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RESEARCH ARTICLE

PARTICULATE (PM_{10}) AND GASEOUS POLLUTANTS (NO_2, SO_2) AND THEIR SOURCES IN THE TIRTHAN VALLEY OF THE GREAT HIMALAYAN NATIONAL PARK, NORTHWESTERN HIMALAYA, INDIA

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Abstract

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The present study assessed the status and possible sources of ambient air quality in the Tirthan Valley of the Great Himalayan National Park; a UNESCO World Heritage Site. After declaring a UNESCO World Heritage site in June 2014 for its unique biological diversity, the study region became more famous for ecotourism activities particularly in the Tirthan Valley. In view of ever increasing tourism and allied activities, the status and possible sources of pollutants like particulate matter less than 10 micron (PM_{10}) in size, gaseous pollutants nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) were assessed. The present study was carried out for the period of 3 years from January, 2015 to December, 2017 in the *Gahidhar* village (1507 m) of the Tirthan Valley. So far, the highest values for PM_{10} and NO_2 were 78.05 µg m^{-3} and 4.46 µg m^{-3} in November, 2017 respectively which were found in the winter months. On the other hand, SO_2 was found to be 3.79 µg m^{-3} in August in monsoon. Results showed that the concentration of all the pollutants during the reporting period was found under permissible limit as prescribed by National Ambient Air Quality Standards (NAAQS), 2009. The study also indicates that there are mainly two sources of the pollution; local and external. The local sources include biomass burning and vehicular emissions while external include long range transport sources through air masses. The study also provides the first ever baseline data of air quality status and sources of the area which will be useful for the future studies including planning and sustainable development of the region.

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Introduction:-

World Health Organization (WHO), 2017 defines air pollution as a contamination of indoor or outdoor environment by different chemical, physical and biological agents that modify the characteristics of the atmosphere. India was listed among top 100 polluted cities of the world in an assessment done by WHO in year 2014. In terms of

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annual average of particulate matter size less than 10 micron (PM_{10}), India ranked 10^{th} with the level of 134 ug m^{-3} (Dholakia et al., 2014). In India, air quality is a serious concern in which particulate matter (PM), sulfur dioxide (SO_2) and nitrogen oxides (NOx), often exceed the National Ambient Air Quality Standards (NAAQS). Air Quality Index (AQI) is defined as a numerical rating that reflects the composite influence on overall quality of a number of air quality parameters which will be helpful not only for advising the public but also for urban planning (Srivastava and Sarkar, 2006). Air itself is a mixture of many gases like nitrogen, oxygen, carbon dioxide, argon, water vapour, etc. Ever increasing anthropogenic activities like burning of fossil fuel, vehicular emission, use of insecticides and pesticides, and developmental activities are some of the factors responsible for air pollution (Subramani, 2012). These pollutants found ubiquitously in the atmosphere and have an important influence on global climate and human health (Buseck and Posfai, 1999). There are number of diseases which are causing due to environmental factors such as air pollution (Cohen et al., 2017; Orioli et al., 2018). Studies on particulate matter less than 10-micron size show that these are responsible for many harmful health effects (Fang et al., 2017; Landrigan et al., 2017; Wang et al., 2018) and diseases like respiratory, skin, lung cancer and even cardiovascular problems (Yang et al., 2016; Ranjan et al., 2016; Dehghan et al., 2018) and many other diseases which are prominent due to pollutants. Besides particulate pollutants, their chemical compositions are also very harmful for the human beings (Panda and Nagendra, 2018; Manju et al., 2018), animals (Hippeli and Elstner, 1993; Lovett et al., 2009), wildlife and plant life (Hippeli and Elstner, 1993; Lovett et al., 2009). These particulate matters come through various sources like traffic emission, construction, fuel combustion, industrial combustion, etc. (Bhanarkar et al., 2005; Goyal and Rao, 2007). However, meteorological parameters such as temperature, water vapour and wind speed may also influence air pollution of any particular geographical area (Sharma et al., 2014).

The present study is carried out in one of the North Western Himalayan Village of *Gahidhar* in the Tirthan valley of the Great Himalayan National Park (GHNP), which is a sub-valley of the Kullu Valley. The Kullu valley is one of the major tourist destinations of the North Western Himalaya and hosts million of tourists every year from different parts of the world. High number of tourist vehicles and biomass burning are influencing the level of air pollution in the region. According to Budeanu (2005), tourism sector brings both positive and negative impacts to the environment and culture of any region. Mass tourism can deteriorate the environment and increase the ecological cost of conservation (Bejder et al., 2006; Buckley, 2011). Air pollution is one of the major concerns in terms of environmental impacts. There are number of studies which have been done on air pollution levels in the region, cities and other parts of the country (Gajananda et al., 2005; Guleria et al., 2011; Sharma et al., 2011a&b; Kar and Mukherjee, 2012; Kuniyal et al., 2015). The air pollution studies so far also explained its impact on the human health such as premature deaths, chronic pulmonary diseases, cardiovascular diseases, immune deficiency, etc. (Gogoi et al., 2008; Guttikunda et al., 2014; Manju et al., 2018). But the study on the status of these pollutants in newly developed tourism areas as well as near to ecological sensitive zones like the GHNP are still lacking. Therefore, our effort is mainly to assess the level and possible sources of these air pollutants in terms of PM_{10}, NO_2 and SO_2 in the Tirthan Valley. The study will therefore provide a baseline data for future studies on similar lines regarding upcoming changes in ages, their climatic impacts and possible mitigation measures to lower their impacts.

Study site:-

The Great Himalayan National Park (GHNP) is situated at the upper catchment of the River Sainj and River Tirthan of Himachal Pradesh. It is one of the India's highest altitudinal mountain Park. It lies between 31^0 38'28"N and 31^0 54'58"N, and 77^0 20'11"E and 77^0 45'00"E with the altitudinal ranges from 2000 m to 5500 m above mean sea level (Pandey and Wells, 1997). The 754.4 km^2 area of the park is naturally protected by high mountain ridges and peaks on its northern, eastern and southern sides. The Tirthan Wildlife Sanctuary (61 km^2), Sainj Wildlife Sanctuary (90 km^2), Ecozone of the park area (265.6 km^2) and the GHNP (754.4 km^2) form the Great Himalayan National Park Conservation Area (GHNPCA) of 1,171 km^2 (WII, 2005; Pandey, 2008). The people living in the region are mostly poor and are dependent on the natural resources for their livelihoods. In these remote areas, people have a very distinctive culture in terms of their fairs and festivals (Tucker, 1999). According to Tandon (1999), a survey to the Great Himalayan National Park indicated that 70-85% of the total households earn their livelihoods through collecting and selling herbs in the region which was restricted after the formation of the park. To provide them an alternative livelihood option, park authorities with the help of some local stakeholders started a society called Biodiversity, Tourism, Conservation and Advancement (BTCA). The society works in close contact with the park authorities, local people, women groups, etc to carry out the ecotourism and other activities in the region. The Great Himalayan National Park was declared as 'UNESCO World Heritage Site' in June, 2014 for its unique biological diversity thus makes it world famous among the tourists and trekkers. The Tirthan valley is becoming one of the major ecotourism destinations in the region attracting a number of tourists every year. With the increase in tourism activities in the region, it is necessary to assess the present environmental conditions such as air pollution, etc. for the better future planning. The ambient air quality indicators were monitored at *Gahidhar* Village ($31^{0}38.426$'N latitude and longitude $77^{0}23.839$'E) in the Tirthan Valley located at an altitude of 1507 m above mean sea level (amsl). According to Census 2011, there were 12,714 people residing in 8 different *Panchayats* (local institutions) of the Tirthan valley. This village is located at a point where most of the developmental works such as construction and tourism related activities for homestays, camps, market, guest house, etc. are in the periphery of 3-4 km. Also, it is at the entry route to the GHNP, it makes ideal location for the air quality sampling (Fig. 1).

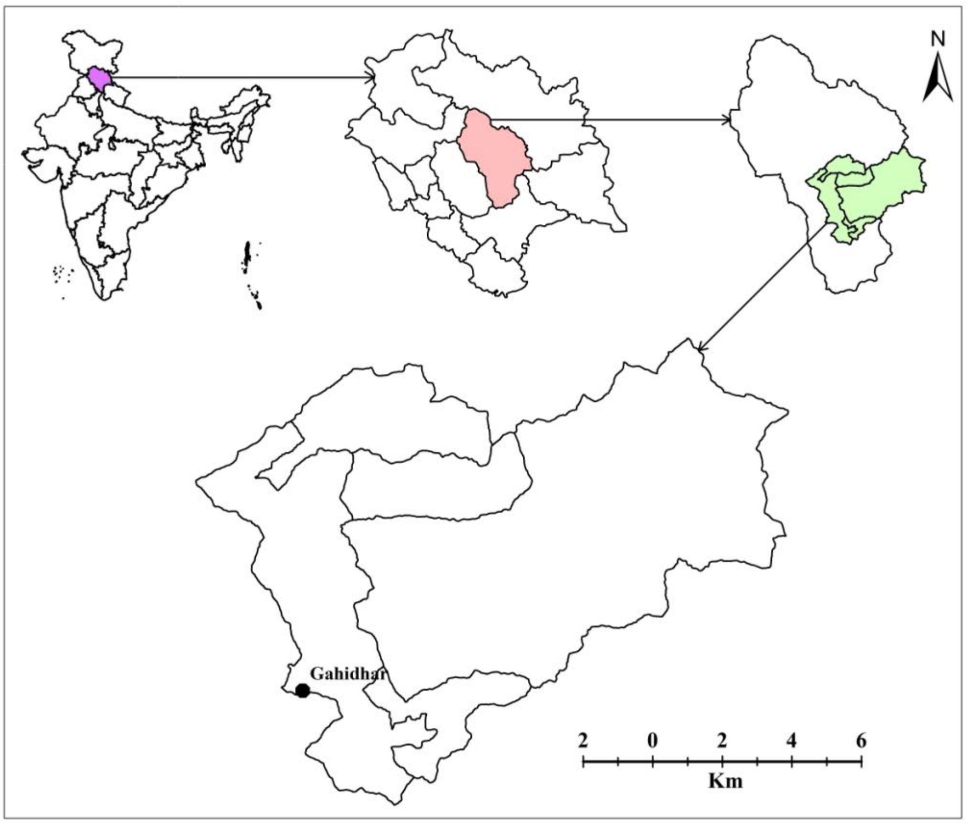

Fig. 1:- Gahidhar village in the Tirthan Valley of the Great Himalayan National Park, Kullu Valley

Method of sampling and analysis:-

Particulate Matter below size 10 micron (PM_{10})

Respirable Dust Sampler (RDS) (Envirotech 460 NL) was used to monitor PM_{10} based on filtration-gravimetric method. For this, Whatman filter paper (20.3×25.4 cm) was used and samples were exposed on daily (24 h) basis for a period of 7 days. The sampling was carried out for 3 years from January 2015 to December, 2017.

PM_{10} was analyzed as follows:
PM_{10} ($\mu g\ m^{-3}$) = (FFPw-IFPw)*10^{6}/(average flow rate*total time)
where, IFPw is the weight of fresh filter paper and FFPw is the weight of exposed filter paper.

Gaseous Pollutants

The gaseous pollutants such as SO_2 and NO_2 were also monitored simultaneously in an attached Impinger with the RDS, and analyzed the same following the modified methods of West and Gaeke (1956) and Jocobs and Hochheiser (1958) respectively. Further, results were obtained for PM_{10} concentration and gaseous pollutants and were compared with the National Ambient Air Quality Standards (NAAQS), 2009.

NO_2 was analyzed as follows:
NO_2 conc (µg m^{-3}) = (µg NO_2 * 20) * 1000/V*10
Where; µg NO_2 = (100 – % NO_2)* 0.3593829; V= time duration * average Flow Rate

Similarly, SO_2 was analyzed as follows:
SO_2 conc (µg m^{-3}) = (µg SO_2 * 20) * 1000/V*10
where µg SO_2 = (100 – % SO_2)* 0.3593829; V= time duration * average Flow Rate

Hybrid Single Particle Lagrangian Integrated Trajectory

Back trajectories provide information about the long range transportation of air masses. The Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model was used to analyze 7-days back trajectory simulation developed by NOAA's Air Resources Laboratory. Trajectories were drawn at three different heights (2500 m, 3500 m and 4500 m) above the ground level for the two highest aerosol (PM_{10}) loading days of the entire study duration. To identify the potential sources of transported aerosols in winter months over the study site, 7-days back trajectories ending 6.00 hrs Coordinated Universal Time (UTC) at 3500 m above ground level (AGL) height were drawn for each day and computed for trajectory clustering and concentration weighted trajectories (CWT) analysis (Seibert et al., 1994). Back trajectories of winter months were grouped in 3 clusters.

Results and Discussion:-

PM_{10} Concentration

The highest ever concentration of PM_{10} (24 hrs) for all the three years was found 78.05 µg m^{-3} in December, 2015 and minimum was found 4.39 µg m^{-3} during September, 2015 with average concentration of 24.98±1.83 µg m^{-3} (Fig. 2 & Table 1). Data also show that PM_{10} concentration during the study period was found under permissible limit as per NAAQS, 2009 guidelines (Table 2). Also, it was observed that the PM_{10} concentration is high during the winter seasons and morning time which could be due to anthropogenic activities like fuelwood burning, etc.

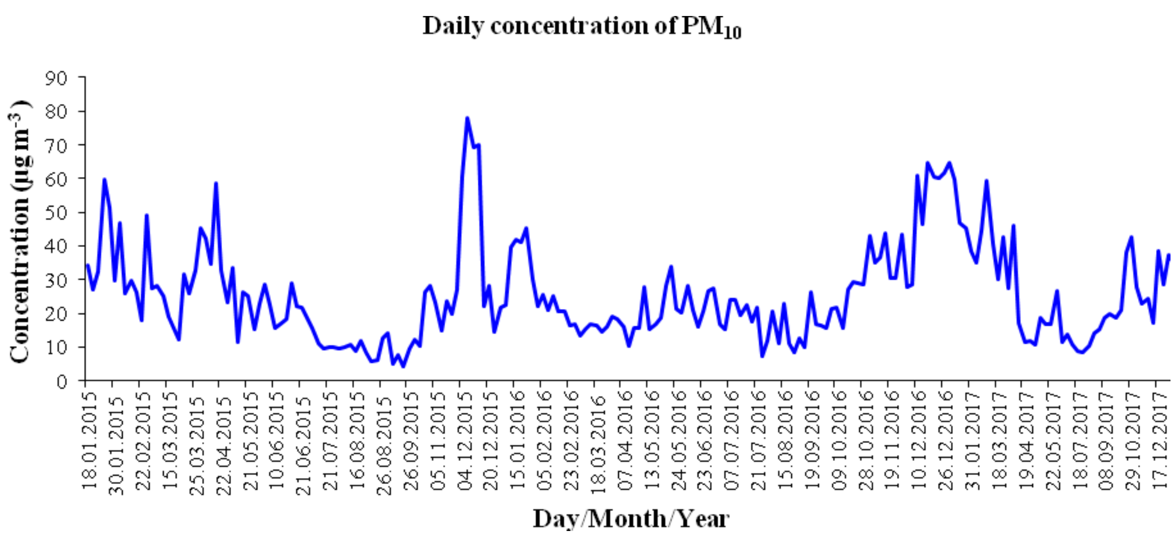

Fig. 2:- Daily concentration of PM_{10}

Concentration of gaseous pollutants: NO_2 and SO_2

Daily concentration of gaseous pollutants like NO_2 was found maximum 4.28 µg m^{-3} on July 05, 2016 for all the three years with an average concentration of 2.02±0.90 µg m^{-3}. On the other hand, minimum NO_2 could be traced as low as 0.16 µg m^{-3} on January 23, 2015. Similarly, maximum concentration of SO_2 in all the three years was found 3.79 µg m^{-3} during August 15, 2016, while its minimum value was 0.05 µg m^{-3} on January 11, 2016 with average concentration of 1.41±0.75 µg m^{-3} (Fig. 3). Yearly average concentration of these pollutants is depicted in Table 1, and NAAQS (2009) in Table 2.

Table 1:- Concentration of PM_{10}, NO_2 and SO_2 during three years- 2015, 2016 and 2017

Parameters	PM_{10}			NO_2			SO_2		
	2015	2016	2017	2015	2016	2017	2015	2016	2017
Samples (n) *	77	84	71	77	84	71	77	84	71
Maximum	78.05	64.67	67.97	3.52	4.28	4.46	2.90	3.79	3.29
Minimum	4.39	7.33	8.56	0.16	0.25	0.38	0.10	0.05	0.33
Average	24.98	25.23	27.66	2.07	2.22	2.04	1.33	1.52	1.66
SD*	16.09	12.83	15.11	0.81	0.97	1.01	0.68	0.89	0.72
SE*	1.83	1.40	1.79	0.09	0.11	0.12	0.08	0.10	0.09

*n indicates number of exposed samples; SD: Standard deviation; SE: Standard error

Table 2:- National Ambient Air Quality Standards (NAAQS), 2009

Pollutants	Average weightage (hrs)	Concentration in industrial, residential, rural and other areas (µg m^{-3})
PM_{10}	24	100
NO_2	24	80
SO_2	24	80

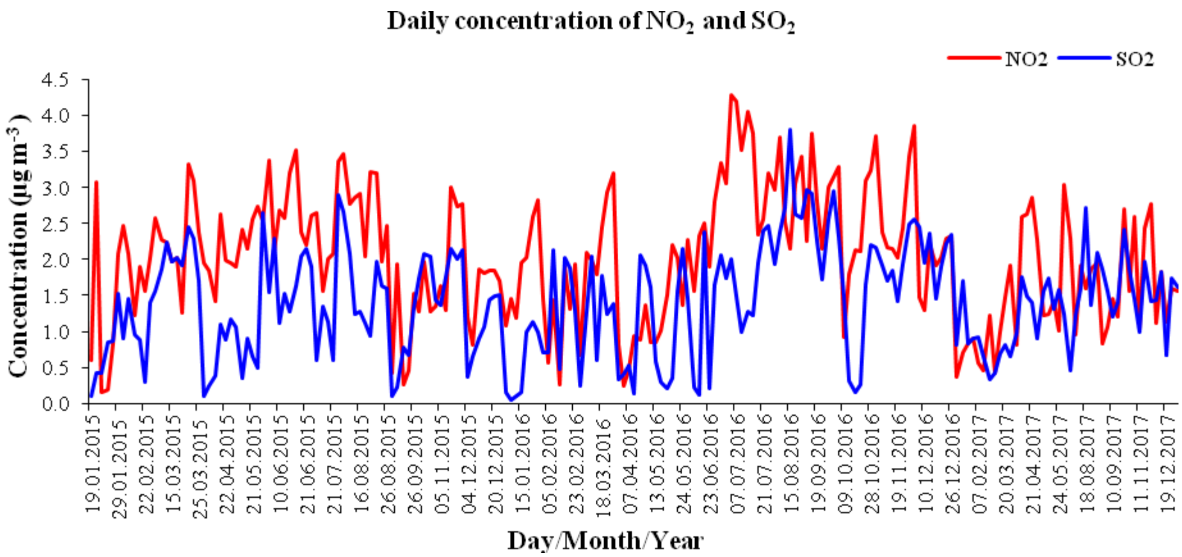

Fig. 3:-Daily concentration of NO_2 and SO_2

Pollution Sources

Local sources

The study shows that the concentration of all the particulate matter (PM_{10}) and gaseous pollutants (NO_2, SO_2) in the study site is very low and under permissible limit as per the NAAQS, 2009 (see Table 2). However, PM_{10} concentration values sometimes touch the NAAQS permissible limits. The level of these pollutants is also influenced by the local sources. These local level sources include vehicular emission and biomass burning like coal, fuelwood, cow dung, agricultural waste, etc. In addition, in absence of any proper management of solid waste, the natives are burning the self generated waste which sometimes also increases the air pollution level in the region.

Long range transport sources

In addition local sources, long range transportation is also responsible for aerosol build up in a particular region (Fig. 4).The highest concentration of PM_{10} was observed as high as 78.05 µg m^{-3} on December 06, 2015. Seven days back trajectories analysis for the same day suggests that air parcels at greater heights (3500 m and 4500 m AGL) reached the experimental site by passing over from the parts of far western regions such as Saudi Arabia, Iran, Afghanistan, Pakistan, etc. and at the shorter heights they reach to the study site from nearby areas. The second highest concentration of particulate matter was observed as 70.01 µg m^{-3} on December 16, 2015. The back trajectory analysis on the same day shows that at greater height, air masses passed over the parts of the western regions like Syria, Iraq, Iran, Turkmenistan, Afghanistan, Pakistan, etc. before reaching to the present experimental site. The air parcels passing over the far western as well as surrounding regions transports particulate matter. These phenomena possibly contributed to aerosol build up in the study region along with local emissions. The previous studies pertaining to the Kullu valley also revealed that these regions are also influenced by dust aerosols originated from the western regions (Kuniyal et al., 2009; Guleria et al., 2011).

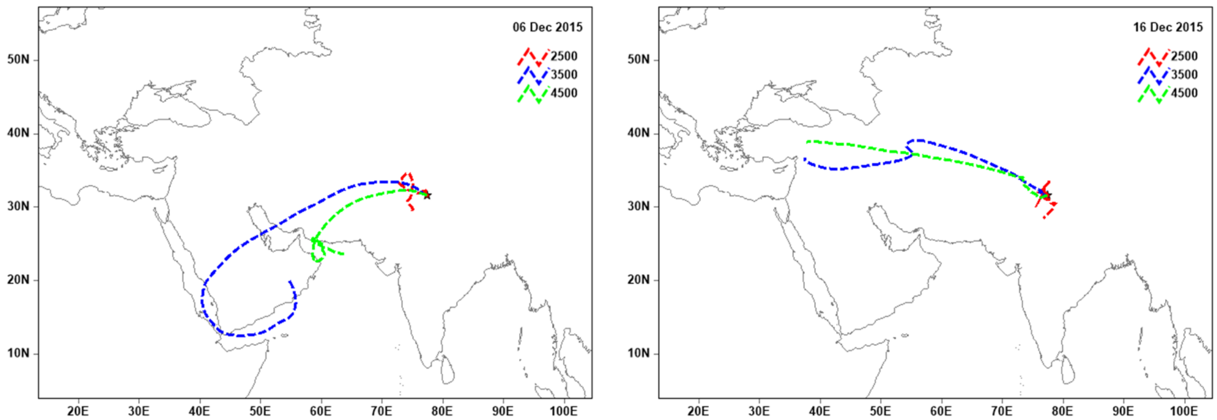

Fig. 4: - Back trajectories during two high aerosol loading days of the study period

Concentrated Weighted Trajectory (CWT) analysis

During the entire study period, PM_{10} concentration was observed higher in winter months. For example, average PM_{10} concentrations from highest to lowest order stood as 54.7±12.95 µg m^{-3} during December 2016, 51.0±10.94 µg m^{-3} during January 2017 and 49.0±26.34 µg m^{-3} during December 2015. It is observed that longer (by distance) trajectories reach from the western desert, Syrian desert, Thar desert and other dry regions of Iran, and Afghanistan to the experimental site. About 25% of the total clusters occupied by cluster 1 and 41% by cluster 3 indicating the source regions from the South West and West directions of the air mass movement to the present study region. On the other hand, 34% of the total three clusters cluster 2 having the shorter (regional) trajectories which over-passed from the South direction of the Indo-Gangetic Plain (Fig. 5). With a view to identify the source evidence, back trajectories were further drawn by way of the CWT analysis to indicate the possible sources contributing to the observed PM_{10} at Gahidhar. It is observed that source of higher PM_{10} concentration above 20 µg m^{-3} is considered to be regional, while PM_{10} up to 20 µg m^{-3} is transported from the western as well as the Indo-Gangetic Plain (see Fig. 5).

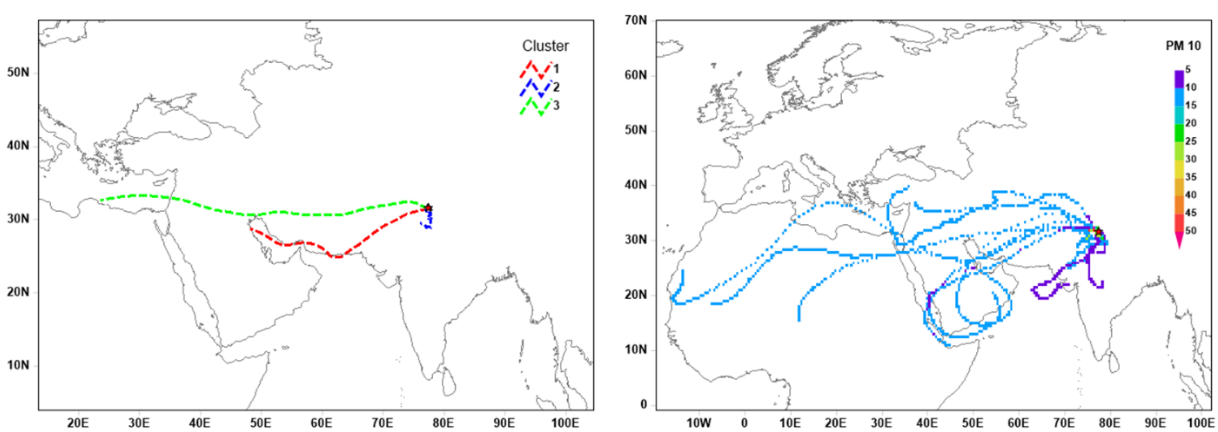

Fig. 5: - Cluster as well as Concentrated Weighted Trajectory (CWT) analysis for PM_{10} during winter period

According to Chatterjee et al. (2010), agricultural practices and biomass burning are the important sources of trace gas emissions in the South East Asian Region. There are number of studies on various anthropogenic as well as natural forest fire incidents which have been affecting the seasonal variations both in particulate and trace gases terms (Gajananda et al., 2005; Gogoi et al., 2008). Temporal variability of the gaseous pollutants is also documented worldwide (Nair et al., 2002; Reddy et al., 2012). Studies also reported that the pollution caused by vehicular emission in tourism sector has been affecting the human health worldwide (Kuniyal et al., 2003; Subramani, 2012; Zhang and Batterman, 2013; Panda and Nagendra, 2018; Chen et al., 2018). The present study also reveals that air pollutants in the Tirthan Valley; a newly developed ecotourism destination in ecozone area of the Great Himalayan National Park, are under permissible limit. It was also observed that these particulate pollutants such as PM_{10} and NO_2 are found more during winter which is also reported by Xiao et al. (2015), and Li et al. (2018) for their study regions in China. The possibilities of high-level pollutants due to anthropogenic activities like fuelwood burning for cooking and heating, vehicular exhaust, and biomass burning are also reported by Gadi et al. (2011) and Bisht et al. (2015). A study by Sen et al. (2017) also concludes that the deterioration in air quality in the Indo-Himalayan Range is due to pollutants undergoing through long range transport sources from the nearby regions of the Indo Gangetic Plain.

Conclusion:-

The Himalayan ecosystem is one of the most complex and diversified regions of the world. Our present study provides a status of air pollutants and its possible sources in the ecozone area of the GHNP. The results show that the concentrations of the particulate and gaseous pollutants in the region are under permissible limit as per the standards of NAAQS (2009). So the level of pollutants could be said satisfactory in view of present health status of human, animal, wildlife and atmospheric conditions. However, when the pollutants are getting high peaks these could be either local or external sources or sometimes due to combination of both in the region. The study also recommends maintaining its current status of pristine environmental conditions of the Tirthan valley through proper policy formation and its implementation. At the same time, involvement of the local stakeholders is must in overall ecotourism activities, and its policy framing for sustainable development of the region.

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