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Study on Correlation of Angstrom Turbidity Coefficient (*β*) with Aerosol Optical Depth (*τ*) over a Period of Two Years (2004-2006) for the Special Mangrove Ecosystem of Sundarbans

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ABSTRACT

A study on the correlation of the angstrom turbidity coefficient (β) with aerosol optical depth (τ) have been studied on the basis of field measurements carried out at Kaikhali (22.022˚N & 88.614˚E) lying in the east coast of India inside the Sundarbans. The angstrom turbidity coefficients have been calculated with respect to the filter channels at 340 nm, 500 nm, 870 nm, 936 nm and 1020 nm of a Sunphotometer. Assessment of the possible influx of the fine particulate concentrations to the total aerosol loading in the area have been made with respect to the calculated angstrom turbidity values for the summer and winter seasons over a period of two years from 2004 to 2006. Substantially high angstrom turbidity coefficient values exceeding 0.2 and indicative of a relatively hazy atmosphere for both the summer and winter periods over these two years from 2004-2006 have been observed. Considering the importance of this fragile mangrove ecosystem of the Sundarbans and also the vulnerability of the area to severe impacts of climate changes, this is indeed a thought provoking issue as far as the policy makers of the country are concerned. In fact, the study has confirmed positive correlation of β with τ.

Keywords: Angstrom Turbidity Coefficient (β); Aerosol Optical Depth (τ); PM_{10}; $PM_{2.5}$; Biodiversity

1. Introduction

Lying to the south of West Bengal, India, the Sundarbans coastal belt truly represents a complex and unique ecosystem encompassing tiger inhabited terrain of mangrove forest and saltwater swamp as part of the lower Gangetic delta. The vast richness in the biodiversity of the area is quite clearly reflected in the wide variety of species prevalent in the area and also variation in the species composition. As a matter of fact UNESCO has truly given recognition to the core area inhabited by these Royal Bengal tigers as an World Heritage Site as early as in 1987 [1] and also as a Biosphere Reserve under UNESCO's Man and Environment programme in the year 2001. The importance of the Sundarbans is well emphasized by the fact that the Sundarban forests also buffer Kolkata (lying about 100 kms from the Sundarbans) from the cyclones generating from the Bay of Bengal [2] which otherwise could have been highly detrimental for the metropolis Kolkata. However the dearth of proper conventional sources of energy in the Sundarbans is a major factor responsible for a host of incomplete combustion activities being practiced in the area. Moreover, there has been a considerable rise in population over the last decade coupled with a host of unplanned economic activities in the area. All of these, particularly the considerable amount of incomplete combustion activities prevailing in the area which give birth to pollutants are bound to affect the rich biodiversity of the area. The pollutants under consideration fall under the classification of the well defined criteria air pollutants as designated by the United States Environmental Protection Agency (USEPA) [3]. Among these criteria air pollutants, considering the adverseness posed by the finer fraction of the particulates, concentration have been provided on these finer fractions of particulates (PM_{10} and $PM_{2.5}$). The undesirable effects of the particulates on areas rich in biodiversity as well as on health have been confirmed from the outcomes of various researches carried out by different research groups globally. In this context studies carried out by researchers and scientists [4-22] may be considered interesting and thought provo-

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king. The concentration of the high finer fractions in the area contribute substantially to the overall aerosol loading of the area. In fact, aerosols interact with both the incoming solar shortwave (SW) and the outgoing terrestrial longwave (LW) radiations as they either scatter or absorb or both scatter and absorb short and longwave radiation. This results in exertion of a more complex effect on climate [23] (Charlson *et al*. 1999). Studies carried out by different research groups and scientists, [24-30] have established the adverse effects of aerosol on areas of rich and unique biodiversity [31]. Considering the adverse implication of the aerosols on the surrounding environment, it has become even more so important to assess the aerosol loadings in order to understand their adverse impact on an area of rich and unique biodiversity such as Sundarbans. As a measure to describe the extent of aerosol loading, reports on the Aerosol Optical Depth (AOD) measured at the site for the five filter channels (340 nm, 500 nm, 870 nm, 936 nm and 1020 nm respectively) during the winter and summer periods over the years from 2004-2006 have been made. To ascertain the presence of high levels of fine particulate matter ($PM_{2.5}$ and PM_{10}) in the area, the aerosol optical depth (τ) values for the above mentioned wavelengths have been correlated with the corresponding angstrom turbidity coefficient (β) values. This has got importance from many angles, mostly to reflect the high occurrence and its associated effects of the fine particulate fractions on the biodiversity and surrounding environment of the Sundarbans.

2. Location and Measurements

Angstrom Turbidity Coefficient

Angstrom turbidity coefficient (β) is a measure of the degree of haziness in the atmosphere. The degree of haziness undoubtedly depends on the absorption and scattering of the light rays by the aerosols present in the atmosphere. As a matter of fact, smaller the size of the particulate fractions greater is its ability to scatter or absorb the light rays. This implies that with decrease in the size of the particulate fractions, the angstrom turbidity coefficient value increases, thereby implying a corresponding increase in the haze problem. Haze is a very important problem related to particularly reduction in atmospheric visibility and also obstruction to free passage to sunlight. The latter effect is of particular concern to areas such as our sampling site, where cultivation is the primary mode of living.

3. Sampling Site Details

Out of the 54 inhabited islands that constitute Sundarban, one of them is Kaikhali, where the measurements were carried out. The sampling site at Kaikhali (22.022˚N and 88.614˚E) (refer **Figure 1**) in Sundarban is at an aerial distance of approximately 100 km from the nearest metropolis Kolkata and lies at the southernmost tip of Indo-Gangetic flow. The site lies at land and sea interface (hence can be also termed as a transboundary area), at the convergence of river Nabipukur with river Matla which eventually drains into the Bay of Bengal. In addition to this, Bay of Bengal also provides the unique opportunity of mixing of marine and sub-continental air masses. One of the basic reasons for choosing this sampling site was that it represents an open area with no obstruction, thereby offering free passage to wind movement and also to dispersion of air pollutants. At the same time, it is under the strong influence of land and sea breezes, which invariably result in the temperature fluctuations in the area.

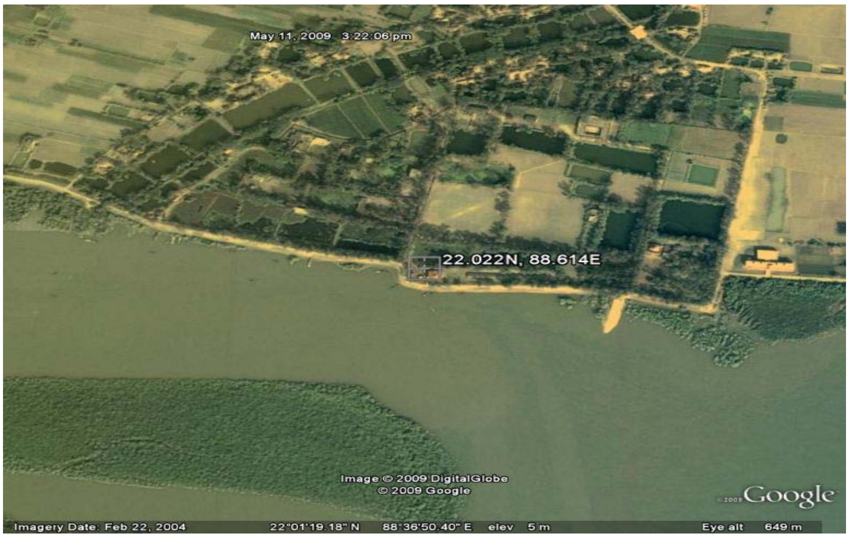

Figure 1. Sampling site at Kaikhali (22.022˚N and 88.614˚E).

4. Measurement Methodology

The PM_{10} was monitored using the Respirable Dust Sampler (Respirable Dust Sampler, Model APM 460 by Envirotech Pvt. Ltd., India) [32]. During sampling, the flow rate was maintained between (0.9 - 1.2) m^3/min as mentioned in the Measurement of Criteria Pollutants in Ambient Air, Laboratory Analytical Techniques Series, 1990-1991, Central Pollution Control Board Guidelines [33]. The flow rate was measured at site with the help of a pre-calibrated orificemeter which is attached to the instrument. The orificemeter was calibrated by varying the discharge through it and measuring the corresponding pressure drop across the orificemeter. The basic mechanism of this Respirable Dust Sampler is based on the principle of cyclone separator (centrifugal action). The RPM (PM_{10}) were retained in the EPM 2000 Glass Microfibre and in the Quartz (QMA) filter papers made by Whatman Asia Pacific Pte Ltd. and the PM_{10} concentration was determined gravimetrically. $PM_{2.5}$ was monitored with the help of Fine Particulate Sampler (Fine Particulate Sampler, Model APM 550 by Envirotech Pvt. Ltd., India) [34]. The FRPM basically comprises of the particulate fractions having aerodynamic diameter less than equals to 2.5 microns. The APM 550 Fine Particulate Sampler employs a set of impactors standardized and documented by United States Environmental Protection Agency (USEPA) to separate the coarse particulates and retain the finer fractions from the air stream. The system consists of a unidirectional air inlet, impactor for particles larger than 10 microns and a $PM_{2.5}$ impactor separated by a length of tube. To ensure that the air entry is unaffected by the wind direction, the air inlet is provided with a circular symmetry and is also designed in such a way so as to keep out rain, insects and very large particles. The inlet section immediately leads to an impactor stage designed to retain particles with an aerodynamic diameter larger than 10 microns. Thus the air stream passing in the down tube comprises only of medium and fine particulates having aerodynamic diameter less than 10 microns. The streamlined air flow of the down tube is enhanced through the nozzle of the well shaped (WINS) impactor. The WINS impactor is designed to trap medium size particulates with an aerodynamic diameter between 2.5 and 10 microns and thereby allowing the particulate fractions less than 2.5 microns to pass through. These fine particulates are retained on a special Teflon (PTFE) membrane filter of 47 mm diameter. The impactor system of the instrument has been designed to operate at an air flow rate of 1 $m^3 \cdot hr^{-1}$ or 16.7 $lt \cdot min^{-1}$. The mass concentration of the $PM_{2.5}$ fractions in the ambient air is calculated as the total mass of particles collected in the Teflon (PTFE) filter paper divided by the volume of air sampled and is expressed in microgram per cubic meter ($\mu g \cdot m^{-3}$) as recorded in the dry gas meter. Aerosol optical depth was measured using a hand held Microtops-II Sunphotometer (Solar Light Co., USA) [35] at the recommended wavelengths of 340 nm, 500 nm, 870 nm, 936 nm and 1020 nm respectively by the World Meteorological Organization respectively. All the measurements employing the sunphotometer and processing the data was carried out in accordance to a standard protocol [36]. The sunphotometer used for the measurement purpose was calibrated both at factory and on land. The long-term stability of the instrument was found to be appreciably good and the degradation of the filter or the drifts in the calibration values were found to be marginal. On land calibrations were carried out with measurements at a high mountain (Tiger Hill, 2555 Mt altitude) in Darjeeling, West Bengal, India above mean sea level using the standard Langley-Bouger technique as per the protocol given for the validation of ocean color satellite [37]. Factory calibrations were carried out in the year 2002. The calibration constants obtained from the data collected at Darjeeling did not show any large variations from the values obtained from the calibrations at factory. In addition, the meteorological parameters (wind velocity and temperature) were also recorded at the sampling site simultaneously for the proper interpretation of the data gathered.

5. Results and Discussions

Data on measurement of the finer fraction of the particulates and aerosol optical depths for the five filter channels have been reported for the summer in **Table 1** and for winter in **Table 2**.

The angstrom turbidity coefficient has been calculated employing the following equation (www.sti.nasa.gov/Pubs/star/star0809.pdf).

$$\beta = \tau\lambda^{\alpha}$$

where, β = angstom turbidity coefficient,

τ = aerosol optical depth for the respective filter channel under observation,

λ = wavelength of the respective filter channel in microns,

α = corresponding angstrom exponent value [24] (Mukherjee *et al.*, 2011).

The values of the angstrom turbidity coefficients have been reported in **Tables 3** and **4** respectively. The meteorological parameters measured during the period 2004 - 2006 have been reported in **Table 5**.

From **Tables 1** and **2** it is observed that the upper range of the fine particulate concentrations are substantially high enough to have serious implication on the biodiversity of the Sundarbans. The ranges of PM_{10} concentration for the periods (2004-2005) and (2005-2006) are (103.86 - 115.01) $\mu g \cdot m^{-3}$ and (106.49 - 117.9) $\mu g \cdot m^{-3}$ respectively whereas the ranges of the $PM_{2.5}$ concentration

Table 1. Statistics of parameters for the year 2004-2005.

Parameters	Year (2004-2005) (Summer Period)			Year (2004-2005) (Winter Period)		
	Mean	Std Dev	Range	Mean	Std Dev	Range
AOD$_{340}$	1.178	1.133	0.448 - 8.488	1.517	0.81	0.99 - 5.27
AOD$_{500}$	0.902	1.194	0.264 - 8.583	1.063	0.26	0.79 - 2.71
AOD$_{870}$	0.591	1.038	0.124 - 8.101	0.530	0.20	0.38 - 2.03
AOD$_{936}$	0.561	1.046	0.098 - 8.113	0.467	0.19	0.32 - 1.96
AOD$_{1020}$	0.597	1.281	0.065 - 8.901	0.404	0.18	0.26 - 1.89
RPM (PM$_{10}$)	76.75	0.17	76.57 - 76.9	108.53	5.79	103.86 - 115.01
FRPM (PM$_{2.5}$)	46.05	0.10	45.94 - 46.14	71.63	3.82	68.55 - 75.91

Note: All concentrations and range of fine particulate fractions are in μg·m^{-3}.

Table 2. Statistics of parameters for the year 2005-2006.

Parameters	Year (2005-2006) (Summer Period)			Year (2005-2006) (Winter Period)		
	Mean	Std Dev	Range	Mean	Std Dev	Range
AOD$_{340}$	1.167	1.016	0.444 - 8.656	1.268	0.978	0.328 - 6.152
AOD$_{500}$	0.836	0.900	0.236 - 6.342	0.847	0.882	0.154 - 5.057
AOD$_{870}$	0.614	1.073	0.112 - 7.989	0.599	0.877	0.074 - 4.957
AOD$_{936}$	0.567	1.047	0.089 - 7.869	0.604	0.915	0.056 - 4.934
AOD$_{1020}$	0.593	1.261	0.056 - 8.126	0.623	1.049	0.038 - 5.908
RPM (PM$_{10}$)	77.58	0.67	76.91 - 78.25	111.68	5.77	106.49 - 117.9
FRPM (PM$_{2.5}$)	45.51	0.58	45 - 46.14	75.94	3.93	72.41 - 80.17

Note: All concentrations and range of fine particulate fractions are inμg·m^{-3}.

have been found to be (68.55 - 75.91) μg·m^{-3} and (72.41 - 80.17) μg·m^{-3} respectively over the same period of study. As notified by the Central Pollution Control Board, Govt. of India [38] for an ecologically sensitive area, the 24 hour mean standard and the annual mean standard for the PM$_{2.5}$ fractions are 60 and 40 μg·m^{-3} respectively whereas that for the PM$_{10}$ fractions, they are 100 and 60 μg·m^{-3} respectively. Considering both the 24 hr as well as the annual mean standards, it is observed from the study that the measured fine particulate concentrations have exceeded these standards appreciably. This is indeed a thought of concern for the rich biodiversity of the Sundarbans. The aerosol optical depth values have been also found to be appreciably high during the winter period with the upper range for the AOD value for the filter channel 340 nm being reported as 6.152 for the period 2005-2006 (refer **Table 2**). From **Tables 3** and **4**, it is observed that the mean values of the angstrom turbidity coefficient for all the filter channels are greater than 0.2, which is an indicative of relatively hazy atomsphere [39] prevailing in the Sundarbans. In general the mean angstrom turbidity coefficient values for the filter channels having shorter wavelength have been found to be high compared to their corresponding values as reported for the summer period (refer **Tables 3** and **4**). The prevalence of relatively hazy atmosphere during the winter period over the years 2004-2006 can indeed be correlated to the occurrence of relatively high fine particulate concentrations prevailing at the sampling site during the same period (refer **Tables 1** and **2**). From **Table 5** it is observed that the range of wind speed and temperature is appreciably low during the winter period over the years 2004-2006. This invariably favours the phenolmenon of thermal inversion which is generally associated with high pollution burden. Moreover during this period the wind velocity is also low (refer **Table 5**) thereby restricting the dispersion of the particulate fractions by confining them locally. The range of PM$_{10}$ and PM$_{2.5}$ concentrations obtained for the summer period over these two years vary from (76.57 - 78.25) μg·m^{-3} and (45 - 46.14) μg·m^{-3} respectively (refer **Tables 1** and **2**). This is low compared to their corresponding winter ranges (refer **Tables 1** and **2**).

Table 3. Angstrom turbidity coefficient values for the period 2004-2005.

Angstrom Turbidity Values (β)	Summer (2004-2005)			Winter (2004-2005)		
	Mean	Max	Min	Mean	Max	Min
β_{340}	0.362	2.608	0.138	0.380	1.320	0.248
β_{500}	0.423	4.021	0.124	0.437	1.114	0.325
β_{870}	0.507	6.956	0.106	0.443	1.698	0.318
β_{936}	0.522	7.547	0.091	0.429	1.801	0.294
β_{1020}	0.610	9.096	0.066	0.414	1.939	0.267

Table 4. Angstrom turbidity coefficient values for the period 2005-2006.

Angstrom Turbidity Values (β)	Summer (2005-2006)			Winter (2005-2006)		
	Mean	Max	Min	Mean	Max	Min
β_{340}	0.331	2.458	0.126	0.432	2.094	0.112
β_{500}	0.372	2.824	0.105	0.424	2.530	0.077
β_{870}	0.522	6.791	0.095	0.521	4.313	0.064
β_{936}	0.525	7.284	0.082	0.565	4.619	0.052
β_{1020}	0.607	8.316	0.057	0.635	6.023	0.039

But in comparison to the annual mean standard for the $PM_{2.5}$ fractions as notified by the Central Pollution Control Board, the value exceeds 40 $\mu g \cdot m^{-3}$. Considering the PM_{10} fractions it is seen that the range for the summer period over these two years also exceeds the annual mean standard of 60 $\mu g \cdot m^{-3}$. Combining the two fine particulate fractions and considering their adverse implications on an environment of rich biodiversity it can be only said that their sources indeed need to be properly identified to reduce their concentrations and thereby curtail their adverse impact on the rich biodiversity of the Sundarbans. Regarding the AOD values it has been observed from **Tables 1** and **2** that the range of AOD for the filter channels 340 nm, 500 nm, 870 nm, 936 nm and 1020 nm over a period of two years from 2004-2006 vary between 0.065 to 8.901 with the maximum average values being obtained for the smaller filter channels of 340 nm and 500 nm. This is an indicative of occurrence of finer fractions in substantial proportion to the coarser fractions [39]. From **Tables 3** and **4** it is observed that the angstrom turbidity coefficient values for all the filter channels are greater than 0.2 over these two years from 2004-2006. This again indicates the existence of relatively hazy atmospheric conditions in the Sundarbans. This atomspheric condition can be indeed accounted for the presence of finer fractions in the atmosphere.

6. Correlation of Angstrom Turbidity Coefficient with Aerosol Optical Depth

The correlation of the angstrom turbidity coefficient with AOD has been done for the summer and winter periods of 2004-2005 and 2005-2006. The correlation plots have been shown in **Figures 2**-**5** respectively.

From **Figures 2**-**5** it is seen that there is a positive correlation between the β values and the τ values with high correlation coefficient being obtained for the summer periods. This can be possibly due to the relative closeness in the occurrences of the two values, justified well by the closeness in the dataset for the particulate fractions recorded during the summer periods over the two years of study (refer **Tables 1** and **2**). The correlation coefficient values for the winter periods over the two years from 2004-2006 have been found to be close to each other. The positive correlation between the two parameters synchronizes well with the occurrence of high fine particulate concentrations recorded in the area (refer **Tables 1** and **2**). Moreover, higher the particulate concentration, higher is the AOD value and hence indirectly the fine particulate concentrations are thus well correlated to the high angstrom turbidity values.

7. Probable Sources

To reiterate, the absence of proper conventional energy sources in the Sundarbans is one of the basic reasons behind the huge combustion of biomass (mostly incomplete) practiced in the area. This intense biomasss combustion can be treated as one of the most important sources contributing to the aerosol loading in the area (both finer particulate fractions as well as the AOD values).

Table 5. Meteorological parameters.

Year	Period	Range of Wind Speed ($km \cdot hr^{-1}$)	Predominant Wind Direction	Range of Temperature (˚C)
Year (2004-2005)	Winter	(5 - 10)	N-E	10 - 20
	Summer	(6 - 15)	S-E to S-W	25 - 35
Year (2005-2006)	Winter	(4 - 10)	N-W	12 - 19
	Summer	(6 - 14)	S-E to S-W	21 - 32

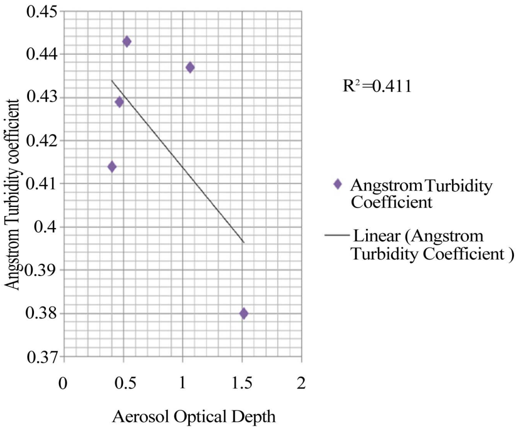

Figure 2. Correlation of angstrom turbidity coefficient (β) with aerosol optical depth (τ) for the winter period of 2004-2005.

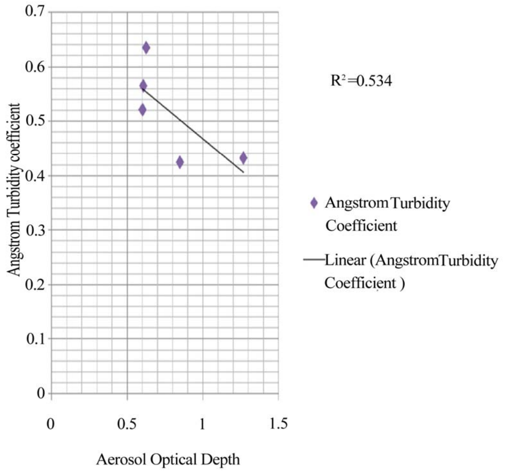

Figure 3. Correlation of angstrom turbidity coefficient (β) with aerosol optical depth (τ) for the winter period of 2005-2006.

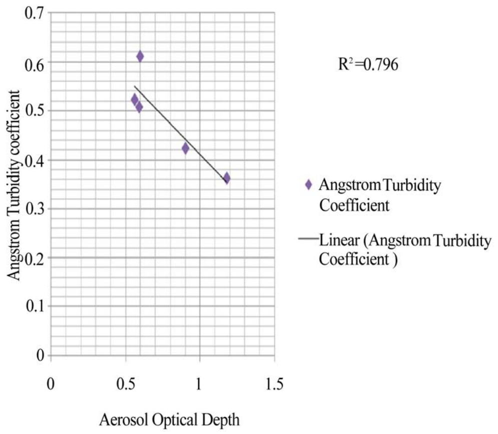

Figure 4. Correlation of angstrom turbidity coefficient (β) with aerosol optical depth (τ) for the summer period of 2004-2005.

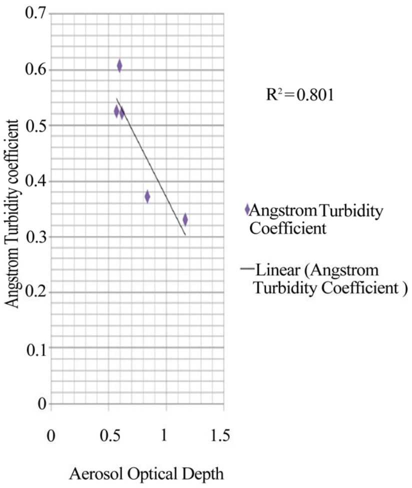

Figure 5. Correlation of angstrom turbidity coefficient (β) with aerosol optical depth (τ) for the summer period of 2005-2006.

Further most of the local anthropogenic activities at the site are dependent on oil fed generators. Due to inferior quality of fuels and incomplete combustion in most cases, these result in the emissions of toxic green house gases in the area which further result into coagulation thereby forming aerosol. This fossil fuel combustion can be held accountable for having a substantial contribution to the aerosol loading over the area. Beside this there are large numbers of diesel driven boats plying in and around the area which can be treated as another probable source contributing to the aerosol loading of the area. To sum up fossil fuel combustion and intense biomass burning may be considered as the most common sources behind the occurrences of these appreciable aerosol loading values reported at the sampling site which has been truly reflected in the corresponding angstrom turbidity coefficient values (refer **Tables 3** and **4**).

8. Conclusion

The angstrom turbidity coefficient values have been found significant enough to suggest the possible influx of fine particulate concentration in the aerosol loading of Sundarbnas. The finer fraction concentrations have been also obtained to be high enough making it serious point of concern to the precious biodiversity of the Sundarbans. All of these suggest the need of adopting stringent measures to protect the fragile ecosystem of the Sundarbans.

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