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Challenges and opportunities in the design and construction of a GIS-based emission inventory infrastructure for the Niger Delta region of Nigeria

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Abstract

Environmental monitoring in middle- and low-income countries are hampered by many factors which include enactment and enforcement of legislations; deficiencies in environmental data reporting and documentation; inconsistent, incomplete and unverifiable data; a lack of access to data; and technical expertise. This paper describes the processes undertaken and the major challenges encountered in the construction of the first Niger Delta Emission Inventory (NDEI) for criteria air pollutants and CO_2 released from the anthropogenic activities in the region this study focused on using publicly available government and research data. The NDEI has been designed to provide a Geographic Information System-based component of an air quality and carbon management framework. The NDEI infrastructure was designed and constructed at 1 km-, 10 km- and 20 km-grid resolutions for point, line and area sources using industry standard processes and emission factors derived from activities similar to those in the Niger Delta. Due to inadequate, incomplete, potentially inaccurate and unavailable data, the infrastructure was populated with data based on a series of best possible assumptions for key emission sources. This produces outputs with variable levels of certainty, which also highlights the critical challenges in the estimation of emissions from a developing country. However, the infrastructure is functional and has the ability to produce spatially resolved emission estimates.

Keywords: air quality, greenhouse gases, emission inventory, infrastructure, Niger Delta, Nigeria, GIS

1. Introduction

Human health and climate change issues arising from air pollution have resulted in increased focus on air quality and carbon emissions management (Kampa and Castanas, 2008). Emission inventories have played a critical role in the assessment, monitoring, modelling and management of emissions of air pollutants and greenhouse gases (GHGs), which have various impacts on human health, vegetation and climate (Banerjee et al. 2011; de Kluizenaar et al. 2001; Parra et al. 2005; Wang et al. 2010). However, the low level of attention given to air quality in low- and middle-income countries (LMICs), despite its devastating impacts on human health, has led to a lack of emission inventories in the majority of developing countries. Consequently, there is paucity of funding allocation to studies that focus on air quality, lack of expertise in the field of emission estimation and air quality modelling and a lack of air quality management frameworks in these countries. An emission inventory serves as a means of recording and structuring information about sources of atmospheric emissions, the processes and activities that release emissions from these sources, and the total emissions being released from the sources; thus providing the opportunity to conduct source apportionment analysis with a view to developing appropriate mitigation measures and abatement techniques to ensure emissions are within acceptable limits.

De Kluizenaar et al. (2001) relied on emissions data estimated by the Irish Environmental Protection Agency (EPA) using the 11 United Nations Economic Commission for Europe Coordination of Information on Air Emissions (UN-ECE CORINAIR) source categories contained in the CORINAIR emissions database to generate spatial distribution maps of SO_2 and NO_x emissions in the Republic of Ireland. The high-resolution emission maps helped them to identify areas with high, medium and low densities of SO_2 and NO_x emissions within Republic of Ireland. Para et al. (2005) used emission inventories to articulate the spatial and temporal distributions of emissions of tropospheric ozone precursor gases in order to assist modelling the behaviour and transport of ozone using a Chemical Transport Model (CTM). Wang et al. (2010) also developed vehicular emissions inventories in Beijing, Shanghai and Guangzhou cities in China from 1995 to 2005 in order to gain understanding of trends of vehicular emissions from mega cities in China. The inventories also assisted in providing information on the major sources of vehicular emissions and their respective contributions to emissions of CO, NO_x, PM_{10} and CO_2 (Wang et al. 2010). Many developed countries (for example, the United Kingdom, the United States and Australia), few developing countries (such as South Africa) and international organisations (such as the European Union and Intergovernmental Panel on Climate Change (IPCC)) have developed comprehensive inventories of emissions of criteria air pollutants and GHGs, which form vital components of their air quality management frameworks (Boden et al. 2010; Bush et al. 2008; DEAT, 2007, 2008; Defra, 2009; http://www.epa.gov/ttn/chief/eiinformation.html; Harrop, 2001; MacCarthy et al. 2010; MacCarthy et al. 2011; Marland et al. 2007; http://naei.defra.gov.uk/; Naiker et al. 2012, Olivier et al. 2001; Reilly et al. 2002). For instance, the United Kingdom's National Atmospheric Emissions Inventory (NAEI) developed for the period of 1990 to 2008 (MacCarthy et al. 2010) relied on datasets such as:

1. Department of Energy and Climate Change (DECC) sub-national statistics on energy use in the UK;
2. Regional energy use data for specific industries or regional data on raw material consumption, or sector-specific production;
3. Major road traffic count data;
4. Domestic and international flight data for all major airports in the UK;
5. Rail company fuel use estimates;
6. Regional housing, employment, population and consumption data;
7. Agricultural surveys (livestock numbers, crop production, fertiliser application); and
8. Land use survey data.

There were instances, during the development of this inventory, when local data of sources were either insufficient or unavailable. In such cases, assumptions and extrapolations of available datasets were used in order to generate a time-series of emissions of air quality gases. However, over the years, improvements in environmental monitoring, reporting and quality assurance methods and protocols have improved data quality and data availability. This has translated to reductions in uncertainties in emission estimates generated from the inventory from the earlier years of the inventory to the most recent years (MacCarthy et al. 2010).

Environmental reporting and regulation, inter-organisational communication, collaboration and consultation form the foundation for the successful development of an emissions inventory (Murrells et al. 2011, NSCA, 2001). However, these critical procedural component of environmental monitoring and management has not been given utmost attention in most developing countries due to the lack of manpower, technical expertise, appropriate legislation and enforcement strategies to ensure compliance with available environmental legislations. Consequently, the majority of developing countries will encounter data limitations towards their quest to estimate emissions of air pollutants from various sources. The international inventories that have emission estimates for developing countries, such as the EDGAR inventory, IPCC, European Commission Joint Research Centre (EC-JRC), the United States' Carbon Dioxide Information Analysis Centre (CDIAC), produce high-level uncertainties in the estimates generated for developing countries like Nigeria. This is because these inventories are not based on accurate data generated from detailed surveys of sources and activities in developing countries.

In order to address this shortcoming in Nigeria, an effort has been made to develop an emissions inventory infrastructure for a region in Nigeria. This paper focuses on the construction of a GIS-based emissions inventory infrastructure using the oil-rich Niger Delta region of Nigeria as a representation of sources and activities in Nigeria (Fig. 1). The construction of the inventory relies on publicly available and accessible government and research-based data, with a view to identifying the existing limitations towards accurate estimation of air emissions in the country. The inventory infrastructure is designed and constructed at low, medium and high-resolutions to serve as a basis for spatially resolved sources of air emissions and estimating emissions from point, line and area sources of criteria air pollutants (CO, CH_4,

NO_x, PM_{10}, SO_2 and VOCs)[1] and CO_2 released from activities in the Niger Delta region. The emissions for which the inventory has been constructed were the main gases released from the activities considered for the study. The activities are:

1. Industrial production, which rely on combustion of fossil fuels and natural gas;
2. Road transportation; and
3. Domestic cooking and lighting using biofuels and fossil fuels.

This paper describes the procedure for designing and constructing the inventory using the bottom-up emission estimation technique (Lindley et al. 1996). Due to the challenges posed by lack of detailed and accurate data, the focus of this paper is the establishment of the NDEI infrastructure, which has been designed to allow increasingly accurate estimates of emissions of air pollutants to be made as and when appropriate data become available, and to identify the data limitations to generating accurate estimates of emission of air pollutants in Nigeria.

(Please, insert Fig. 1 here)

Fig. 1 Map of the study area

2. Emission of air pollutants and CO_2 in the Niger Delta

The few studies carried out on air quality and carbon emissions management in Nigeria suggest that there are air pollution problems across the country, which emanate from industrial processes, domestic activities, waste disposal, transportation and oil and gas activities concentrated in the Niger Delta, especially gas flaring, oil refining and construction (Ajao and Anurigwo, 2002; Baumbach et al. 1995; Taiwo, 2005). This is supported by the observations of the European Commission, Joint Research Centre (JRC) / Netherlands Environmental Assessment Agency (PBL) on the sources of significant emissions of atmospheric pollutants and GHGs in Nigeria (EC-JRC/PBL, 2010). Resulting from these emissions, Taiwo (2005) observed that concentrations of CO and SO_2 measured at landfill sites, industrial estates and public motor parks or traffic stations exceed the Nigerian national standards set up by the defunct Federal Environmental Protection Agency (FEPA, 1991) and the World Health Organisation standards (Environmental Protection UK, 2009).

The emission estimates from EC-JRC/PBL (2010) are based on the most recent available information for Nigeria. These estimates are generalised, as they are not the result of detailed surveys of the specific processes and activities in industries and other sectors that release them. They also indicate the lack of up-to-date emissions data for the country. Furthermore, the lack of spatial resolution for the data also limits the knowledge and understanding of the sources in relation to sinks and receptors of the pollution, which is important for effective management of air pollution. Due to the lack of available

[1] Criteria air pollutants is based on classification by the United States Clean Air Act (CAA), which require that concentration standards and limits are set for them in order to protect human health (USEPA website: http://www.epa.gov/air/criteria.html). The Nigerian National Air Quality Standards (NAQS) were developed based on this classification (FEPA, 1991).

mechanisms for systematic estimation of emissions in Nigeria (Baumbach et al. 1995; Taiwo, 2005), and an absence of open-source inventories, there is no verifiable emission inventory database available for the Niger Delta. For example, in the Niger Delta, there is no publicly available evidence to verify that the enterprises operating in the region carry out comprehensive assessments or measurements of emissions from their installations, offices and other activities. This is despite previously publicised efforts through the Niger Delta Environmental Survey (NDES) of 1995 conducted by the Environmental Resource Manager Limited (ERML) (ERML, 1997; Manby, 1999) and Shell Petroleum Development Corporation (SPDC) air quality assessment proposal in 2006 (SPDC, 2006).

The Nigerian National Environmental Standards and Regulations Agency (NESREA) has stated its intention to update Nigeria's obsolete National Air Quality Standards (NAQS) (see http://nesrea.org/our_strategy.php), which were originally established by FEPA in 1991 (FEPA, 1991). As part of the development of this new approach to management, it is important that spatially resolved emissions information with good temporal resolution is available to support decision makers. Such an emission database would enhance the process of deriving indigenous emission factors required for estimating emissions from various sources within the region. The aim in developing the NDEI infrastructure of fundamental air pollutants and carbon emissions is to provide an easy-to-use, easy-to-update and spatially-resolved Geographic Information System (GIS)-based platform for estimating emissions from anthropogenic activities in a developing economy. The inventory will also provide a platform for identifying data gaps that need to be filled by appropriate agencies and organisations within the Niger Delta in order to provide accurate emissions estimates from the identified sources.

3. Construction of the Niger Delta Emission Inventory – methods and materials

The infrastructure is designed and constructed based on the capabilities and inter-operability of spreadsheets and GIS. The spreadsheet which contains the basic emission inventory infrastructure where details of the sources are inputted and the process of estimating emissions is carried out is based on the functionalities of Microsoft Excel. The results are then linked to the GIS using the spatial attributes of the data for spatial analysis, mapping and visual display of results. The GIS also serves as the repository of spatial data from which the data contained in the spreadsheets are updated. ESRI ArcGIS 10.1 was used for the GIS operations of this study. The spatial datasets used in the inventory are industries, location of offices in Port Harcourt City, flow stations, airports, helipads, roads and settlements. Grids of 1 km x 1 km, 10 km x 10 km and 20 km x 20 km are created to serve as the high-, medium- and low-resolutions of the inventory. The emission inventory infrastructure consists of three components based on the categories of emission sources identified within the Niger Delta – point (mainly industries and use of industrial generators in offices within Port Harcourt City), line (roads) and area sources (settlements / households). These sources and their specific activities used in the construction of the inventory are discussed further in subsequent sub-sections of this paper. Emissions from power generation, agricultural land and shipping will be included in future development of the inventory.

The general equation for calculating emissions based on emission factors is applied to all the sources contained in the inventory. According to the United States Environmental Protection Agency, USEPA (1995), the general formula is given by:

1. Uncontrolled release of emissions

$$E_{kpy,i} = [A * OpHrs] * EF_i \quad (1)$$

2. Controlled release of emissions:

$$E_{kpy,i} = [A * OpHrs] * EF_i * [1 - (CE_i/100)] \quad (2)$$

Where:

$E_{kpy,i}$	= emission rate of pollutant i, kg/yr
A	= activity rate, t/hr
OpHrs	= operating hours, hr/yr
EF_i	= uncontrolled emission factor of pollutant i, kg/t
CE_i	= overall control efficiency of pollutant i

Except where indicated that there are specific emission control measures, it is generally assumed that the processes are uncontrolled. This assumption is based on the laxity in the enforcement of regulations in Nigeria, which gives emitters the leeway of not installing emission abatement control devices.

3.1. Point-source emission inventory

The methodological approach for point-source emissions involves a critical assessment of all the identified point sources and their attributes. These include location of the sources, the operations or activities carried out that contribute to the release of air pollutants, the rate of activities at the sources, pollutants released during specific activities, and characteristics of the point of release (such as stacks, industrial chimneys and generator chimneys). The categorisation of the identified sources followed the 15 industrial sectors in Nigeria, as published by the Nigerian National Bureau of Statistics, NBS (2009a). These were further subdivided into 49 operational categories, with one categorised as ‘unknown’. For example, the oil and gas production sector consists of 3 operational sub-categories of flow station, petroleum refining and processing, and natural gas production.

Due to a lack of access to site-specific data, the production processes of each industry are unknown, so the inventory infrastructure was developed using industry standard operations and processes. Emission factors used are based on the comprehensive AP-42 Emissions Factor Database developed by the USEPA. The emission factors are considered to be similar to factors applicable in Western Europe and Asia. This is considered acceptable as the industrial equipment used in the Niger Delta is imported from North America, Europe and Asia. In view of the lack of site-specific data, the estimates generated from the point source emission inventory for the Niger Delta, which are expected to rely on location, activity and other statistical data available for each identified source (Orthofer and Winiwarter, 1998), cannot have their accuracy confirmed. However, the infrastructure possesses the flexibility for modifying and updating the specific industrial processes as and when such information may become available. When site specific data are available, the reliance on the AP-42 emissions factors is expected to generate estimates that will be lower than that which may be present in the Niger Delta. This is partly due to an observed laxity in enforcement of emission controls and standards in Nigeria (Uchegbu, 1998), which is thought to lead to the installation of fewer emission control systems and/or the adoption of lower cost and less effective solutions. Weiss et al. (2009) suggest the emission estimates should be adjusted by a factor of 15% for the Niger Delta based on adjustment factors stated in UNFCCC non-Annex I Party Countries. Major assumptions applying to the NDEI point source inventory include:

1. Where emission factors for uncontrolled processes are available, they will be used, except where there is available information for the specific source that indicates the kind of emission abatement and control technology installed.
2. In view of laxity in enforcement of emission standards (Uchegbu, 1998), the highest available emission factors are used where uncontrolled emission factors or source specific information is not available.
3. Due to inadequate power supply from the national grid (Adenikinju, 2003; Gnansounou et al. 2007), all the industries and offices operating in the Niger Delta are assumed to rely on the use of diesel-fuelled industrial generating sets to generate electricity for specific hours on each day of operation. The generators are generally considered to have capacities greater than 184 kW (approximately 250 horsepower) (US EPA, 1996a). The estimated fuel consumption at full load is assumed to be approximately 54.5 litres[2] (approximately 2 million British Thermal Units, MMBtu)[3] per hour.
4. Diesel-fuelled generators with outputs greater than 447.6 kW (approximately 600 horsepower) are used by oil and gas flow stations (US EPA, 1996b). Fuel consumption is assumed to be approximately 135.1 litres (5 MMBtu) per hour[4].

3.2. Line-source emission inventory

The line-source inventory component of the NDEI infrastructure considers only exhaust emissions from categories of road vehicles present in the region. These categories are cars, buses[5] (or light goods vehicle - LGV), lorry/trailers (or heavy goods vehicle - HGV), and motorcycles / tricycles (two-wheeled / three-wheeled vehicles). The emission inventory adopted the categories and comprehensive exhaust emission factors database for road vehicles developed for the United Kingdom as documented by Boulter et al. (2009). The emission factors were calculated using the equation specified by Boulter et al. (2009) as:

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[2] Source: http://www.dieselserviceandsupply.com/temp/Fuel_Consumption_Chart.pdf. The estimate is based on the full load fuel consumption of a 200 kW diesel generator.

[3] 1 US gallon = 3.78541178 litres. 1 litre = 0.03663802 MMBtu

[4] Source: http://www.dieselserviceandsupply.com/temp/Fuel_Consumption_Chart.pdf. The estimate is based on the full load fuel consumption of a 500 kW diesel generator.

[5] Buses are mainly 10- to 18-seater buses

$$y = k * (a + bx + cx^2 + dx^3 + ex^4 + fx^5 + gx^6) / x \quad (3)$$

Where:

y	=	Emission factor in g/km
x	=	Speed in km/hr
k	=	adjustment factor introduced to situations where an emission factor was required for a vehicle category having no emissions data in g/km.

a, b, c, d, e, f and g are constant coefficients derived from the fit of a 6th-order polynomial to the values calculated using regression curves of the relationships between vehicle speed and emission of specific pollutant from different categories of vehicles used by Boulter et al. (2009) in the process of deriving emission factors.

Calculating the emission factors for the inventory were based on the assumptions contained in Table 1.

(Please, insert Table 1 here)

The European emissions standards have been relied on by many developing countries, especially in Asia, to estimate vehicular emissions (Hao et al. 2003; Klimont et al. 2001; Wang et al. 2010). In view of this, and the fact that the majority of vehicles in the Niger Delta are imported from Europe and North America, the application of the European emissions standards to the Niger Delta is considered to be appropriate. The line-source emission inventory incorporates all the categories of vehicle emission standards available from pre-Euro 1 category to Euro 5 category. The inclusion of up to Euro 5 emission standards in the design of the NDEI underscores its robustness to incorporate standards that are currently unavailable in the Niger Delta, but which are envisaged to be available in the near or far future. However, Euro-2 standard was used to estimate emissions from the road sector in the region. This is because the Nigerian government is currently implementing Euro-2 standards countrywide (). This is also in line with the implementation in other developing countries, especially in Asia (Hao et al. 2006; Klimont et al. 2001). The line emission inventory has been based on a very limited amount of data that has been used to generate generic traffic profiles for 3 types of road (highways, commercial – major and minor, and residential). These profiles have been based on the following assumptions:

1. Cars, LGVs and motorcycles are fuelled by petrol, while HGVs are fuelled by diesel.
2. It is estimated that there are 20 vehicles per 1000 people in Nigeria in 2005 (African Development Fund, ADF 2007)
3. The percentages of road vehicle categories registered in the Niger Delta in 2004 is estimated at 64% motorcycles, 25% cars, 7% buses and 3% HGVs (NBS, 2009b).

4. Traffic densities on highways, commercial (major and minor roads), and residential roads are assumed to be 2300, 1933, and 700 vehicles per hour respectively. This is based on estimates generated by Bada and Akande (2010) for Abeokuta[6], an urban area in Southwest Nigeria.
5. Motorcycles are mainly used for local and intra-community transportation. Consequently, the use of motorcycles is assumed to be limited to major roads, minor roads and residential roads.
6. Average travel time for all categories of vehicle is assumed to be 87 minutes (1.45 hours), based on Oni (2010). These are generalised estimates of travel time for vehicles on the roads in Lagos[7]. This assumption is applied to both rural and urban areas in the Niger Delta. Greater uncertainties are incorporated in estimates due to the fact that traffic in Lagos is considered to be higher than other urban areas in Nigeria.
7. Uncertainties associated with emissions of particulate matter from paved and unpaved roads are high. Therefore, these sources are not included in the inventory at this stage, although the infrastructure has been prepared to receive these data when the uncertainties are reduced. In view of this, only particulate matter released from vehicle exhausts are considered at this stage.

Based on these assumptions, estimates of the number of vehicles by category in each of the nine states of the Niger Delta, and disaggregated hourly traffic counts on the road classes in the Niger Delta, have been derived (Tables 2 and 3).

(Please, insert Table 2 here)

(Please, insert Table 3 here)

The line-source emissions inventory is based on the road network database of the Niger Delta shown in Fig. 2.

(Please, insert Fig. 2 here)

Fig. 2 Map of the road network in the Niger Delta used for the construction of the NDEI. Inset shows road network map in Benin City, one of the main cities in the Niger Delta

The GIS database containing the road network was linked to Microsoft Excel to create additional fields containing relevant emission factors and activity data based on the specified assumptions. The total sum of emission of pollutants was estimated for all the vehicle categories for each road segment in the region. The emission density was calculated for each road. A selection process was carried out to identify all the 1 km, 10 km and 20 km grids that contain or intersect road features. The road segments that fall within each grid was identified and the road lengths estimated. Using the estimated road length and emission

[6] Abeokuta is an urban area in Southwest Nigeria. The main professions in the city are civil service, trading, tie and dye, and pottery (Bada and Akande, 2010).

[7] Lagos is a major urban centre in Southwest Nigeria, with an estimated population of 9 million based on the 2006 population census in Nigeria (NBS, 2009b). It is the second most populated city in Nigeria (NBS, 2009b).

density per road, the emissions from each road segment was estimated and allocated to the specific grid the segment falls into. The segment layer was exported into the spreadsheet component of the emission inventory infrastructure, where the total sum of emission for each grid was calculated. The worksheets containing the total emissions per grid were exported as tables into GIS, where they were spatially linked with the original grid layers using the grid unique identifiers. From the linked GIS database, maps showing grid-based spatial distribution of emissions of air pollutants were generated for visual display.

3.3. Area-source emission inventory

Residential sources, defined by domestic cooking and lighting activities by households within geographical boundary represented by settlement area, are the only area source considered in the infrastructure of the emission inventory. The methodology used for the estimation of air pollutants from domestic cooking and lighting activities in the emissions inventory is documented by Fagbeja et al. (2013). The process of estimating emissions from residential sources followed through derivation of population estimates for settlements; derivation of number of households within each settlement; identification of most appropriate emission factors; determination of average hours used for cooking and lighting using personal generators; and the application of the general equation of emission estimation as contained in Equation 1.

A total of 6,718 settlements were identified in the Niger Delta region (Fig. 3). The settlement database was derived from a combination of land use mapping and settlement mapping studies carried out in Nigeria in 1996 and 2005 respectively (Ademiluyi et al. 2008; Agabje and Fagbeja, 2006; Fagbeja et al. 2013). The settlement database had the limits of the areas covered by urban, semi-urban and rural settlements in the Niger Delta clearly defined.

The settlements were classified into urban (population above 20,000), semi-urban (population between 5,000 and 20,000) and rural (population below 5,000) areas based on the population classification of the Niger Delta Regional Development Plan (NDDC, 2006). Based on NDDC (2006), percentage composition of settlements in the Niger Delta as 1% urban, 5% semi-urban and 94% rural, a more rigorous classification process was carried out in order to refine the upper and lower benchmarks for the settlement categories (Table 4).

(Please, insert Fig. 3 here)

Fig. 3 Map of the 6,715 settlements identified in the Niger Delta for the construction of the NDEI

(Please, insert Table 4 here)

Official population estimates in Nigeria have been disaggregated only to local government level and are not available at community / settlement level. Consequently, this study derived population estimates for the settlements in the Niger Delta using existing assumptions and the most reliable population estimates available for some of the identified settlements within the region. Population estimates for 275 settlements within the Niger Delta were obtained from World Gazetteer (2010). Population estimates can be derived based on the relationship that exists between settlement built-up (or dwelling) area and the population of the settlement, assuming the entire settlement area constitutes a dwelling area. This relationship is considered universal (Narrol, 1962; Tobler, 1969; Wiessner, 1974), and it is represented by the arithmetic equation:

$$A = a * \mathrm{P}^{\mathrm{b}} \quad (4)$$

Where

A = Area of built-up area within a settlement

a = coefficient of proportionality[8], which depends on the units of area measurements and the building and living culture within a settlement (Tobler, 1969).

P = Population within a settlement

b = positive exponent, estimated to be 0.88 (Narrol, 1962; Tobler, 1969).

However, due to the absence of coefficient of proportionality derived specifically for the cultures of the Niger Delta, the above relationship between settlement built-up area and population could not be used. An alternative relationship identified by (Kvamme, 1997)[9] was used. According to Kvamme (1997), there exists a logarithmic relationship between settlement built-up areas and population. Consequently, logarithmic relationships were established using the known population estimates obtained from the World Gazetteer (2010) for 275 settlements and their corresponding area (Table 5). The 275 settlements with population estimates were categorised into urban, semi-urban and rural communities based on their population and sizes obtained from the settlement database. Settlements were excluded from the assessment if their population estimates did not correspond with the area banding indicated in Table 4. Then, scatter plots of population against settlement sizes for each category of settlements were generated, and logarithmic equations showing their relationships were generated. The equations derived for each settlement category were then applied to estimate populations of all other settlements in the settlements database. Settlements with known populations retained their known populations in the final database.

(Please, insert Table 5 here)

Having derived the population for each settlement in the Niger Delta using the method described above, the number of households within each settlement was then estimated by dividing the derived settlement population with the average household size for each settlement category in the Niger Delta. The average household size in the Niger Delta is assumed to be 8 persons for households in rural settlements and 6 persons for households in semi-urban and urban settlements (NDDC, 2006). In addition, the percentages of households that rely on various fuels for cooking and domestic lighting (NBS, 2009a) were applied to

[8] The coefficient of proportionality is a variable whose value can be estimated based on building and living culture in a particular place. There is no value estimated for any part of Nigeria or West Africa. Therefore, no value can be assumed for the Niger Delta.

[9] According to Kvamme (1997), logarithmic relationships between settlement size and population are reliable showing "*less skewness and the extremity of outlying data points are reduced*".

generate emission estimates for this source category. A summary of the total number of households in the Niger Delta, the percentages of households by cooking fuel and lighting is given in Table 6.

Domestic activities are a source of emissions of both conventional air pollutants and CO_2. The emission factors for these activities were selected from available emission factors developed for regions with cooking cultures and fuel composition similar to the Niger Delta. Emission factors for wood fuel and charcoal developed for West Africa (Brocard et al. 1998) and Zhang and Morawska (2002) were adopted. Emission factors for kerosene combustion in wick stoves and natural gas combustion from the Chinese emission factors database (Zhang et al. 2000) were adopted for burning of kerosene and natural gas for cooking. Emission factors for the use of petrol-fuelled generators available from the US Environmental Protection Agency (USEPA) AP-42 Emissions database was adopted (USEPA, 1996b) (Table 7). Estimated daily cooking energy consumption in Nigeria (Anozie et al. 2007) was assumed for the Niger Delta (Table 8). Furthermore, the percentage distributions of household by type of cooking fuel and by type of electricity supply in each of the States of the Niger Delta were obtained from NBS (2009c). These distributions were generally applied to proportionally estimate emissions from each of the identified domestic activities.

(Please, insert Table 6 here)
(Please, insert Table 7 here)
(Please, insert Table 8 here)

4. Results and discussion

The results of the emission inventory construction process are articulated and discussed based on each component of the infrastructure. It is important to note that the purpose of this paper is not to provide accurate estimates of emissions, but to highlight existing impediments to accurate estimation of emissions in Nigeria and to demonstrate the ability of the constructed inventory infrastructure to produce increasingly refined results as and when appropriate data are used as input.

4.1. The Niger Delta point source emission inventory infrastructure

The estimates generated from this source inventory were not reliable due to inadequate publicly available data. Consequently there are considerable uncertainties in the estimates. However, the process has clearly shown where data gaps currently exist and could support the future development of data gathering templates and mechanisms towards perfecting the emission estimation using the inventory. Fig. 4 and Fig. 5 show 10 km x 10 km and 20 km x 20 km grid results of the point source emission inventory infrastructure generated over the Niger Delta respectively. Sources of significant uncertainties in the point-source component of the inventory include:

1. The unrealistic assumption that 100% of the emissions released at various stages of industrial production enter the atmosphere without abatement or control.

2. The spatial datasets in the NDEI database are not complete over the region. For instance, emissions are estimated from use of generators in offices within Port Harcourt city, while offices within other cities are not considered due to the lack of information on their locations.
3. The quantities of raw materials used by industries are not available, thereby necessitating the use of arbitrary values in some instances. In other instances where assumptions and inferences could not be made, the values were not filled in the inventory. Consequently no emission estimates were generated for such scenarios

In view of these unquantifiable uncertainties, the estimates generated from this component of the NDEI are extremely unreliable at present.

(Please, insert Fig. 4 here)

Fig. 4 10 km x 10 km grid based emission inventory for CO emissions from point sources. The unit of CO emission is thousands of tonnes per year (‘000 Tonnes/Year).

(Please, insert Fig. 5 here)

Fig. 5 20 km x 20 km grid based emission inventory for CO emissions from point sources. The unit of CO emission is thousands of tonnes per year (‘000 Tonnes/Year).

4.2. Niger Delta line-source emission inventory infrastructure

The estimates generated from the inventory are based on various highly generalised assumptions derived from available information. The uncertainties associated with these estimates arise due to the absence of data specific to road categories, average travel time on specific roads, and number of vehicles on each road category. In addition, the available data were not collated for a particular year because of the lack of consistency in data gathering by public agencies and access to available data for research. The generalisation in the assumptions applied across the road categories introduced a level of uniformity in the results obtained from the inventory (See emission estimates and distributions in Fig. 6 and Fig. 7). Consequently, the differences in emission estimates generated are due to the differences in the lengths of the road segments. In addition, road data (Fig. 2) are incomplete, as residential roads in some of the major cities (Akure, Ondo, Asaba, Yenagoa, Calabar, Eket, and Aboh) are not available. The non-inclusion of the residential road network within these cities in the database clearly gives an indication that traffic on residential roads contributes significant emissions from road traffic, when estimates are compared with areas with residential roads included (Fig. 7). Despite these uncertainties, the inventory provides a spatial distribution of emissions that can help inform other areas with a possibility of high rates of emission from line sources. Following the observed spatial distribution of emissions, urban and semi-urban areas are expected to produce high rates of emissions when data are available. Assessments of individual roads in order to generate more specific information are expected to produce more accurate emission estimates.

(Please, insert Fig. 6 here)

Fig. 6 10 km x 10 km grid based emission inventory for NOx emissions from road network. The unit of NOx emission is millions of tonnes per year.

(Please, insert Fig. 7 here)

Fig. 7 20 km x 20 km grid based emission inventory for NOx emissions from road network in the Niger Delta. The unit of NOx emission is millions of tonnes per year.

4.3. Niger Delta area source emission inventory infrastructure

The area source emission inventory infrastructure consists of the spreadsheet and the GIS components, which were linked based on the unique identifier of the grids containing either entire settlements or segments of settlements (in cases where settlements intersect two or more grids). Emission values were estimated and allocated to grids based on the emission density for each settlement and the size of settlement segments that fall within each grid square. Fig. 8 and Fig. 9 show some of the maps produced from the area-source component of the NDEI.

(Please, insert Fig. 8 here)

Fig. 8 Map showing the 10 km x 10 km grid distribution of PM_{10} emissions from settlements in the Niger Delta. The unit of PM_{10} emission is tonnes per year (Tonnes/Year).

(Please, insert Fig. 9 here)

Fig. 9 Map showing the 20 km x 20 km grid distribution of PM_{10} emissions from settlements in the Niger Delta. The unit of PM_{10} emission is tonnes per year (Tonnes/Year).

Out of the estimated 13,329 settlements in the Niger Delta (NDDC, 2006; UNDP, 2006), only 6,715 settlements were identified in the inventory's settlement database. The remaining settlements that were not captured in the settlement database are rural fishing and farm settlements with population ranging from 50 to 500 or generally less than 1,000 (NDDC, 2006; UNDP, 2006). However, the process of deriving the population of the region produced results that represented an overestimation of 3% above the official projected population of the region for 2010. If the settlements unaccounted for are taken into consideration, the population estimate derived from the inventory would have been an overestimation of 11% to the official projected population of the Niger Delta for 2010 (Fagbeja et al. 2013). Table 9 summarizes the official 2010 population of each State of the Niger Delta compared with the population derived from this study.

The process of estimating population for the Niger Delta was necessitated due to the lack of population data disaggregated to community levels in Nigeria. Considering the impact of population on emissions of air pollutants, the lack of population estimates at community level constitute challenges to accurate estimation of emissions and spatial variability. Consequently the emission estimates generated from residential activities in the Niger Delta and their spatial distribution (approximately 35% accurate) have uncertainties introduced as a result of unverifiable settlement population; incomplete settlement database; generalisation in the input data; lack of comparable data; outdated and generalised emission factors; reliance on proxy information and use of assumptions to generate many of the activity data (Fagbeja et al. 2013).

(Please, insert Table 9 here)

4.4 Limitations, challenges and relevance of the Niger Delta emission inventory infrastructure

Although the functionality of the emission inventory infrastructure has been demonstrated, further developments are required. The limitations of the inventory clearly highlight the challenges that subsist in the development of an emissions inventory in a developing country like Nigeria, as exemplified by the Niger Delta. The challenges encountered in the development of the inventory exemplify the typical challenges encountered by developing countries in addressing environmental issues. The challenges border on data availability, legislative, management and institutional frameworks, technical capacity, and funding. A summary of the challenges and limitations encountered during the construction of the inventory and proposed solutions is highlighted in Table 10.

The construction of this inventory could act as a catalyst to the development of an air quality management framework in Nigeria. Its availability and the data gaps identified through its development are expected to culminate in the identification of the public and private institutions and stakeholders that collect data relevant for estimating emissions in Nigeria, as demonstrated by the United Kingdom's National Atmospheric Emissions Inventory (NAEI) (McCarthy et al. 2010). This will further inspire collaborative efforts with these stakeholders towards the development of standardised data collection mechanisms and subsequently, a robust environmental reporting framework which the Federal Ministry of Environment will build on and strengthen with appropriate legislation. Currently, the World Bank is developing a Pollution Management and Environmental Health (PMEH) programme, which will consider developing air quality management framework (AQMF) for cities within selected developing countries. Nigeria has been selected to be a part of this study, with the City of Lagos considered as pilot. The PMEH programme clearly identifies the lack of detailed source-apportionment database and emissions inventory for air pollutants at local (city) and national levels in many developing countries including Nigeria as a major deficiency in health-based air quality management. Consequently, the programme seeks to develop multi-sectoral and institutional frameworks in managing emissions of air pollutants and developing emissions inventories from domestic, vehicular (road), waste / dumpsite, and industrial sources. The development of an emissions inventory and source apportionment form two critical components of the 10 work packages (WP) upon which the air quality management (AQM) component of the PMEH is based. Consequently, the AQM component of the PMEH programme stands to gain from the experience of this study towards actualising this critical component of air quality monitoring and management.

4.5 Future outlook

The development of the emissions inventory infrastructure will benefit from a pilot survey to be conducted in the Niger Delta region in which representative sample for each of the identified sources will be selected and site-specific information collected. This will form the basis for the development of a more robust infrastructure, which will serve as a better representation of the Niger Delta. For the process of gathering site data, templates will be designed for each industry concerning the types of data they need to collect for generating accurate emission estimates. The templates will be designed using the data needs and gaps already identified through the construction of the inventory. Such templates will form part of the process to enhance the operations of the relevant regulatory bodies to coordinate systematic and consistent environmental reporting mechanism. They will also constitute sources of fundamental datasets for the Nigerian National Geospatial Data Infrastructure (NGDI), which is being developed with the National Space Research and Development Agency (NASRDA) as the lead agency (Agbaje and Fagbeja, 2006; Kufoniyi and Agbaje, 2005). A well established site data gathering and reporting process will ensure standardisation of data collation for each source category, and will form the basis for the development of localised emission factors for the region, which will also enhance the accuracy of emission estimates generated from the inventory. It should be noted that not all major sources of emissions are included in the inventory at this stage. Further development should incorporate sources including electricity generation, agriculture, biomass burning and waste disposal.

Although the inventory provides emission estimates on an annual basis, the processes that release emissions are assessed based on hourly rates of emission release. However, the inventory generalises the hourly rates of activities. Consequently, a further refinement of the inventory will reduce the level of generalisation by incorporating hourly-specific profiles, which can then feed into daily profiles from which annual estimates are generated. Such refinement will provide the opportunity for enhanced assessments of the temporal profiles of release of emissions from specific sources. And this is important for risk assessment at different time-scales, which stands to enhance knowledge-based decision-making and development of an air quality management framework for Nigeria.

4.6 Integration of the NDEI into an air quality management framework

The Niger Delta Emissions Inventory (NDEI) infrastructure aims to record and structure information about sources of atmospheric emissions, the processes and activities that release emissions from these sources and the total emissions released from the sources within the region. It forms a critical resource in estimating emission from sources, model the dispersion of emissions and assess the exposure of humans and the environment to the possible impacts of the emissions within the region and its environs. As air quality measurements and monitoring are relevant only when they exist within an AQM framework, the NDEI will be integrated with other components of an AQM framework for the region in order to formulate policies that ensure the achievement of the objectives of the framework. The NDEI will form a critical part of the establishment of the air quality management system (AQMS), which is scientific- and research-based. This component of the Air Quality Management Plan (AQMP) integrates air quality monitoring, emission inventories and dispersion modelling. The implementation of this stage of the plan leads to the identification of data gaps. The air pollution problems identified at this stage are critically assessed. Such issues arise from the identification of sources of significant emissions, areas where air quality goals are exceeded and exposure of population and environment to pollution. This stage also involves identified pollutants, emitters and areas of concern are prioritised for further actions. The identification of the problems resulting from the implementation of the emissions inventory (together with monitoring and modelling) will lead to the development and implementation of intervention strategies, which include raising awareness amongst the stakeholders, setting standards, enforcing regulations, deployment of economic instruments and air quality management plans.

5. Conclusions

The Niger Delta Emission Inventory (NDEI) is a critical infrastructure development that will assist air quality and carbon emission specialists to identify the opportunities and the deficiencies in actualising a detailed air quality assessment and management system for the Niger Delta. The infrastructure development has provided a platform to identify the existing data and policy gaps, and prompt the development of appropriate templates and robust mechanisms for data collection, collation and dissemination. The visual display offered by the infrastructure will assist policy makers to appreciate the air quality scenario in the region, thereby enabling them to develop and test appropriate policies and legislation to improve the quality of air and also reduce carbon dioxide emissions in the Niger Delta.

The emission inventory considers point, line and area sources of air pollutants and carbon dioxide within the Niger Delta. The focus of the inventory is its design and infrastructure. Due to inadequate and potentially inaccurate data, the emission inventory is populated with data based on a series of best possible assumptions, which have been documented. Consequently, the results obtained from the inventory have a high level of uncertainty inherent within them. In addition, there is no reference year for the emission estimates generated from this research due to the fact that available information is used irrespective of the periods for which it is available. However, efforts were made to base assumptions on information available from the year 2000.

The emissions estimates should be treated as uncertain for all of the identified sources. However, the results produced by the inventory demonstrate the functionality of the inventory infrastructure. This is an indication of the reliability of the inventory infrastructure to produce better quality outputs as and when appropriate data for specific reference years are used as input.

References

Adenikinju, A.F. (2003) Electric infrastructure failures in Nigeria: a survey-based analysis of the costs and adjustment responses. Energy Policy 31:1519-1530.

Ademiluyi, A.I., Okude, A.S. and Akanni, C.O. (2008) An appraisal of land use and land cover mapping in Nigeria. African Journal of Agricultural Research 3:581-586.

African Development Fund, ADF (2007) Federal Republic of Nigeria: Rural access and mobility report – appraisal report. http://www.afdb.org/fileadmin/uploads/afdb/Documents/Project-and-Operations/NG-2007-038-EN-ADF-BD-WP-NIGERIA-RURAL-ACCESS-AND-MOBILITY-PROJECT.PDF.

Agbaje, G.I. and Fagbeja, M. (2006) Creation of the national geo-spatial data infrastructure (NGDI) fundamental datasets from medium-resolution satellite imagery – NigeriaSat-1 for sustainable national development. AARSE 6th International Conference, Cairo 2006.

Akinyede, J. (2008) Nigeria's satellite programme development: prospects and challenges. 37th COSPAR Scientific Assembly, 13 – 20 July 2008, Montreal Canada.

Ajao, E.A. & Anurigwo, S. (2002) Land-based sources of pollution in the Niger Delta, Nigeria. Ambio 31:442-445.

Anozie, A.N., Bakare, A.R., Sonibare, J.A., and Oyebisi, T.O. (2007) Evaluation of cooking energy cost, efficiency, impact on air pollution and policy in Nigeria. Energy 32:1283-1290.

Bada, S.B. and Akande, E.A. (2010) Greenhouse gases concentrations in the atmosphere along selected roads in Abeokuta, Ogun State, Nigeria. Ethiopian Journal of Environmental Studies and Management 3:78-82.

Baumbach, G., Vogt, U., Hein, K.R.G., Oluwole, A.F., Ogunsola, O.J., Olaniyi, H.B., and Akeredolu, F.A. (1995) Air pollution in a large tropical city with high traffic density – results of measurements in Lagos, Nigeria. The Science of the Total Environment 169:25-31.

Benerjee, T., Barman, S.C. and Srivastava, R.K. (2011) Application of air pollution dispersion modelling for source-contribution assessment and model performance evaluation at integrated industrial estate-Pantnagar. Environmental Pollution 159:865-875.

Boden, T., Marland, G. and Andres, J.R., (2010) National CO_2 Emissions from Fossil Fuel Burning, Cement Manufacture, and Gas Flaring: 1751 – 2006. Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831-6335: Carbon dioxide Information Analysis Centre.

Boulter, P.G., Barlow, T.J., and McCrae, I.S. (2009) Emission factors 2009: Report 3 – exhaust emission factors for road vehicles in the United Kingdom. Published Project Report PPR356. TRL Limited, June 2009. http://www.dft.gov.uk/pgr/roads/environment/emissions/report-3.pdf.

Brocard, D., Lacaux, J., and Eva, H. (1998) Domestic biomass combustion and associated atmospheric emissions in West Africa. Global Biochemical Cycles 12:127-139.

Bush, T., King, K., Passant, N. and Tsagatakis, I. (2008) NAEI UK emission mapping methodology 2005. Report number AEAT/ENV/R/2511 – Issue 1. AEA Energy and Environment.

Chizea, F.D. and Ejimanya, J.I. (2007) Nigeriasat-2: technical parameters, operational perspectives and target applications. Nigerian Journal of Space Research 3:111-119.

De Kluizenaar, Y., Aherne, J. and Farrell, E.P. (2001) Modelling the spatial distribution of SO_2 and NO_x emissions in Ireland. Environmental Pollution 112:171-182.

Department for Environmental Affairs and Tourism, DEAT (2007) The 2007 national framework for air quality management in the Republic of South Africa. DEAT, South Africa.

Department for Environmental Affairs and Tourism, DEAT (2008) Manual for air quality management planning in South Africa. Zanokuhle Environmental Services, Overport, South Africa.

Department of Environment, Food and Rural Affairs, Defra (2009) Local Air Quality Management: Technical Guidance LAQM.TG (09). London, UK: Department of Environment, Food and Rural Affairs.

Environmental Protection UK (2009) Pollution control handbook 2009. Environmental Protection UK, Brighton, UK. 360 pp.

Environmental Resources Managers Limited, ERML (1997) Niger Delta environmental survey final report phase 1: volume 1 – environmental and socio-economic characteristics. ERML, 1997.

European Commission, Joint Research Centre (JRC)/Netherlands Environmental Assessment Agency (PBL) (2010) Emission database for global atmospheric research (EDGAR). Release version 4.1. Website: http://edgar.jrc.ec.europa.eu.

Fagbeja M.A., Hill, J.L., Chatterton, T.J., Longhurst, J.W.S. and Akinyede, J.O. (2013) Residential-source emission inventory for the Niger Delta – a methodological approach. Journal for Sustainable Development, 6 6:98-120.

Federal Environmental Protection Agency, FEPA (1991) National interim guidelines and standards for industrial effluents, gaseous emissions and hazardous wastes. Environmental Pollution Control Handbook. FEPA, Lagos. Nigeria 1991.

Gnansounou, E., Bayem, H., Bednyagin, D. and Dong, J. (2007) Strategies for regional integration of electricity supply in West Africa. Energy Policy 35:4142-4153.

Hao, J., Hu, J., and Fu, L. (2006) Controlling vehicular emissions in Beijing during the last decade. Transport Research Part A 40:693-651

Harrop, O. (2001) Air Quality Assessment and Management: A Practical Guide. 1st Edition ed. London, UK: Taylor and Francis.

Kampas, M. and Castanas, E. (2008) Human health effects of air pollution. Environmental Pollution 151:362-367.

Klimont, Z., Cofala, J., Schopp, W., Amann, M., Streets, D.G., Ichikawa, Y., and Fujita, S. (2001) Projections of SO_2, NO_x, NH_3, and VOC emissions in East Asia up to 2030. Water, Air, and Soil Pollution 130:193-198.

Kufoniyi, O. and Agbaje, G.I. (2005) National geospatial data infrastructure development in Nigeria: the journey so far. Paper presented at FIG Working Week 2005 and GSDI-8. Cairo, 16-21 April, 2005. http://www.fig.net/pub/cairo/papers/ts_41/ts41_07_kufoniyi_agbaje.pdf.

Kvamme, K.L. (1997) A wider view of the relationship between settlement size and population in the Peruvian Andes. American Antiquity 62:719-722.

Lindley, S.J., Longhurst, J.W.S., Watson, A.F.R. and Conlan, D.E. (1996) Procedures for the estimation of regional scale atmospheric emissions—An example from the North West Region of England. Atmospheric Environment 30 17:3079-3091.

MacCarthy, J., Brown, K., Webb, N., Passant, N., Thistlethwaite, G., Murrells, T., Watterson, J., Cardenas, L., Thomson, A., Pang, Y., Manning, A., Walker, C., Sneddon, S., Mould, R. and Martinez, C. (2011) UK Greenhouse Gas Inventory, 1990 to 2009. Report number: AEAT/ENV/R/3150.Oxfordshire, UK: National Atmospheric Emissions Inventory, AEA Group.

MacCarthy, J., Li, Y., Murrells, T.P., Okamura, S., Passant, N., Sneddon, S., Martinez, C., Thomas, J., Thistlethwaite, G. and Misselbrook, T. (2010) Air Quality Pollutant Inventories for England, Scotland, Wales and Northern Ireland: 1990 – 2008. Report number: AEAT/ENV/R/3073.Oxfordshire, UK: National Atmospheric Emissions Inventory, AEA Group.

Manby, B. (1999) The price of oil: corporate social responsibility and human rights violations in Nigeria's oil producing communities. London. Human Rights Watch. http://hrw.org/reports/1999/nigeria.

Marland, G., Boden, T. and Andres, R. J. (2007) Global, Regional, and National CO_2 Emissions Trends: A Compendium of Data on Global Change. Tennessee, USA: Carbon Dioxide Information Analysis Centre, Oak Ridge National Laboratory, U.S. Department of Energy.

Murrells, T.P., Passant, N.R., Thistlewaite, G., Wagner, A., Li, Y., Bush, T., et al. (2011) UK emissions of air pollutants 1970-2009. AEA, Harwell, Oxfordshire, UK

Naroll, R. (1962) Floor area and settlement population. American Antiquity 27:587-588.

Naiker, Y., Diab, R.D., Zunckel, M. and hayes, E.T. (2012) Introduction of local air quality management in South Africa: overview and challenges. Environmental Science and Policy 17 0:62-71.

National Bureau of Statistics NBS, (2006) The Nigerian Statistical Fact Sheets on Economic and Social Development. National Bureau of Statistics, Abuja, Nigeria.

National Bureau of Statistics, NBS (2009a) Social Statistics in Nigeria. NBS, Abuja. 399pp. http://www.nigerianstat.gov.ng/ext/latest_release/ssd09.pdf.

National Bureau of Statistics, NBS (2009b) Annual abstracts of statistics, 2009. National Bureau of Statistics, Abuja, 2009. 518pp.

National Bureau of Statistics, NBS (2009c) Social Statistics in Nigeria. NBS, Abuja. 399pp. http://www.nigerianstat.gov.ng/ext/latest_release/ssd09.pdf.

National Society for Clean Air and Environmental Protection, NSCA, (2001) Air Quality Action Plans: Interim Guidance for Local Authorities. United Kingdom: National Society for Clean Air and Environmental Protection, NSCA.

Niger Delta Development Commission, NDDC (2006) Niger Delta Development Regional Master Plan. http://www.nddc.gov.ng/?page=masterplan.

Olivier, J.G.J., Berdowski, J.J.M., Peters, J.A.H.W., Bakker, J., Visschedijk, A.J.H., and Bloos, J.J. (2001) Applications of EDGAR including a description of EDGAR 3.2: reference database with trend data for 1970-1995. National Institute for Public Health and the Environment (RIVM), Bilthoven, Netherlands.

Oni, A.G.O. (2010) Tackling road traffic congestion in a developing country – a contemporary approach. Journal of Applied Sciences Research 6:529-542.

Onyeka E.C. (2006) Relating the Nigerian reference frame and AFREF. 5th FIG Regional Conference, Accra Ghana, 8 – 11 March 2006. http://geoinfo.uneca.org/afref/AFREFAccra2005/ws01_03_onyeka.pdf.

Orthofer, R. and Winiwarter, W. (1998) Spatial and temporal disaggregation of emission inventories. In: Power, H. and Baldasano, J.M. (Eds.), Air pollution emission inventory. Volume 3. Computational Mechanics Publications, Southampton, UK. Pp 51-70.

Parra, R., Jimenez, P. and Baldasano, J.M. (2006) Development of the high spatial resolution EMICAT2000 emission model for air pollutants from the north-eastern Iberian Peninsula (Catalonia, Spain). Environmental Pollution 140:200-219.

Reilly, J., Mayer, M. and Harnisch, J. (2002) The Kyoto Protocol and Non-CO_2 Greenhouse Gases and Carbon Sinks. Environmental Modeling and Assessment 7 4:217-229.

Shell Petroleum Development Corporation, SPDC (2006) People and the environment. Shell Nigeria Annual Report 2006. Shell Visual Media Services, London.

Taiwo, O. (2005) The case of Lagos – air quality improvement project. Lagos Metropolitan Area Transport Authority. Website: www.cleanairnet.org/ssa/1414/articles-69320_Taiwo.pdf.

Tobler, W. (1969) Satellite confirmation of settlement size coefficients. Area I:30-34.

Uchegbu, S.N. (1998) Environmental management and protection. Precision Printer and Publishing, Enugu, Nigeria.

United Nations Development Programme, UNDP, (2006) Niger Delta Human Development Report. Abuja, Nigeria: United Nations Development Programme.

United States Environmental Protection Agency, USEPA (1995) AP 42 compilation of air pollutant emission factors, Volume 1: stationary point and area sources. 5th Edition. http://www.epa.gov/ttn/chief/ap42/index.html.

United States Environmental Protection Agency, US EPA (1996a) Emission factor documentation for AP-42 Section 3.3 – Gasoline and diesel industrial engines. In: AP42, Fifth Edition, Volume I Chapter 3: Stationary Internal Combustion Sources. http://www.epa.gov/ttn/chief/ap42/ch03/final/c03s03.pdf.

United States Environmental Protection Agency, US EPA (1996b) Emission factor documentation for AP-42 Section 3.4 – Large stationary diesel and all stationary dual-fuel engines. In: AP42, Fifth Edition, Volume I Chapter 3: Stationary Internal Combustion Sources. http://www.epa.gov/ttn/chief/ap42/ch03/final/c03s04.pdf.

Wang, H., Fu, L., Zhou, Y., Du, X. and Ge, W. (2010) Trends in vehicular emissions in China's mega cities from 1995 to 2005. Environmental Pollution 158:394-400.

Weiss, M., Neelis, M., Blok, K, and Patel, M. (2009) Non-energy use of fossil fuels and resulting carbon dioxide emissions: bottom-up estimates for the world as a whole and for major developing countries. Climate Change 95, 369-394.

Wiessner, P. (1974) A functional estimator of population from floor area. American Antiquity 39:343-350.

World Gazetteer (2010) Nigeria: largest cities and towns and statistics of their population. http://www.world-gazetteer.com/wg.php?x=&men=gcis&lng=en&des=wg&srt=npan&col=abcdefghinoq&msz=1500&geo=-158.

Zhang, J., Smith, K.R., Ma, Y., Ye, S., Jiang, F., Qi, W., Liu, P., Khalil, M.A.K., Rasmussen, R.A., and Thorneloc, S.A. (2000) Greenhouse gases and other airborne pollutants from household stoves in China: a database for emission factors. Atmospheric Environment 34:4537-4549.

Zhang, J., & Marawska, L. (2002). Combustion sources of particles: 2. Emission factors and measurement methods. *Chemosphere* 49, 1059-1074. doi: 10.1016/S0045-6535(02)00240-0.

African Regional Centre for Space Science and Technology Education in English,

Obafemi Awolowo University Campus,

Ile-Ife, Nigeria.

21 December, 2016.

The Editor-in-Chief,

Environmental Science and Pollution Research Journal.

Dear Sir,

RESPONSE TO REVIEWER'S COMMENTS: ESPR-S-16-04892

Please, find below the authors' responses to all the comments of the reviewer of the technical paper.

1. The criteria air pollutants are classified using the United States Clean Air Act (CAA) classification, which require that concentration standards and limits are set for them in order to protect human health (USEPA website: http://www.epa.gov/air/criteria.html). The Nigerian National Air Quality Standards (NAQS) were developed based on this classification (FEPA, 1991). See Footnote 1 in the revised manuscript.

The emissions inventory infrastructure was constructed to estimate emissions of only CO_2 as the main greenhouse gas from the activities considered. The text has been modified to specify the activities considered for the construction of the inventory. The activities focus mainly on combustion of fossil fuels and biofuels in vehicles, industries, homes (for domestic cooking and lighting) and industrial processes.

2. The unit of activity rate has been modified according to the 1996 IPCC Guidelines to indicate the magnitude of human activity resulting in emissions or removals taking place during a given

period of time. Consequently, *t* has been added to the unit of Activity Rate for Equations (1) and (2).

3. Equation 2: the % has been removed as the unit of CEi in order to perfectly represent the context of usage in the equation, which already indicates it is a percentage.

4. In Equation 3, the value of *k* is g/km. This is so because the constant is an adjustment factor used in situations where an emission factor was required for a vehicle category having no emissions data. The values of adjustment factor are derived and available based on vehicle type, vehicle weight/engine capacity, fuel type and Euro emission standard category. Constant *a* does not have a unit.

5. Sources of tables were mentioned in the title of the tables and their descriptions, except for the tables derived by the authors of the paper in the process of implementing the research methodology. However, the tables derived by the authors have been so labelled as having their sources from the study itself.

6. In Table 4, the equations were derived from the scatter plots to establish the logarithmic relationship between population and settlement built-up area according to Kvamme (1997). This portion of the paper has been modified to give a better explanation of the process in Section 3.3.

7. Emissions factors of different fuels used for the calculation of emissions from domestic cooking cannot be incorporated into Table 5. The emission factors used for the study and their sources are contained in Table 7.

8. In Section 3.3, emission estimates were based on population that was further disaggregated to number of households using average household size in each of the States of the Niger Delta, and activity data. In the Niger Delta (and in Nigeria), population estimates are not available at settlement level. The lowest level of disaggregation of population is Local Government Areas. Consequently, the research had to rely on the establishment of a relationship between settlement built-up area and population using the available 275 settlements with known population

estimates within the region (available from www.worldgazetteer.com). The process of estimating the population relied on the application of the equations generated through the establishment of the logarithmic relationship between size of built-up areas and population (Kvamme, 1997) as contained in Table 5. A more robust explanation of the process has been incorporated into Section 3.3 and is supported with Tables. Additional Tables added to the Section are ***Table 6: Percentage distribution of households by types of fuel for cooking and types of electricity supply for domestic lighting in the nine States of the Niger Delta in 2007***; ***Table 7: Compilation of emission factors adopted for domestic cooking and lighting activities in the Niger Delta***; and ***Table 9: Comparison of the 2010 projected population estimates obtained from 2006 National Population Census with the derived population estimates for the inventory***. Table 9 provides the population figures for different States of the Niger Delta as estimated from the 2006 National Population Census. The table further shows a comparison of these estimates with estimates derived for each State from the population derivation process for settlements in the inventory database.

9. Section 3.2 has been modified to indicate how Figures 4 and 5 (now Figures 6 and 7) relate to the road network. The modifications include the inclusion of a new figure showing the road network in the Niger delta used for the study (Figure 2) and a brief explanation of the GIS operations carried out to estimate emissions and link emission values to grid cells.

10. The estimates generated by the NDEI at this stage have very limited reliability due to data lack of data to fill up gaps, especially from the point-source component of the inventory. A validation would be carried out when a pilot data collection exercise is carried. The main purpose of this paper is to present the process undertaken, highlight the critical challenges in the construction of an emissions inventory and discuss how these challenges can be overcome. In addition, Section 4.6 has been added in order to incorporate how the NDEI will link a management framework.

11. Details of the software used for the study has been included in Section 3 on Materials and Methods.

12. A table (Table 10) has been included in Section 4.4 to summarise the problems and potential solutions. The sources of potential solutions were generalised, however, notes have been added to indicate the specific bodies in Nigeria responsible for necessary actions.

With regards,
Mofoluso A. Fagbeja, PhD.

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Fig. 1 Map of the study area

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Fig. 5 20 km x 20 km grid based emission inventory for CO emissions from point sources. The unit of CO emission is thousands of tonnes per year (‘000 Tonnes/Year)

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Fig. 7 20 km x 20 km grid based emission inventory for NOx emissions from road network in the Niger Delta. The unit of NOx emission is millions of tonnes per year

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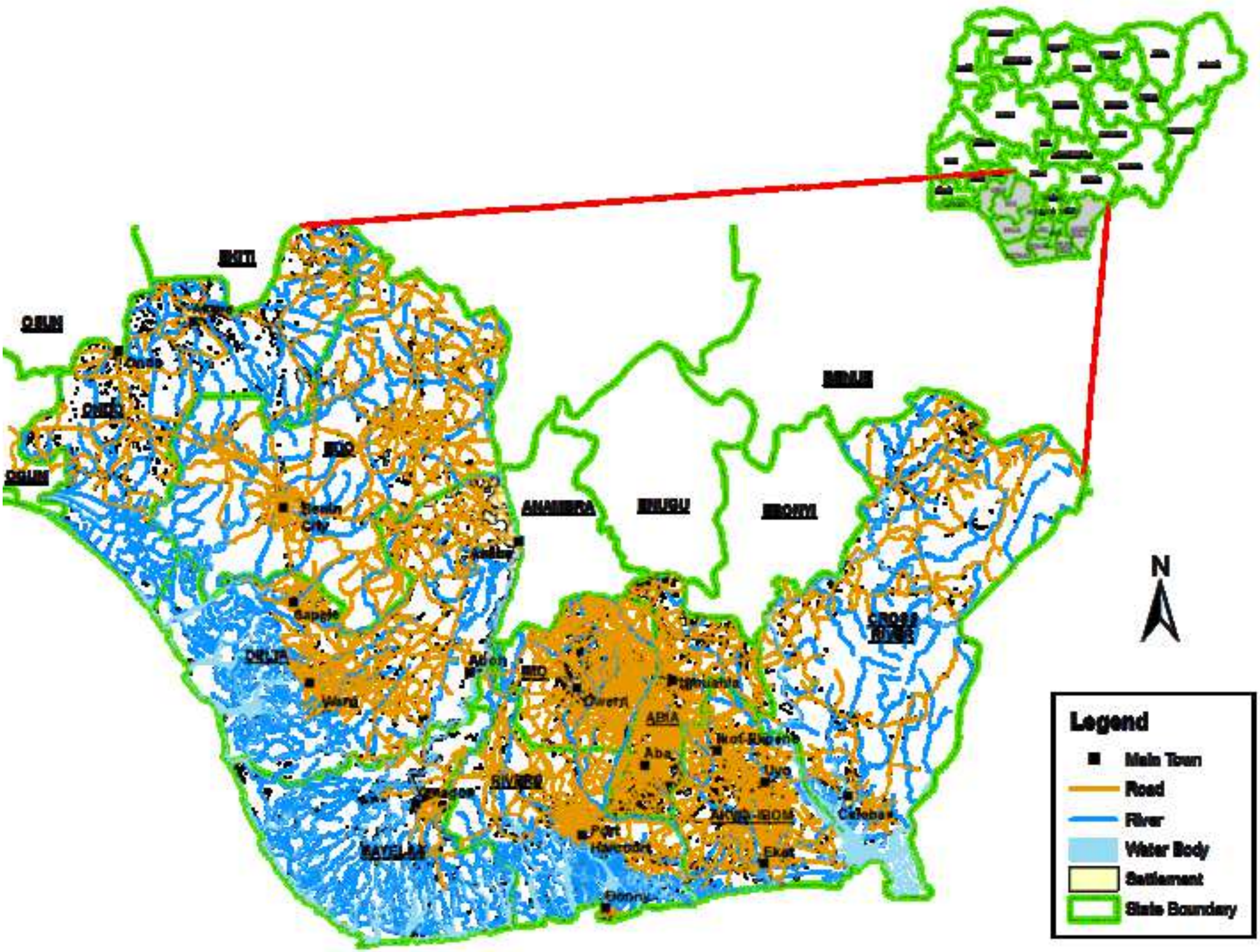
EKITI
OSUN
ONDO
OGUN
EDO
Benin City
Sapele
DELTA
Warri
ANAMBRA
ENUGU
EBONYI
BENUE
CROSS RIVER
IMO
Owerri
ABIA
Umuahia
Aba
Ikot-Ekpene
Uyo
AKWA-IBOM
Eket
Calabar
RIVERS
Port Harcourt
Bonny
BAYELSA
N
Legend
Main Town
Road
River
Water Body
Settlement
State Boundary

Figure 1 Greyscale

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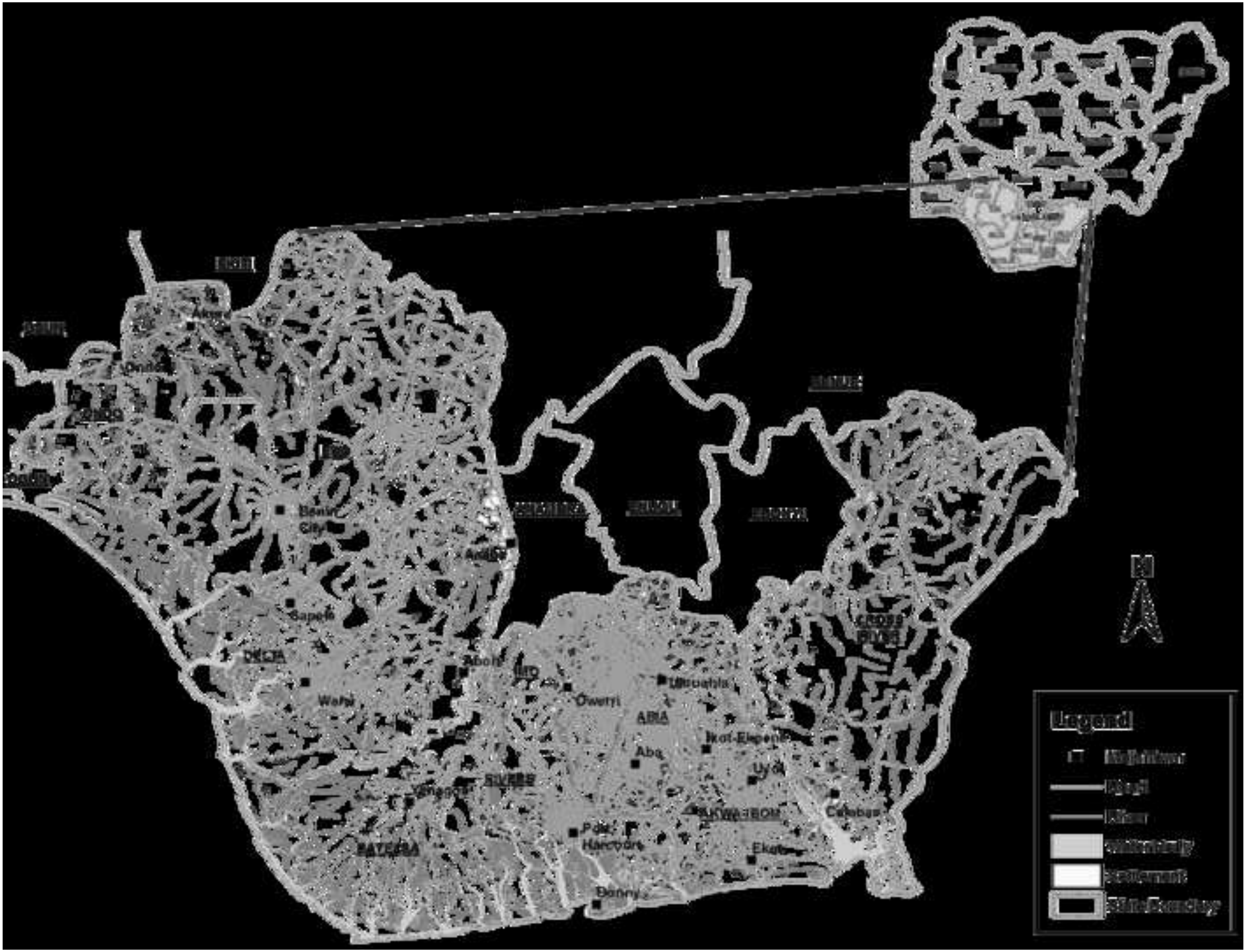

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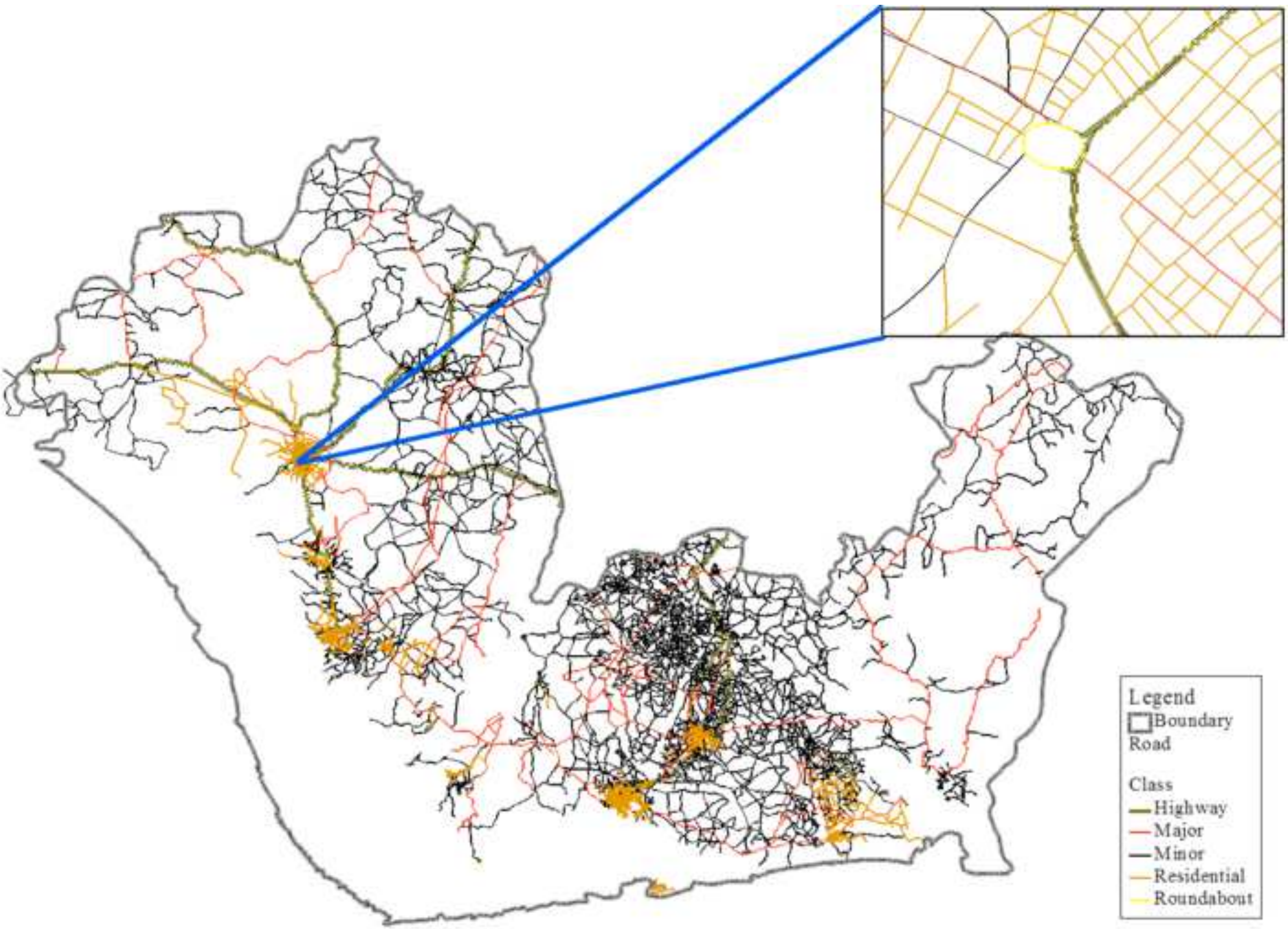

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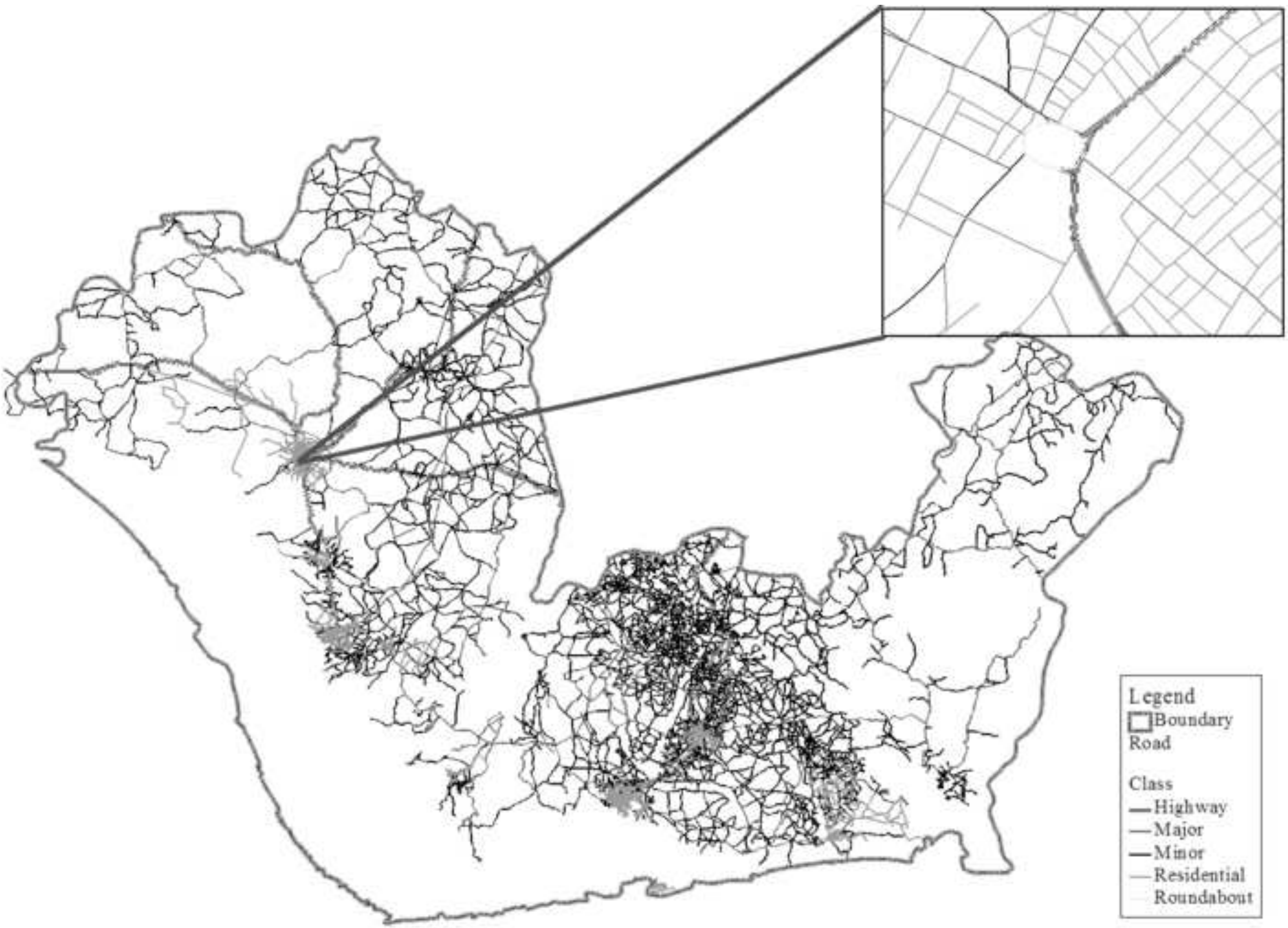

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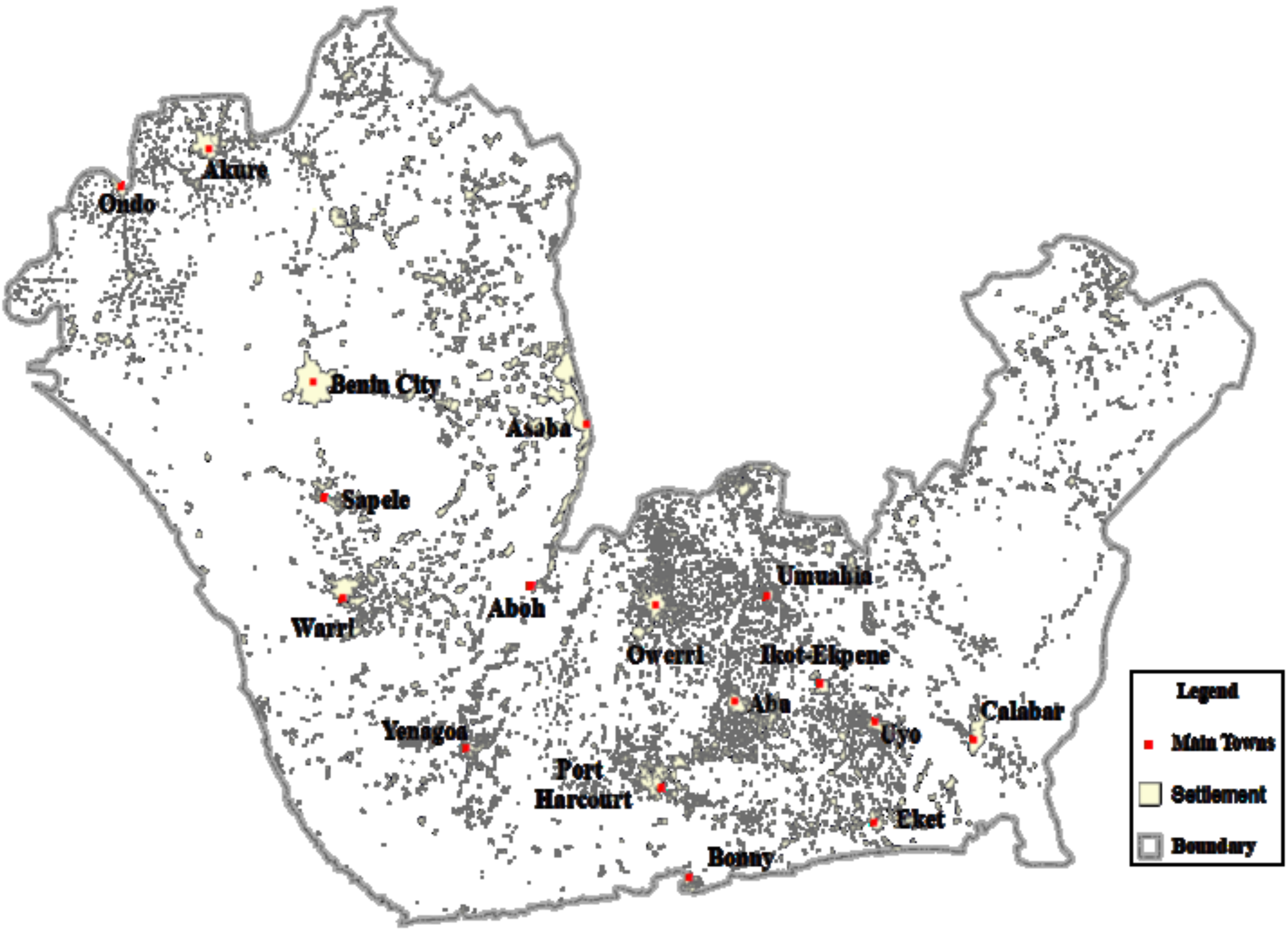

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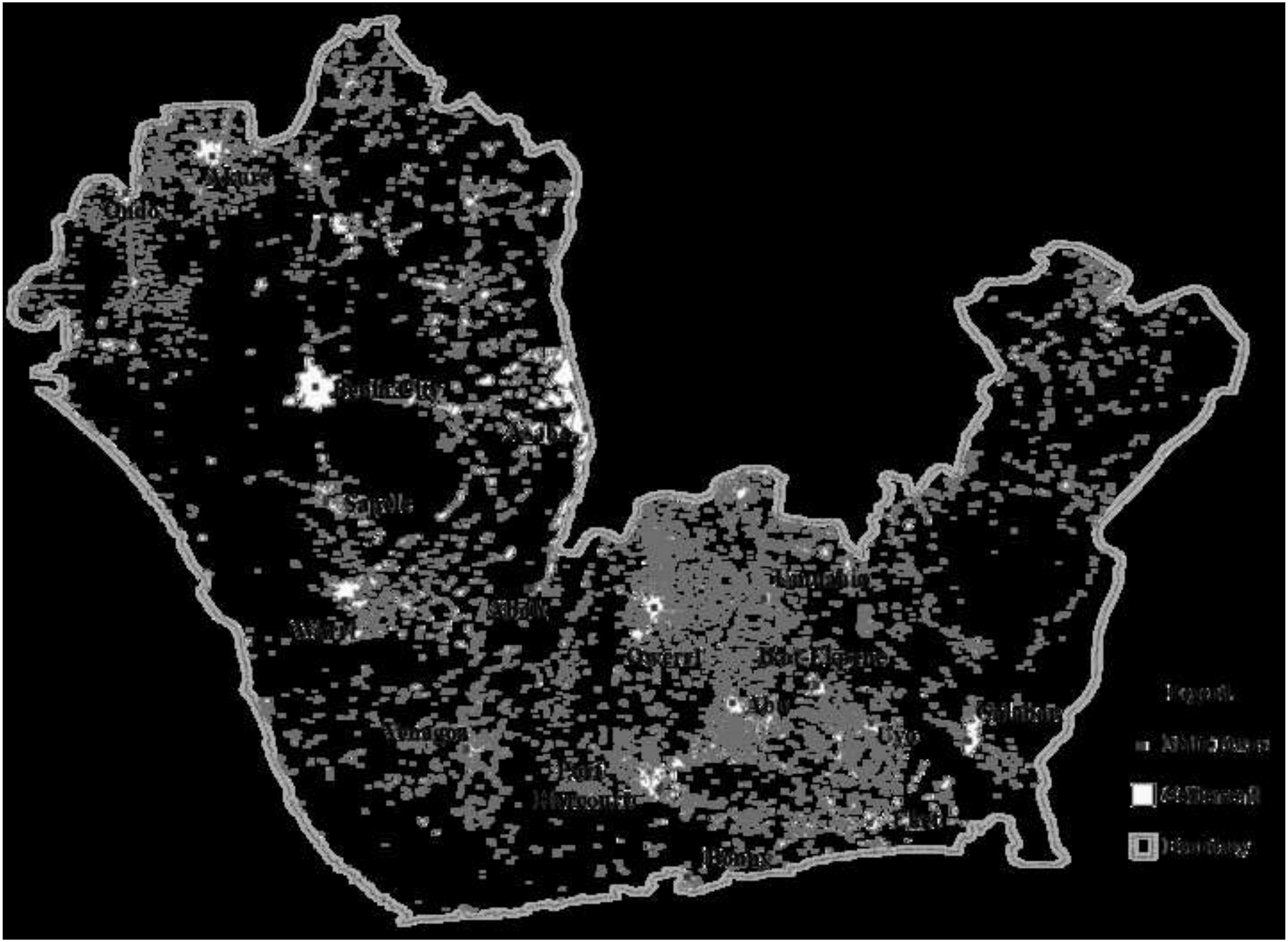

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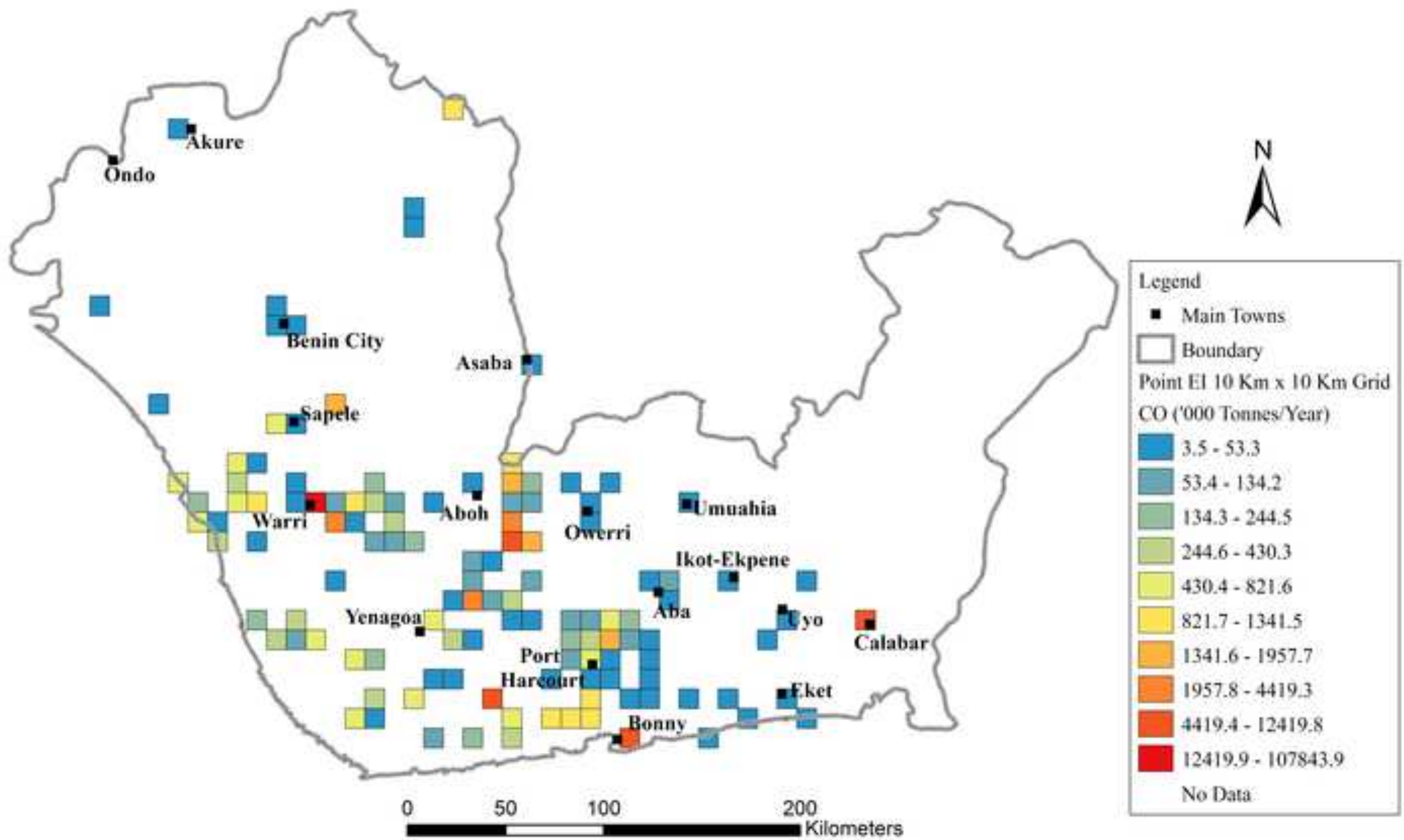

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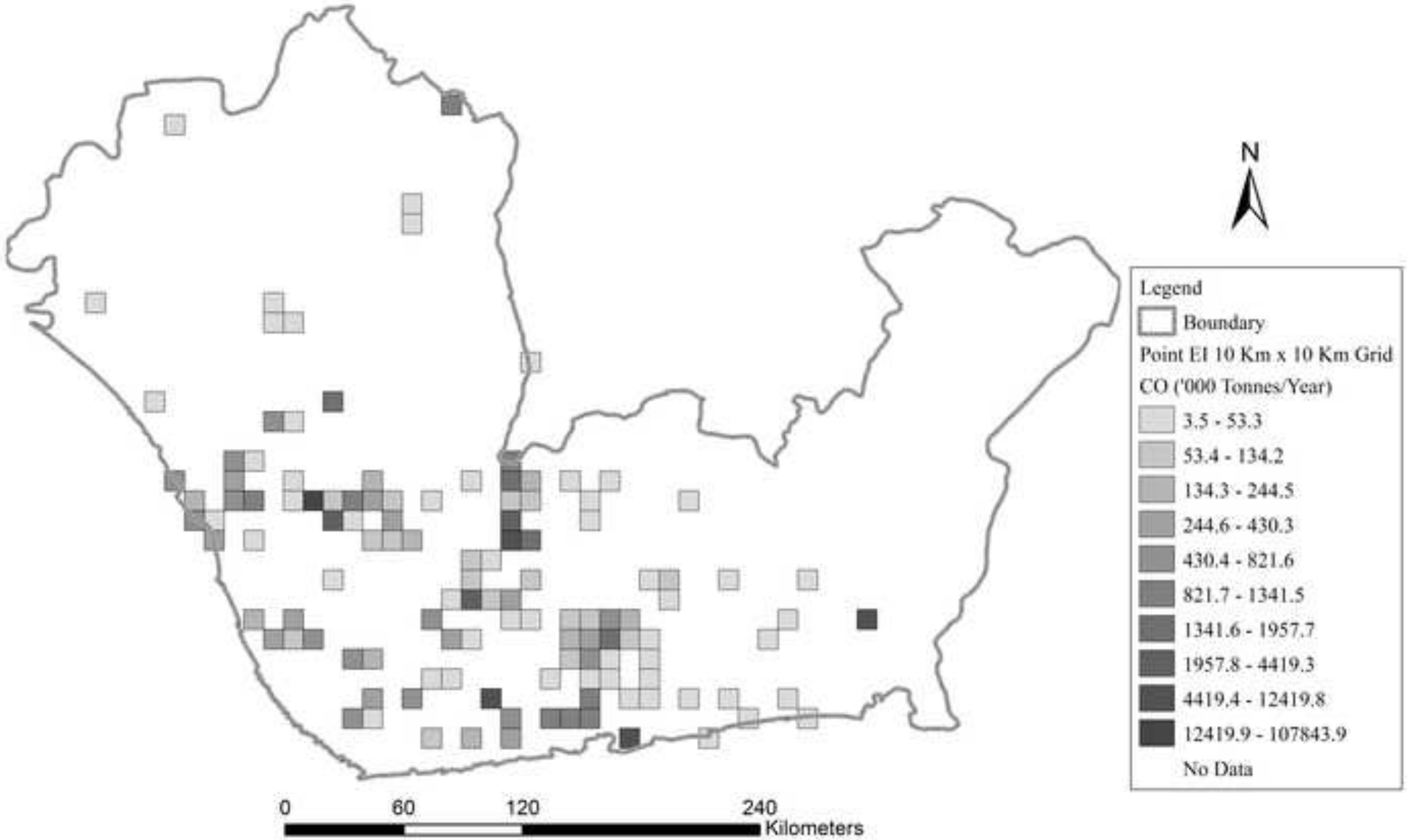

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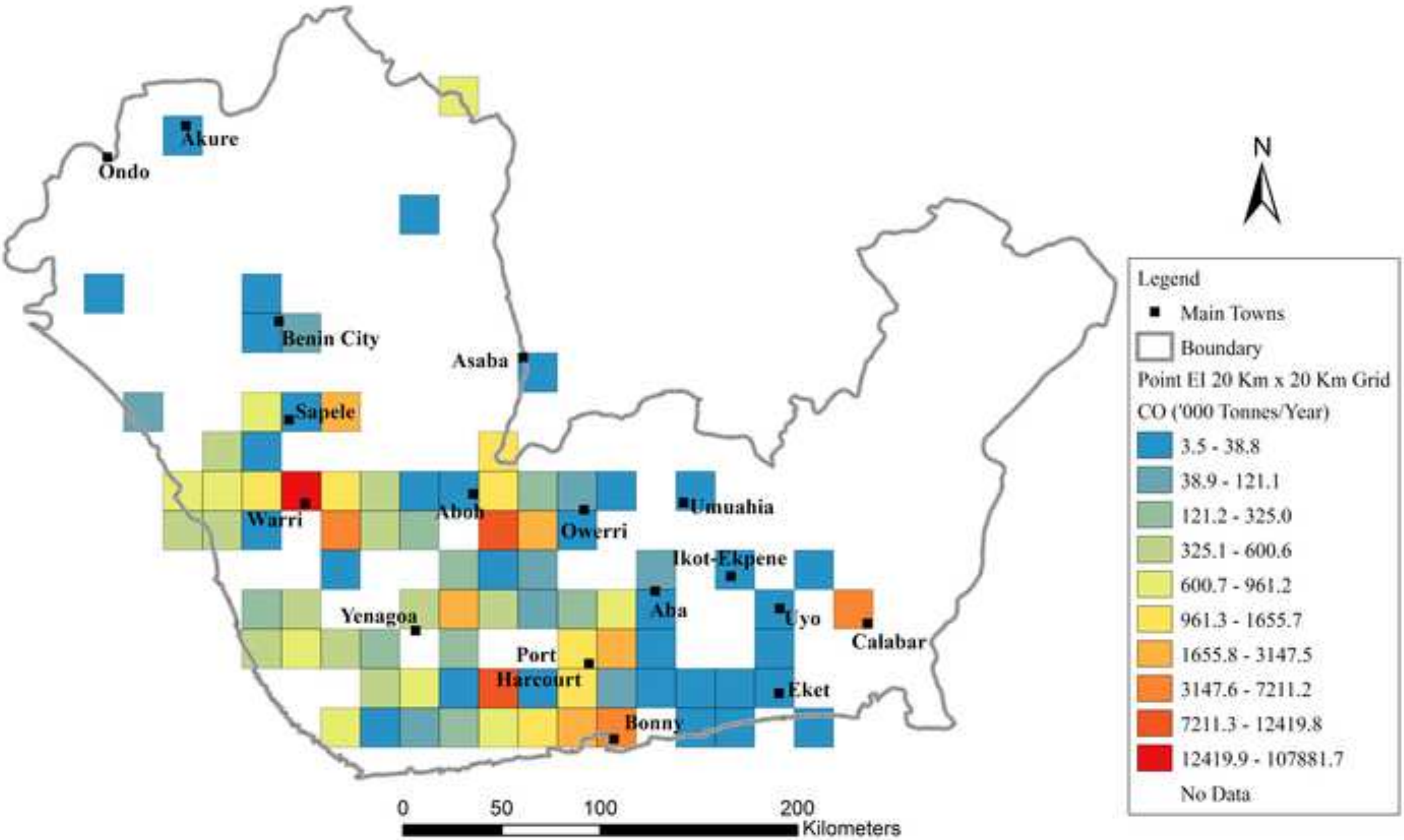

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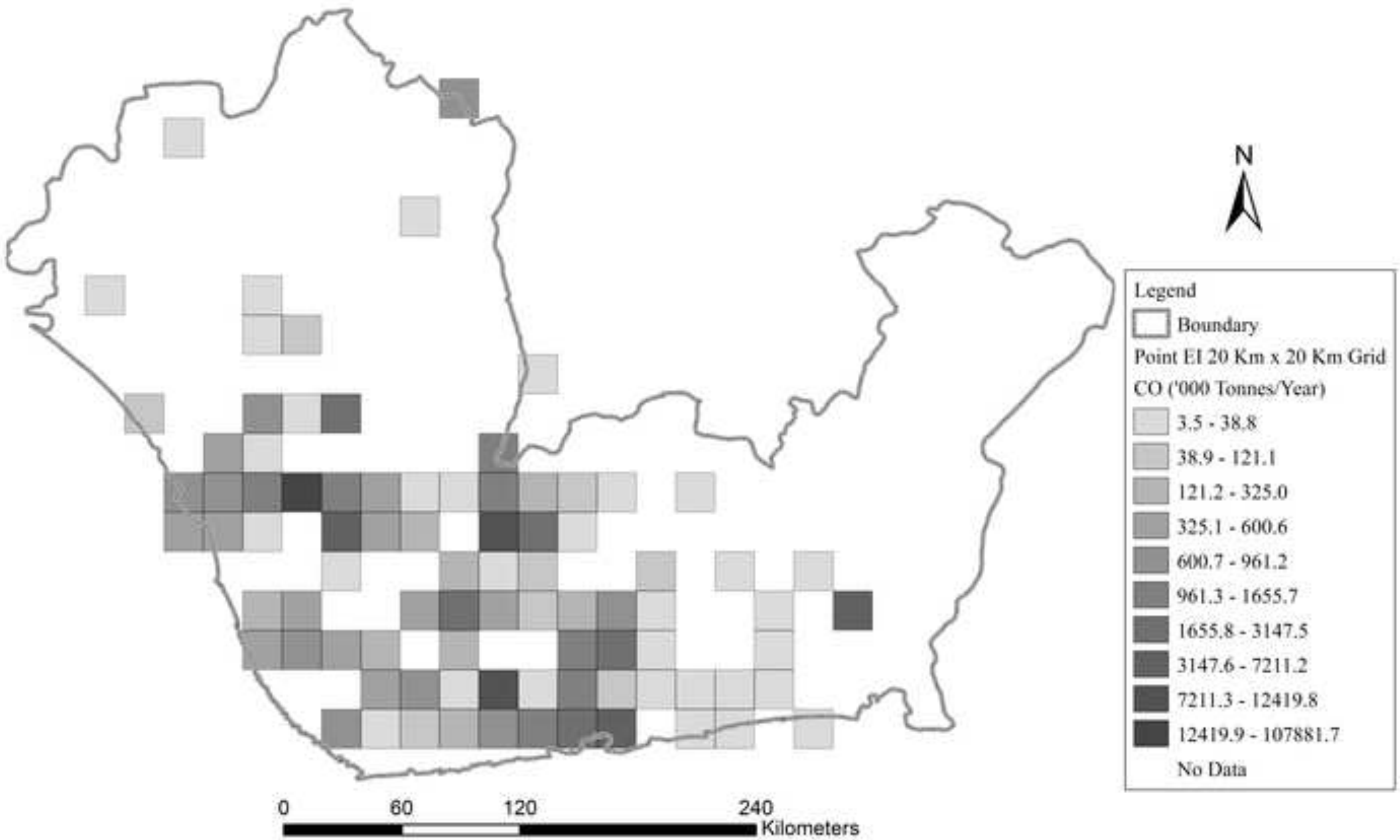

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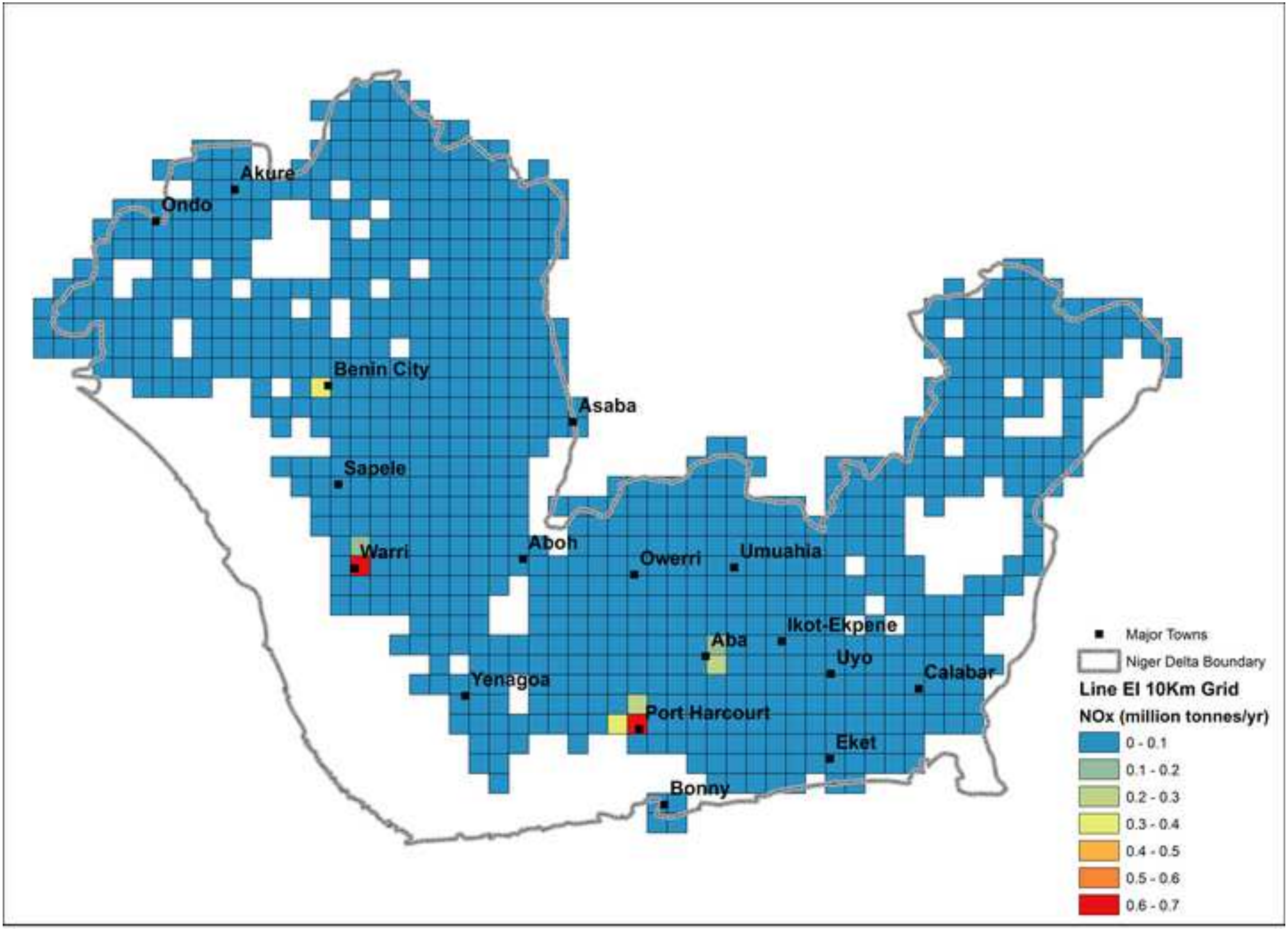

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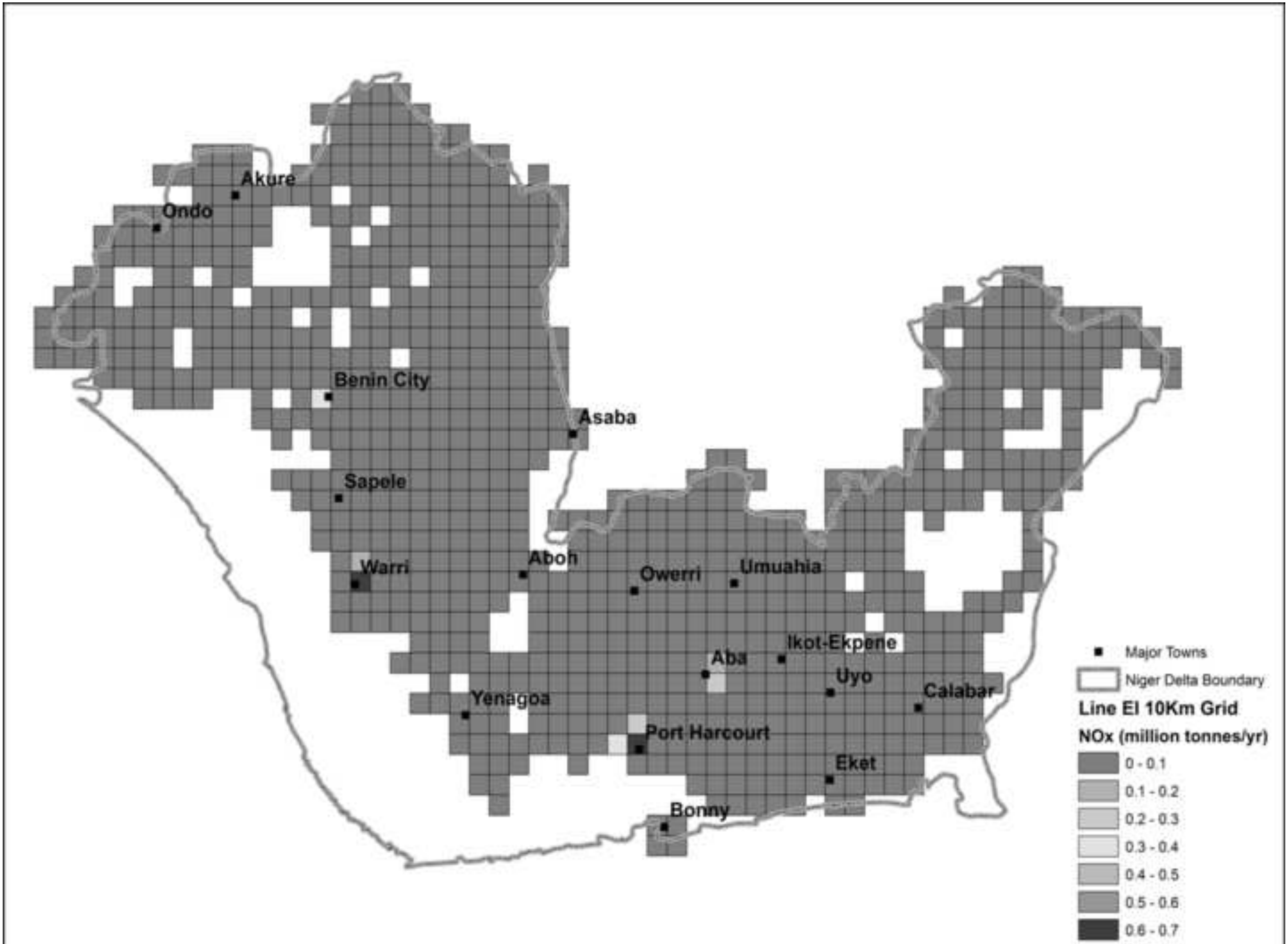

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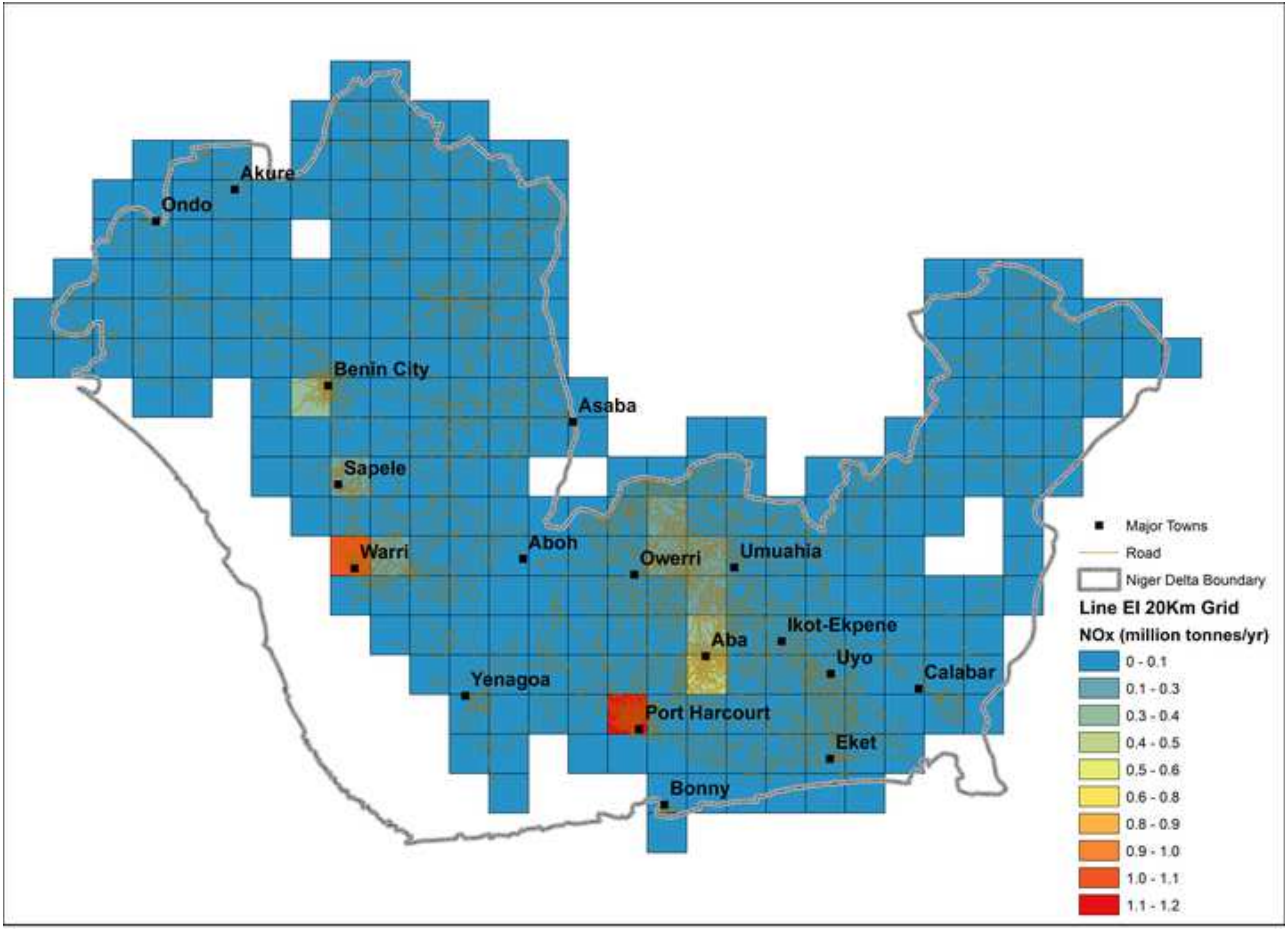

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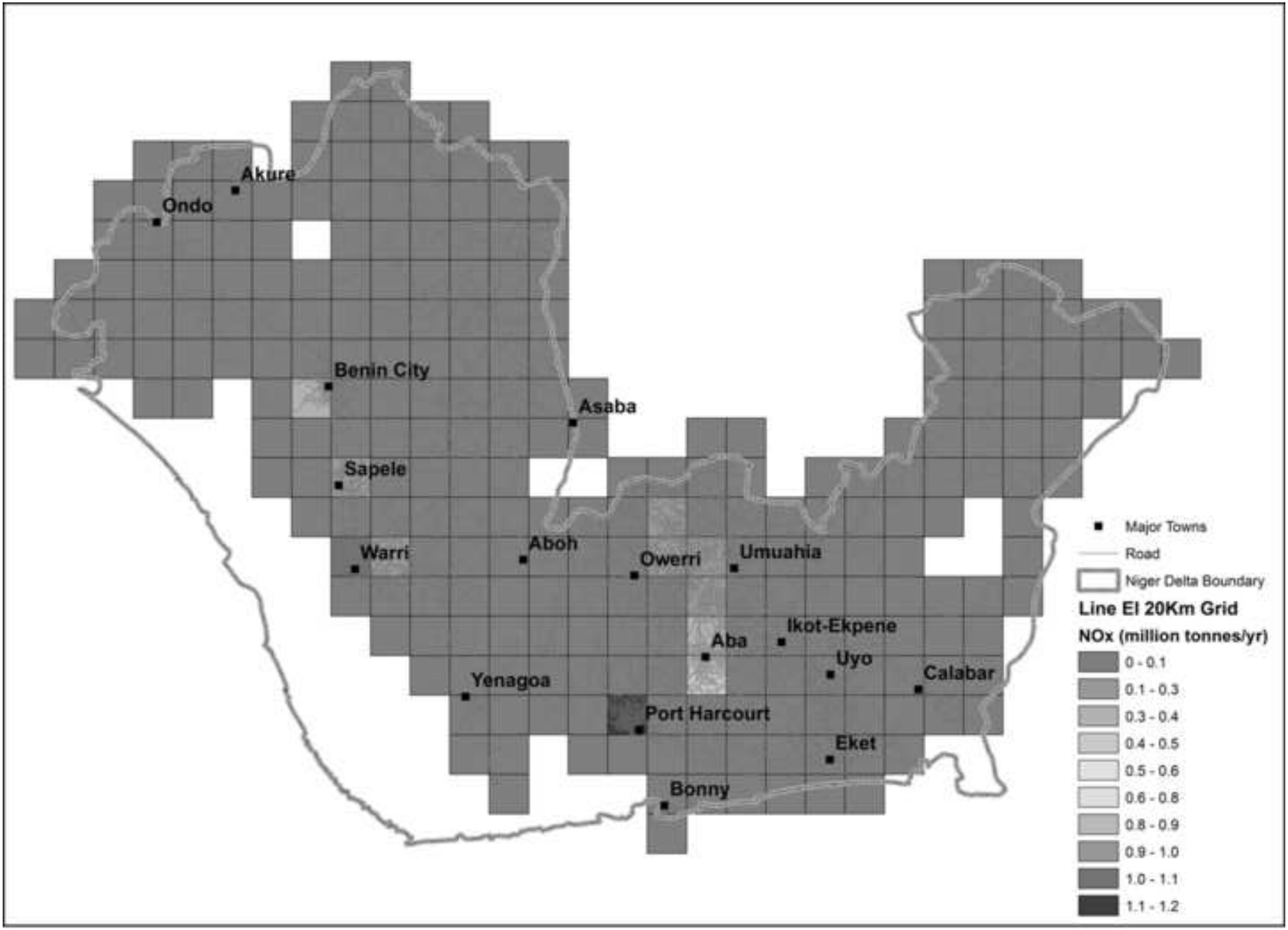

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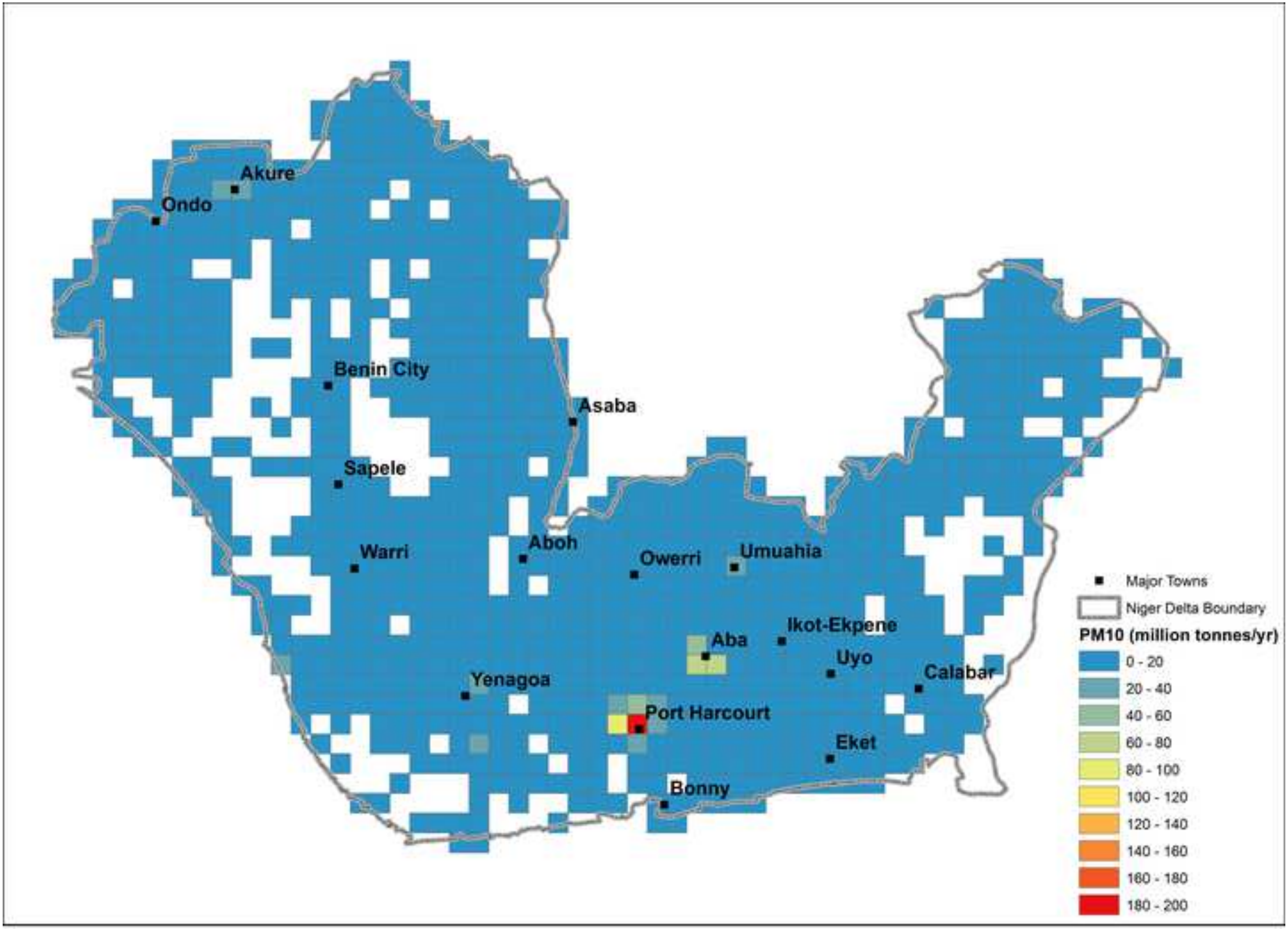

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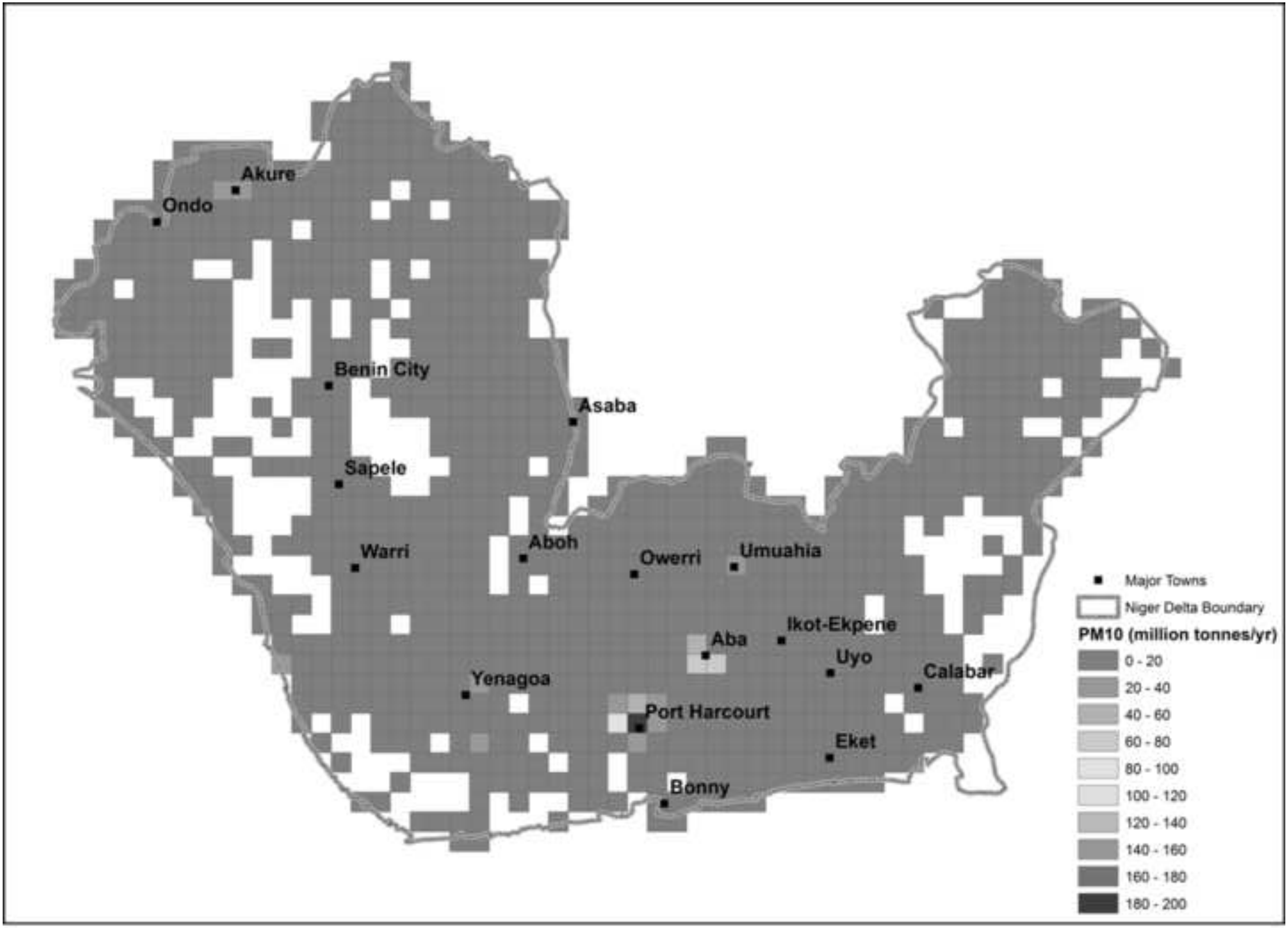

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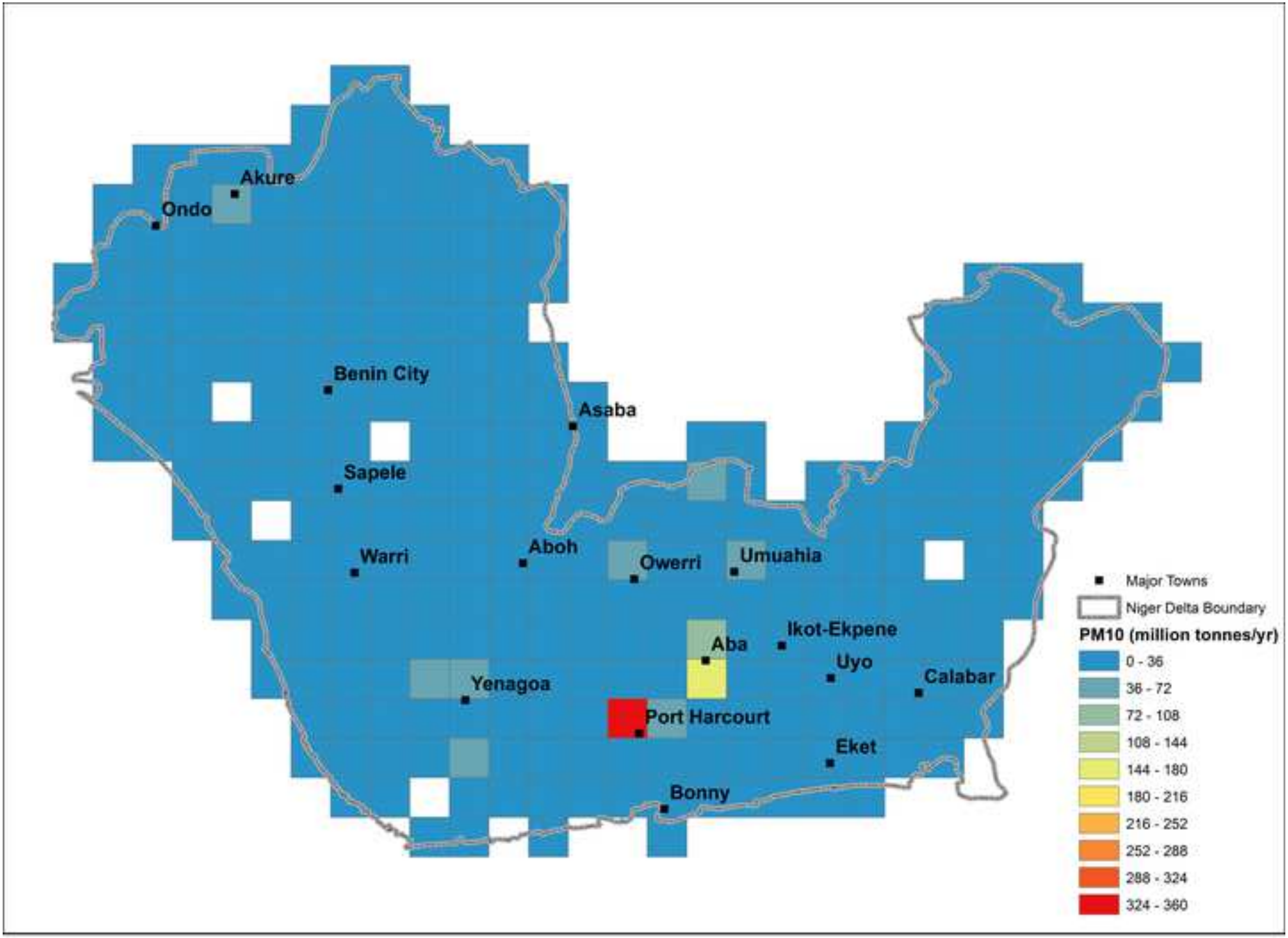

Figure 9 Greyscale

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List of Tables

Table 1: Summary of assumptions [a] applied to estimate emission factors used for each vehicle category and road class in the Niger Delta (Fagbeja et al., 2013).

Vehicle category	**Engine size (cc) / weight class**	**Fuel type**	**Av speed – highway (km/hr)**	**Av speed – major road (km/hr)**	**Av speed – minor road (km/hr)**	**Av speed – residential (km/hr)**
Cars	1400 - 2000	Petrol	100	60	60	40
Buses (LGVs)	All	Petrol	80	50	50	30
Lorries / Trailers (HGVs)	All	Diesel	60	45	30	30
Motorcycles (MC)	150 - 250	Petrol	80	60	60	40

[a] Vehicle weights have been taken from weight categories available from Boulter et al (2009) based on the assumption that the majority of cars and motorcycles in the Niger Delta have small engines. Based on personal knowledge, cars, buses (LGVs) and motorcycles in the Niger Delta use petrol, and lorries / trailers (HGVs) use diesel. Average speeds of the vehicle types on the road categories were reasonable arbitrary values, due to a lack of information on speed limits for Nigeria. There was no information about the Nigerian Highway Code available from the Federal Road Safety Commission of Nigeria (FRSC) website (http://www.frsc.gov.ng/).

Table 2: Assumed estimated number of vehicles [a] for each State of the Niger Delta (Fagbeja et al, 2013).

State	Population (2006)	Number of vehicles (2005)	Number of 4-wheel vehicles				Number of 2-wheel vehicles
			Cars	Buses	HGVs	Others	
Abia	2 833 999	56 680	14 170	3968	1700	567	36 275
Akwa-Ibom	3 920 208	78 404	19 601	5488	2352	784	50 179
Bayelsa	1 703 358	34 067	8517	2385	1022	341	21 803
Cross-River	2 888 566	57 771	14 443	4044	1733	578	36 973
Delta	4 098 391	81 968	20 492	5738	2459	820	52 460
Edo	3 218 332	64 367	16 092	4506	1931	644	41 195
Imo	3 934 899	78 698	19 675	5509	2361	787	50 367
Ondo	3 441 024	68 820	17 205	4817	2065	688	44 045
Rivers	5 185 400	103 708	25 927	7260	3111	1037	66 373

[a] Estimates for the total number of vehicles are derived from the estimated population of the states in 2006 (NBS, 2009a) and the estimated 20 vehicles per 1,000 people in Nigeria in 2005 (ADF, 2007). Estimated number of cars, buses, HGVs and motorcycles in the Niger Delta based on the assumptions that in 2004, 64% all vehicles are motorcycles, 25% are cars, 7% are buses, 3% are HGVs and 1% are undefined ‘others’ (NBS, 2009b).

Table 3: Estimated disaggregated hourly traffic count [a] on the road classes in the Niger Delta (Fagbeja et al, 2013).

Road Class	**Car**	**Bus**	**Motorcycle**
Highway	1610	690	-
Major Road	406	174	1353
Minor Road	406	174	1353
Residential Road	147	63	490

[a] Estimates are generated based on average hourly traffic densities documented by Bada and Akande (2010), and percentage distribution of vehicles types on Nigerian roads (ADF, 2007). Estimates for highways are based on the assumption that motorcycles do not operate on highways.

Table 4: Classification of settlements in the Niger Delta into rural, semi-urban and urban classes based on population range and area benchmarks (Fagbeja et al., 2013).

Class	**Population range**	**Lower areal extent benchmark (km^2)**	**Upper areal extent benchmark (km^2)**	**Number of Settlements**	**Error (%)**
Rural	Below 5,000	0.0001	1.0000	6129	0.5
Semi-urban	5001 to 20 000	1.0001	9.0000	540	11.3
Urban	20 001 and above	9.0000	227.0000	49	8.9

Table 5: Settlement size categories, population estimation equations and mean errors derived from the process of establishing settlement size-population relationship. 275 settlements with known population and area estimates were used for the derivation process (Fagbeja et al, 2013).

Settlement Aerial Category	**Settlement Class**	**Equation**	**Error (%)**	**Observations/Remarks**
0 – 0.99 km^2	Rural	Population = -14.14 ln (Area) + 3882.6	1.8%	65 settlements used
1 to 9.99 km^2	Semi-urban	Population = 2653.4 ln (Area) + 7703.9	12.3%	87 settlements used
10 – 19.99 km^2	Urban	Population = 139 250 ln (Area) – 276 509	5.9%	12 settlements used
20 – 49.99 km^2	Urban	Population = 263 324 ln (Area) – 700 463	6.5%	4 out of 6 settlements were used to derive formula.
50 – 99.99 km^2	Urban	Population = 787 652 ln (Area) – 2 000 000	129.3%	Population of all settlement in this category are known
100 km^2 - above	Urban	Population = 294 790 ln (Area) – 1 000 000	38.3%	Population of all settlement in this category are known.

Table 6: Percentage distribution of households [a] by types of fuel for cooking and types of electricity supply [b] for domestic lighting in the nine States of the Niger Delta in 2007. Source: NBS (2009a), NDDC (2006), Fagbeja et al, 2013.

State	**Estimated no. of households from emissions inventory**	**Domestic Cooking**				**Domestic Lighting**	
		Fuel wood (%)	**Charcoal (%)**	**Kerosene (%)**	**Electricity and gas (%)**	**PHCN & RE (%)**	**PG (%)**
Abia	799,505	73.6	0.0	25.8	0.7	44.6	21.6
Akwa-Ibom	574,665	81.0	0.4	18.3	0.2	49.0	12.8
Bayelsa	245,514	57.6	0.2	41.3	0.9	20.1	56.9
Cross-River	375,851	79.8	0.3	19.6	0.2	54.6	8.3
Delta	805,521	76.6	0.5	21.3	1.6	62.7	7.1
Edo	728,074	78.7	0.5	18.6	2.2	80.7	2.4
Imo	692,761	85.1	0.4	13.6	0.9	69.9	9.4
Ondo	921,325	66.7	0.3	32.6	0.4	58.0	13.0
Rivers	754,492	65.2	0.7	31.3	2.8	32.0	31.4
Total / Average	**5,897,708**	**73.9**	**0.4**	**24.4**	**1.2**	**53.1**	**18.1**

[a] The estimated number of households for the settlements located within each State of the Niger Delta has been derived by dividing the derived population of the settlements category by the average number of household per settlement category in the Niger Delta (NDDC, 2006).

[b] The types of electricity supply identified are PHCN – Power Holding Company of Nigeria (National Grid); RE – Rural Electrification; PG – Personal Generator

Table 7: Compilation of emission factors adopted for domestic cooking and lighting activities in the Niger Delta.

Activity	Pollutant	Emission Factors	Data source
Cooking – Fuel wood	CO	30 g C/kg dry fuel	Brocard et al., 1998
	CO_2	400 g C/kg dry fuel	Brocard et al., 1998
	CH_4	1.5 g C/kg dry fuel	Brocard et al., 1998
	NO_x	0.7 g N/kg dry fuel	Brocard et al., 1998
	PM_{10}	3.82 g/kg dry fuel	Zhang and Morawska, 2002
Cooking - Charcoal	CO	25 g C/kg dry fuel	Brocard et al., 1998
	CO_2	170 g C/kg dry fuel	Brocard et al., 1998
	CH_4	0.5 g C/kg dry fuel	Brocard et al., 1998
	NO_x	0.29 g N/kg dry fuel	Brocard et al., 1998
	PM_{10}	0.829 g/kg dry fuel	Zhang and Morawska, 2002
Cooking – Kerosene	CO	8.7 g C/kg fuel	Zhang et al., 2000
	CO_2	3120 g C/kg fuel	Zhang et al., 2000
	CH_4	0.0436 g C/kg fuel	Zhang et al., 2000
	NO_x	0.618 g N/kg fuel	Zhang et al., 2000
	PM_{10}	0.134 g/kg fuel	Zhang et al., 2000
	SO_2	0.0331 g S/kg fuel	Zhang et al., 2000
	VOC	0.295 g C/kg fuel	Zhang et al., 2000
Cooking – Gas/Electricity	CO	0.236 g C/kg fuel	Zhang et al., 2000
	CO_2	3440 g C/kg fuel	Zhang et al., 2000
	NO_x	2.89 g N/kg fuel	Zhang et al., 2000
	PM_{10}	0.113 g/kg fuel	Zhang et al., 2000
	SO_2	0.0014 g S/kg fuel	Zhang et al., 2000
Lighting - Petrol Generator Exhaust	CO	0.99 lb/MMBtu	USEPA (1996)
	CO_2	154 lb/MMBtu	USEPA (1996)
	NO_x	1.63 lb/MMBtu	USEPA (1996)
	PM_{10}	0.1 lb/MMBtu	USEPA (1996)
	SO_2	0.84 lb/MMBtu	USEPA (1996)
	TOC	2.1 lb/MMBtu	USEPA (1996)
Lighting – Petrol Generator Evaporation	TOC	0.09 lb/MMBtu	USEPA (1996)
Lighting – Petrol Generator Crankcase	TOC	0.69 lb/MMBtu	USEPA (1996)
Lighting – Petrol Generator Refuelling	TOC	0.15 lb/MMBtu	USEPA (1996)

Table 8: Estimated daily and hourly cooking energy consumption in Nigeria assumed for the construction of emission inventory infrastructure for the Niger Delta. Source of national estimate: Anozie et al. (2007); hourly consumption estimate assumed by Fagbeja et al. (2013).

Cooking fuel	**Estimated daily consumption per household (kg)**	**Estimated hourly consumption per household (kg)**
Fuel wood	0.8344	0.3651
Charcoal	0.8344	0.3651
Kerosene	0.3981	0.1742
Cooking gas/Electricity	0.06	0.0263

[a] Hourly consumption estimate is based on the assumption that cooking is carried out for 16 hours in a 7-day week.

Table 9: Comparison of the 2010 projected population estimates [a] obtained from 2006 National Population Census with the derived population estimates for the inventory [b]. Source of 2006 National Population Census and annual population growth rate: NBS, 2009b.

State	2006 National Population Census Estimates	Projected 2010 Population Census Estimates	Derived 2010 Population Estimate for Inventory	Percentage Error (%)
Abia	2,845,380	3,214,955	5,060,759	36.5
Akwa-Ibom	3,902,051	4,408,873	3,564,541	-23.7
Bayelsa	1,704,515	1,925,908	1,507,456	-27.8
Cross River	2,892,988	3,268,747	2,435,921	-34.2
Delta	4,172,445	4,714,388	5,200,952	9.4
Edo	3,233,366	3,653,335	4,586,559	20.3
Imo	3,927,563	4,437,699	4,706,819	5.7
Ondo	3,460,877	3,910,397	5,073,167	22.9
Rivers	5,198,716	5,873,957	4,527,540	-29.7
Total	**31,337,901**	**35,408,259**	**36,663,714**	**3.4**

[a] Projected 2010 population estimates were derived by applying a national population growth rate of 3.1% per year.

[b] The derived 2010 population estimate was based on 6,718 settlements (Fagbeja et al, 2013), which is 6,614 settlements less than the number of settlements identified in the Niger Delta by NDDC (2006).

Table 10: Summary of the limitations and challenges of developing the Niger Delta Emissions Inventory infrastructure and proposed solutions

S/No	Identified Limitation / Challenge of NDEI Infrastructure Development	Proposed Solutions to Limitations / Challenges
1	Lack of consistent, complete, accurate and verifiable data	- Identification and coordination of public and private institutions that collect data by the Central Government body responsible for environmental monitoring and management [a]. This body will provide a platform for institutional interaction to determine standards and multi-sectoral mechanisms for timely collection, collation and dissemination of environmental datasets relevant for emission estimation - Strengthening environmental regulation and reporting mechanisms through legislations, and integration of these into existing institutional frameworks. - Leverage on remote sensing and Geographic Information Systems (GIS) technology to support collection of complete spatial datasets on sources of emissions and also support the development of spatially-enabled inventories [b]
2	Lack of access to industry- / site-specific operational / activity data, which necessitated the reliance on industry standard operations	- Funding support to carry out on-site collection of information on industrial processes, road traffic and demography, energy consumption and other data upon which more reliable assumptions could be made. This will rely on the data collection templates and mechanisms put in place as identified in Item 1 above. - Random data collection pilot study to improve the accuracy of the activity and process data for the inventory, and reduce generalizations and uncertainties in the emission estimates. - Development of appropriate emission factors localised to the Niger Delta [c] - Partial reconstruction of the emissions inventory, especially the point-source component of the inventory, to accommodate site-specific industrial processes that are not industry standard.
3	Lack of an Air Quality Management Framework	- An emissions inventory becomes relevant to air quality management when it exists within an air quality management framework. Therefore, a national framework for the management of air quality should be developed by the Central Government body responsible for air pollution monitoring and management. - Increased awareness and attention given to having a national emissions inventory infrastructure, which will improve technical, administrative and legislative efforts for data collection, process verification and development of

S/No	Identified Limitation / Challenge of NDEI Infrastructure Development	Proposed Solutions to Limitations / Challenges
		methodologies towards the construction of a national inventory
4	Lack of automatic update capability in the inventory when changes are made on either the spreadsheet or GIS platform	- Building technical capacity in algorithm development to develop algorithms that can support automatic updates of changes made to the inventory on both the GIS and spreadsheet platforms [c].

[a] The Central Government body in Nigeria that is responsible for air quality monitoring and management is the Federal Ministry of Environment (FMEnv). Under the FMEnv, the National Environmental Standards Regulation and Enforcement Agency (NESREA) is responsible for setting air quality standards and enforcing the regulations.

[b] The Nigerian National Space Research and Development Agency (NASRDA) currently operates high spatial resolution satellite, NigeriaSat-2, which can support collection, mapping and updating spatial data of emission sources in Nigeria.

c The technical expertise available at the Nigerian National Space Research and Development Agency (NASRDA) can be further developed to accommodate algorithm development.