

# Correlation between Atmospheric Turbidity and Water Turbidity

Joy Ifeoma Emeodi<sup>1\*</sup>, Uchechukwu Vincent Okpala<sup>2</sup>, Bartholomew Chike Ordunze<sup>3</sup>, Precious C. Uzoma<sup>4</sup> and Josiah C. Abara<sup>5</sup>

<sup>1,2</sup>Department of Industrial Physics, Chukwuemeka Odumegwu Ojukwu University, Anambra State Nigeria

<sup>3,4</sup>Department of Physics/Electronics, School of Applied Sciences, Imo State Polytechnic, Omuma Imo State Nigeria

<sup>5</sup>Federal Poly, Nekede, Imo State Nigeria

\*Correspondent Author

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## ABSTRACT

The interaction between atmospheric turbidity and water turbidity is an important factor in meteorology, climatology, limnology, and oceanography, with important applications in air and water pollution monitoring. Understanding their correlation provides insights into coupled atmosphere–hydrosphere processes affecting coastal environments. This study examined the seasonal and inter annual correlation between atmospheric turbidity, expressed by the Linke turbidity factor (TL), and water turbidity at two coastal stations in Lagos, Nigeria. Three years of data (October 2007–September 2010) were analyzed for NIOMR Jetty and Victoria Beach. Water turbidity was compared against atmospheric turbidity indices for both wet and dry seasons. The correlation results between atmospheric turbidity and water turbidity for Victoria Beach Section, and NIOMR Jetty revealed distinct seasonal and spatial variations. During the dry season, the correlation coefficients for Victoria Beach Section (−0.137, −0.66 and −0.803), indicated moderate to strong negative correlations, suggesting that as atmospheric turbidity increased, water turbidity decreased. For the NIOMR Jetty, the correlation coefficients (−0.44, −0.68 and 0.032) showed predominantly negative to negligible relationships, indicating that variations in atmospheric turbidity have little consistent effect on water turbidity during the dry period. During the wet season, the correlation coefficients for Victoria Beach Section (0.661, 0.46 and −0.19) and NIOMR Jetty (0.688, −0.18 and 0.51) reveal mostly moderate positive correlations, suggesting that increased atmospheric turbidity corresponds with increased water turbidity, likely due to rainfall-induced run off and sediment loading. Finally, the findings indicated that the relationship between atmospheric and water turbidity was negative during the dry season and positive during the wet season; highlighting the role of rainfall, surface runoff, and suspended particle transport. Correlations were generally stronger in the wet season, with July showing the highest association, indicating that rainfall-driven runoff, and particulate loading jointly influenced atmospheric scattering, and water-column clarity. Seasonal variability in turbidity has significant implications for aquatic ecology, primary productivity, and recreational water use. Integrating atmospheric and hydrological parameters into monitoring frameworks can enhance pollution control, and sustainable coastal management strategies.

**Keywords:** Atmospheric turbidity, water turbidity, Linke turbidity factor, seasonal variability, Lagos coast, air–water pollution.

## INTRODUCTION

Solar radiation is the primary driver of atmospheric and hydrological processes on Earth. As solar energy traverses the atmosphere, it is attenuated through absorption by gases, and scattering by aerosols, giving rise to atmospheric turbidity (Iqbal, 1983; Sen, 2008). Contemporary studies show that aerosol loading, humidity, and precipitation, significantly modulate atmospheric optical depth, especially in tropical coastal regions (Adegun et

al., 2018; Ravelo-Pérez et al., 2020). Atmospheric turbidity not only influences climate and visibility, but also governs the amount and spectral quality of solar radiation reaching terrestrial and aquatic surfaces.

Water bodies, which cover over 70% of the Earth's surface, are highly sensitive to changes in incident solar radiation, and particulate loading (Kirk, 1994; Mobley, 1994). Water turbidity, caused by suspended sediments, phytoplankton, and organic matter, regulates light penetration, thermal structure, and primary productivity (Bilotta & Brazier, 2018; Liu et al., 2017). Increased turbidity reduces photosynthetically active radiation, disrupts aquatic ecosystems, and degrades recreational and aesthetic water quality (Wetzel, 2001; Gray, 2014).

Recent research increasingly recognizes the coupled nature of atmospheric and aquatic turbidity, particularly in coastal and estuarine environments; where aerosols, rainfall, and land-derived sediments interact dynamically (Babanin & Haus, 2017; Zhang et al., 2022). Rainfall enhances aerosol scavenging, while simultaneously increasing surface runoff, and sediment transport into water bodies, often producing positive correlations, between atmospheric and water turbidity during wet seasons (Chen et al., 2021; Peterson et al., 2018). Conversely, dry seasons characterized by dust transport and minimal runoff, may yield weak or inverse relationships (Adegun et al., 2018; Odjugo & Ikhuoria, 2019).

In rapidly urbanizing coastal cities such as Lagos, these interactions are further complicated by anthropogenic emissions, shoreline modification, and altered drainage systems (Adeniyi & Oladipo, 2018; Nwilo et al., 2020). Despite their importance, empirical studies linking atmospheric turbidity indices with in situ water turbidity measurements in West African coastal zones remain limited.

This study addressed the aforementioned gap, by examining the correlation between atmospheric turbidity, quantified using the Linke turbidity factor (Linke, 1922; Ineichen & Perez, 2002), and water turbidity at two Lagos coastal stations. The gap was closed through the following objectives;

- (i) estimating the seasonal and annual variations in atmospheric turbidity,
- (ii) analyzing the corresponding variations in water turbidity, and
- (iii) quantifying the dry- and wet-seasonal correlation patterns.

The results contributed to a better understanding of air–water optical coupling, in tropical coastal environments, and supported improved environmental monitoring strategies.

## METHODOLOGY

### Data Collection

Direct solar radiation data were obtained from the Meteorological Station (NECOP), at the University of Lagos, under air mass 2 conditions. Water turbidity data were collected from the Nigerian Institute of Oceanography and Marine Research (NIOMR), Victoria Island, Lagos, for two coastal sampling stations: NIOMR Jetty and Victoria Beach Section. The dataset covered a three-year period from October 2007 to September 2010. Water turbidity measurements were carried out by NIOMR., using a HORIBAU-10 Multimeter Water Checker, which measured multiple water quality parameters including turbidity.

Atmospheric turbidity was estimated, using a modified formulation of the Linke turbidity factor (TL), compatible with the standard air mass 2 model. The Linke turbidity factor was adopted, due to its robustness in representing the combined effects, of aerosols and atmospheric water vapor, under clear-sky conditions, and its extensive application in tropical, and subtropical regions (Ineichen & Perez, 2002; Gueymard, 2003). Comparative studies have further demonstrated that TL remained a reliable proxy for atmospheric clarity in regions, where continuous aerosol optical depth measurements were unavailable (Jacovides et al., 1996; Ravelo-Pérez et al., 2020). Monthly average Linke turbidity values derived from meteorological data, were subsequently correlated with observed water turbidity measurements, to assess coupled atmospheric–hydrological processes influencing coastal waters.

The Ineichen–Perez model expressed in equations 1.1-1.12, was employed to compute the Linke turbidity factor for Lagos;

$$TLI = \{11.1 * \ln(b \cdot I_0 \varepsilon / B_{ncI}) / m(y_s^{true})\} + 1 \quad 1.1, \text{ (Linke, 1922; Kasten, 1996; Iqbal, 1983)}$$

Where;

$$\varepsilon = \frac{\text{actual distance of the sun from earth}}{\text{Average distance of the sun from the earth}} \quad 1.2$$

$\varepsilon$  = sun–earth distance correction

$$b = 0.664 + 0.163 / fh_1 \quad 1.3$$

$b$  = multiplication coefficient, (Iqbal, 1983; Duffie & Beckman, 2013)

$$fh_1 = \exp(-\text{altitude} / 8000) \quad 1.4, \text{ (Kasten, 1980; Iqbal, 1983)}$$

$I_0$  = solar constant

$$B_{ncI} = \frac{B_{horizontal}}{\cos \theta_z} \quad 1.5, \text{ (Iqbal, 1983; Duffie & Beckman, 2013)}$$

$B_{ncI}$  = normal clear sky beam radiation

$m(y_s^{true})$  = optical air mass, (Kasten, 1988)

$\theta_z$  = zenith angle

$y_s$  = solar altitude

$B_{horizontal}$  = beam radiation on the horizontal surface

$$\delta = 23.45 \sin \left\{ \frac{360(284 + n)}{365} \right\} \quad 1.6, \text{ (Cooper, 1969; Duffie & Beckman, 2013)}$$

$$w = (2 / 15) \cos^{-1}(-\tan \phi \tan \delta) \quad 1.7, \text{ (Duffie & Beckman, 2013; Iqbal, 1983)}$$

$\delta$  = declination

$\phi$  = latitude

$W$  = hour angle

$$m(y_s^{true}) = \frac{P/P_0}{\sin y_s^{true} + 0.50572 (\sin y_s^{true} + 6.07995) - 1.6364} \quad 1.8 \text{ (Kasten, 1988; Kasten & Young, 1989)}$$

$$P/P_0 = \exp(-z / zh) \quad 1.9, \text{ (U.S. Standard Atmosphere, 1976; Iqbal, 1983).}$$

$z$  = the site elevation

$zh$  = the scale height of the Rayleigh atmosphere near the earth surface equal to 8484.5 m.

$$Y_{true} = Y_s + \Delta Y_{refr} \quad 1.10, \text{ (Michalsky, 1988)}$$

$$\sin Y_s = \sin \phi \sin \delta + \cos \phi \cos \delta \cos w \quad 1.11, \text{ (Duffie & Beckman, 2013; Iqbal, 1983)}$$

$$\Delta Y_{refr} = 0.061359(180/\pi)[0.1594 + 1.1230(180/\pi)Y_s + 0.65656(180/\pi)^2 Y_s^2] / [1 + 28.9344(180/\pi)Y_s + 277.3971(180/\pi)^2 Y_s^2] \quad 1.12, \text{ (Meeus, 1991; Michalsky, 1988).}$$

Seasonal (dry and wet) and annual variations in water turbidity for both NIOMR Jetty, and Victoria Beach stations, were analyzed over the three-year period (October 2007–September 2010). Correlation analyses were performed, to examine the relationship between atmospheric, and water turbidity. Seasonal correlation coefficients ( $r$ ), were determined for both stations. Finally, mean monthly water turbidity values, and atmospheric Linke turbidity, were plotted to identify months with the highest frequency of turbidity occurrence.

## RESULTS AND DISCUSSIONS

**Table 1;** Mean monthly water turbidity values for 2007/2008, 2008/2009 and 2009/2010 respectively, for NIOMR Jetty.

2007/2008		2008/2009		2009/2010	
Month	Water Turbidity (NTU)	Month	Water Turbidity (NTU)	Month	Water Turbidity (NTU)
Oct	25.35	Oct	_____	Oct	16.87
Nov	19.48	Nov	_____	Nov	15.53
Dec	3.88	Dec	_____	Dec	4.14
Jan	0.76	Jan	6.25	Jan	7.77
Feb	0.14	Feb	4.45	Feb	5.50
Mar	2.72	Mar	14.83	Mar	6.18
Apr	0.91	Apr	8.69	Apr	1.19
May	2.86	May	52.63	May	7.62
Jun	6.90	Jun	14.71	Jun	4.56
Jul	27.86	Jul	42.93	Jul	38.45
Aug	33.77	Aug	17.96	Aug	28.96
Sept	_____	Sept	11.62	Sept	_____

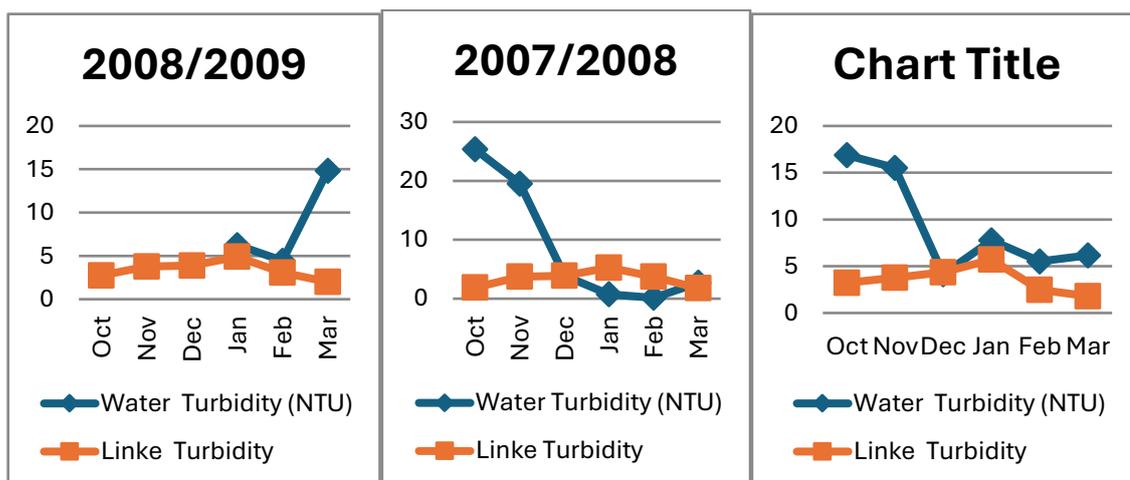
**Table 2;** Mean monthly water turbidity values for 2007/2008, 2008/2009 and 2009/2010 respectively, for Victoria Beach section.

2007/2008		2008/2009		2009/2010	
Month	Water Turbidity (NTU)	Month	Water Turbidity (NTU)	Month	Water Turbidity (NTU)
Oct	19.56	Oct	_____	Oct	206.60
Nov	21.33	Nov	_____	Nov	118.20
Dec	11.12	Dec	_____	Dec	20.14
Jan	8.79	Jan	36.24	Jan	36.57
Feb	11.36	Feb	41.94	Feb	53.60
Mar	6.20	Mar	205.00	Mar	28.21
Apr	8.00	Apr	207.00	Apr	52.66
May	9.20	May	194.90	May	36.21
Jun	34.00	Jun	159.60	Jun	69.08
Jul	40.80	Jul	229.80	Jul	202.28
Aug	57.33	Aug	159.50	Aug	157.50
Sept	_____	Sept	106.90	Sept	_____

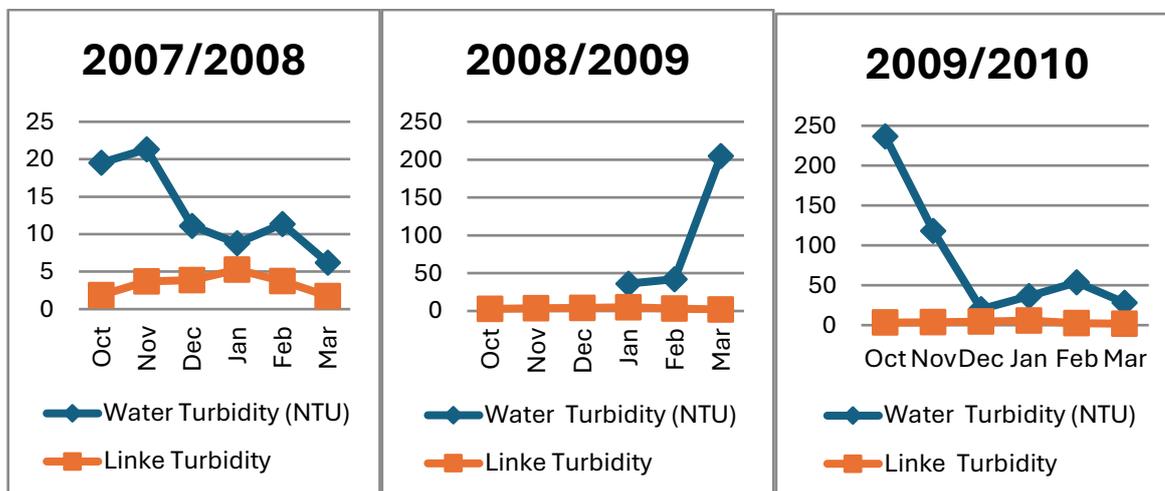
**Table 3;** Mean monthly Linke Turbidity( $T_L$ ) values for 2007/2008, 2008/2009 and 2009/2010, respectively.

2007/2008		2008/2009		2009/2010	
Month	Linke Turbidity	Month	Linke Turbidity	Month	Linke Turbidity
Oct	1.86	Oct	2.74	Oct	3.23
Nov	3.71	Nov	3.76	Nov	3.79
Dec	3.87	Dec	3.90	Dec	4.35
Jan	5.27	Jan	4.90	Jan	5.71
Feb	3.72	Feb	3.09	Feb	2.47
Mar	2.75	Mar	2.00	Mar	1.80
Apr	1.83	Apr	1.33	Apr	2.30
May	2.78	May	3.11	May	5.26
Jun	2.68	Jun	4.64	Jun	6.16
Jul	2.95	Jul	5.56	Jul	8.62
Aug	2.61	Aug	3.19	Aug	4.97
Sept	2.47	Sept	1.38	Sept	1.42

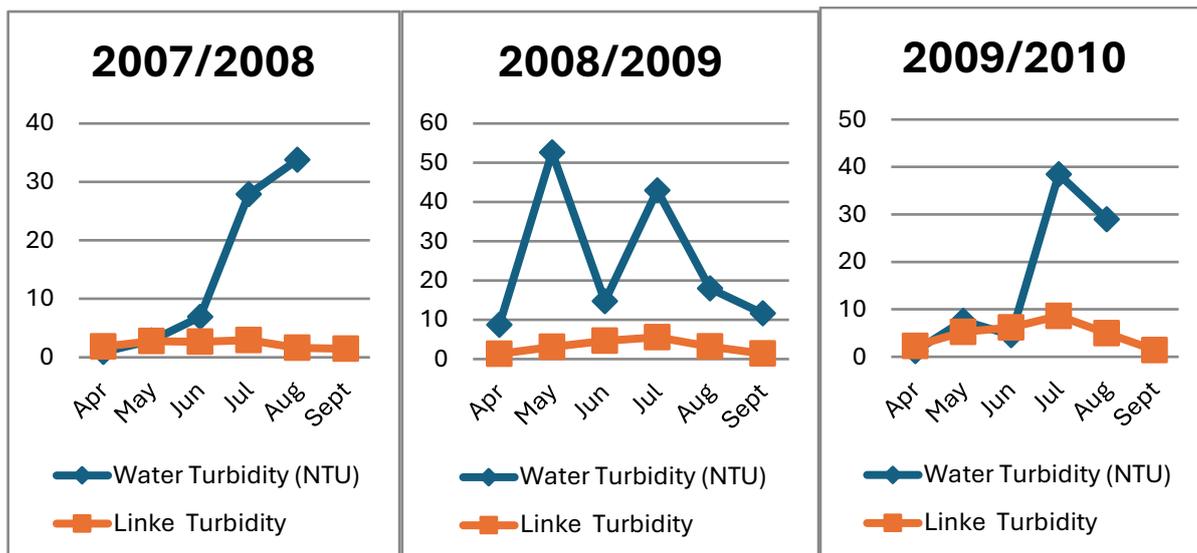
The empty spaces in the recorded data of tables 1-2, may have resulted from equipment malfunction or labor disruptions during the study period.



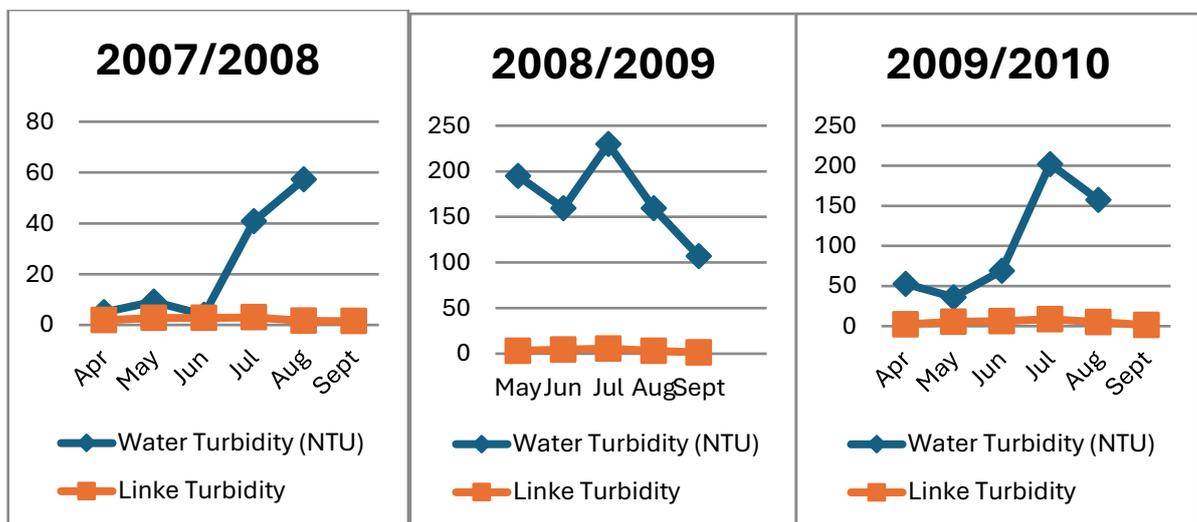
**Figure 1;** the seasonal correlation between water turbidity, and atmospheric turbidity for 2007/2008, 2008/2009 and 2009/2010 respectively, for NIOMR Jetty during dry season.



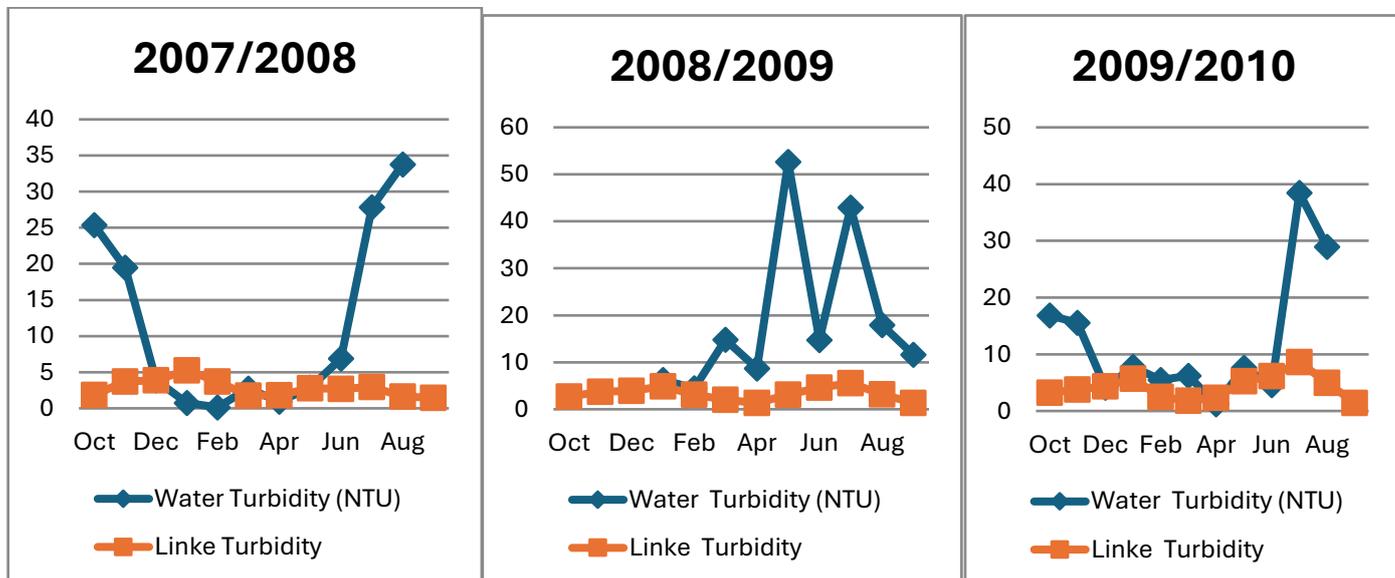
**Figure 2;** the seasonal correlation between water turbidity and atmospheric turbidity, for 2007/2008, 2008/2009 and 2009/2010 respectively for Victoria Beach Section during dry season.



**Figure 3;** the seasonal correlation between water turbidity, and atmospheric turbidity, for 2007/2008, 2008/2009 and 2009/2010 respectively for NIOMR Jetty during wet season.

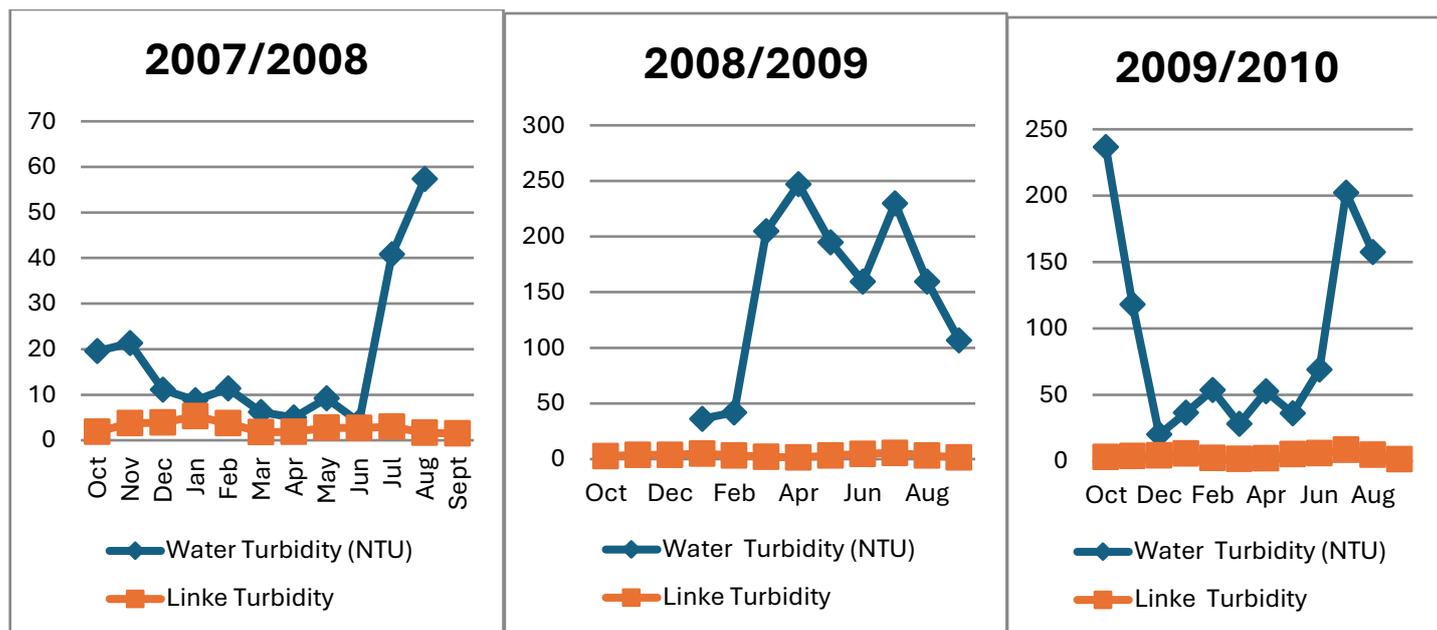


**Figure 4;** the seasonal correlation between water turbidity, and atmospheric turbidity, for 2007/2008, 2008/2009 and 2009/2010 respectively, for Victoria Beach Section during wet season.



**Figure 5;** the annual correlation between water turbidity, and atmospheric turbidity, for 2007/2008, 2008/2009

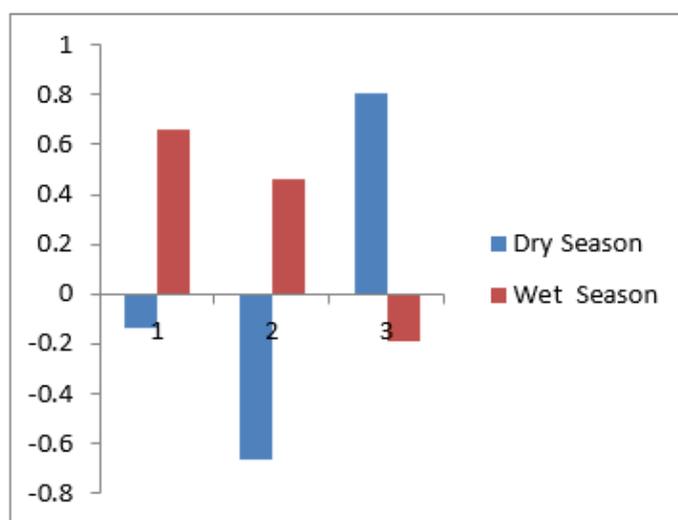
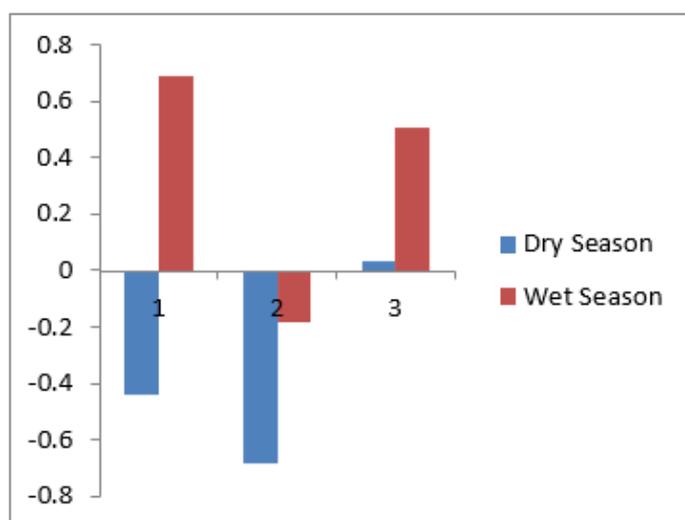
and 2009/2010, respectively for NIOMR Jetty.



**Figure 6;** the annual correlation between water turbidity and atmospheric turbidity for 2007/2008, 2008/2009 and 2009/2010 respectively for Victoria Beach Section.

By analyzing figures 1, 2, 3 and 4, it was seen that the mean values of water turbidity, for NIOMR Jetty, Victoria Beach Section, and atmospheric turbidity varied in the following ways:

1. From the month of October to March (dry season) were 8.92, 57.00 and 3.41, respectively.
2. From the month of April to September (wet season) were 18.85, 108.24 and 3.45, respectively.
3. The smallest values of 0.14, 4.00 and 1.33 respectively, occurred during dry season.
4. The highest values of 52, 229.80 and 8.62 respectively, occurred during wet season.



**Figure 7a and b;** the correlation coefficient graph, between atmospheric turbidity, and water turbidity during dry Season and wet Seasons, for NIOMR Jetty and Victoria Beach Section, respectively.

The correlation results between atmospheric turbidity, and water turbidity for NIOMR Jetty and Victoria Beach Section in figure 7, revealed distinct seasonal and spatial variations. During the dry season, the correlation coefficients for the NIOMR Jetty were  $-0.44$ ,  $-0.68$  and  $0.032$ . Figure 7 (a) shows mostly negative to negligible relationships, indicating that variations in atmospheric turbidity, have little consistent effect, on water turbidity during the dry period. For Victoria Beach Section, the correlation coefficients were  $-0.137$ ,  $-0.66$  and  $-0.803$ .

Figure 7(b) indicates moderate to strong negative correlations, suggesting that as atmospheric turbidity increased, water turbidity generally decreased. This inverse relationship may be attributed to limited rainfall, and reduced surface runoff. Increased atmospheric dust and aerosols did not significantly influence water clarity. Moreover, the dry season pattern suggests that both locations experienced weak to strong negative relationships, reflecting the influence of stable weather, minimal precipitation, and reduced particulate exchange, between air and water.

In contrast from figure 7 (a), during the wet season, the correlation coefficients for NIOMR Jetty results were 0.688,  $-0.18$  and  $0.51$ , which revealed mostly moderate positive correlations. Similarly, from figure 7(b), Victoria Beach Section results were  $0.661$ ,  $0.46$  and  $-0.1$ , showing that the relationship between atmospheric, and water turbidity was moderately positive, with one weak negative correlation. These positive relationships showed that increased atmospheric turbidity, corresponds with increased water turbidity. It is likely due to rainfall-induced runoff, erosion, and sediment loading that simultaneously raised, both atmospheric and aquatic particulate levels (Miller, 2007). Similarly, rainfall increased the atmospheric water vapor and aerosols, leading to higher turbidity levels (Jacovides et al., 1996).

Finally, the findings indicate that the relationship between atmospheric and water turbidity, was negative during the dry season, and positive during the wet season, for both studied sites. This seasonal contrast highlights the significant role of rainfall, surface runoff, and suspended particle transport, in influencing air–water turbidity interactions along coastal environments, such as NIOMR Jetty and Victoria Beach. These seasonal patterns were consistent with regional hydro climatic studies of Lagos (Adejuwon, 2012; Ndom, 2009). These weak correlations suggest that, although atmospheric and water turbidity shared some seasonal drivers, local hydrological and anthropogenic factors, likely played a larger role, in determining water clarity (Davies-Colley & Smith, 2001).

## CONCLUSION AND RECOMMENDATION

### Conclusion

Water clarity and light penetration were critical factors, influencing both ecological balance, and recreational water use. Atmospheric and water turbidity served as essential indicators, for evaluating air and water pollution levels, as well as, determining the attenuation of solar radiation; reaching the Earth's surface and water bodies, under cloudless conditions. Data obtained from the meteorological station (NECOP) were utilized to calculate the Linke turbidity factor, while water turbidity measurements from the Oceanography Institute (NIOMR Jetty and Victoria Beach Section), were employed to correlate atmospheric and water turbidity. The variations observed in atmospheric and water turbidity were influenced by seasonal, monthly, and hourly changes. The Lagos atmosphere remained predominantly moist, and warm throughout the year. Elevated turbidity levels were primarily attributed to maritime, and Saharan origins, particularly during the harmattan period (December to February). During the dry season, lower correlation between atmospheric, and water turbidity was observed due to sediment settling, despite increased atmospheric dust. Conversely, the wet season (around July) exhibited higher correlation values, as both atmospheric and water turbidity was elevated, due to runoff and suspended matter. Reduced transparency between June and October corresponded with increased flood water influx, while clearer conditions were recorded in September, November and December, aligning with prior theoretical predictions.

### Recommendation

Future studies should apply alternative atmospheric clarity models, and satellite-derived aerosol products, alongside the Linke turbidity factor, to improve comparative validation. Integrating underwater irradiance measurements, and Beer–Lambert-based attenuation analyses, would further advance understanding of energy transfer, across the air–water interface, benefiting limnological, oceanographic, and environmental management applications.

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