monthly basis. Respirable particulate matter (PM_{10}), fine particulate matter ($PM_{2.5}$), sulphur dioxide and nitrogen dioxide ranged from 29-401 µg/m^3, 13-184 µg/m^3, 5.9-92.6 µg/m^{3}and 3.7-33 µg/m^3, respectively. The annual mean concentrations varied from 118-227 µg/m^3, 47-82 µg/m^3, 10-51 µg/m^3, 11-41 µg/m^3 for PM_{10}, $PM_{2.5}$, sulphur dioxide and nitrogen dioxide, respectively. In most of the sampling locations both the particulate matter fractions exceeded the permissible limit as prescribed in National Ambient Air Quality Standard (NAAQS). The AQI ranged from 28 to 106, which falls under Good and Satisfactory category of pollution as per the Central Pollution Control Board (CPCB) standards except at A-11 which falls under Moderate category. The AQHI was in the range of 5.9 to 15.8, which was alarming indicating Moderate to Very Higher Risk to the people. The present findings throw light on the prevailing scenario in the ambient air quality of the studied region, thereby suggesting for strict implementation and thorough control measures for reduction of particulate matters in the air.

Keywords: Air pollution; AQHI; AQI; gaseous pollutant; Kachchh; particulate matter.

1. INTRODUCTION

Air quality degradation is one of the inevitable impacts of developmental activities such as industrialization and urbanization leading to health implications on human and animals [1]. Both particulate matter (PM) and gaseous pollutants contribute to such degradation. PM, a mixture of extremely small particles and liquid droplets made up of acids, organic chemicals, metals and dust particles, has been widely studied due to their potential impact on the human, and environment, climate forcing (IPCC 2013a). While, the particles larger than 10 µm originate mainly from natural sources, *viz*., windborne sea spray and calcium- and iron-rich dust, the ones below 10 µm size arise mostly from anthropogenic sources, e.g. fuel combustion, industrial processes, vehicular emissions, and non-industrial fugitive sources such as tobacco smoke [2]. Natural sources of PM include volcanoes, fires, dust-storms and aerosolized sea salt. Particle size <10 µm are more toxic because they easily enter through respiratory system and get trapped in the alveoli leading to cardiovascular and respiratory disorders [3]. Research on health implications of air pollution has been on focus since the last two decades [4].

Although, the contamination of environment due to dust particulates and toxic gases emanating through fossil fuel burning and industrial processes draws serious attention for their potential threat to the ecosystem [5,6,7]. such contamination in regions with industrial clusters and large ports is a matter of concern. The emissions from large industrial complexes and port establishments can adversely impact the surrounding coastal atmosphere, as a result higher pollution load in the ambient air (Basha et al 2010). Such regions need to be examined periodically and the status need to be interpreted through indices for ease of understanding. Air Quality Index (AQI) represents the status of the air environment in a particular area at a given time. It is the measure of the overall pollutant concentration w.r.t. the prescribed national standards of pollutants and identifies the anticipated effect on health and environment. Air Quality Health Index (AQHI) is a tool to protect your health using the AQHI scale value (0 – 10). The score represents the status of air quality at given time. It helps to understand the highly sensitive people for doing outside activities (Table 4). Various studies in this regard have been undertaken all over the globe focusing mainly on the ambient air quality status Azmi et al. [8] Barman et al. [7] Yadav et al. [9] Prusty [10] Mukhopadhyay and Mukherjee [11] Rai et al.

[12] Barman et al. [13] Tripathee et al. [4] Sateesh et al. [14] Yu et al. [15].

In view of the above specifics, a comprehensive assessment was carried out in Gandhidham region of Kachchh district in Gujarat. The area is known for one of oldest and busiest port establishment in the country, i.e. Kandla Port Trust, recently renamed as Deendayal Port Trust (DPT). The DPT is in first position among all the Major Ports of India w.r.t. cargo handling for the most of the years in last decade. Further, there has been a slew of upgrades and capacity expansions in berths and other additional activities in the DPT area, leading the DPT to initiate integrated developmental activities. Such activities require monitoring of ambient air quality (AAQ) in the regional scale to keep the management authorities abreast of prevailing scenario. Further, consequent upon the tax incentives declared by the Gujarat State Government as part of post-earthquake restoration and normalization measure, around 151 new industrial projects with an investment of Rs 4785 crores were proposed and/or established in Kachchh district by March 2004. Most of these industries were located in an around Gandhidham, thereby making cumulative impact of such industries along with the port activities inevitable. Further, due to semiarid climatic conditions, the dry wind has the potential to carry polluted air with dust particles to a long extent, which may cause severe health problem to surrounding residential and degradation to environment. Thus, the present study was carried out to

i. facilitate the scientific community in understanding the environmental impacts of ongoing activity and take timely and effective measures for mitigation of negative impacts, where required, and
ii. investigate the AAQ in Gandhidham region and presenting the prevailing scenario through different indices such as AQI and AQHI.

2. MATERIALS AND METHODS

2.1 Study Area

The present assessment was conducted in and around Gandhidham (23° 4’ 48” N and 70° 7’ 48” E) in Kachchh district, Gujarat (Fig. 1). Coastal and inland environmental settings of Gandhidham are similar to other parts of Kachchh, for its climatological peculiarities such as aridity, geomorphology, coastal and terrestrial ecosystems. Summers are hot and dry, the temperature may reach upto 43ºC and in winters, sometimes it may falls to 5°C also accompanied by cold waves. The average annual temperature and rainfall is 29.8°C and 375mm, respectively. The annual average humidity is 60% and average wind speed range from 11 m/s with maximum wind speed of 16.61 m/s during June. Overall, the climate of the region is characterized by long hot summer, cold winter and overall aridity. The study zone covers various landscapes like forests, agriculture, industries, mining areas, grasslands, mangroves, salt pans, rocky barrens, wetlands and wasteland. The major sources of atmospheric emissions in and around Gandhidham region are dominant industrial activities including land clearing, removal of overburden, vehicular movement, manufacturing of chemicals and their formulations. In addition, different activities associated with port operations, *viz*., loading and unloading of various mineral salts and raw materials of several processing and manufacturing industries have been carried out at Deendayal Port, Gujarat. Other port activities include loading, unloading and storage of several petroleum products, coal, salts, different chemical products, exotic woods materials, etc. which attract small and medium scale entrepreneurs to transport, storage and process of such raw materials.

2.2 Details of Sampling Sites

Reconnaissance was carried out to gain basic understanding about the existing ecosystem types and to identify the strategic locations for ambient air quality monitoring. For the purpose of obtaining an overall picture about air quality parameters in the region, different locations like industrial, residential and busy highway along with control site were considered and accordingly the ambient air quality monitoring stations (AAQMS) were selected following Central Pollution Control Board [16] guideline. The stations were selected to obtain representative picture of the air quality in the region by considering different characteristic features, *viz*., (i) sensitivity of the station, (ii) source of pollutants, (iii) meteorological parameters such as predominant wind direction, (iv) human settlements, (v) provisions of electricity and safety of the instruments, (vi) height of instrument fixation, and (vii) accessibility of the station. Total 11 AAQMS were selected with respect to industrial, residential and busy highway (Fig. 1). Of them, 4 are in residential area, 4 are in industrial area and 3 are in Busy Highways. The details of Ambient Air Quality Monitoring Stations (AAQMS) are presented in Table 1.

2.3 Sampling and Analysis

Ambient air sampling was carried out in the identified locations on monthly basis. For the sampling of PM_{10} (respirable suspended particulate matter (RSPM)), Respirable Dust Sampler (RDS, make: Ecotech, model: APM460 BL) was used. The sampling was carried out for 24 h at an air flow rate of 1.0 to 1.3 m^3/min using glass microfibre filter paper (make: Whatman, type: GF/A, size 20.3 × 25.4 cm). The sampling of $PM_{2.5}$ (fine particulate matter) was carried out for 24 h using a fine particulate sampler (FPS, make: Ecotech, model no APM 550) using polytetrafloroethylene filter paper (PTFE, diameter 46.2 mm) supported by a polypropylene ring with a fixed air flow rate of 1 m^3/h. The sampling of SO_2 and NO_2 was carried out using a gaseous attachment (make: Ecotech, model: APM 411 TE) attached with the suction outlet of RDS through a suction pipe. Potassium tetrachloromercurate (0.04 M) was used for sampling of SO_2 and a mixed solution of sodium hydroxide and sodium arsenite was used for the sampling of NO_2 as absorbing solution. The analysis of the samples was carried out as per the analytical method prescribed by CPCB [16]. Further, the annual average concentration of criteria pollutants PM_{10}, $PM_{2.5}$, SO_2 and NO_2 were empirically estimated.

Table 1. Details of AAQMS

Sl No.	AAQMS Code	Location Name	Area Particulars	Major Activities	Remarks
1.	A-1	Ganesh Nagar	Busy Highway	Predominantly human habitations	In proximity with Kandla Adani Special Economic Zone (KASEZ) and adjacent to Kandla Port Highway with heavy traffic
	A-2	Kakubhai Parikh School	Industrial Area	Industrial activities	The area is covered with the cluster of the small-scale industries and the site very adjacent to the oil refinery.
	A-3	Marine Police station	Busy Highway	Transportation, mobile source of pollution	It situated on Pandit Jawaharlal Nehru Road, which connects Kandla Port. Heavy-duty diesel engine vehicular movement and loading and unloading of various goods and other related products. Also, Sea spray may also contribute to the remarkable amount of PM.
	A-4	Ahir Salt Industry	Industrial Area	Industrial activities mainly handling liquid material	Loading and unloading of the liquid and allied material and adjacent to site, IFFCO plants is located and area with predominantly industrial activities.
	A-5	Rampar Village	Residential Area	Human habitation and natural vegetation	This was also considered as a control site; no industrial activities carried out & highway is located.
	A-6	Padana city	Industrial	Village is	The city falls on the busy

Sl No.	AAQMS Code	Location Name	Area Particulars	Major Activities	Remarks
			Area	Surrounded by the industrial units	highway, the larger industrial units were operating in and around this site. Vehicular movement is seen.
	A-7	Anjar GIDC	Busy Highway	Predominantly industrial activities and little human habitation	Opposite to that site, Anjar city was situated near to site Anjar Bypass Road heavy-duty traffic was travel bypass on this road
	A-8	Yashodadham	Residential Area	Predominantly human habitation and surround with Industries on north side	It is junction points of major highway units to form NH - 41 from sub highways are, NH - 50, NH 8A, Kandla port road, mobile source of the pollutant was noted.
	A-9	Khari Rohar	Residential Area	Human habitation	This is backyard of the Kandla port, the transportation of PM and sea spray is a major source of PM.
	A-10	Bharapar	Industrial Area	Industrial activities	Around the village there are three big industrial units was located, so industrial activities are the dominant source of pollutants followed by the transportation.
	A-11	Devaliya	Residential Area	Human habitation	The village surround by agricultural field, only domestic source of pollution was seen, household burning of wood is the prime source of PM.

2.4 Air Quality Index (AQI)

An index is a form of equation which combines different variables in a mathematical expression to arrive at a single number for overall assessment, and in case of air quality index, the variables are criteria pollutants [17]. Environmental Protection Agency (EPA) defines Air Quality Index (AQI) as an index for reporting daily air quality. It provides insights on the magnitude of the pollution of ambient air and associated health impacts.

$$AQI = 1/4 \times [(IPM_{10}/SPM_{10}) + (IPM_{2.5}/SPM_{2.5}) + (ISO_2/SSO_2) + (INO_2/SNO_2)] \times 100$$

Where, SPM_{10}, $SPM_{2.5}$, SSO_2 and SNO_2 represent the values as prescribed as per revised Ambient Air Quality Standards (AAQS) as prescribed by CPCB [16] and IPM_{10}, $IPM_{2.5}$, ISO_2 and INO_2 represent the observed concentration of pollutants. Further, the selection of pollutant primarily depends on AQI objective, data availability, averaging period, monitoring frequency, and measurement methods. Based on AQI range, CPCB [16] has framed AQI categories to determine the overall health status of an environment (Table 3).

2.5 Air Quality Health Index (AQHI)

The Air Quality Health Index (AQHI) is a public information tool which provides insights about health implications of air pollution on a daily basis [18]. The AQHI, developed by Canadian Government, provides sense to make decisions to cut down short term exposure to air pollution by modifying the action during increased level of pollution. The AQHI provides a number from 1 to 10+ that indicates health risks associated with local air quality (Table 4). For estimation of AQHI, the concentration of NO_2, Ground Level Ozone (O_3) and $PM_{2.5}$ are only considered [19]. But in the present study we analyzed both coarse and fine fraction of Particulate Matter (PM_{10} and $PM_{2.5}$) and SO_2 and NO_2. The choice of gaseous pollutants and PM is based on their representation of different sources of air pollution. NO_2 represents emissions from vehicular exhaust, SO_2 as fossil fuel burning, and PM_{10} represents a wide spectrum of particles, where the mass consists largely of mechanically generated from industrial and road dust particles, and $PM_{2.5}$ represents the finer fraction of particulate matter.

$$Ci = 10\ (Vc/Vs)$$

$$AQHI = (C1 \times C2 \times C3 \times C4 \ldots\ldots)^{1/n}$$

Where Ci = ith Pollutant, Vc = Observed Concentration of ith Pollutant, Vs = Standard concentration of ith Pollutant, n = No. of pollutants.

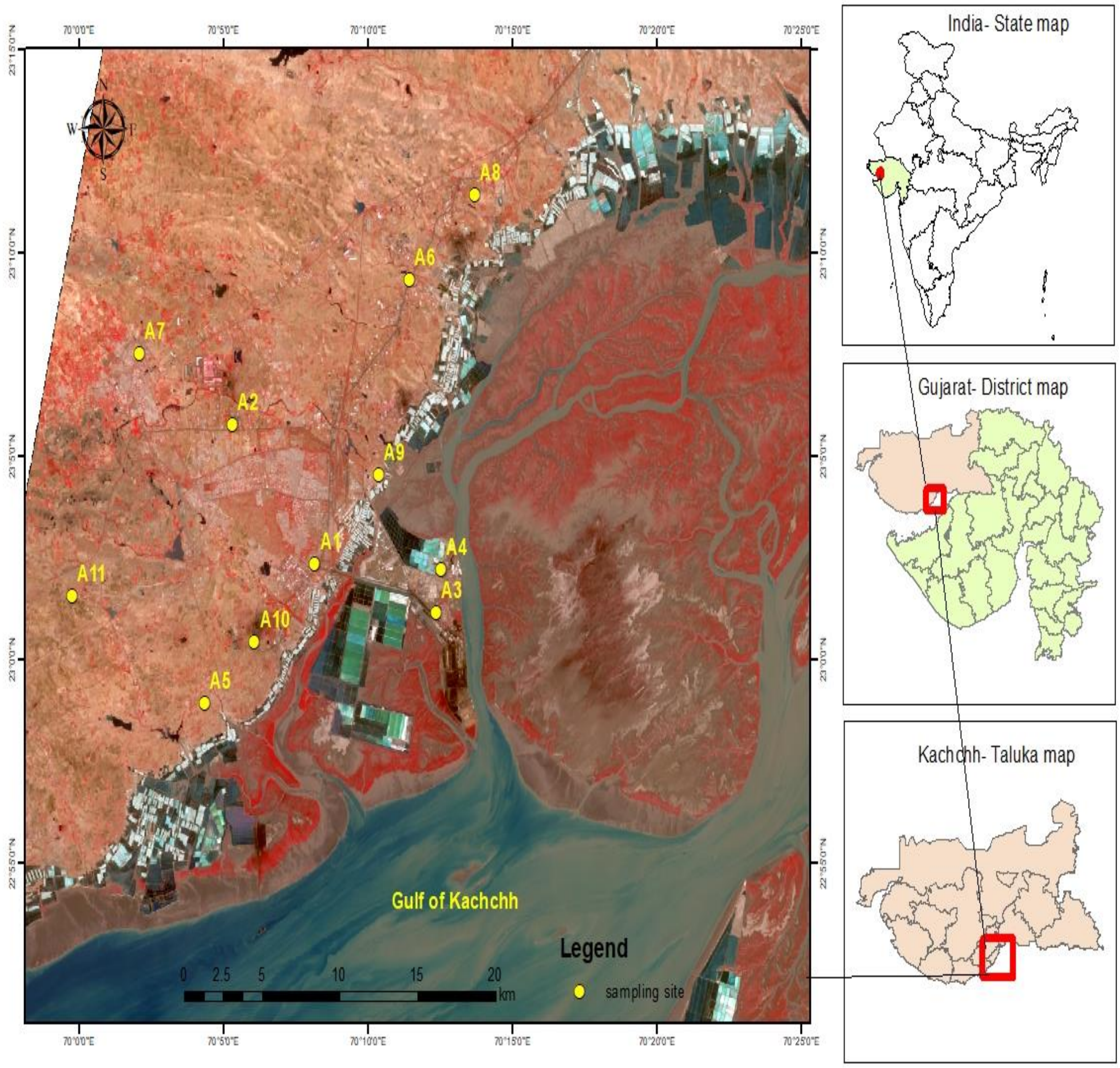

Fig. 1. Study area map with ambient air quality monitoring stations

Table 2. Prescribed limits of air quality parameters

Pollutant	Time Weighted Average	Concentration in Ambient Air	
		Industrial, Residential, Rural and Other Areas	Ecologically Sensitive Area (notified by Central Government)
	Annual*	50	20
SO_2 (µg/m^3)	24 hours**	80	80
	Annual*	40	30
NO_X(µg/m^3)	24 hours**	80	80
Particulate Matter (size less than 10 µm) or PM_{10} µg/m^3	Annual* 24 hours**	60 100	60 100
Particulate Matter (size less than 2.5 µm) or $PM_{2.5}$ µg/m^3	Annual* 24 hours**	40 60	40 60

Source: CPCB [16] pp III

Table 3. AQI range and categories

AQI Range	AQI Category
0-50	Good
51-100	Satisfactory
101-200	Moderate
201-300	Poor
301-400	Very Poor
401-500	Severe

Source: CPCB [16]

Table 4. AQHI categories

AQHI Range	Risk Factor	Health Message	
		At risk Population	General Population
1-3	Low	Enjoy your usual outdoor activities	Can do outdoor activities
4-6	Moderate	Avoid strenuous activities outdoor. Children and the elderly should also avoid outdoor physical exertion.	No need to change your plan for the outdoor activities, unless you don't experience the symptoms like coughing, throat irritation and difficulty in breathing.
7-10	High	Reduce or reschedule strenuous activities outdoor. Children and the elderly should also avoid outdoor physical exertion.	Reduce or reschedule strenuous activities outdoor if you don't feel well.
Above 10	Very High	No activities are allowed, stay indoor	No activities are allowed, stay indoor.

Source: www.theweathernetwork.ca (accessed on 10.10.2020)

2.6 Data Analysis

The analytical data were subjected to a suite of statistical tests for better inference and understanding of the AAQ scenario in the study area. The basic descriptive statistics and two-tailed correlation matrix. The descriptive analysis was done using MS Excel software (MS Office 2010) and MEGASTAT 8.8. All the reported differences in the text represent significance at $\alpha = 0.05$ level.

3. RESULTS AND DISCUSSION

3.1 Particulate Matter (PM_{10} and $PM_{2.5}$)

The PM_{10} concentration exhibited significant spatio-temporal variation among the sampling stations. In the present study PM_{10} and $PM_{2.5}$ concentration were higher than the prescribed limits (in NAAQS) at several stations. The background concentration of PM_{10} ranged from 29-401 µg/m^3 (Fig. 2 and Table 5) with annual average mean of 179±69 µg/m^3. Only 24 out of 132 samples were found confirming to the NAAQS standards i.e. concentrations ≤100 µg/m^3. The annual mean observed was higher at all the sampling sites as compared to NAAQS (≤60µg/m^3). The highest concentration of PM_{10} (401 µg/m^3 at A-10) was recorded during January, which might be due to the cumulative impact of industrial activities in and around the location. Within 1 km radial distance from the said location, three industrial units are operational, of which one iron and steel industry was a major one in contributing PM from the chimney of furnace and also associated vehicular movements due to the industrial activities. The role of atmospheric inversion especially subsidence and advective inversions (owing to the topography of the location) can't be ruled out. The role of temperature inversion in such higher concentrations of PM as localized events has been described by Mishra et al. [1]. The lowest concentration of 29 µg/m^3 at A-3 location during September could be ascribed with higher wind speed facilitating horizontal dispersion of the particle in the atmosphere, which can take away the pollutant. During winter anticyclonic condition prevails, which is characterized by calm or very low wind, resulting in little dispersion or dilution of pollutants thereby causing localized accumulation/higher concentration of the PM_{10} in the lower atmosphere [20].

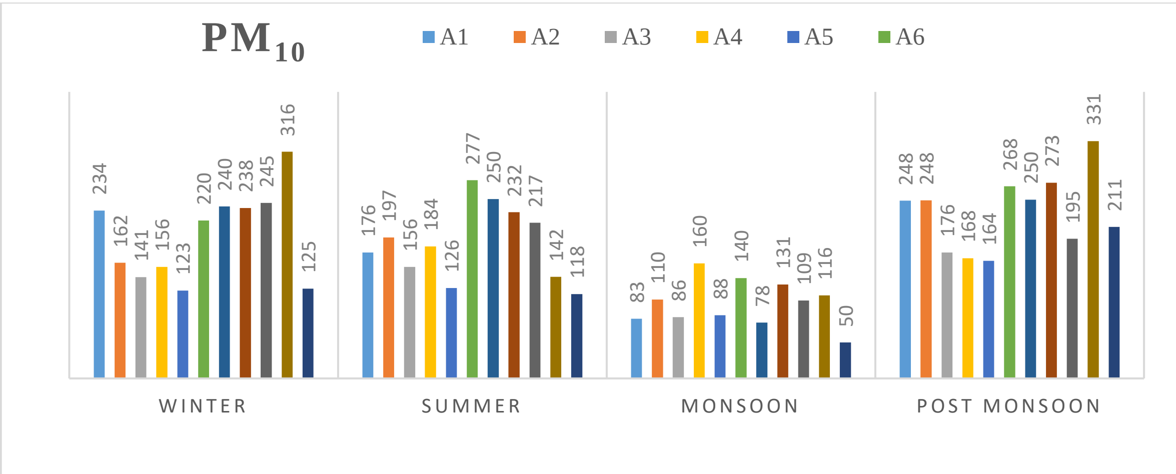

Fig. 2. PM_{10} Concentration and Seasonally variation

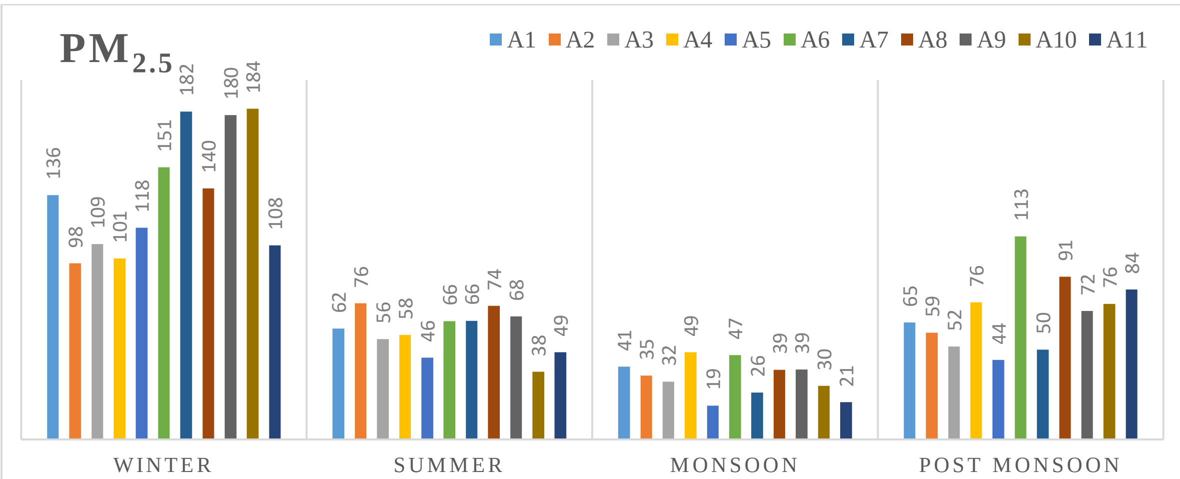

Fig. 3. $PM_{2.5}$ Concentration and Seasonally variation

Table 5. Concentration of monitored air pollutants in an around Gandhidham city

LOCATION	Min	Max	AVG. PM_{10} (µg/m³) (Std Dev.)	CPCB Limit (24hrs)	Min	Max	AVG. $PM_{2.5}$ (µg/m³) (Std Dev.)	CPCB Limit (24hrs)	Min	Max	AVG. SO_2 (µg/m³) (Std Dev.)	CPCB Limit (24hrs)	Min	Max	AVG. NO_x (µg/m³) (Std Dev.)	CPCB Limit (24hrs)
A-1	59	265	179(69)	100 (µg/m³)	14	136	67(33)	60 (µg/m³)	18	55	31(15)	80 (µg/m³)	13	41	20(4)	80 (µg/m³)
A-2	92	294	175(56)		21	111	65(25)		12	40	20 (20)		15	48	27(3)	
A-3	29	205	138(50)		21	109	56(27)		15	36	25(14)		18	39	30(5)	
A-4	89	235	168(39)		24	104	60(27)		16	42	28(18)		12	28	18(7)	
A-5	70	232	122(46)		14	118	47(27)		8	11	10(17)		7	15	11(2)	
A-6	75	393	227(79)		39	151	82(38)		24	41	29(22)		13	33	23(4)	
A-7	54	336	205(82)		13	182	69(50)		13	35	22(18)		12	31	18(4)	
A-8	92	290	215(60)		22	161	77(44)		18	39	28(13)		14	30	20(5)	
A-9	62	310	193(65)		17	180	77(47)		16	50	27(20)		12	35	19(4)	
A-10	64	401	211(120)		20	184	68(49)		32	86	51(21)		32	55	41(5)	
A-11	43	280	118(65)		15	112	53(34)		10	17	13(8)		11	19	15(3)	

The finer fraction of the PM ($PM_{2.5}$) ranged between from 13-184 μg/m^3 (Fig. 3). The annual mean was higher than NAAQS limits (≤40 μg/m^3) at all the sampling sites (Table 5). The highest level of $PM_{2.5}$ was recorded in January (A-10 location) and the lowest in August (at A-7). There are an array of sources of emissions of $PM_{2.5}$ at ground level, which includes wood-burning stoves, forest fires, diesel engines, natural sources, non-road vehicles, agricultural burning, and fugitive emissions of industries [21,22,23] of which, diesel engines, unpaved roads, industrial operations are some of the major sources of emission in the present case. On the whole, the observed order of areas for PM level was industrial > highways > residential. When inhaled, $PM_{2.5}$ can travel deep into the lungs, and cause or aggravate heart and lung diseases. The dust emanating from the haul roads in the study area seems to have contributed considerably to the suspended particulate matter (SPM) content in the lower atmosphere. The amount of PM_{10} and $PM_{2.5}$ was recorded higher during winter and post monsoon as compared to summer and monsoon. This is in agreement with the findings of a study carried out by Gupta et al. [24] at a port and harbor region of Navi Mumbai.

Meteorology plays an important role in air quality by affecting the advection, diffusion and dispersion of PM which is mainly determined by variables such as wind direction, precipitation, solar radiation, cloudiness, relative humidly and wind speed.
Table ***7*** and Fig. 10) (Xu et al. 2016). The concentration was higher during post monsoon and winter which could be attributed to the thermal inversion and foggy condition at lower level causing considerable amount of aerosols which accumulate in lower level of the Earth's atmosphere. However, during monsoon, the PM level remains low due to wash out effect and wet deposition conditions.

The ratio of $PM_{2.5}$ and PM_{10} as estimated for winter, summer, monsoon and post monsoon seasons ranged from 0.58-0.95, 0.23-0.41, 0.21-0.48 and 0.2-0.45, respectively (Fig. 9). Highest ratio was recorded in winter and post monsoon and lowest during summer. During winter, cold air is denser and moves slower than warm air. Cold air traps the pollution but also doesn't whisk it away. So, in winter pollutant remains in place for much longer and therefore is breathed in at a higher rate than during the summer, viz., vehicular movements and transportation, and combustion. While in summer the ratio was lower due to high dry wind velocity which carries the air pollutant away from its origin (Tiwari et al 2014).

To maintain the PM_{10} and $PM_{2.5}$ concentrations, it is suggested that massive plantations of indigenous species must be taken up and maintained around the study area. Trees having high dust trapping efficiency such as *Azadirachta indica, Cassia fistula, Delonix regia, Ficus religiosa, Pterocarpus marsupium* should be grown alongside the roads. Water sprinkling and covered transport system should be adopted at the source of generation of PM. The air pollution tolerance index (APTI) from the leaves of the plant of the chosen roadside species was calculated by Chaudhry and Rathore in 2018, and the effect of the seasons was taken into consideration.

3.2 Gaseous Pollutant (SO_2 and NO_2)

The concentration of SO_2 was in a range of 08 to 86 μg/m^3 (Fig. 4 and Table 5), thereby indicating that the level of SO_2 was within the prescribed NAAQ standards (≤80 μg/m^3) with few exceptions (A-6, A-9 and A-10). Slightly higher concentration may be related to the prevalence of high wind speed or due to intense solar radiation and increased photochemical activity over the sampling sites. Further, the annual mean value of SO_2 for all the samples were within the limits prescribed by NAAQS (≤50 μg/m^3) with few exceptions like A-2 and A-6. These two sites recorded higher annual mean owing to their proximity to the industrial area. Further, it was observed that SO_2 emission, though insignificant, was more at non-industrial sites in comparison to industrial sites.

Table 6. Correlation matrix of air quality parameter and health indices

	PM_{10}	$PM_{2.5}$	SO_2	NO_2	AQI	AQHI
PM_{10}	1					
$PM_{2.5}$	0.930**	1				
SO_2	0.727*	0.607*	1			
NO_2	0.656*	0.566	0.527	1		
AQI	0.220	0.185	0.329	0.462	1	
AQHI	0.750*	0.682*	0.477	0.867*	0.304	1

***. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed). N=11*

Table 7. Meteorological Parameters observed during the sampling period

Parameters	Particulars
Sampling period	January – December 2018
Wind speed (km/h)	12.1- 28.5 km/h
Gust	18.1 -37.2 km/h
Prevailing wind direction	North, North-West and South
Air temperature (°C)	20 – 43ºC
Relative humidity (%)	34- 70 %
Rain days	0 to 32.84 mm

Source - KPT EIA report (2017)

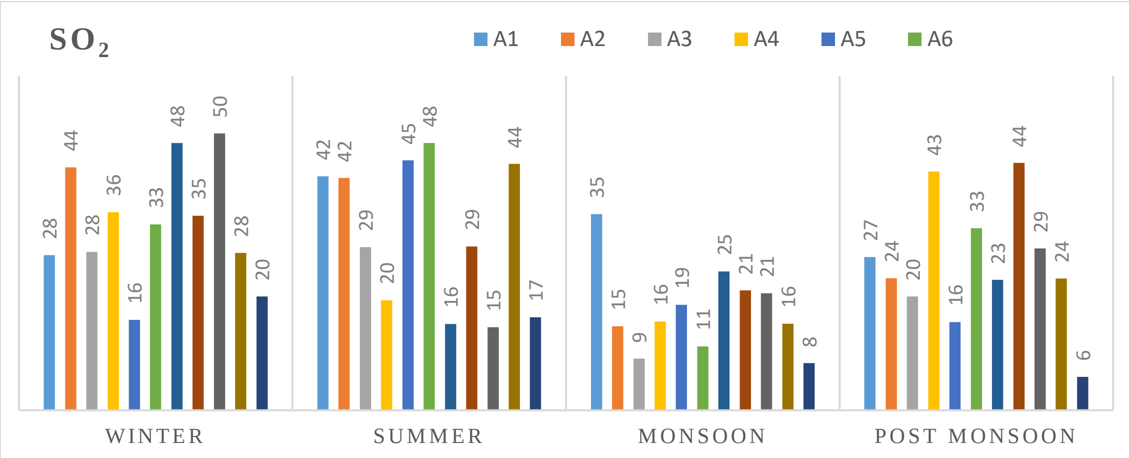

Fig. 4. SO_2 Concentration and Seasonally variation

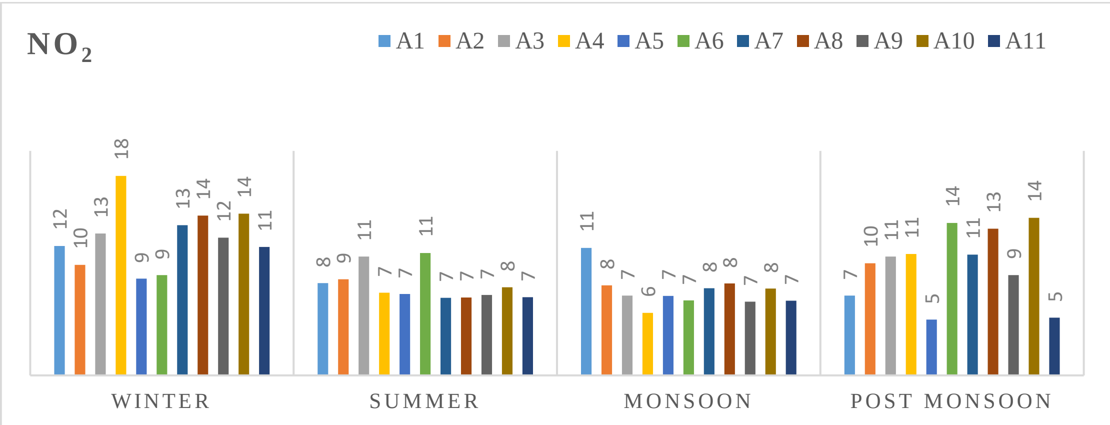

Fig. 5. NOx Concentration and Seasonally variation

The NO_2 values were between 07 and 55 µg/m^3 (Fig. 5 and Table 5) which were within the limits prescribed by NAAQS (≤80 µg/m^3). further, the annual mean value was within the limits (≤40 µg/m^3) for all the stations except A-3 which was in proximity to the national highway with heavy traffic. There was mixed vehicular traffic observed during the sampling duration, wherein small/light vehicles were found using either petrol or CNG, whereas heavy vehicles largely rely on diesel. However, heavy traffic also emits a complex mixture of gases and PM and various chemical compounds that are toxic to the environment such as NOx, O_3 and water vapors, which are precursor compounds for the production of different complex compounds [25].

SO_2 and NO_2 are universal atmospheric pollutants and important constituents of automobile exhaust and industrial emissions [10].

In addition to the ongoing industrial activities, the increasing number of vehicles around the site and nearby villages might have added levels of gaseous pollutants. Most of the air pollutants were highest in winter followed by post monsoon, summer and monsoon but the variation is negligible at all the locations.

3.3 Air Quality Index (AQI)

The Air Quality Index (AQI) may act as a valuable tool, and a proxy assessment of ambient air quality to determine the healthy status of environs [26]. The values of AQI in the present study were derived using the concentration of PM_{10}, $PM_{2.5}$, SO_2, and NO_2. With AQI values between 28 and 106, most of the sites fell under Good category (0 to 50) to Satisfactory category (50-100) with the exception at A-10 falling under Moderate category (100-150), designated by CPCB [16]. The seasonal variation was observed in AQI values with higher values in winter followed by post

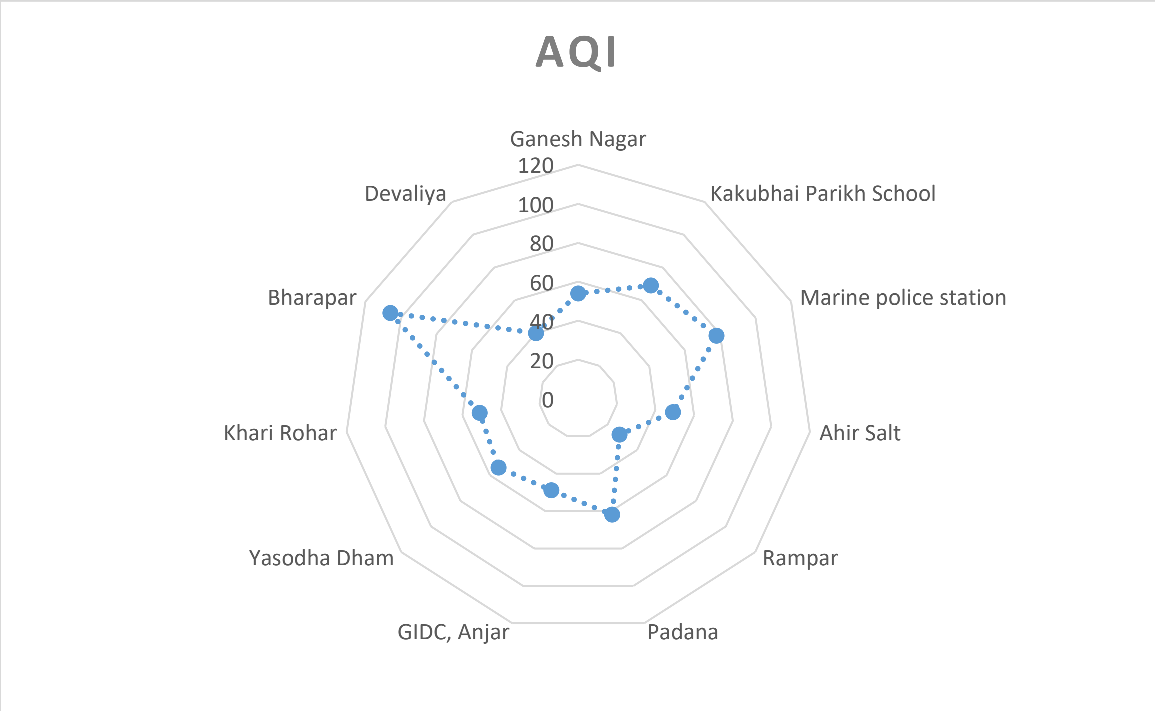

Fig. 6. Spatial Variation in AQI in Gandhidham Area

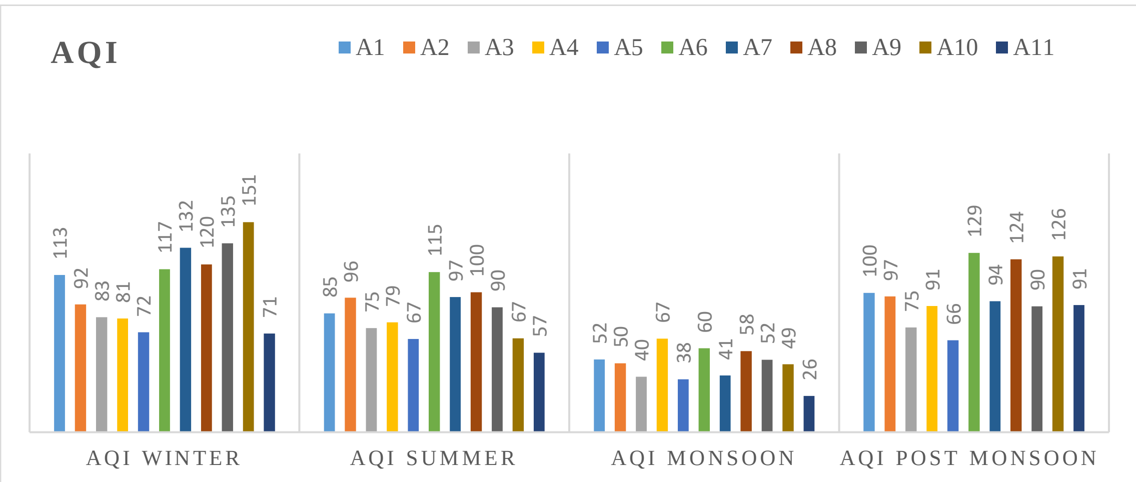

Fig. 7. Seasonal Variation in AQI in the Gandhidham Area

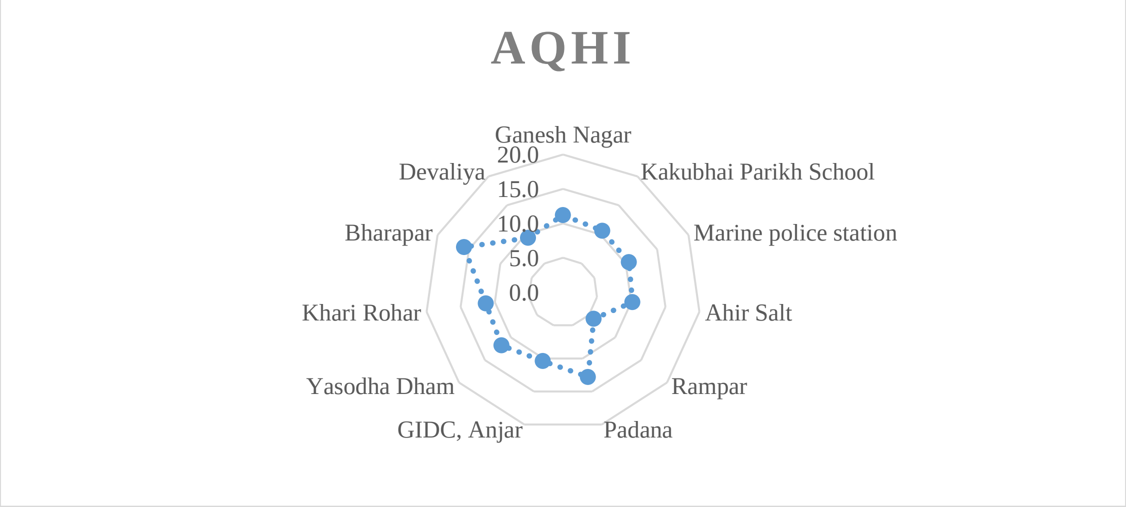

Fig. 8. Spatial variation in AQHI in the Gandhidham area

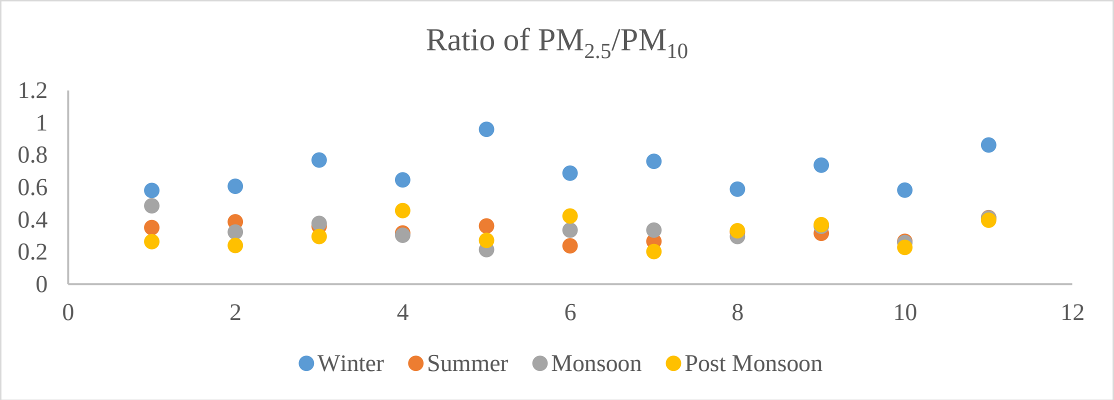

Fig. 9. Seasonal Variation in the Ratio of $PM_{2.5}$ and PM_{10}

monsoon, summer and monsoon (Fig. 6 and Fig. 7). The outranged results of AQI in and around study area may cause minor breathing discomfort to sensitive people as a temporary uneasiness, which can be ameliorated within a short-time period, based on individuals' health and hygiene, susceptibility counterforce, and immunity capacity [27]. The AQI values are useful for the general public to know air quality in a simplified way and decision makers to know the trends of events and to chalk out corrective measures strategies to control pollution [28,29].

3.4 Air Quality Health Index (AQHI)

The Air Quality Health Index (AQHI) is a tool that measures air quality in terms of health. AQHI provides a number from 1 to 10+ to indicate the level of health risk associated with local air quality. AQHI in the present study was in the range of 3.8 - 8.7 which was under Moderate to higher Risk category (Fig. 8). The highest AQHI was recorded at A-10 and lowest at A-5. It is apparent that those residing near A-10 site might be suffering from various health-related problems like, COPD, cardiovascular disease and heart disease. A similar study was carried out by Du et al (2020) using 3 criteria pollutants i.e. NO_2, O_3 and PM. This index pays particular attention to people who are sensitive to air pollution. It provides them with advice on how to protect their health during air quality levels associated with low, moderate, high and very high health risks [30,31].

3.5 Correlation Coefficient

In the present study PM_{10} showing positively correlation (<0.5) with the all-other parameters except AQI (>0.5) it indicates that the source of

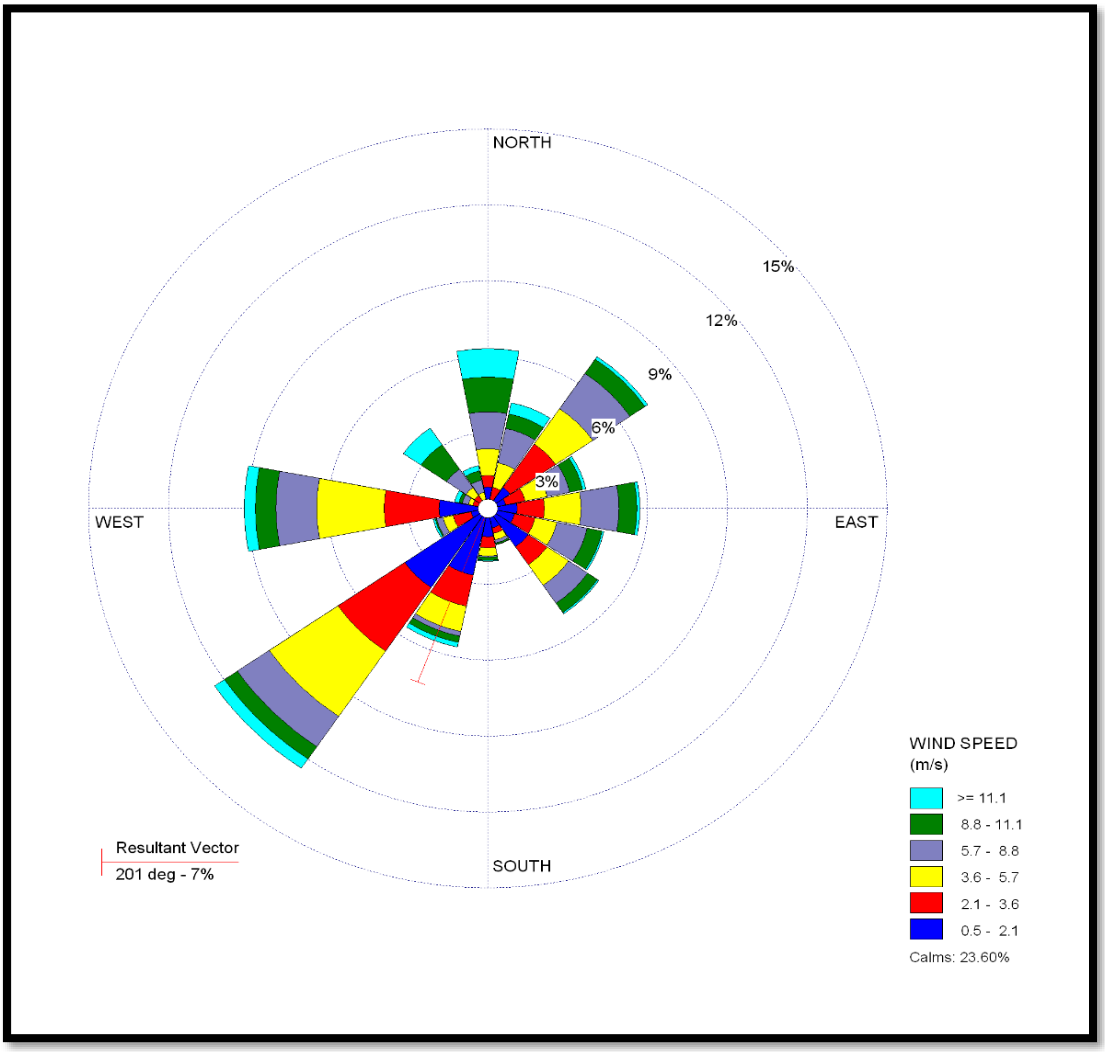

Fig. 10. Windrose Map of study area during the sampling days

PM is more or less similar to the other pollutants and shows a strongly correlation with FPM (0.930) having uniform distribution in the atmosphere. However, AQI is also poor while AQHI has strong positive correlation with PM. This indicates that PM_{10} and $PM_{2.5}$ concentrations squarely influence the value of AQHI, as well as air quality of the environs (Table 6) [32-34].

4. CONCLUSIONS

The present investigation was based on the ambient air quality monitoring for PM, Gaseous pollutant at 11 strategic locations in and around Gandhidham, Kachchh. The study area is highly polluted with PM. The ongoing industrial activities without proper environmental management strategies and heavy-duty diesel engine mobile source of pollution seemed to have caused the degradation of the surrounding environment. The levels of SO_2 and NO_2 were well within the permissible limits as prescribed by NAAQS. AQI revealed that the air quality fell under “Moderate category” category at A-10 and for the rest, it was under Satisfactory category and Good category (0-50). The values AQHI indicate moderate to high risk for the local people.

Ani industry should adopt proper air pollution controlling devices and modern technology to control air pollution at the source of generation. Moreover, regulatory authorities must ensure that industries obey their moral and social responsibilities to protect the environment. Overall, the air quality in and around Gandhidham is in a satisfactory condition (except major threats of PM_{10} and $PM_{2.5}$), which could be ameliorated by implementing the above-mentioned managerial steps and strategic plans to live a safer and healthy life. Authors suggest the periodic estimation of air and gaseous pollutants at frequent intervals on regular basis to check the level of such obnoxious pollutants in and around Gandhidham city.

ACKNOWLEDGEMENT

We are thankful to Mr. Gautam Priyadarshi (KSKV Kachchh University), Mr. DP Das, Ms. Sonia Benjamin and Ms. Antara Sengupta for their help in the collection and analysis of samples and Director GUIDE and Dr. BAK Prusty for the support throughout the study period.

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

1. Mishra SR, Pradhan RP. Prusty BAK, Sahu SK.. Meteorology drives ambient air quality in a valley: a case of sukinda chromite mine one among ten most polluted areas in the world. Environ. Monit Assess. 2016;188:402.
2. Seinfeld JH, Pandis SN. Atmospheric chemistry and physics: from air pollution to climate change. New York: Wiley; 2006.
3. Makkonen U, Hellén H, Anttila P, Ferm M. Size distribution and chemical composition of airborne particles in south-eastern Finland during different seasons and wildfire episodes in 2006. Sci. Total Environ. 2010;408:644–651.
4. Tripathee L, Kang S, Rupakheti D. Zhang Q, Huang J, Sillanpaa M. Water-Soluble Ionic Composition of Aerosols at Urban Location in the Foothills of Himalaya, Pokhara Valley, Nepal. Atmosphere. 2016; 7(102):24454-24472.
5. Sharma K, Singh R, Barman SC, Mishra D, Kumar R, Negi MPS, Mandal SK, Kisku GC, Khan AH, Kidwai MM, Bhargava SK. Comparison of trace metals concentration in PM10 of different location of Lucknow city. Bull. Environ. Contamination and Toxicology. 2006;77:419-426.
6. Jayaraman GN. Air quality and respiratory health in Delhi. Environ. Monit. Assess. 2007;135: 313-325.
7. Barman SC, Kumar N, Singh R. Assessment of urban air pollution and its probable health impact. J. Environ. Biology. 2010;31(6):913-920.
8. Azmi SZ, Latif MT, Ismail AS, Juneng L, Abdul Aziz Jemain A. Trend and status of air quality at three different monitoring stations in the Klang Valley, Malaysia. Air Qual Atmos & Health. 2010;3:53–64.
9. Yadav SK, Kumar V, Singh MM. Assessment of ambient air quality status in urban residential areas of Jhansi city and rural residential areas of adjoining villages of Madhya Pradesh. Int. J. Adv. Eng. Tech. 2012;3(1):280-285.
10. Prusty BAK. Ambient air quality surveillance and indexing in an around mining clusters in western kachchh region Gujarat India. Open J. Air Pollut. 2012; 1:22-30.
11. Mukhopadhyay S, Mukherjee R. Assessment of Ambient Air Quality of Purulia Town, Purulia District, West Bengal, India. Biolife. 2013;1(4):189-194.
12. Rai P, Panda LL, Chutia BM, Singh MM. Comparative assessment of air pollution tolerance index (APTI) in the industrial (Rourkela) and non-industrial area (Aizawl) of India: An eco-management approach. Afr. J. Environ. Sci. Technol. 2013;7(10): 944-948.
13. Barman SC, Kisku GC, Khan AH. Assessment of Ambient Air Quality of Lucknow City during Pre-Monsoon, Final Technical Report: Environmental Monitoring Division, CSIR: Indian Institute of Toxicology Research, Lucknow. 2015;26.
14. Sateesh M, Soni VK, Raju PVS, Mor V. Cluster analysis of aerosol properties retrieved from a sky-radiometer over a coastal site: Thiruvananthapuram, India, Atmos. Pollut Res; 2017. Available:http://dx.doi.org/10.1016/j.apr.2017.09.002
15. Yu M, Zhu Y, Lin CJ, Wang S, Xing J, Jang C, Huang J, Huang J, Jin J, Yu L. Effects of air pollution control measures on air quality improvement in Guangzhou, China. J. Environ. Management. 2019;244:127–137.
16. CPCB. Guidelines for Manual Sampling & Analyses. (Guidelines for the Measurement of Ambient Air Pollutants,

Vol. I), Central Pollution Control Board, National Ambient Air Quality Series. 2013;NAAQMS/36/2012-13. 62.
17. Bishoi B, Prakash A, Jain VK. A comparative study of air quality index based on factor analysis and US-EPA methods for an urban environment. Aerosol Air Qual. Res. 2009;9(1):1–17.
18. Stieb DM, Burnett RT, Doiron MS, Brion O, Shin HH, Economou V. A New Multipollutant, No-Threshold Air Quality Health Index Based on Short-Term Associations Observed in Daily Time-Series Analyses, J. Air Waste Manag. Assoc; 2008. Available:https://doi,10.3155/1047-3289.58.3.435
19. Olstrup H. An Air Quality Health Index (AQHI) with Different Health Outcomes Based on the Air Pollution Concentrations in Stockholm during the Period of. 2020;2015–2017. Available:http// doi:10.3390/atmos11020192.
20. Panda BK, Panda CR. Estimation of ambient air quality status in Kalinga Nagar industrial complex in the district of Jajpur of Odisha. Int. J. Environ. Sci. 2012;3(2):767-775.
21. WHO, Air Quality Guidelines for Europe. 2nd Ed., Reg. Publ. Eur. Ser. 91: 288. World Health Organization (WHO) Reg. Off., Europe, Copenhagen. 2000;273.
22. WHO. Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide. Global Update 2005. Summary of Risk Assessment, World Health Organization, 2005;WHO/SDE/PHE/OEH/06.02. 22.
23. Simon H, Allen DT, Wittig AE. Fine Particulate Matter Emissions Inventories: Comparisons of Emissions Estimates with Observations from Recent Field Programs. J. Air Waste Manag. Assoc. 2008;58(2): 320-343.
24. Gupta AK, Patil RS, Gupta SK. Influence of meteorological factors on air pollution concentration for a coastal region in India. Int. J. Environ Pollu. 2004;21:253–262.
25. Ali M, Athar M. Air pollution due to traffic, air quality monitoring along three section of national highway N5, Pakistan. Environ. Monit. Assess. 2008;136:219-226.
26. Zlauddin A, Siddique NA. Air quality index (AQI) - A tool to determine ambient air quality. Pollut. Res. 2006;25:885-887.
27. Panda RB, Panda G, Amitshreeya R, Sahu SK. Air quality index of Balasore town, Orissa. Pollut Res. 2011;30(2):131-133.
28. Chaudhary IJ, Atmospheric Pollution Research; 2018. https://doi.org/10.1016/j.apr.2018.04.006
29. Environmental Monitoring of Kandla Port Trust 2017. 1st Annual Report, Detox Corporation PVT. Limited.
30. Mishra Orris JB. 2000. MEGASTAT. Version 8.8, Available:http://www.mhhe.com/bstat.
31. USEPA Air Quality Index: A Guide to Air Quality and Your Health. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, USA. 2008;12
32. USEPA. Air Quality Index: A Guide to Air Quality and Your Health. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, USA. 2008;12
33. West PW, Gaeke GC. Fixation of sulphur dioxide as sulfitomercurate (11) and subsequent colorimetric determination. Annals of Chemistry. 1956;28: 1819-1916.
34. Available:www.theweathemetwork.ca

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/116205