# The Need for Optimized Analytical Zones in LMICs: Problematizing the Ward Zoning System in Nigeria

Eleojo Abubakar



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Eleojo O. Abubakar*[1, 2]

[1]School of Geography, Politics and Sociology
Newcastle University, UK

[2]Department of Geography and Environmental Studies
Kogi State University, Anyigba
PMB 1008, Kogi State, Nigeria

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**Summary**

Well-known zoning problems in spatial analysis include MAUP, ecological fallacy, small numbers problem and gerrymandering. These are more acute in LMICs like Nigeria, wherein extant zoning systems are both dated and likely to be grossly suboptimal because they are products of manual zone design methods. Using automated zone design method, this study problematizes extant ward zoning system in Nigeria, with remedial insights on their empirical spatial optimization. Some distal implications are also explicated from an equity-sensitive perspective. Current zoning biases are products of historical processes of inequality in political power, which were entrenched by successive military regimes post-independence.

**KEYWORDS:** Zoning Systems, Automated Zone Designs, MAUP, Data Aggregation Zones, Nigeria.

## 1. Introduction

An in-depth interrogation of the data aggregation zones used for socio-spatial analysis is invaluable in enhancing our fundamental understanding of space, place and society (Irwin, 2007:119). Hence, it is necessary to analyze the extent to which extant zoning systems are congruent with standard zone design criteria or the bespoke data aggregation requirements for a particular application (Thygesen et al., 2015, Riva et al., 2008). Standard zone design criteria include: balance, homogeneity, contiguity and compactness, as well as the need to maximize users' utility of published statistics by avoiding small population sizes (Cockings and Martin, 2005, Ralphs and Ang, 2009, Kalcsics, 2015, Zhao and Exeter, 2016). Optimized zoning systems meet the foregoing criteria and are often automatically created with the aid of appropriate spatial optimization algorithms. For socio-spatial analysis, optimized zones are helpful in minimizing or bypassing many pervasive down-sides of existing sub-optimal zoning systems, such as: the small numbers problem (Cromley and McLafferty, 2012:153), the Modifiable Area Unit Problem (MAUP) (Openshaw, 1984, Wong, 2009,), ecological fallacy (Paelinck, 2000), the Uncertain Geographic Context Problem (UGCoP) (Kwan, 2012), gerrymandering (Chou and Li, 2006, Rush, 2000) and aggregation-induced errors in location modelling (Fotheringham et al., 1995, Sadigh and Fallah, 2009).

Therefore, this study interrogates and problematizes the ward zoning system of the study area using automated zone design methodology (Guo and Wang, 2011, Spielman and Logan, 2013, Zhao and Exeter, 2016). Among other things, it features an innovative exploitation of unconventional data types in a Low and Middle Income Country (LMIC), Nigeria, where dire spatial data paucity greatly limits socio-spatial analyses at small-area scales (Mohammed et al., 2012, Tomintz and García-Barrios, 2014).

* e.o.abubakar2@newcastle.ac.uk

It fills important empirical knowledge gaps by helping to answer the following questions: (1) what are the conceptual and practical problems of the current ward zoning system as well as their potential causes and consequences? (2) In data-scarce contexts like Nigeria, how can optimized analytical small-area zones be developed for spatial analysis in human-social application domains?

### 1.1. The Study Area

Kogi State in Nigeria, a LMIC, is the study area of this study. It is well-acknowledged that in terms of geodemographic characteristics, Kogi State is a microcosm of the entire country; hence, it is a good representative of Nigeria (Omotola, 2008). **Figure 1** is a map of Nigeria, showing Kogi State which in turn shows extant Local Government Areas (LGAs). Figure 3A shows extant ward zoning systems for the three (3) select LGAs of this study.

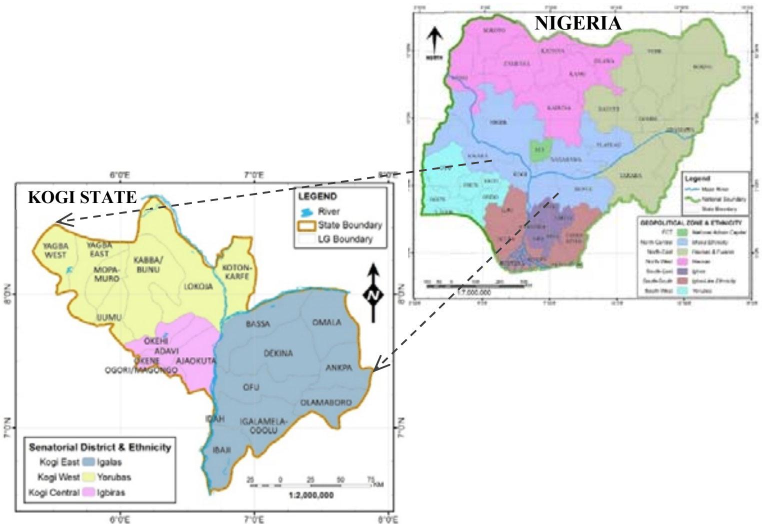


**Figure 1** Nigeria Showing Kogi State with the LGAs therein

## 2. Methods

### 2.1. Software Tools

AZTool software which is one of the most robust and popular tool for implementing automated zone designs, was used in this study (Cockings et al., 2011, 2013, Cockings and Martin, 2005, Mokhele et al., 2016). Ralphs and Ang (2009) and Cockings (2013) provide excellent overviews of the use on the AZTool for the automated creation of optimized zoning systems. ArcGIS 10.5 Desktop was used to generate a hexagonal tessellation of 1 sqkm for the study area, which served as the Building Block Area (BBAs) for the automated zone designs of this study.

### 2.2. Data Types and Sources

The main dataset used in this study is the 1 square kilometer gridded demographic dataset from WorldPop Project (Tatem, 2017). The other is the ward geographies for select Local Government Areas (LGAs) of Kogi State, prepared by an NGO, eHealth Africa, obtained from the Vaccination Tracking System (VTS) website (http://vts.eocng.org/geometry_export/, assessed by August, 2019).

### 2.3. Method of Data Analysis

This study followed the standard procedure of using the AZTool to develop optimized small-area zoning system for any context, which can be divided into three stages as follows (Martin, 2000): (1) The design and attribution of Building Block Areas (BBAs); (2) The application of hard zoning constraints; (3) The application of soft zoning constraints. The data processing workflow for this study is illustrated in Figure 2. The specific zone design criteria used in developing two versions of optimized ward zoning system which emulates extant wards in the study area (with regards to mean zonal population) is presented in **Table 1**. In addition to outputting optimized zoning systems for an area of interest, AZTool produces relevant descriptive statistics for: population, zone compactness (i.e. the Perimeter to Area Ratio, P2A) and zone homogeneity, as shown in Tables 2 to 4. Therefore, AZTool helped to calculate the foregoing parameters for the extant ward zoning system as well as for the optimized synthetic ward zoning system developed in this study.

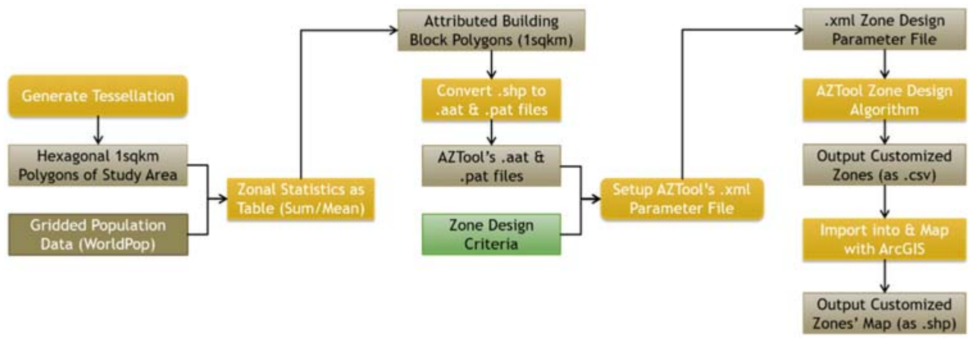


**Figure 2** Workflow for the Automated Development of Optimized Ward Zones in the Study Area

**Table 1** Zone design criteria used for the automated creation of synthetic wards that emulate the number of extant wards in (parts of) the study area

| Constraint/Criteria | Emulating Extant Wards in 3 Select LGAs | | | |
|---|---|---|---|---|
| | **Value** | **Weight (%)** | **Value** | **Weight (%)** |
| Minimum population threshold | False | - | False | - |
| Maximum population threshold | False | - | False | - |
| Target Population† | 21315 | 100 | 21315 | 100 |
| Target tolerance (%) | 10 | - | 25 | - |
| Zones Count based on Target Population | True | - | True | - |
| Respect Higher Region (True/False) | True: LGA | - | True: LGA | - |
| Homogeneity (IAC) | True | 100 | True | 500 |
| Compactness ($P^2/A$) | True | 200 | True | 1000 |
| Resulting Zoning System | Figure 3C (and Table 3) | | Figure 3D (and Table 4) | |

## 3. Presentation and Discussion of Results

The results of empirically problematizing the extant ward zoning systems (of the 3 mappable LGAs) as well as comparing their characteristics with some optimized synthetic replicas are provided in Figure 3 as well as Table 2, Table 3, Table 4, and then summarized in Table 5 below. Since the derived synthetic/analytical wards are optimized, they provide an equitable (or balanced) socio-spatial depiction of what the distribution of wards (per LGA) should be if the current overall number of wards in the select LGAs was equitably distributed amongst them. Based on the optimized synthetic wards for the 3 select LGAs, Dekina LGA currently has a deficit of 5 wards while Ibaji and Kabba have a surplus of 1 ward and 4 wards respectively (see Table 5). This shows an inequitable distribution of wards amongst the selected LGAs, implying that the current ward zoning system greatly favours Kabba LGA to the disadvantage to Dekina LGA.

In terms of population balance, optimized synthetic wards are more equitable than the extant wards. From Figure 3B, the population of extant wards range from 3,924 – 68,695. However, one version of optimized wards has population of 20,677 – 21,644, while the other has population of 19515 – 23,469. This disparity is summarized by the Standard Deviation (SD) of population which is 14,804 across all the extant wards, while the two versions of optimized wards have SDs of 346 and 979 respectively. With increasing SD comes increasing inequalities or inequities. In this regard, it can be seen (from Table 2) that the most inequities in population across extant wards is exhibited by Dekina with a SD of 15,721 while the least inequity is possessed by Ibaji with a SD of 8,444. In a similar vein, many of the optimized synthetic wards are more compact and homogeneous than the existing wards in the three LGAs considered. In addition to the staggering inequality in between-ward population, as well as other

† This parameter makes the zone design algorithm produce the desired number of zones in instances where optimized zones are expected to emulate the number of extant zones.

well-known tyrannies of spatial analysis (highlighted in Section 1), the current wards have a mean population of 21,315 (for the three select LGAs) which is arguably too large for small-area analysis of some socioeconomic phenomena including primary healthcare services in the study area (NPHCDA, 2012). Where available as maps, the use of extant wards for socio-spatial analysis such as planning the location of primary healthcare facilities and other public sector facilities implies that privileged LGAs and Senatorial Districts (in terms of number of wards) are likely to be privileged in a similar vein. For instance, they are likely to receive better healthcare coverage than other places, thereby perpetuating social-spatial inequities in related phenomena, such as spatial accessibility of primary healthcare in the study area.

Furthermore, the distribution of political power/representation, the collection of public sector data, as well as public sector policies, plans, programmes and strategies in Nigeria are usually based on these extant districts/zones (either administrative, political, statistical, etc) that have been found to be inequitable and suboptimal. This is therefore a dire and foundational structural inequity that drives/perpetuates and intensifies socio-spatial inequity in many other spheres of the Nigerian society, including socio-economic and health status.

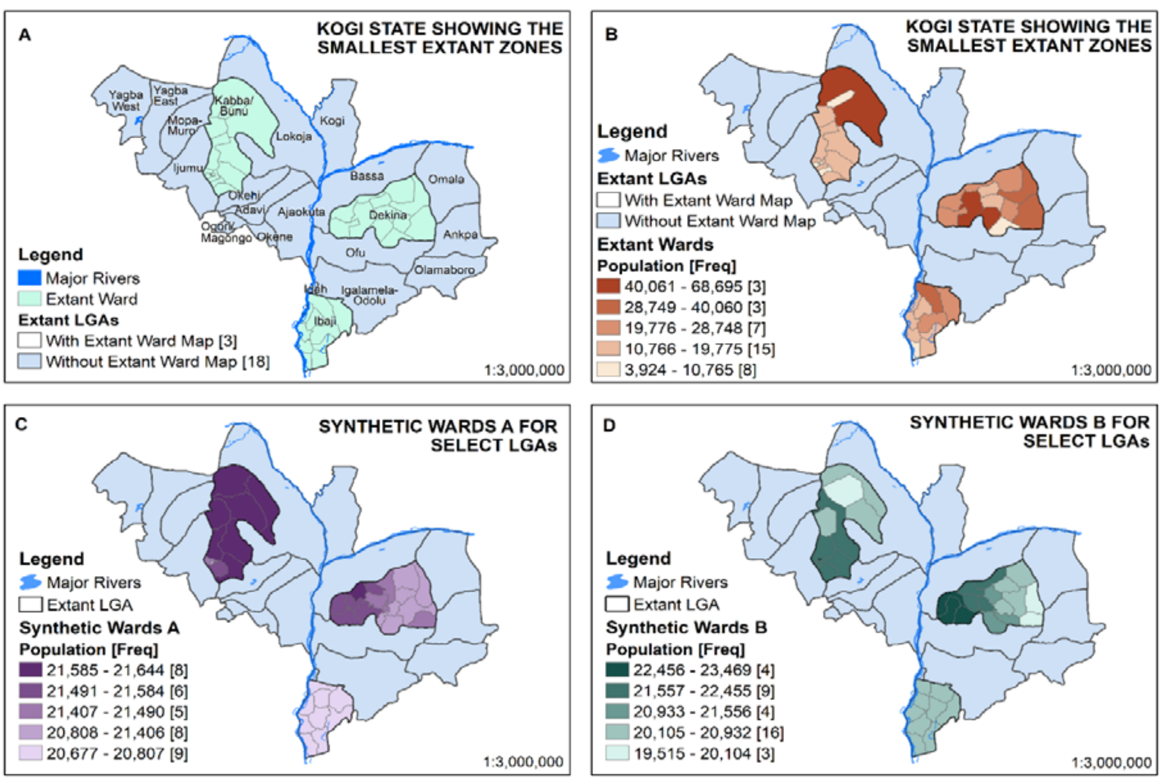


**Figure 3** Extant versus synthetic wards, for 3 select LGAs in the study area (see **Table 1** for the zone design criteria of Figures C and D)

**Table 2** Soft zoning attributes of extant unoptimized wards per Select LGAs, see Figure 3A and B for the associated maps.

| LGA | Ward Count | Population Min | Population Max | Population Mean | Population SD | Population Total | P2A Min | P2A Max | P2A Mean | P2A SD | P2A Score | IAC Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dekina | 12 | 10612 | 68695 | 30410.417 | 15720.887 | 364925 | 23.27 | 53.717 | 34.023 | 9.549 | 408.28 | -0.007 |
| Ibaji | 10 | 8323 | 38453 | 18663.2 | 8443.866 | 186632 | 22.774 | 38.49 | 31.874 | 4.409 | 318.737 | -0.007 |
| Kabba | 14 | 3924 | 61758 | 15414 | 13784.915 | 215796 | 13.856 | 57.176 | 33.267 | 12.652 | 465.735 | 0.023 |
| All 3 | 36 | 3924 | 68695 | 21315.361 | 14803.925 | 767353 | 13.856 | 57.176 | 33.132 | 9.937 | 1192.751 | 0.022 |

**Table 3** Soft zoning attributes of optimized wards per select LGAs (for population balance), see Figure 3C and Table 1 for the relevant map and zone design criteria respectively.

| LGA | Ward Count | Population Min | Population Max | Population Mean | Population SD | Population Total | P2A Min | P2A Max | P2A Mean | P2A SD | P2A Score | IAC Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BBA | 6554 | 2 | 4902 | 117.082 | 247.514 | | 13.856 | 13.856 | 13.856 | | 90814.888 | 0.009 |
| Dekina | 17 | 21364 | 21603 | 21466.176 | 80.016 | 364925 | 24.634 | 49.487 | 35.739 | 8.775 | 607.57 | -0.004 |
| Ibaji | 9 | 20677 | 20807 | 20736.889 | 44.732 | 186632 | 22.411 | 44.967 | 30.646 | 6.291 | 275.816 | -0.007 |
| Kabba | 10 | 21349 | 21644 | 21579.6 | 87.494 | 215796 | 20.785 | 58.7 | 34.958 | 10.563 | 349.575 | 0.027 |
| All 3 | 36 | 20677 | 21644 | 21315.361 | 345.606 | 767353 | 20.785 | 58.7 | 34.249 | 9.038 | 1232.962 | 0.009 |

**Table 4** Soft zoning attributes of optimized wards per select LGAs (for shape compactness and population homogeneity), see Figure 3D and Table 1 for the relevant map and zone design criteria respectively.

| LGA | Ward Count | Population Min | Population Max | Population Mean | Population SD | Population Total | P2A Min | P2A Max | P2A Mean | P2A SD | P2A Score | IAC Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BBA | 6554 | 2 | 4902 | 117.082 | 247.514 | | 13.856 | 13.856 | 13.856 | | 90814.888 | 0.009 |
| Dekina | 17 | 19515 | 23203 | 21466.176 | 1076.326 | 364925 | 20.785 | 59.683 | 30.246 | 8.698 | 514.174 | 0.018 |
| Ibaji | 9 | 20542 | 20932 | 20736.889 | 114.082 | 186632 | 21.885 | 35.243 | 27.607 | 4.207 | 248.466 | -0.007 |
| Kabba | 10 | 20104 | 23469 | 21579.6 | 1029.676 | 215796 | 19.245 | 73.101 | 34.86 | 18.273 | 348.604 | 0.023 |
| All 3 | 36 | 19515 | 23469 | 21315.361 | 979.089 | 767353 | 19.245 | 73.101 | 30.868 | 11.84 | 1111.244 | 0.011 |

**Table 5** The difference between the number of extant wards and synthetic wards for the three select LGAs in the study area

| LGAs | Number of Wards | | Number of extant minus number of synthetic wards |
|---|---|---|---|
| | **Extant Wards** | **Synthetic Wards** | |
| Dekina | 12 | 17 | -5 |
| Ibaji | 10 | 9 | 1 |
| Kabba | 14 | 10 | 4 |
| All 3 | 36 | 36 | - |

Without adequately controlling for the effects of these structural inequities in the existing zoning system, international sample survey programs (like the Multiple Indicator Cluster Survey (MICS) and the Demographic and Health Survey (DHS)), plans, policies, and public interventions (and so on) that are implicitly or explicitly based on these extant suboptimal administrative/political zones will therefore produce inferences/findings that are biased and misrepresentational as a function of the extent of inequity in the extant zones utilized. Weighting adjustments (like post-stratification weighting) used to correct for representational errors in the statistical analysis of sample surveys mainly account for social (and demographic) biases in complex multi-stage sampling designs of surveys (Pfeffermann, 1996, Brady et al., 2018, Campbell and Berbaum, 2010). These weighting adjustments are in themselves products of spatial zoning systems which are inherently suboptimal in Nigeria, as this study has abundantly shown. Although useful with natural or concrete groupings (like households, sex, religion etc.), weighting adjustments that are a function of suboptimal artificial zoning systems (like administrative or census enumeration zones), are likely to perpetuate and/or intensify socio-spatial biases that are inherent in the arbitrary zoning systems upon which they are based. Therefore, the use of weighting adjustments which remedy only one aspect of representational bias (i.e. the social aspect), is of little remedial effect because of the well-acknowledged cyclic and self-reinforcing relationship between the social and spatial dimensions of human society (Soja, 1980, 2010).

Indeed these extant sub-optimal administrative zoning systems are products of historical processes of inequities in political power, the effect being that population groups and/or regions that were disadvantaged/deprived or suppressed (in terms of political power) at the time of the creation or modification of these regions, suffer dire disadvantage in the resulting zoning system. For instance, the extant zoning system in Nigeria were all created by various totalitarian military regimes, most of which were led by members of the same ethno-religious group or geopolitical region of the country. These historical processes of power inequity is manifest in contemporary times, and is reinforced or perpetuated (in part) by the entrenched inequity of extant administrative/political zoning systems. Consequently, in addition to the current clamour for (constitutional) restructuring in the country, there is a need for routine redistricting of the political/administrative zoning system - a form of geopolitical restructuring. In addition to helping to resolve the currently biased zoning system, routine automated redistricting is necessitated by changing demographics and is the standard practice in many High Income Countries.

## 4. Conclusion

Even though the redesign of the extant zoning systems in Nigeria is a Political Districting Problem (PDP) which requires additional zone design criteria to the ones considered in this study (Bozkaya et al., 2011, Webster, 2013, Kalcsics, 2015, Goderbauer and Winandy, 2018), it is necessary for relevant authorities to be aware and mindful of these concerns. Consequently, instead of relying on extant zoning systems which have been found to be very suboptimal and biased in Nigeria, optimized analytical zoning systems should be developed for various applications, as a way of bypassing extant zoning problems. These will help to fully control for covert inequities that are often perpetuated by the extant zoning system in Nigeria. Agencies responsible for statistical data collection, especially those that use probability sampling techniques as well as spatial analysts are also encouraged to pay greater attention to the inherent inefficiencies of extant administrative/political zones in the country. With some places having much more number of administrative zones than others, there is a tendency for sample surveys based on these extant zoning system to over-represent the demographic and socioeconomic attributes of such places, while the attributes of other places with fewer assigned administrative zones are underrepresented and/or suppressed. Among other things, it is not likely that the usual respondent/case weighting routines employed for statistical analysis purposes are able to adequately account for this type of representational bias.


## 5. Acknowledgements

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## 6. Biography

Eleojo is currently rounding off the writing of his doctoral thesis in (quantitative) human geography. His current research project focuses on geographies of primary healthcare services in Nigeria, employing a spatial mixed methods design. Eleojo is interested in the application of advanced spatial analytics in SDG- and policy-relevant socioeconomic domains.

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