Journal of Sustainable Development in Africa (Volume 12, No.1, 2010)

ISSN: 1520-5509

Clarion University of Pennsylvania, Clarion, Pennsylvania

WIND CLIMATOLOGY IN ENVIRONMENTAL PLANNING FOR SUSTAINABLE AIR POLLUTION MANAGEMENT IN THE NIGER DELTA, NIGERIA

By: B. Pius Utang, C. Okoko Ogba, and Olatunde S. Eludoyin

ABSTRACT

The paper justifies the importance of environmental planning, with the integration of wind climatology for air quality issues, in sustainable development. Wind climatology, which is relevant in environmental sustainability, provides an understanding of air pollution diffusion and transport, including the variations in spatio-temporal context. Data on wind speed and direction for different parts of the region as well as surface vector winds at 925 hPa level over the region were obtained for some stations and from NCEP/NCAR/NOAA reanalysis project data sets. Analyses were based on percentages and tables. Thematic maps showing synoptic winds for four months, representing the first quarter of each season were prepared and analyzed with ArcView version 3.3 GIS facility. Analyses suggest spatial variation in concentration and dispersion of pollutant at different temporal scales, attributed mainly to differential wind direction and speed, while the coastal meteorology, such as surface inversions, could be additional contributor to pollutant concentration and variation at the short-term. On the basis of the Wind Climatology (WC) in the region, pollution concentration is generally high, while dispersion is low. The allocation of residential areas far away from industrial and oil/gas installations, and high traffic road networks, separated by wide areas of green belts, are valuable options in spatial planning. The need for allocation of space for residential use upwind of pollution sources was also advocated. This calls for understanding the prevailing wind condition.

Keywords: air quality, environmental planning, pollution dispersion, sustainable development, wind climatology

INTRODUCTION

The concept of sustainable development 'aims' at promoting environmental sustainability, as it amounts to one conception or theory of, and strategy for, environmental sustainability (Dobson, 1998). It is akin to environmental sustainability as it focuses on development that meets environmental, social and economic needs of the present generation without compromising the same benefits for the future generations.

Since environmental sustainability is concerned with the sustenance of a particular aspect or feature of natural capital that is critical to the production and reproduction of human life (Norton, 1992 in Dobson, 1998), it is inherent in sustainable development. An important critical natural capital, whose quality is often undermined in development in many third world countries, because emphasis is on economic growth, is air. One policy and planning instrument which facilitates the realization of environmental sustainability in sustainable development is environmental planning.

Environmental planning implies more effective planning for now and the future within environmentally dictated confines (Baele, 1980). It incorporates spatial planning, which refers to methods used by the public sector to influence the distribution of people, facilities and infrastructure, and activities in spaces of various scales, including land use planning, urban planning, regional planning and national spatial plans (Bownman, 2008).

The additional impetus is environmental effectiveness in which environmental considerations in planning should take account of the likely effects of development on the natural environment, mankind and man-made structures (Baele, 1980). Environmental planning as aspect of spatial planning goes beyond traditional land use planning to integrate policies for the development and use of land with other policies and programmes which influence the nature of places and how they function (www.planning.portal.gov.uk, in Bowman, 2008). This is planning that defines, develops and protects the environment.

Environmental planning as used in this paper is akin to planning at regional scale, which encourages the consideration and identification of environmental activities and aspects in proposed development plans (Hyde and Reeve, 2001) and the factors which affect the elements of the activities that can interact with the environment (aspects). One of such aspects is atmospheric emissions, which have the potential of causing atmospheric pollution.

Within the Niger delta region are several activities whose input or outputs are capable of interacting with the environment to create impact on the ambient air quality. Because of the dynamic nature of the atmosphere, ambient air pollutions are generally dynamic in space-time dimension, depending on the vagaries of the weather and prevailing climate. Thus, although ambient air pollution can have local character due to local emission sources, fluctuations in the concentration are mainly meteorologically induced (NAS, 1992).

Airborne pollutants can travel hundreds, perhaps thousands of kilometers to other cities or unpolluted wilderness, where they are deposited. For instance the acidic pollutants responsible for the massive fish kills in Sweden's Tovdal River Basin are blown from industrial England into Scandinavia (Chiras, 1994). Hence, the spatial variation in air pollution concentration is hinged on the space variation of sources as well as atmospheric gradients (pressure, wind and temperature).

Wind climatology provides an understanding and rapid appraisal of the dynamics of air pollution. It is valuable to integrate the spatial nature and dynamics of this climatic determinant of air pollution dispersion in spatial plans. This would contribute to the empirical explanation of spatial pattern of pollution.

This paper attempts to justify the importance of integrating wind climatology in spatial planning. This is to ensure that the goal environmental sustainability is achieved. In doing this, the paper examines the spatial and temporal distribution of wind speed and direction as surrogates for understanding pollutants concentration and dispersal.

THE UNDERLYING ISSUES

The Niger Delta region is Strewn with myriads of land uses such as trade and industry, housing and road construction, crude oil and gas mining, refuse and waste disposal activities, and power generation, which are environmentally sensitive activities, that are likely to cause attrition of the ambient air quality.

Already some mitigation measures aimed at point source control have been in place, but the increasing concentration of human activities makes increasing uncontrollable emissions eminent. Monitoring of air emissions and gaseous wastes discharged at specific sources through continual air quality sampling and visual checks for leakages, which as purported in National Policy on the Environment (1999), has mostly been at the dictates of oil companies. These, no doubt, provide information that portrays the establishment as operating within acceptable limits.

Studies carried out at different locations show differential concentration and distribution of ambient air quality parameters (NDES, 1997). On the whole, suspended particulate matter (SPM) was more concentrated and reportedly came from both natural and anthropogenic sources. These were found downwind more than upwind, implying the influence of wind direction. The values of acidic precursors (SO_x) varied spatially, with more concentration in the west than east. This suggests a reflection of variation in emissions sources and/or horizontal atmospheric gradients.

The expected spatial pattern of ambient air pollution concentration, given certain climatic and physiographic underlying determinants has not been articulated. Specifically, the influence of wind speed and direction on the distribution and spatial variation of air pollution has not been established nor justified for the Niger Delta. Knowledge of this needs to be applied in spatial planning, which aims at environmental sustainability.

Spatial planning at whatever level involves land use planning and is expected to contribute to the improvement of air quality, in the long-term, by strategic location and allocation of polluting activities and vulnerable population. This would encourage spatial structures and activities that would minimize pollution emission and build-up (Bertaud, 2002 in Rigby and Toumi, 2008).

The land use characteristics of the cities in the region affect the ventilation situation. This is characterized by built-up, and as noted by Eum (2008) high building-to-land ratio (ratio of the area covered by buildings to the area of the plot) and high floor area ratio (ratio of total building square footage to the area of the plot) result in high aerodynamic surface roughness. These cause a weak wind speed; hence low pollutants diffusion.

Differential friction influences vertical dispersal of pollutants (Bornstein and Johnson, 1997 in Rigby and Toumi, 2008), while high concentration of building with little open spaces increases the risk of trapping pollutants at near surfaces and the redirection and reduction of wind speed.

Those in winds aloft are dispersed faster than those at or close to the surface. Thus turbulent diffusion is extinguished at the surface and within the atmospheric boundary layer where pollutants are transported by force of molecular diffusion (Rosenberg, 1974).

In the Niger Delta, fugitive pollutants are expected, hence monitoring air quality and understanding the spatio-temporal pattern/variation is imperative. Unfortunately, apart from the fact that spatial plans in the past have been characterized by misallocation (in some cases distortions by unscrupulous elements in public offices) of land uses, the allocation of pollution activities with consideration of wind speed and direction and other atmospheric parameters has not been taken into consideration.

It must be emphasized that the Niger Delta is a coastal milieu, with its distinctiveness, being an area that atmospheric conditions are generally dynamic and highly energetic (NAS, 1992), and constantly under the influence of winds. Pollutants concentration can be influenced by these atmospheric conditions, hence the need for considering this in regulation of human activities in any development plan.

The effects of pollution are universal and continuously experienced, not only in congested urban areas, but also in remote rural areas (Manawadii and Samarakoon, 2007). Even within the urban areas, there could be no statistically significant different in the mean concentration of pollutant in different land uses (Saksena at al, 2001).

In the current regional development plan (the Niger Delta Regional Development Master Plan, 2006), some environmental considerations are incorporated, but the process of development as articulated in the plan is skewed towards developmental needs, without a balance with environmental sustainability. However, issues concerning air pollution impact mitigation are given attention only in the plan policies for environmental intervention (policy En7) through source emission monitoring, regulation and enforcement measures. The complex climatic characteristics of this coastal milieu, with the possibility of inversions and local scale concentration of pollutants are not addressed. These can only be assessed when the climatic environment is understood in totality and the relationship between the components and air pollution are articulated.

WIND SPEED/DIRECTION AND AIR POLLUTION PATTERNS

Air pollutants are dynamics in spatio-temporal context, having local, regional and continental scale effects. Winds, which equalize imbalance in pressure and mainly influenced by the presence or absence of friction (APTI, 2005), contribute significantly to pollutant dispersion.

Studies have proven that upwind location have less pollutant concentration than downwind, confirming that a comparatively high concentration of pollutants are found on sites, which lie either low in attitude, in the downwind location or close to the source of pollution (Garcia et al, 2007; Hung et al, 2005; Tsai et al, 2004).

During light wind speeds and stable atmospheric conditions, pollutants tend to accumulate in the stagnant air around emission sources and can accelerate background concentrations (Garcia et al 2007). In cases of wind speed below $2ms^{-1}$, the concentration of pollutants increases and becomes uniformly distributed around areas within the source zones (Hung et al 2005 and Tsai et al, 2004). Stagnant weather conditions with low wind speed contribute to accumulation of pollutants at ground level (Chiu et al, 2005, in Hung et al, 2005).

Variations in pollutant concentration hinges on the prevailing wind direction (Wan-Li, 2001; Rouse and McCutchen, 2008). In examining the effects of regional wind on air pollution in an urban setting for instance, Rouse and McCutchen (2008) identified a pattern of dual pollution cells of equal intensity on the down town business area and the industrial zone. Pollution levels were observed to be twice as great under east wind with accompanying stability as winds from all the sections. With a change in wind direction new pollution patterns are formed, thus regional wind systems associated with transport of trace gases can be successfully used to predict the pattern of air pollution (Corsmeir et al, 2005).

WIND SPEED/DIRECTION IN THE NIGER DELTA

Station based data indicate that eight prevailing winds are common, but the dominant ones are Southerly, Southwesterly, Westerly and Northwesterly winds. The winds are more fairly distributed in all directions, but southwesterly and westerly winds predominate in the region in January, with a frequency of about 20 percent (NDES (1997; Ojo, 1977). In July, the westerly, southwesterly and southerly winds are predominating, with little to no trace of the easterlies because of the Northward position of Inter Tropical Discontinuity (ITD) (Ojo, 1977). The values of the westerly are comparatively low because of the influence of the southerly winds, arising from its coastal location. These vary between stations as shown in Table 1.

In terms of speed, table 1indicate that the stations show general high percentage of calm and light wind speed, followed by gentle breeze. This however varies between individual stations. In winter (July), the percentage of calm (0-0.2ms^{-1}) is higher, followed by light breezes (1.6-3.3 ms^{-1}), light air (0.3 – 1.5 MS^{-1}) and then gentle breeze (3.4 – 5.4^{-1}). In summer (July) Light breezes are more dominant, followed by calm, gentle breeze and then light air. Winds with speed of 5.5 – 7.9 ms^{-1}) are rare and occur occasionally, especially during the onset of heavy rainfall or thundering activities (Oliver, 1972 in NDES, 1997).

Table 1 (a): Percentage Wind Direction and Speed for Selected Stations in the Niger Delta (January and July)

	DIRECTION								SPEED (MS^{-1})				
Location	NE	E	SE	S	SW	W	NW	N	0-0.2 (CALM)	0.3-1.5	1.6-3.3	3.4-5.4	5.5-7.9
January conditions													
Akure	8.42	8.18	7.57	14.16	14.29	20.39	8.42	5.50	13.06	13.06	53.84	19.29	0.98
Benin	6.53	5.25	2.34	7.30	10.50	10.50	4.68	3.26	49.68	12.21	20.51	16.82	1.77
Warri	2.59	0.73	1.29	18.63	14.57	12.36	6.27	11.26	32.28	15.13	31.92	19.58	1.10
Port Harcourt	7.98	0.54	0.54	6.09	4.74	8.86	11.07	3.52	46.04	8.05	24.61	17.58	3.72
Owerri	10.62	2.07	3.11	7.18	12.56	9.73	8.78	4.35	42.09	32.57	15.87	5.66	3.80
Uyo	19.51	4.54	10.06	3.56	8.47	4.19	23.19	13.00	12.76	25.77	47.61	13.74	0.12
Calabar	12.4	3.0	3.7	13.9	13.4	12.3	16.2	12.4	-	-	-	-	-
Total	68.05	24.31	28.61	70.9	78.53	78.33	78.61	53.29	195.91	106.79	194.36	92.67	11.49
Mean	9.72	3.47	4.09	10.13	11.22	11.19	11.23	7.61	32.65	17.80	32.39	15.45	11.92
July conditions													
Akure	0.36	0.72	1.79	14.23	34.09	36.84	4.06	0.72	7.17	7.89	45.58	33.37	5.98
Benin	1.35	1.94	2.98	11.71	18.12	17.06	6.25	1.04	39.59	8.88	26.99	20.14	4.40
Warri	-	-	1.86	32.44	19.36	11.36	0.56	1.49	32.03	17.13	30.54	18.25	1.68
Port Harcourt	0.37	0.44	1.11	9.53	23.87	12.79	5.40	0.74	45.75	9.01	18.11	19.44	7.69
Owerri	0.58	1.91	7.51	15.97	25.04	18.03	4.41	0.58	26.29	35.86	25.87	8.65	3.33
Uyo	4.38	3.00	17.15	11.14	28.16	10.98	11.89	1.38	12.02	42.05	36.80	7.63	1.50
Calabar	5.9	2.6	5.5	19.6	24.1	13.8	8.3	5.1	-	-	-	-	-
Total	14.66	10.61	31.94	114.58	172.74	120.8	40.88	11.05	162.85	120.82	183.89	107.48	24.58
Mean	2.44	1.77	4.56	16.37	24.68	17.26	5.84	1.58	27.14	20.14	30.65	17.91	4.10

Source: NDES (1997); Ojo (1977)

Figure 1: January Wind

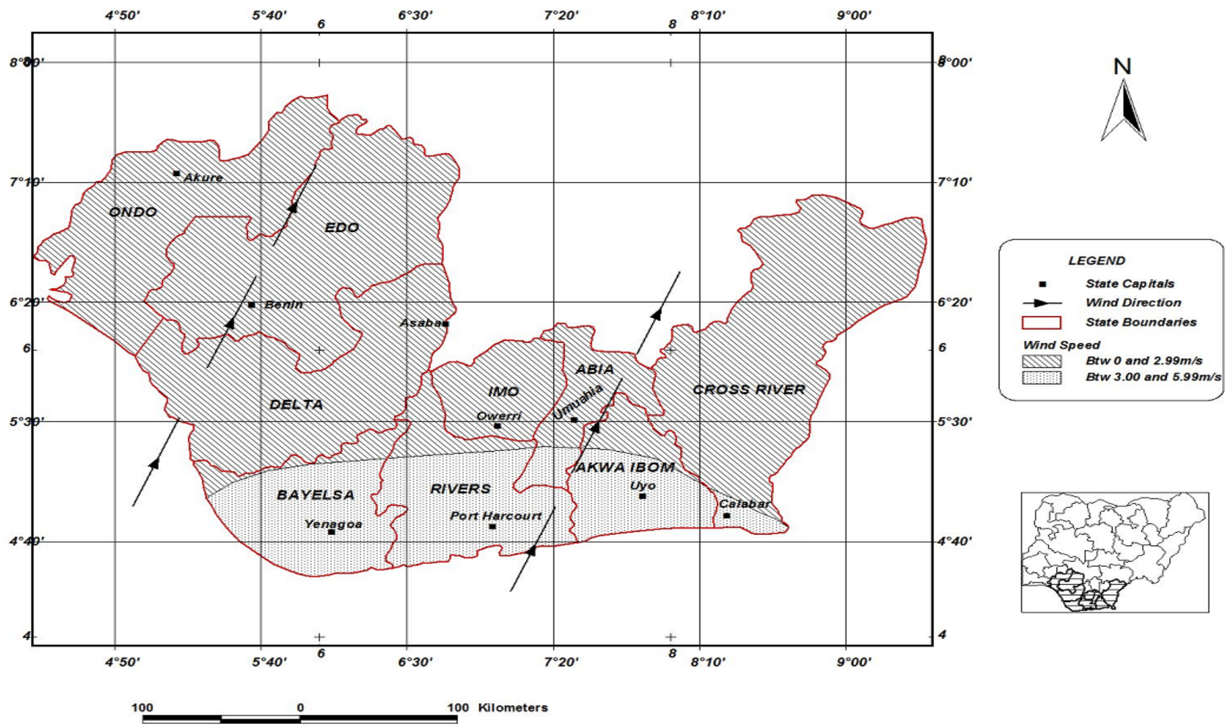


Figure 2: April Wind

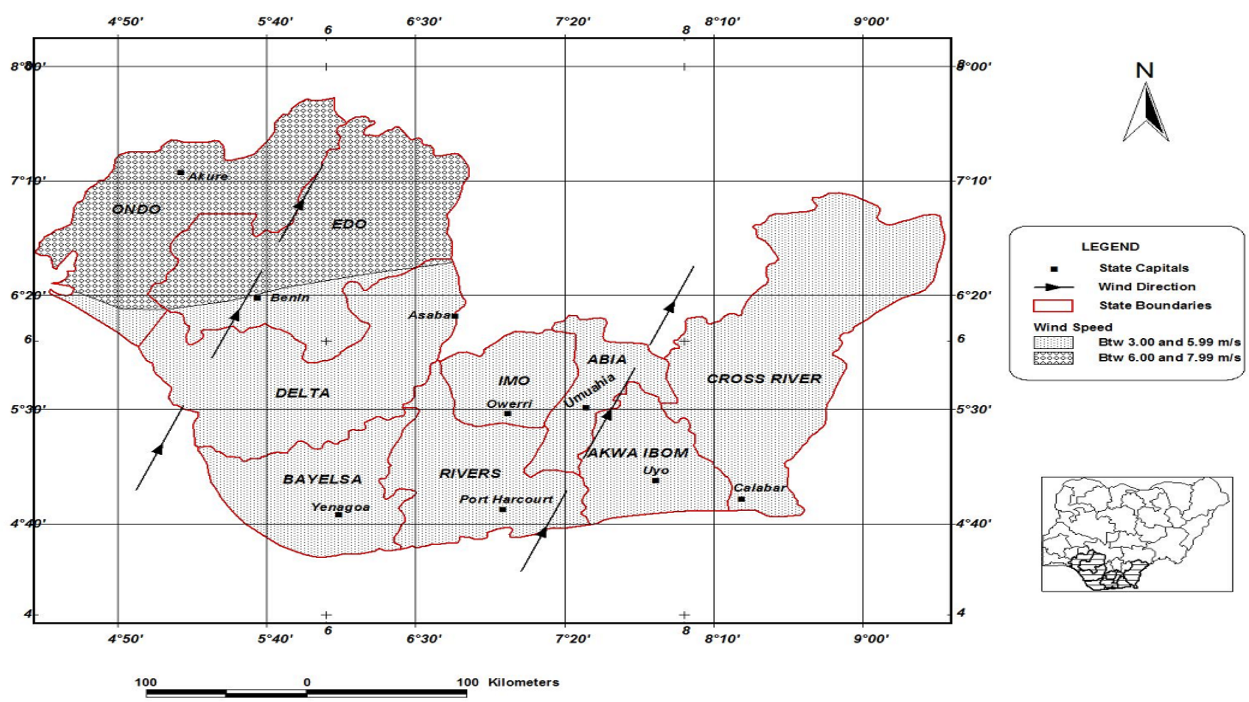


Figure 3: July Wind

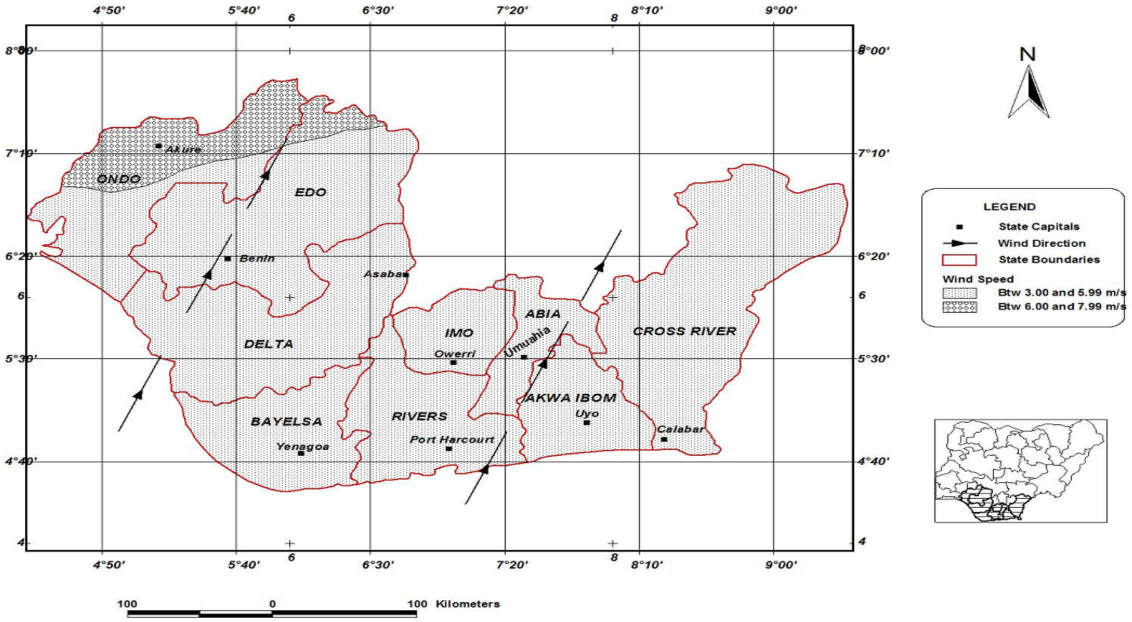
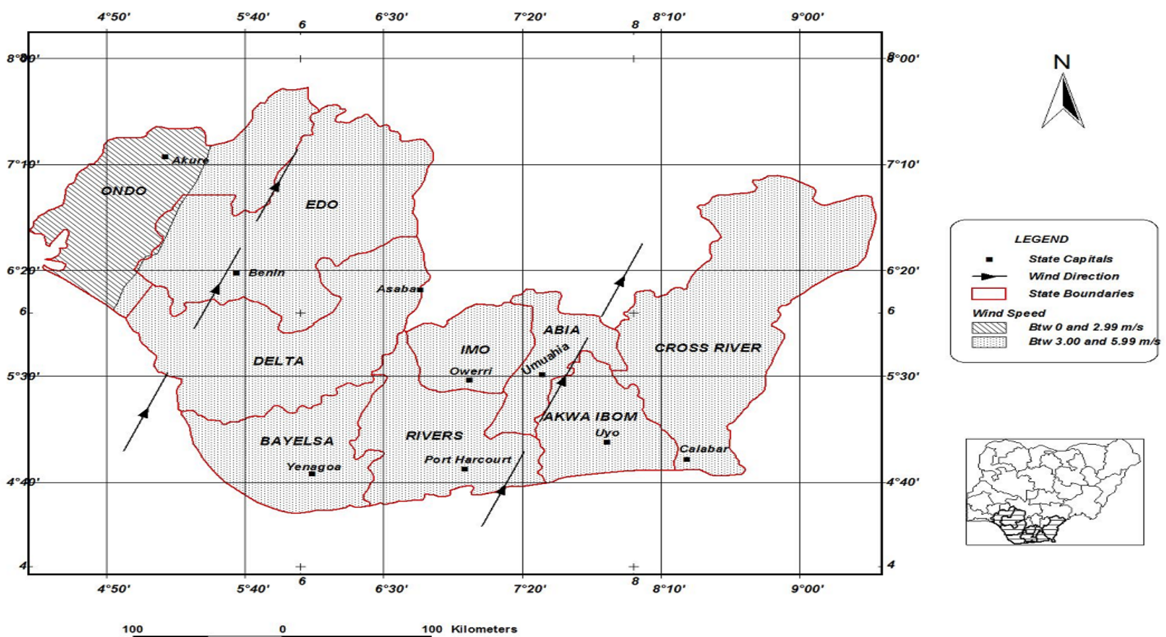


Figure 4: October Wind



The synoptic wind climatology derived from the global wind system obtained from

NCEP/NCAR/NOAA reanalysis project, the southwesterly predominates. The conditions in four months, representing the first quarter of each season is presented in Figs 1 – 4. Summary of the mean condition based on reanalysis data is as shown in Table 2.

Table 2: Percentage Area Coverage of Synoptic Wind Speed per Month

Month	Percentage Coverage		
	0-2.99	3-5.99	6-7.99
Jan	78.96	21.04	0
Feb	17.5	82.5	0
Mar	0	100	0
Apr	0	73.4	26.6
May	0	100	0
Jun	0	100	0
Jul	0	91.9	8.1
Aug	0	100	0
Sept	0	100	0
Oct	9.2	90.8	0
Nov	100	0	0
Dec	100	0	0
Mean	31.6	60	8.4

Source: Analysis result (2009)

Synoptic wind system as obtained from NCEP/NCAR/NOAA reanalysis data indicates variation between 0-2.99, 3-5.99 and 6-7.99ms^{-1}. These vary between months and seasons. As shown in Figs 1-4 and table 2, the percentage area coverage indicates that gentle breezes were dominant.

IMPLICATIONS FOR POLLUTANT PATTERNS AND SPATIAL PLANNING

Pollutants dispersion and transportation will not be generally favored. Any dispersion will be more in the North East direction. This would be worst in most of the dry season (November - January). Based on the station data, July winds are mainly light, but the synoptic condition shows more of gentle breezes. On the whole the gentle breezes, which dominate the wet season, also imply high concentration of pollutants, with little dispersion. During both periods, pollutants would be concentrated in the eastern flanks of the emission zones/sources.

The relatively low wind speed in the region therefore favours pollutant accumulation in most parts of the Niger Delta. This is, particularly evident in the stagnant air around emission sources, with potential for elevated background concentrations (Garcia et al, 2007).

High pollutant concentration in the dry season would be compounded by the low atmospheric humidity during this period. Reduced water vapour allows infrared radiation to pass into space, producing ground level temperature inversions after sundown and lower mixing heights. These combine with high evening traffic emissions in cities, can lead to pollution build-up near the ground (NAS, 2003).

Station based data justifies local variations in climate due to local environmental conditions, such as differences in boundary layer height. This makes modeling air pollution dispersion using only global and meso-scale wind patterns not representative of local, site specific conditions (Rigby and Toumi, 2008). Surface roughness and thermal properties of an area influence pollutant dispersion, and these would influence wind turbulence and speed (NAS, 1992).

Understanding this is very important in spatial planning, especially in the decision to design structures such as stacks for stationary source emission and the location/allocation of space for various uses. The basic tenet of spatial (environmental) planning is not about following a single goal but about balancing goals of economic development and those of protection and conservation of nature and cultural heritage (Daniels and Daniels, 2003).

Appropriate and guided land use regulation with the integration of wind climatology is a valuable tool for the sustenance of good air quality. Environmental related activities inherent in spatial plans have environmental (air) aspects and impact. To reduce pollution impact, require the understanding of the direction of pollutant dispersion.

CONCLUSION AND POLICY RECOMMENDATIONS

Comprehensive development planning, with sustainability dimension, must perforce establish the linkage between air quality, landscape, and transportation systems. Since planning is futuristic, the environmental aspects and impact of proposed developments and transportation systems on air quality, including wind components should be integral part of any development plan for the Niger Delta. This implies that the Natural Resource Inventory section of the plan should contain information on local and regional air quality, including synoptic and local winds.

The coastal milieu is where different characteristic winds operate. These include sustained winds driven by synoptic pressure field and Land and Sea Breeze Systems (LSBS). The later is a diurnal thermally driven circulation in which a definite surface convergence zone exists between air streams having over-water versus overland histories (NAS, 1992. These LSBS are known to re-circulate and trap pollutants released in or becoming entrained into the circulation.

Winds, in an attempt to equalize imbalances in pressure gradient, always carry along any impurity therein. The dispersion of pollutants is influenced by the speed and direction of winds and the presence or absence of friction. These must be taken into consideration in the allocation of land uses. For instance, in urban built-up areas or areas with thick vegetation, pollutant concentration is higher. The understanding of this is very useful for planning urban structures and industrial vis-à-vis residential land uses. Creating green belts in between these land uses and allowing a substantial distance between them would be valuable planning option.

In addition, although the prevailing wind system is mostly the southerly and westernizes, the direction often changes with season, having a more fairly well distributed patterns in almost all the directions. Thus pollution dispersion during the dry season would be favored in all direction, whereas the rainy season pattern would be towards the eastern direction. This would be complicated by the height of emission and location of inversion layer which affects pollutant dispersion and transport.

The implication is that residences should be far away from source of pollution and emission height enough to avoid concentration at the surface as a result of frictional effects. Highways with heavy traffic should be designed with green areas along them as buffer between the highways and residences or buildings. This regulation should be enshrined in all plans and steps taken for compliance.

Winds are variable in space and time in direction and speed and this variability is applicable to pollution emission and concentration. The synoptic and local conditions need to be incorporated in spatial planning. The preparation of series of wind roses showing prevailing wind directions and speeds for individual stations at different times would justify times of low and high atmospheric pollution concentration and dispersion. Knowledge from wind roses would therefore provide specific information, not only on the types of weather situation which must be associated with various pollution conditions, but also the significant directions and speeds of movement of pollutants can be obtained (Mather, 1974).

REFERENCES

Air Pollution Training Institute APTI (2005) Basic air pollution meteorology. Self instructional manual. Retrieved from www.epa.gov/apti 3/10/2008

Beale, J. G (1980). The manager and the Environment: General Theory and Practice of Environmental Management. Oxford, Pergamon press

Bowman, V (2008) What is spatial planning? Retrieved from http://en.wikipedia.org/wiki/spatial-planning 22/3/2009

ChirasD. D. (1994) Environmental Science. Action for the future. California, The Benjamin Cummings Publishing

Corsmeir, U., Behrandt, R., Drobinski, P. & Kottmeir, C (2005). The mistral and its effect on air pollution transport and vertical mixing. Atmospheric Research, 74 (1-4): 275-302

Daniels, T. & Daniels, K. (2003). The Environmental Planning Handbook for Sustainable Communities and Regions. Chicago, Planners Press.

Dobson, A. (1998) Justice and the environment. Conception of environmental sustainability and dimensions of social justice, New York, Oxford University Press

Eum, J. (2008). Climate information and spatial planning in Seoul. Tu International 62, July 2008.

Federal Republic of Nigeria (2006) Niger Delta Regional Development Master Plan

Garcia, R., Hart, J. E., Davis, M. E,. Reaser, P., Natkin, J., Laden, F., Garshilk, E. & Smith, T. J. (2007). Effect of wind on background particle concentration at truck freight terminals. Journal of Occupational Environment and Hygiene, 4 (1): 34-48

Hung, I., Deshpande, C. G., Tai, C. & Huang, S. (2005). Spatial and temporal distribution of volatile organic compounds around industrial park of Taiwan. Aerosol and Air Quality Research, 5 (2): 141-253.

Hyde, P. & Reeve, P. (2001). Essentials of Environmental Management. Leicestershire, The Institution of Occupation Safety and Health

Manawadii, L. & Samarakoon, L. (2007). Identification of air pollution potential areas and its temporal and spatial patterns of the city of Colombo- Applying GIS and RS. Pathumthani, Thailand; Asian Institute of Technology

Mather, J. R. (1974). Climatology. Fundamentals and applications. New York, McGraw-Hill

National Academy of Science NAS (1992). Coastal meteorology: A review of the state of the science. Retrieved from http://www.nap.edu 14/8/2008

National Academy of Science NAS (2003) Managing carbon monoxide pollution in meteorological and topographical problem areas. Retrieved from http://www.nap.edu 12/5/2008

National Policy on Environment (1999). Abuja, Federal Environmental Protection Agency

Niger Delta Environmental Survey NDES (1997). Environmental and socio-economic characteristics. NDES 1: 48-74

Ojo. O. (1977). The climates of West Africa. London, Heinemann.

Rigby, M. & Toumi, R. (2008). London air pollution climatology. Indirect evidence for urban boundary layer height and wind speed enhancement. Atmospheric Environment, 42: 4932-4947. Retrieved from www.sciencedirect.com 12/k3/2009

Rosenberg, N. J. (19740. Microclimate: the biological environment. New York; John Wiley and Sons

Rouse, W. R. & McCutchen, J. G (2008). The effect of the regional wind on air pollution in Hamilton, Ontario. Canadian Geographer, 14 (4): 271 – 285

Saksena, S., Joshi, V. & Patil, R. S (2001). Determining spatial pattern in Delhi ambient air quality data using cluster analysis. Working Paper, East-West Center

Tsai, C., Aggarwal, S. G., Chang, C. & Hung, I. (2004). Concentration profiles of acidic and basic air pollutants around an industrial part of Taiwan. Water, Air and Soil Pollution, 151 (1-4): 287-304

Wan-Li, C. (2001). Spatio-temporal variations of sulphur dioxide pattern with wind conditions in central Taiwan. Environmental Monitoring and Assessment, 66 (1): 77-98