Air Pollution Climatology in Spatial Planning for Sustainable Development in the Niger Delta, Nigeria

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Key words: Air quality; Air pollution climatology; Pollution dispersion; spatial planning; Sustainable Development

ABSTRACT

The paper, while highlighting the relevance of spatial planning in sustainable development, justifies the need for integration of air quality issues arising from climatologic understanding in such planning. The paper specifically underscored the role of air pollution climatology in providing an understanding of pollution diffusion and transport, and variation in spatio-temporal context. Data on wind speed and direction, pipelines and flow station, population density, and industrial vis-à-vis residential land use in a typical industrial urban area, were used. The land use and typical coastal meteorology of the region was also considered as determinants of direction of pollution concentration and spatial variation. Analysis was descriptive, with table and maps analyzed. These were used to illustrate the spatial and temporal variation of pollutant dispersion and concentration. This was attributed to wind influence, while the coastal meteorology contributes to pollutant concentration. In exploring the workability of integrating Air Population Climatology (APC) in spatial planning in a coastal milieu, the paper recommended the allocation of adequately wide right-of-way and distant residential areas from pollution source areas. In addition is the need for allocation of space for residential use upwind of pollution sources.

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1. INTRODUCTION

The concept of sustainable development is commonly used in contemporary development plans which aim at promoting environmental sustainability. Since this focuses on development that meets environmental, social and economic needs of the present generation without compromising the same benefits for the future generations, one policy and planning instrument which promotes such development ethos is spatial planning.

The role of spatial planning in sustainable development can therefore not be overemphasized. Spatial planning refers to methods used by the public sector to influence the distribution of people and activities in spaces of various scales, including land use planning, urban planning, regional planning and national spatial plans (Bownman, 2008 in http://en.wikipedia.org/wiki/spatial-palnning). Spatial planning goes beyond traditional land use planning to bring together and 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). This spatial planning should be such that defines, develops and protects the environment.

Spatial planning as used in this paper is akin to regional environmental planning, encompassing rural and urban land use planning that encourages the consideration and introduction of environmental aspects into existing and proposed development plans. One of such considerations is air pollution and the environmental determinants of the spatial and temporal variations.

Ambient air pollutions are generally dynamic in space-time dimension and this depends to a large extent on the vagaries of the weather and climate. Thus, although ambient air pollution can have local character due to local emission sources, fluctuations in the concentration are mainly meteorologically include. Here, the spatial variation in air pollution concentration is hinged on the space variation of sources as well as atmospheric gradients which results in diffusion and transportation to areas outside the source. Air pollution climatology provides an understanding of these dynamics of air pollution and it is valuable to integrate the spatial nature and dynamics of pollution in spatial plans. This would provide an exposition of existing spatial pattern of pollution, not only on the basis of existing land use pattern and population distribution, but also on the dynamics of the spatial pattern as a result of atmospheric dynamics.

This paper attempts to justify the importance of integrating air pollution climatology in spatial planning, to ensure that the desire for environmental sustainability is achieved. In doing this, the paper examines the spatial distribution of oil, gas, and population concentration, as culpable sources of atmospheric pollutants. In the spatial/temporal pattern of wind speed and direction are determined with a view to emphasize the possible human impacts arising the effects of climate on the distribution of pollutants.

2. THE PROBLEMATIC

Generally 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. These are environmentally sensitive activities, which are not only likely to cause attrition of the ambient air quality because of emission there-from, but are already manifesting in this direction. Although effort at point source control has been in place, the increasing concentration of human activities makes increasing uncontrollable emissions eminent.

Existing information as at 1991 – 1994 (NDES, 1997) from selected studied carried out at different locations show differential concentration and distribution of ambient air quality parameters. On the whole, suspended particulates matter (SPM) was more concentrated and was reported to come from both natural and anthropogenic sources. These were found downwind than upwind. This suggests the influence of wind direction. The values of acidic precursors (SO_x) varied spatially, with more concentration in the west than east. This and other ambient air pollution levels were considered generally a reflection of emissions and the efforts that is made to control such emissions.

The spatial pattern of ambient air pollution and the underlying imperatives for the pattern, apart from being source regions, has not been articulated. The influence of climate, particularly wind speed and direction on the distribution and spatial variation of air pollution has been established. Knowledge of this, need to be applied in spatial planning which aims at environmental sustainability. Spatial planning at whatever level 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). Unfortunately, apart from the fact that such 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 population and atmospheric parameters has not been taken into consideration.

The current regional development plan (the Niger Delta Regional Development Master Plan, 2006) is not free from this gap. Although some environmental considerations are incorporated, the process of development as articulated in the plan is skewed towards developmental needs, without a balance with environmental sustainability. Although issues concerning air pollution impact mitigation are given much attention in the plan policies for environmental intervention (policy En7) through source emission reduction 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.

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.

3. LAND USES AND AIR POLLUTION PATTERNS

Indicators of spatial variation in air pollution have been provided on the basis of land uses, technology, urban – rural dichotomy and regional transportation system (EPA, 2001). Regional development patterns are usually heterogeneous, hence spatial distribution of ambient air quality. Apart from this, air pollutants can be transported from one land use to another, depending on the topography, wind and pressure gradients.

In the Niger Delta, although such a study has not been carried out, the spatial pattern of air pollutants can perforce be attributed to the differential land uses pattern. The major land uses that are culpable sources of air pollution in the Niger Delta as in other parts of the world are urban industrial and transportation, and petroleum and gas exploitation. A concentration of industrial activities is in the urban areas, while oil and gas facilities across urban and rural areas, particularly in the Southern flank (Fig. 1). These areas correspond with those high population densities, hence high vulnerability to exposure (Fig. 1).

In the urban areas there has been effort at earmarking zones for all industry away from metropolitan areas in other to ensure environmental improvement. This is largely failing as much agglomeration is talking place amidst increasing population influx. The case of Port Harcourt City is a clear example (Fig 2).

The land use characteristics of Port Harcourt, as shown is Fig. 2, affect the ventilation situation. The land use is predominantly 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. Table 2 shows that 53 percent of the wind speeds in Port Harcourt is less than 3.1 m/s, suggesting generally low pollutant diffusion.

The urban industrial areas of the Niger Delta, such as Port Harcourt, are therefore, major areas of pollution concentration, but as noted by Manawadii and Samarakoon (2007), the effects of pollution are universal and continuously experienced, not only in congested urban areas, but also in remote rural areas. 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). Our study on the urban-rural dichotomy in rain water quality as surrogate for air pollution variation show that a difference existed between the rural water quality and that of the urban. However, urban differences in terms of land uses were not much. This suggested that even residential areas emit air pollutants and it is also possible that the proximity to the industrial area was responsible.

Other land uses such as transportation, and oil and gas facilities found in region suggest that the area is under high risk of air quality attrition. Fig 2**,** which shows the distribution of oil facilities, indicates that the oil and gas flow stations and pipelines are concentrated in south central part of the region, where population density is high.

It should be noted that the land cover characteristics influence the climatic impact on pollutant dispersion (diffusion and transportation). The vegetation of the area in addition to build-up in high human concentration and industrial activity areas affects the heat flux as well as wind gradients and speed. Generally the Niger Delta area, apart from the high build-up areas in urban settlements is characterized mainly by forested vegetation of different types (fig.5). The height of the tress affects the boundary layer climatic (micro-climatic) conditions, which may change rapidly at different spatial scales. As noted by Rigby and Toumi (2008), wind speed and boundary layer height are very important variables in air pollution climatology. Because boundary layer height often changes, modeling air pollution dispersion using only global and meso-scale wind patterns may not represent local conditions. This implies that surface roughness and thermal properties of an area influence pollutant dispersion, as these would influence wind turbulence and speed.

Apart from the vegetation of the Niger Delta, there is a dichotomy between urban and rural areas in terms of pollutant dispersion. Hence, as noted by Bornstein and Johnson (1997) in Rigby and Toumi (2008), Surface roughness leads to decrease wind speed in urban areas, compared to rural areas.

4. **WIND SPEED/DIRECTION** THE **IN THE NIGER DELTA**

Air pollutants are dynamics in spatio-temporal context; hence they have local, regional and continental scale effects. These have been attributed to meteorological dynamics, particularly winds. Generally winds help to equalize imbalance in pressure that result from differential heating of the earth's surface, always following the pressure gradient and being influenced by the presence or absence of friction (APTI, 2005).

Because of the differential friction, which is influenced by the boundary layer characteristics, pollutants 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).

Studies have proven that wind speed and direction influence air pollution dispersion and concentration. Generally, upwind location have less pollutant concentration than downwind (Garcia et al, 2007) 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 (Hung et al, 2005; Tsai et al, 2004).

It is also observed that 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). To Hung et al (2005) and Tsai et al (2004), in cases of wind speed below $2ms^{-1}$, the concentration of pollutants increase and becomes uniformly distributed around areas within the source zones, while stagnant weather conditions with low wind speed contributes to accumulation of pollutants at ground level (Chiu et al, 2005, in Hung et al, 2005).

Wan-Li (2001) and Rouse and McCutchen (2008) also note that variations in pollutant concentration hinges on the prevailing wind direction. In examining the effect 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. This confirms Corsmeir et al's (2005) assertion that regional wind systems associated with transport of trace gases can be successfully used to predict the pattern of air pollution. These winds themselves can be successfully predicted using data of operational weather forecast models.

The prevailing winds in the Niger Delta change with time of the year and location. Generally during the year, eight prevailing winds are common, but the predominant ones are Northerly, Northeasterly, Southerly, Southwesterly, Westerly and Northwesterly. The percentage occurrence of these winds varies with location and Season. Although Ojo (1977) indicates that the southwesterly and westerly winds predominate in the region in January, a frequency of about 20 percent, this varies between stations. However, the winds are more fairly distributed in all directions (NDE, 1977). Table 1 shows these apparent variations. In July, the westerly, including southwesterly and southerly winds are predominating, with little to no trace of the easterlies because of the Northward position of Inter Tropical Discontinuity (ITD). However, the values of the westerly are comparatively low because of the influence of the southerly winds, arising from its coastal location. This also varies between stations as shown in table 1.

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

Location	DIRECTION								SPEED (MS^{-1})				
	NE	E	SE	S	SW	W	NW	N	0-0.2 (CALM)	0.3-1.5	16-33	3.4-5.4	5.5-7.9
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

Source: NDES (1997); Ojo (1977)

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

Location	DIRECTION								SPEED (MS^{-1})				
	NE	E	SE	S	SW	W	NW	N	0-0.2 (CALM)	0.3-1.5	16-33	3.4-5.4	5.5-7.9
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)

In terms of speed, reports indicate that the stations show general high percentage of calm/wind speed <$2ms^{-1}$) for 1990 and 1991. This however varies between individual stations, with Akure and Uyo Showing lower calm during the hours between 0600 and 1800 (Table 3).

In all the percentage of calm is higher during the dry season (January) then during the ranging season (July). Generally, light breezes (1.6-3.3 ms^{-1}) are more dominant followed by gentle breeze (3.4 – 5.4^{-1}) and then light air (0.3 – 1.5 MS^{-1}).

Winds with speed of 5.5 – 7.9MS^{-1}) are rare and occur occasionally, especially during the onset of heavy rainfall or thundering activities (Oliver, 1972 in NDECS, 1997). The values and nature of direction varies with season. This is illustrated with data for Port Harcourt as shown in Table 2

Table 2: Monthly Surface Mean Wind Direction and Speed (2004-2009)

Wind speed/direction	J	F	M	A	M	J	J	A	S	O	N	D	YEAR
Direction	NE	NW	W	SW	SW	SW	SW	SW	W	SW	NW	NE	2004
Speed (m/s)	2.58	2.06	3.09	4.12	5.15	5.15	5.15	4.12	3.09	4.12	3.09	3.09	
Direction	E	N	SW	SW	SW	SW	SW	SW	SW	SW	W	NE	2005
Speed (m/s)	4.12	2.06	3.09	2.06	4.12	3.09	5.15	6.19	5.15	3.09	2.06	3.09	
Direction	NE	W	SW	SW	W	SW	SW	SW	SW	W	E	NE	2006
Speed (m/s)	3.09	3.09	4.12	3.09	4.12	5.15	4.12	4.12	5.15	4.12	3.09	2.58	
Direction	NE	NE	SW	SW	SW	SW	SW	W	SW	SW	W	E	2007
Speed (m/s)	3.09	2.06	2.58	4.12	3.09	4.12	5.15	4.12	4.12	3.09	3.09	3.09	
Direction	NE	E	W	SW	SW	W	SW	SW	SW	SW	NE	NE	2008
Speed (m/s)	2.06	3.09	4.12	2.06	4.12	5.15	6.19	4.12	4.12	4.12	2.06	3.09	
Direction	NE	SW	-	-	-	-	-	-	-	-	-	-	2009
Speed (m/s)	3.09	3.09											

5. IMPLICATIONS FOR POLLUTANT PATTERNS

The implications of the above on air pollution dispersion (diffusion and transport) are far reaching. Generally as noted by NDES (1997), pollutants dispersion and transportation will not be favoured during the early morning hours and late nights. In addition, dispersion will be favoured more in all direction during the dry season. However, more pollutants would be concentrated in the direction of the prevailing winds. During both the dry and wet season pollutants would be concentrated in the eastern flanks of the emission zones/sources.

The relatively low speed of wind in the region also 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). In addition, the higher percentage of calm during, the dry seasons means high concentration of pollutants during this period than in the rainy season.

The understanding of 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. For instance, residential areas need to be allocated space far away from industrial and gaseous emission facilities, while also having wide right-of-way on heavily concentrated road networks and nodes.

6. CONCLUSION AND POLICY RECOMMENDATION

The importance of integrating air pollution climatology in development planning cannot be over-emphasized. The concept of development as used here is akin to what Mabogunje calls ‘Spatial reorganization' and can equally be likened to development that ensures environmental sustainability. A major climatic parameter to be considered is the wind system, which can be responsible for apparent shifts in pollutant concentration and distribution in space and time.

Although interest is in the coastal milieu, where different characteristic winds operate, emphasis in this paper is on sustained winds driven by synoptic pressure field. This is not to rule out the significance of Land and Sea Breeze Systems (LSBS), a diurnal thermally driven circulation in which a definite surface convergence zone exists between air streams having over-water versus overland histories (NAS, 1992). In fact these systems are known to re-circulate and trap pollutants released in or becoming entrained into the circulation.

On the whole, winds in an attempt to equalize imbalances in pressure gradient, which results from differential heating of the earth’s surface, always carry along any impurity therein. The distance, speed and nature of pollution dispersion is influence by the presence or absence of friction. Thus in urban build-up areas or areas with thick vegetation pollutant concentration would be higher. This understanding 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. This is particularly useful since turbulent diffusion is less prominent near the surface where structures and activities are located and pollutants are transported by molecular diffusion, which does not alter the gravity of their health impacts.

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 favoured 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 is high enough to avoid over concentration at the surface as a result of frictional effects. High ways with heavy traffic should be designed with green areas along them as right of ways a distance from buildings. This regulation should be enshrined in all plans and steps taken for compliance.

Air quality problems and the establishment of 'independent' monitoring stations to provide routine information on the true quality of air in the region is imperative. Wind and temperature maps should be integral part f spatial planning.

Winds are variable in space and time in direction and speed and this variability is applicable to pollution emission and concentration. This confirms that frequency studies or wind roses under particularly significant events or for specific time intervals need to be determined for as many locations in the Niger Delta as possible. This should be followed by the preparation of series of wind roses showing prevailing wind directions and speeds for individual stations at times of times of low and high atmospheric pollution. And as noted by Mather (1974), from wind roses specific information, not only on the types of weather situation which must be associated with various pollution conditions, but also on the significant directions and speeds of movement of pollutants cad be obtained.

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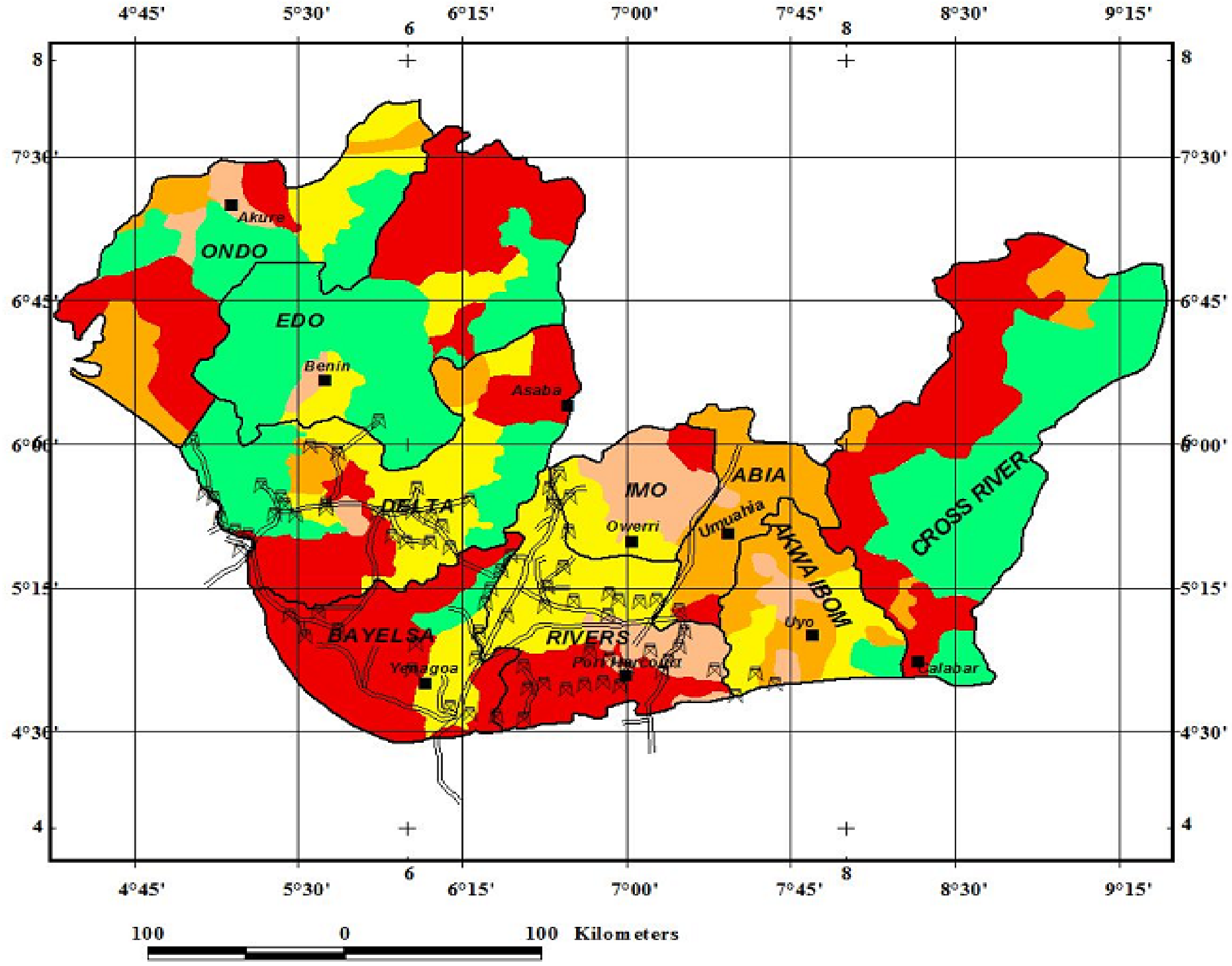
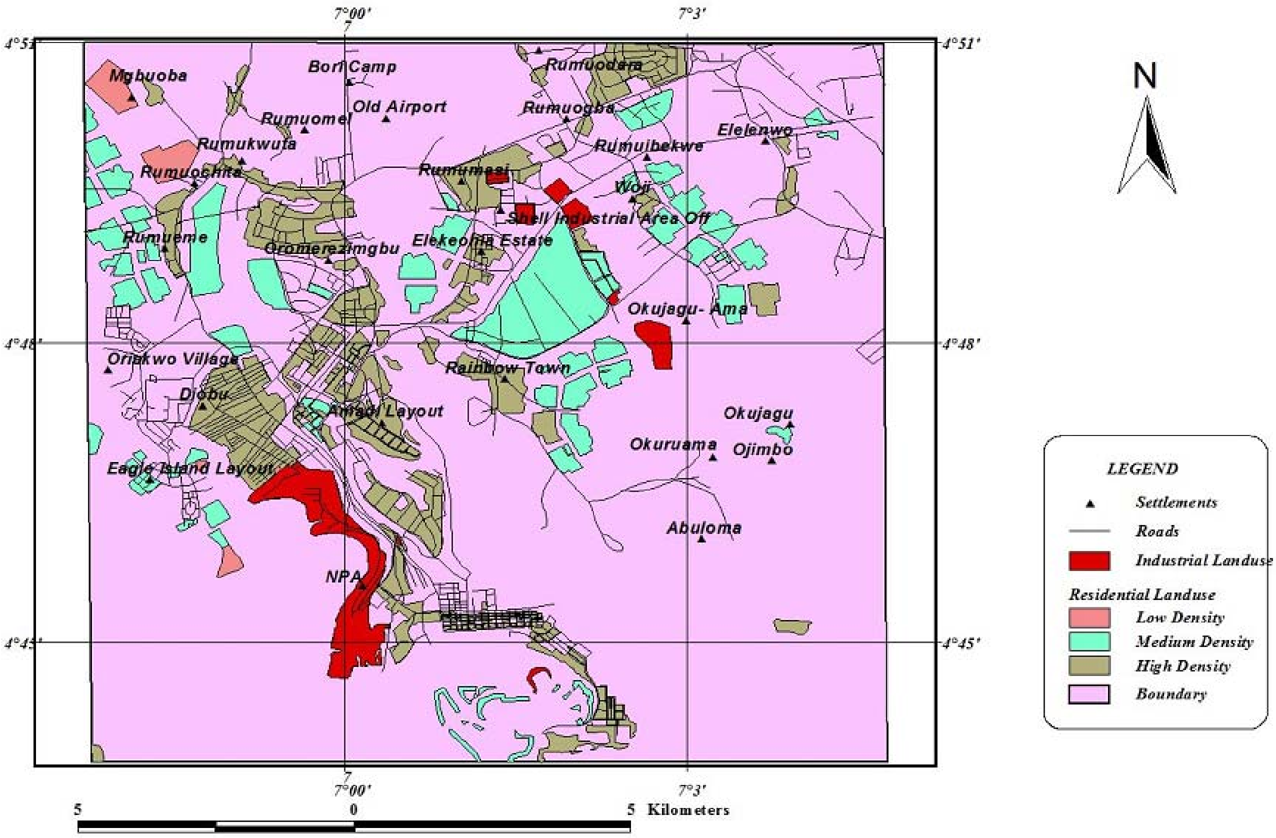


Fig. 1: Population Density, Some Existing Flow Stations and Pipelines in the Niger Delta
Source: Federal Government of Nigeria, 2006.


7°00'
7°3'
4°51'
4°48'
4°45'
Mgbuoba
Bori Camp
Rumuodara
Rumuomel
Old Airport
Rumuogba
Rumukwuta
Rumuibekwe
Elelenwo
Rumuochita
Rumumasi
Woji
Shell Industrial Area Off
Rumueme
Oromerezimgbu
Elekeohia Estate
Okujagu- Ama
Oriakwo Village
Rainbow Town
Diobu
Amadi Layout
Okujagu
Okuruama
Ojimbo
Eagle Island Layout
Abuloma
NPA
N
LEGEND
Settlements
Roads
Industrial Landuse
Residential Landuse
Low Density
Medium Density
High Density
Boundary
5
0
5 Kilometers