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Review of Mobile Coverage
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Abstract

Mobile technology is associated with a variety of positive development and social outcomes, and as a result reaching the "final frontier" of uncovered populations is an important policy issue. In this paper, we use the most recent available data to estimate the proportion of the population living in areas without mobile coverage globally and in selected regions and countries, and use spatial analysis to identify where these populations are concentrated. We then compare our coverage estimates to data from previous years and estimates from the most recent literature to provide a picture of recent trends in coverage expansion, considering separately the trends for coverage of urban and rural populations. We find that mobile coverage expansion rates are slowing, as easier to reach urban populations in developing countries are now almost entirely covered and the remaining uncovered populations are more dispersed in rural areas and therefore more difficult and costly to reach. This finding may support the argument that market liberalization alone will not be sufficient to expand mobile coverage to the "final frontier," and that unless rural incomes rise, some form of subsidy will likely be required to achieve full mobile coverage.

Introduction

The Global System for Mobile Communications Association (GSMA) labels the 10 to 15 percent of the world's population estimated to lack access to mobile coverage as the "the final frontier of connectivity" (GSMA, 2014). This population of individuals is widely held to be primarily located in developing countries, and especially concentrated in rural areas. Remoteness and a lack of supporting infrastructure contribute to a high cost base for the proliferation of mobile networks in most of the areas that currently lack coverage. In addition, the potential return on investment for mobile operators is sometimes not favorable due to low population densities and a largely low-income customer base (Buys, et al., 2009), hypothesized to slow (and potentially end) the expansion of mobile coverage by private mobile network operators (MNOs) in developing countries.

Reaching the "final frontier" in developing countries is an important policy issue, as mobile technology is associated with various positive economic and social outcomes (for reviews, see World Bank, 2012; Aker & Mbiti, 2010; Bhavnani, et al., 2008). However, the absence of publicly available data limits our understanding of exactly where this uncovered population is, and how much coverage trends are slowing. The most recent studies of mobile coverage and adoption across multiple developing countries present coverage data from 2010 (World Bank, 2012). Our goal is to update the literature on the state of mobile coverage rates in developing countries in Africa and Asia. We use industry coverage data from the GSMA and Collins Bartholomew and population density data from LandScan to estimate access to mobile coverage, expressed as the percentage of the population that is covered both overall and in rural and urban areas.

Identifying currently uncovered populations is most important if market returns are insufficient to induce private companies to cover the "final frontier." Revenue in these areas is unlikely to change dramatically, as population densities and income change slowly. Concerns about the commercial viability of expanding coverage to the "final frontier" has led analysts to focus on the supply side, and the cost of providing coverage. Efforts to expand mobile access include government efforts to foster stable regulatory environments and promote competition among mobile service providers (Bhavnani, et al., 2008;

Buys, et al., 2009), and the promotion of new mobile access technologies by private companies such as Google, Facebook, and Microsoft (GSMA, 2014). But it is unclear to what extent market liberalization will contribute to coverage expansion, and whether some form of subsidization or public provision is necessary if universal coverage is the goal.

Our paper is organized as follows: We begin by reviewing the literature on mobile coverage in developing countries. Next, we use the most current data to update coverage estimates, based on 2012 coverage data, of the number of people living outside of mobile coverage using the most recent available figures from proprietary data, and compare levels of coverage for urban and rural populations. We use spatial analysis to identify "uncovered" areas in different regions of Africa and Asia and in the countries of Ethiopia, Kenya, Nigeria, Tanzania, Uganda, Bangladesh, Indonesia, and Pakistan[1]. We overlay these coverage maps with data on population density to highlight areas with significant populations that do not have mobile coverage. Finally, we compare our coverage estimates to data from previous years and estimates from the most recent literature to provide a picture of recent trends in coverage expansion. Together, these contributions present an updated review of the state of mobile coverage in developing countries within Africa and Asia, to inform decisions of policy-makers and organizations interested in using mobile technology as a tool for development.

Literature Review

The hypothesized commercial benefits of mobile coverage, as recently classified in new work by Dillon, Aker, Blumenstock & Komanzi (2015), include reducing price heterogeneity across markets (Aker & Fafchamps, 2010; Jensen, 2007; Rashid & Elder, 2009), providing direct price, weather and other valuable information to farmers (Aker & Mbiti, 2010; Camacho & Conover, 2012; Dillon, 2011; Fafchamps, & Minten, 2010; Nakasone, 2014) and facilitating financial transactions through mobile money (Aker, 2014; Blumenstock, Eagle, & Fafchamps, 2014; Kendall & Voorhies, 2014; Must & Ludewig, 2010). The World Bank's 2012 "Maximizing Mobile" Report details evidence of benefits from mobile technology in seven areas: agriculture, health, finance, economic development, governance, education, and gender equality. The empirical support is thus far mixed, though the widespread and rapid adoption of mobile phones suggests that the ability to communicate, if only among family and friends, has value to customers, even if applications to markets have been slower to emerge.

Despite considerable activity over the past decade around the benefits of mobile access, less recent work has been done on mobile coverage in developing countries – possibly due to limited publicly available data. The latest country-level estimates of mobile coverage are in the World Bank's 2012 report, "Maximizing Mobile." This report includes country tables with mobile coverage figures from the International Telecommunication Union (ITU) for 2005 and 2010, when available. The World Bank estimates that 90 percent of the overall global population had mobile coverage in 2010, compared to 94 percent of the population in a subset of 100 countries with data availability in 2005 and 2010. The report analyzes these 100 selected countries and finds significant gains in coverage among low and middle income countries, from 82 percent of the population in 2005 to 91 percent in 2010. However, the report does not analyze whether or how trends in coverage expansion may be changing, focusing instead on evaluating the potential benefits of mobile technology.

We do know that as of 2010 mobile coverage rates were continuing to increase across Africa and Asia, although the rate of increase was slowing as networks expanded into less economically viable areas, such as areas with low population density, low road density, or that are not connected to the country's electricity grid (Williams, Mayer, & Minges, 2011; Bhavnani, et al., 2008). A 2010 study from the Center for Global Development (Aker & Mbiti, 2010) reports that access to and use of mobile telephony in sub-Saharan Africa increased dramatically over the past decade. The authors find that 60 percent of the population had mobile phone coverage in 2008 compared to 10 percent in 1999, though the geographic rollout of coverage has been uneven, with especially slow expansion in "Ethiopia, Somalia and the landlocked countries of Central and West Africa." Several studies find that coverage is strongly and positively associated with potential demand factors, such as population density and per capita income, and with the competitiveness of the mobile phone sector. However, cost drivers such as higher elevation and distance from main roads and urban centers are negatively associated with coverage expansion (Aker & Mbiti, 2010; Buys, et al., 2009; World Bank, 2012; Williams, Mayer, & Minges, 2011).

Much of the literature on mobile coverage contends that liberalization of mobile networks is needed to expand mobile coverage (Buys, et al., 2009; Donner, 2008). Bhavnani, et al. (2008) report that the main driver of mobile coverage growth

[1] These regions and countries were selected for individual review by the Bill & Melinda Gates Foundation's (BMGF) Financial Services for the Poor team, which initially requested this review of mobile coverage.

is private sector investment, assisted by favorable enabling legal and regulatory environments. However, they find that in many developing countries, regulatory policies and a lack of functioning institutional mechanisms hinder competition and private sector involvement in the provision of ICT infrastructure and services, especially to rural communities. Varoudakis and Rossotto (2004) describe the relative lack of liberalization of mobile networks in the Middle East and North Africa, and find a relationship between higher levels of mobile penetration and market competitiveness. Aker & Mbiti (2010) suggest that the increase in mobile coverage in Africa is related to changes in the mobile market structure of African countries. In 1999, 85% of African countries provided all international mobile traffic through an incumbent monopoly, and under 10% of countries had fully liberalized markets where MNOs were granted their own international gateway licenses. By 2009, nearly 50% of African countries had fully liberalized markets, around 25% had partially deregulated markets, and under 30% still had mobile network monopolies (Aker & Mbiti, 2010). Buys, et al. (2009) investigate the determinants of disparities in mobile coverage in sub-Saharan Africa and report that improvements in a competitiveness index are strongly related to increased mobile coverage. Williams, Mayer, & Minges (2011) find that once a country issues its fourth mobile license, penetration rates increase by an average of about 4 percentage points per year. The World Bank (2012) reports that even in countries with low mobile tariffs, lack of competition leads to lower mobile coverage, limiting mobile access.

In a 2011 World Bank study on Africa's Information and Communications Technology (ICT) infrastructure that used 2009 coverage data, Williams, Mayer, & Minges describe the current state of market liberalization across Africa as "incomplete." Although most countries have at least 3 operators, evidence exists that most countries can support more operators. The authors argue that the most important factor for increasing universal access will be maintaining competition between network providers. They maintain that this competition should be based on providing commercial incentives for operators through tax policies, for example, reducing taxes on equipment and on ICT services for remote or rural areas. The study reports that some countries have attempted subsidies through universal service fund schemes, whereby small usage fees fund network expansion into more rural areas, but recommends that implementing direct-subsidy mechanisms should be a "last resort policy measure." The authors argue that competition has proved to be a much more effective way of providing access for the majority of rural areas, while universal service funds financed from sector levies raise overall prices, thereby excluding the poorest. The authors advocate implementing cost-reduction strategies for operators such as regulatory measures for infrastructure sharing between operators, power sharing, contractual agreements between operators to sell power into local or national grids, lifting restrictions on skilled staff mobility, and subsidizing emerging technologies.

Dymond & Oestmann (2003) and Buys, et al. (2009) similarly argue that while some coverage gaps can be minimized first through liberalization, the market will not expand coverage to certain populations and regions without specific mandates or incentives by the government or other stakeholders. While Buys, et al. (2009) find that a generalized improvement in competition policy could lead to huge improvements in cell phone area coverage in sub-Saharan Africa, their simulation suggests that coverage expansion would be concentrated in areas with relatively dense populations, leaving a coverage gap for low-density rural populations. This line of research does not view market liberalization and intervention as mutually exclusive, but as sequential. The argument separates the market inefficiency gap, which can be addressed through market liberalization, and the "true access gap" in coverage for populations that will not be served "even with the most optimal, efficient and liberalized market conditions" (Dymond & Oestmann, 2003). The World Bank's approach to financing telecommunications infrastructure in the developing world follows this logic, prioritizing market liberalization and recommending targeted intervention only when necessary (World Bank, 2006). Such interventions may be needed to ensure the expansion of mobile coverage to high-cost areas where private MNOs may not see an opportunity for profit.

Williams, Mayer, & Minges (2011) report that high levels of investment in network infrastructure and a steady geographic expansion of networks have been underway in most developing countries in sub-Saharan Africa, with more than 80% of the investments made by private operators coming from companies based in Africa or the Middle East. However, they estimate that 8% of Africa's population lives in areas that would be unprofitable to service. Examples of such areas include the Central African Republic, the Democratic Republic of the Congo, Liberia, and Madagascar, which all have coverage caps greater than 25%. The study finds that a total expenditure of $15.5 billion would be required over the course of 8 years to expand basic GSM network coverage to Africa's entire population. Of this $15.5 billion, nearly half, $6.9 billion, would cover areas that are rated as potentially commercially viable, with the remainder supporting coverage expansion to unprofitable areas. As a result, the authors repeat the true access gap argument and report that "even in the most favorable policy and incentive environment, in most countries in Africa a small but significant proportion of the population will be found in areas that are not commercially viable," requiring some form of direct financial subsidy as an incentive for MNOs to expand into these areas.

Methodology

Using geographic information systems (GIS) tools in ArcGIS version 10.2, we determine the spatial extent of mobile coverage using 2012 data from Collins Bartholomew in ESRI shapefile format and WGS84 datum, and provided by the data visualization organization SpatialDev. Collins Bartholomew is a private research firm that uses industry-reported coverage data primarily from the GSM Association (GSMA), among other sources, such as directly from telecommunications companies and national telecommunications regulatory providers. GSMA data include metrics on the performance of 1,140 operators and 1,153 Mobile Network Operators (MNOs) across 3,505 networks, 65 groups, and 236 countries worldwide. Although these data are the best available and the Collins Bartholomew supplements the GSMA data with information from other sources, the data are self-reported by the mobile network provider and do not capture all providers, but only those who choose to submit their data. In spite of these limitations, the data from Collins Bartholomew are more recent and accurate than data from previous studies of mobile coverage.

We also use the LandScan 2012 High Resolution Global Population Data Set to layer population density over the coverage data, which allows us to estimate the number of people living outside of mobile coverage areas, accurate to within 1 square kilometer. Our analysis also uses data from the Global Rural-Urban Mapping Project, Version 1 (GRUMPv1) to analyze rural and urban populations living inside and outside of mobile coverage. Urban and rural areas are estimated at a 30 arc-second resolution, producing 1 km grids that define designations using a combination of variables: population counts, settlement points, and the presence of nighttime lights. Urban refers to contiguous lighted cells or approximate urban extents based on buffered settlement points for which the total population is greater than 5,000.

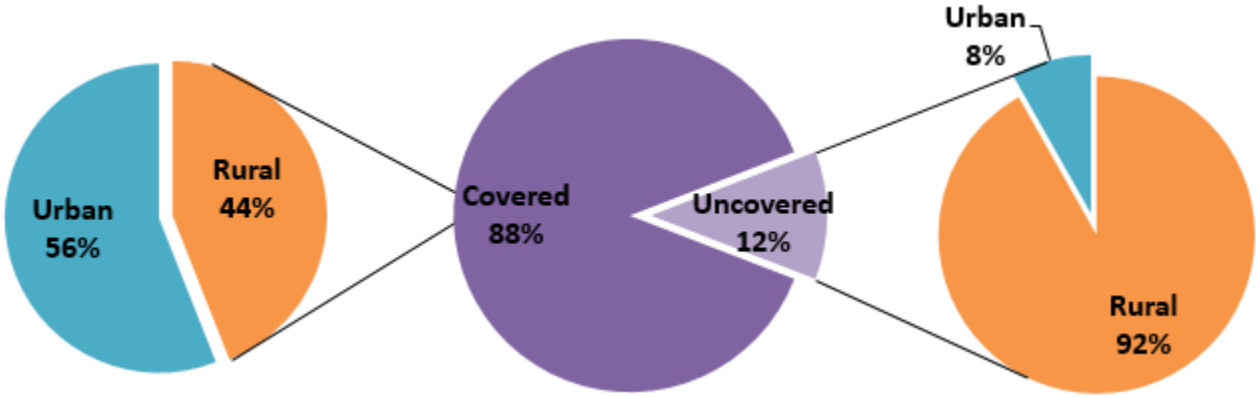
Using these data, we assess the current state of mobile coverage globally and in selected regions and countries. Where the data are available, we also compare current levels of coverage with earlier estimates from the GSMA or from previous studies in order to estimate trends in coverage expansion. This analysis answers questions about the current extent of mobile coverage, where populations lacking mobile coverage are located geographically, and how coverage has expanded in developing countries. "Original estimates" in the tables that follow refer to those either provided directly by SpatialDev using Collins Bartholomew GSMA data, or our adaptations additionally using GRUMPv1 and LandScan data.

Results

Global Mobile Coverage Estimates

Our analysis of 2012 data on population density from LandScan and mobile coverage from Collins Bartholomew indicates that 11.7 percent of the world's population, a total of just under 821 million people, live in areas without mobile coverage. Using GRUMPv1 data we find that of that 11.7 percent without mobile coverage, 91.8 percent are located in rural areas. In contrast, just 44 percent of the population with mobile coverage live in rural areas. These estimates, presented in Figure 1, clearly illustrate that the main coverage gap exists in rural areas, where 49.6 percent of the world's population are located.

Figure 1. Percentages of world population with and without mobile coverage.



Source: LandScan, 2012; Collins Bartholomew, 2012; GRUMPv1, 2012.

We compare the mobile coverage figures from our analysis to estimates from the literature of coverage in previous years. Since much of the literature focuses on mobile coverage in sub-Saharan Africa, we also include estimates of coverage in this region. These estimates are presented along with our original estimates in Table 1.

Table 1. Estimates of the percentage of the population with mobile coverage, 1999-2012

Year	1999	2003	2006	2008	2009	2010	2012
Global		61 [c]		80 [d]		90 [c]	88.3 [f]
Sub-Saharan Africa	9.1 [a,b]		54.5 [a]	60 [e]	61 [b]		67.7 [f]
Sub-Saharan Africa, Urban	17 [b]				90 [b]		95.7 [f]
Sub-Saharan Africa, Rural	5 [b]				48 [b]		57.8 [f]

[a] Buys, et al., 2009

[b] Williams, Mayer, & Minges, 2010

[c] World Bank, 2012

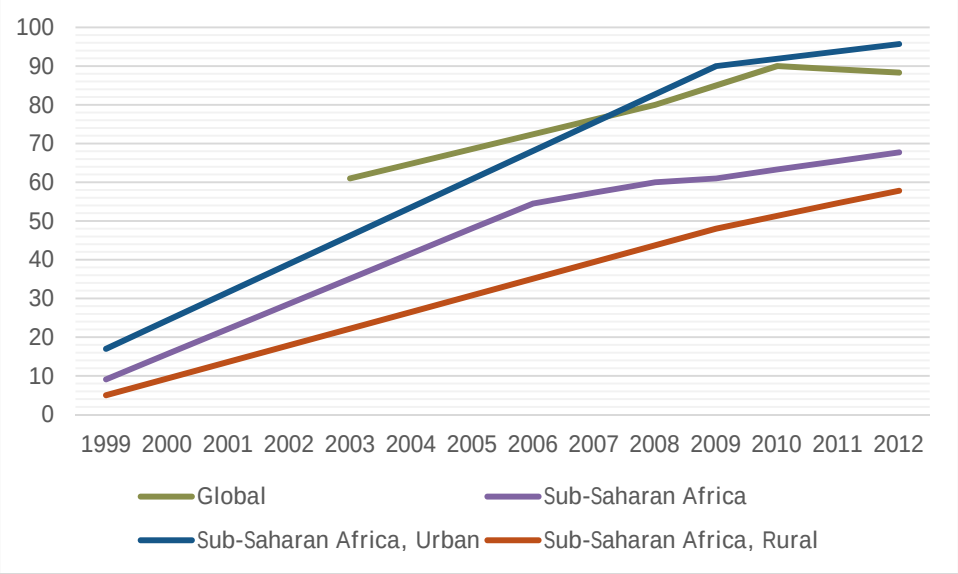
[d] Bhavnani, et al., 2008

[e] Aker & Mbiti, 2010

[f] Original estimates

Figure 2 illustrates the changes in the rates of mobile coverage expansion, using the coverage estimates from Table 1. The global population that lives in areas with mobile coverage has increased by over 27 percentage points between 2003 and 2012. This change in coverage represents a 3 percentage point average increase per year during this time period. If we divide the period in two relatively equal parts, we find a 3.8 percentage point average annual increase between 2003 and 2008, and a 2.1 percentage point average annual increase between 2008 and 2012. The rate of coverage expansion in this period is brought down by the decrease in the estimate of the percentage of the world population with mobile coverage between 2010 and 2012[2].

Figure 2. Trends in percentage of the population with mobile coverage, 1999-2012



Source: This figure was developed using the coverage estimates from Table 1. Values for years with no coverage data were estimated using the average change in mobile coverage between the years where coverage data estimates were available.

[2] The 2010 estimate that 90% of the world's population had mobile coverage was taken from the International Telecommunication Union (ITU). The fall in estimated coverage between 2010 and 2012 may be due to the use of different coverage data between the ITU and Collins Bartholomew, our data source. However, it is possible that coverage did fall. For example, population growth rates in areas without mobile coverage may have exceeded population growth in areas with mobile coverage, which is likely since most areas without mobile coverage are in developing countries with higher fertility rates. We cannot confirm the actual reason for the fall in reported mobile coverage with the data available.

In sub-Saharan Africa, 9.1 percent of the population had mobile coverage in 1999 compared to 67.7 percent in 2012, a 58.6 percentage point increase over 13 years. If we again divide this period into two parts, we find that mobile coverage increased by an average of 6.5 percentage points per year between 1999 and 2006, but by just 2.2 percentage points per year between 2006 and 2012.

If the rate of global coverage expansion from 2008 to 2012 continued, global mobile coverage would reach 100 percent by 2018. However, extrapolating the rate of coverage expansion in sub-Saharan Africa indicates that this is unlikely to happen. If coverage expansion continued at the same rate as the average from 2006 to 2012, mobile coverage in sub-Saharan Africa would not reach 100 percent of the population until 2027. Moreover, it is unlikely that coverage will continue to expand at historical rates, as reaching increasingly isolated populations will likely be more costly and less remunerative.

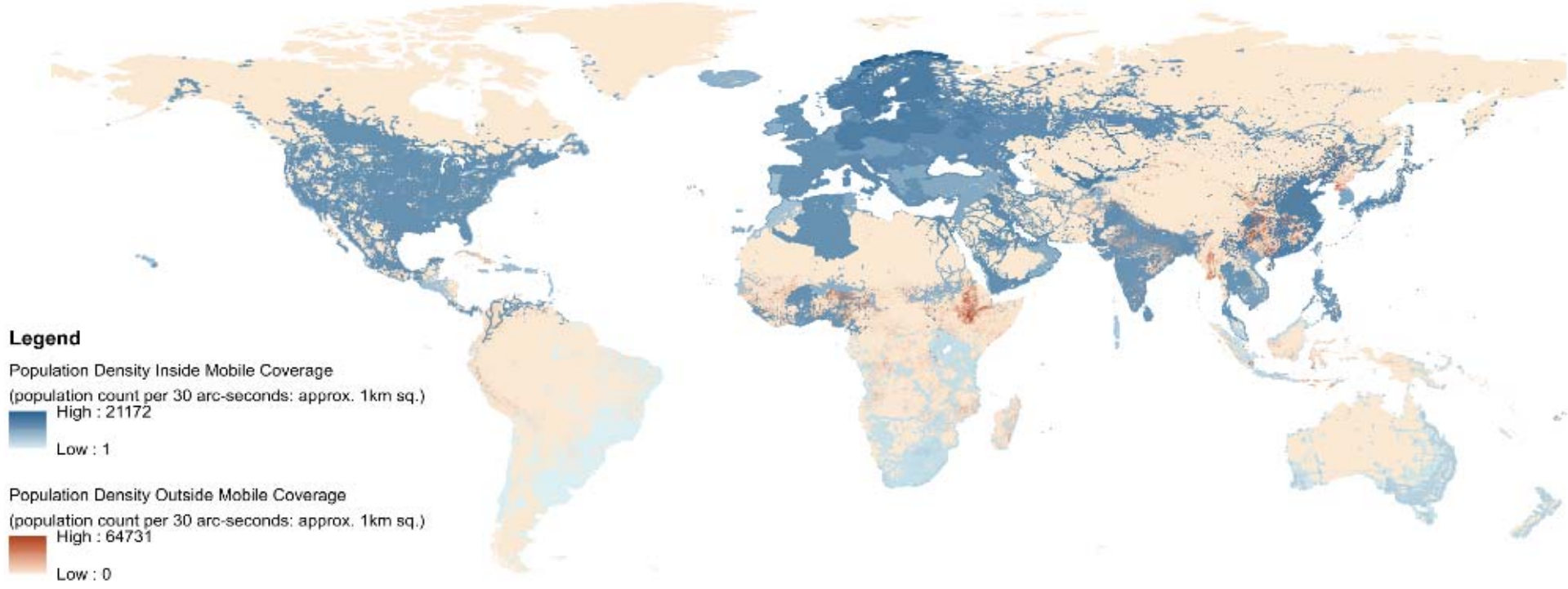
We estimate that 91.8 percent of those who still lack mobile coverage are located in rural areas. The less economically viable areas into which mobile networks are now expanding are generally characterized by low population density, low road density, difficult geography, and lack of proximate electricity grids (Williams, Mayer, & Minges, 2011; Bhavnani, et al., 2008). These factors could all combine to continue to decrease the rate of coverage expansion, as market forces no longer provide a sufficient incentive for MNOs to expand. Several studies argue that some form of government intervention may therefore be required to reach the remaining populations without mobile coverage (Dymond & Oestmann, 2003; Buys, et al., 2009, Williams, Mayer, & Minges, 2011).

An analysis of the trends in mobile coverage in urban and rural areas in sub-Saharan Africa reinforces our finding most of the remaining coverage expansion will need to take place in rural areas. While rural mobile coverage has greatly increased, the majority of the expansion of coverage to date has taken place in urban areas. The percentage of the urban population in sub-Saharan Africa with mobile coverage increased from 17 in 1999 to 95.7 in 2012, an increase of 78.7 percentage points over 13 years. For rural populations, the percentage with mobile coverage increased by 52.8 percentage points over this time period. As more of the urban population has gained mobile coverage, the overall rate of coverage expansion has slowed, to just 1.9 percentage points per year between 2009 and 2012. While the rate of coverage expansion to rural populations is higher, it is still relatively low at 3.3 percentage points per year. At these rates, 100 percent of the urban population would have mobile coverage by 2015, while the rural population would not have full coverage until 2026.

The populations living without mobile coverage are not spread evenly in rural areas, and future rates of coverage expansion will depend on the characteristics of where these populations are located. Figure 3 presents a map of global population density in areas with and without mobile coverage. Populations with mobile coverage are shaded in blue, with more densely populated areas represented by darker shadings. Populations without mobile coverage are shaded in orange. Figure 3 shows that the majority of the populations in North America, Europe, Australia, and the Middle East and North Africa live in areas with mobile coverage. There are some small concentrations of populations without mobile coverage in South America, Southern Africa, and Central Asia, but the majority of the global population without mobile coverage is concentrated in East, West, and Central Africa and in South, East and Southeast Asia.

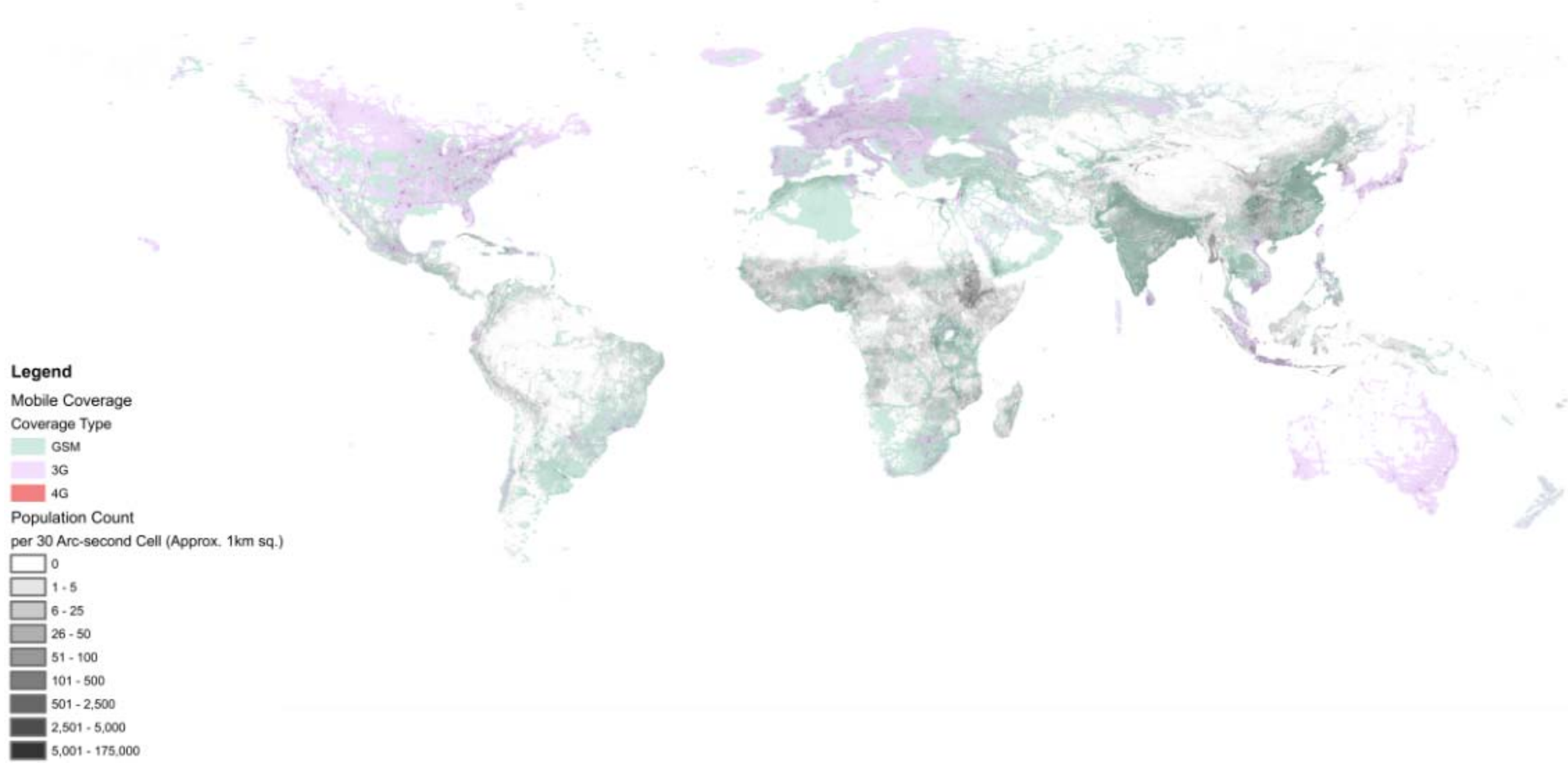
Figure 4 provides greater detail on the different types of mobile coverage globally. Most high-income countries are largely covered by third-generation (3G) networks, which allow for faster mobile data connections. This coverage is shown by the areas shaded in purple. Such coverage is becoming more common in middle-income countries such as Indonesia and South Korea, and in large cities worldwide. The spread of 3G and even 4G coverage has the potential to greatly add to the benefits of mobile coverage as connections become faster and information becomes easier to access. However, the most common form of mobile coverage remains the Global System for Mobile Communications (GSM), the second-generation digital cellular networks that replaced analog cellular networks and that have developed over time to include data communications. This coverage is shown by the areas shaded in green, which primarily cover main population centers and transportation routes such as roadways, rivers, and coastal areas. Areas shaded in gray in Figure 4 highlight where populations without mobile coverage are concentrated.

Figure 3. Global population density of areas with and without mobile coverage.



Source: SpatialDev, 2014.

Figure 4. Global population density of areas with different types of mobile coverage.



Source: SpatialDev, 2014.

Regional Mobile Coverage Estimates

Similarly to Figure 3, Figure 4 shows that most concentrations of populations living without mobile coverage are located in East, West, and Central Africa and in South, East and Southeast Asia. However, Figure 4 more clearly shows that there are also populations without mobile coverage in South and Central America and in parts of the Middle East, North Africa, and Central Asia. More detailed coverage maps of selected regions are included in Appendix A[3]. Populations living in areas without mobile coverage are represented by the areas covered by shades of gray.

Table 2 presents 2012 estimates of mobile coverage in the main global regions with populations living outside of coverage. The majority of the remaining 30.4 percent of the world's population living outside coverage is located in Russia and China. The table confirms the impression from the above coverage maps that East, West, and Central Africa and South and Southeast Asia are the primary regions with large populations living outside of mobile coverage, with 60.5 percent of the global uncovered population. However, while there are large populations living outside of coverage in all of these regions, the level of coverage varies widely, from a high of 92 percent of the population covered in South Asia to a low of just 54.4 in Central Africa.

Table 2. Regional estimates of the percentage of the population with mobile coverage (2012)

Region	Percent of World's Population Living Outside Coverage	Percent of Population Outside Coverage in Region	Percent of Rural Population Outside Coverage in Region	Percent of Urban Population Outside Coverage in Region	Number of People Living Outside of Coverage in Region (Millions)
West Africa	9.7%	24.6%	34.2%	1.4%	79.2
Southern Africa	1.7%	14.7%	26.7%	0.5%	13.7
Central Africa	8.1%	45.6%	61.7%	4.7%	66.2
East Africa	14.6%	39.5%	44.5%	13.2%	119.4
North Africa	1.1%	4.4%	11.3%	0.4%	8.9
Central America & Caribbean	1.1%	11.1%	20.0%	4.0%	9.4
South America	5.4%	11.2%	33.5%	2.4%	44.4
South Asia	17.0%	8.0%	12.0%	1.4%	139.3
Southeast Asia	11.1%	14.7%	22.0%	3.7%	90.8
Total, Selected Regions	69.6%	-	-	-	571.3

Source: Original estimates.

The majority of the uncovered populations in these regions are located in rural areas. In all regions except for East Africa, less than 5 percent of the urban population lacks mobile coverage. On the other hand, a much larger percentage of the rural populations do not have coverage. These patterns indicate that continued coverage expansion in these regions will become more difficult and costly as MNOs move from covering the densely-concentrated urban populations with relatively good infrastructure to more dispersed rural populations that may be difficult to reach and that lack roads and electricity infrastructure to complement coverage expansion. These coverage patterns further support the argument that external support will be needed to incentivize MNOs to expand their networks to reach these populations.

[3] These regions were selected for individual review by the Bill & Melinda Gates Foundation's (BMGF) Financial Services for the Poor team, which initially requested this review of mobile coverage.

National Mobile Coverage Estimates

The Financial Services for the Poor (FSP) team at the Bill and Melinda Gates Foundation requested a closer analysis of eight developing countries in order to evaluate differences in national-level mobile coverage trends that are not evident in aggregated regional-level figures.

Table 3. National estimates of the percentage of the population with mobile coverage (2012)

Country	Percent of World's Population Living Outside Coverage	Percent of Population Outside Coverage in Country	Percent of Rural Population Outside Coverage in Country	Percent of Urban Population Outside Coverage in Country	Number of People Living Outside of Coverage in Country (Millions)
Bangladesh	0.1%	0.5%	0.8%	0.0%	0.9
Pakistan	1.0%	4.3%	7.8%	0.4%	7.6
Indonesia	4.6%	15.5%	26.0%	1.2%	38.1
Ethiopia	9.9%	89.3%	95.5%	41.8%	81.5
Kenya	0.4%	8.8%	11.5%	0%	3.4
Uganda	0.1%	3.0%	3.4%	0%	1.1
Tanzania	0.4%	7.3%	8.8%	0%	3.4
Nigeria	4.7%	22.9%	31.9%	0.0%	38.9
Total, Selected Countries	21.3%	-	-	-	175.1

Source: Original estimates.

This national-level coverage analysis confirms that the majority of uncovered populations are concentrated in rural areas. In fact, data from three of these countries indicates that 100 percent of their urban populations have mobile coverage, and in four others urban coverage is over 98 percent. Only in Ethiopia does a large proportion of the urban population lack mobile coverage.

Ethiopia stands out with a much lower rate of overall coverage than any of the other countries. In fact, Ethiopia alone accounts for nearly 10 percent of the world's uncovered population, and over 68 percent of the population living outside of coverage in East Africa. While Indonesia and Nigeria also have large populations without mobile coverage, these are largely in rural areas. According to Williams, Mayer, & Minges (2011), a key contributing factor to the low rate of coverage in Ethiopia is the communications monopoly enjoyed by Ethio Telecom, the state-owned telecommunications company, supporting the argument that market liberalization is critical for coverage expansion. Recent news releases indicate that the network plans to partner with Ericsson, Huawei, and ZTE to expand coverage in Ethiopia to 85% of the population (Geeska Afrika Online, 2014), but data on coverage levels more recent than 2012 is not available.

Buys, et al. (2009) provide estimates of the rates of mobile coverage for sub-Saharan African countries in 1999 and 2006. Their study uses mobile coverage data from the GSMA and population data from GRUMPv1. We also use population data from GRUMPv1, but our coverage estimates are based on data from Collins Bartholomew, which incorporates data from the GSMA as well as individual telecommunications companies. As a result, the coverage estimates should be comparable but may be affected by differences in data sources. The World Bank (2012) provides coverage estimates for 2005 from the International Telecommunication Union (ITU)[4], and we include these data for Bangladesh, Pakistan, and Indonesia. Table 4 combines the Buys, et al. (2009) and World Bank (2012) data with our 2012 coverage estimates, and presents calculations of the rates of coverage growth for the periods in which data is available.

[4] The World Bank (2012) report does not describe what method is used by the ITU to estimate levels of coverage.

Table 4. Changes in the mobile coverage in selected sub-Saharan African countries

Country	Percent of Population with Mobile Coverage, 1999[a]	Percent of Population with Mobile Coverage, 2005[b]/2006[a]	Percent of Population with Mobile Coverage, 2012[c]	Average Annual Growth in Coverage, 1999-2012 (percentage points/year)	Average Annual Growth in Coverage, 1999-2006 (percentage points/year)	Average Annual Growth in Coverage, 2006-2012 (percentage points/year)
Bangladesh	-	80% [b]	99.5%	-	-	2.8
Pakistan	-	36% [b]	95.7%	-	-	8.5
Indonesia	-	90% [b]	84.5%	-	-	-0.8
Ethiopia	0.0%	10.1% [a]	10.7%	0.8	1.4	0.1
Kenya	0.0%	91.8% [a]	91.2%	7.0	13.1	- 0.1
Uganda	10.0%	96.9% [a]	97.0%	6.7	12.4	0.0
Tanzania	3.0%	55.7% [a]	92.7%	6.9	7.5	6.2
Nigeria	0.0%	59.7% [a]	77.1%	5.9	8.5	2.9

[a] Buys, et al., 2009

[b] World Bank, 2012

[c] Original estimates

The findings on the rates of coverage expansion in the selected sub-Saharan Africa countries reflect our earlier findings on sub-Saharan Africa as a whole. Coverage expansion was primarily concentrated in the early 2000s, with average growth as high as 13.1 percentage points per year in Kenya. Nigeria and Tanzania are still experiencing significant average annual growth in mobile coverage, but rates of coverage expansion since 2006 are uniformly lower, and are nearly 0 in Ethiopia, Kenya, and Uganda. In Kenya we find a fall in mobile coverage, which may indicate that the population in areas without coverage has grown more quickly than the population in areas with coverage during this time period.

In most of these countries, the slowdown in the rate of mobile coverage expansion can be explained by the increasing difficulty of reaching the remaining populations without coverage. Kenya, Uganda, and Tanzania all have coverage levels of over 91 percent, meaning there is no longer much room for fast coverage expansion, especially as in all of these countries all urban populations currently have mobile coverage. Nigeria still has 22.9 percent of its population living outside of mobile coverage, but almost 100 percent of this population lives in rural areas. Ethiopia again stands out because, although the vast majority of the population lacks mobile coverage, the average rate of coverage expansion between 2006 and 2012 was just 0.1 percentage points per year.

We cannot estimate changes in the rates of coverage expansion for the other three targeted countries without earlier coverage estimates. However, we find that Bangladesh significantly expanded coverage between 2005 and 2012, and now has nearly universal coverage. Pakistan increased coverage very rapidly during this period, but the rate of expansion must be slowing down as they now have a high level of coverage, and 95 percent of those that remain without coverage are located in rural areas. Our estimates indicate that the proportion of the population with mobile coverage in Indonesia actually fell between 2005 and 2012. This fall may be due to greater population increases in areas without coverage, or may be due to measurement differences between the ITU, the source of the 2005 estimates, and Collins Bartholomew, the source of our 2012 estimate.

Conclusion

A common argument in the literature is that mobile network liberalization, or allowing greater competition between mobile network operators (MNOs), would lead to higher levels of mobile coverage (Aker & Mbiti, 2010; Bhavanani, et al., 2008; Buys, et al., 2009; Donner, 2008; Varoudakis & Rossotto, 2004; World Bank, 2012). However, several analysts (Dymond & Oestmann, 2003; Williams, Mayer, & Minges, 2011) contend that external support beyond market liberalization will be

needed to incentivize MNOs to expand their networks to achieve universal mobile coverage. A World Bank study estimated that $15.5 billion would be needed to expand mobile coverage to Africa's entire population, including $8.6 billion to cover areas that the authors classify as not commercially viable (Williams, Mayer, & Minges, 2011). The authors contend that private MNOs will not expand into these areas without some form of financial subsidy.

Our estimates from the recent available data indicate that 11.7 percent of the world's population, a total of just under 821 million people, live in areas without mobile coverage. Using GRUMPv1 data we find that of this 11.7 percent without mobile coverage, 91.8 percent are located in rural areas. This finding has significant implications for the likelihood of market-led coverage expansion. The less economically viable areas into which mobile networks are now expanding are generally characterized by low population density, low road density, difficult geography, and lack of proximate electricity grids (Williams, Mayer, & Minges, 2011; Bhavnani, et al., 2008). These factors could all conspire to continue to decrease the rate of coverage expansion, as market forces no longer provide a sufficient incentive for MNOs.

Regional and national analyses of trends in the percentage of the population living in areas with mobile coverage indicate that coverage expansion rates are falling. For example, sub-Saharan Africa experienced a 58.6 percentage point increase in mobile coverage between 1999 and 2012. However, if we divide this period into two parts, we find that mobile coverage increased by an average of 6.5 percentage points per year between 1999 and 2006, but by just 2.2 percentage points per year between 2006 and 2012, as coverage in urban areas reached 95.7 percent in 2012 compared to 57.8 percent in rural areas. In our analyses of the global regions with the majority of the world's uncovered populations, we found that in all regions except for East Africa (due to the very low rates of coverage in Ethiopia), less than 5 percent of the urban population lacks mobile coverage. Mobile coverage expansion rates are slowing as MNOs move from covering the densely-concentrated urban populations with relatively good infrastructure to more dispersed rural populations that are more difficult and costly to reach. Thus, as Williams, Mayer, & Minges (2011) and others contend, in the absence of significant increases in rural income or decreases in the costs of reaching rural populations, some form of subsidy is likely required in order to achieve full mobile coverage.

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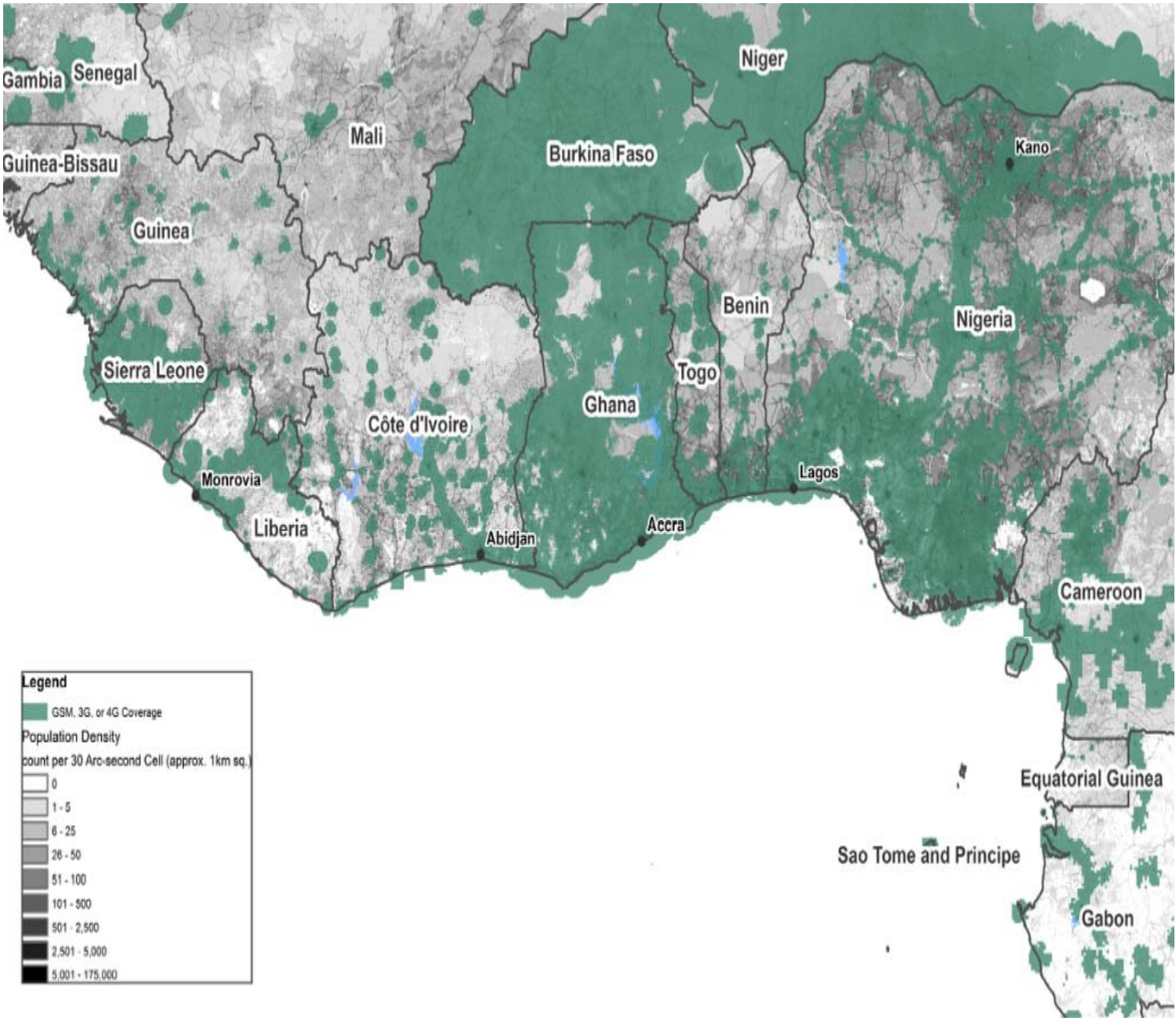
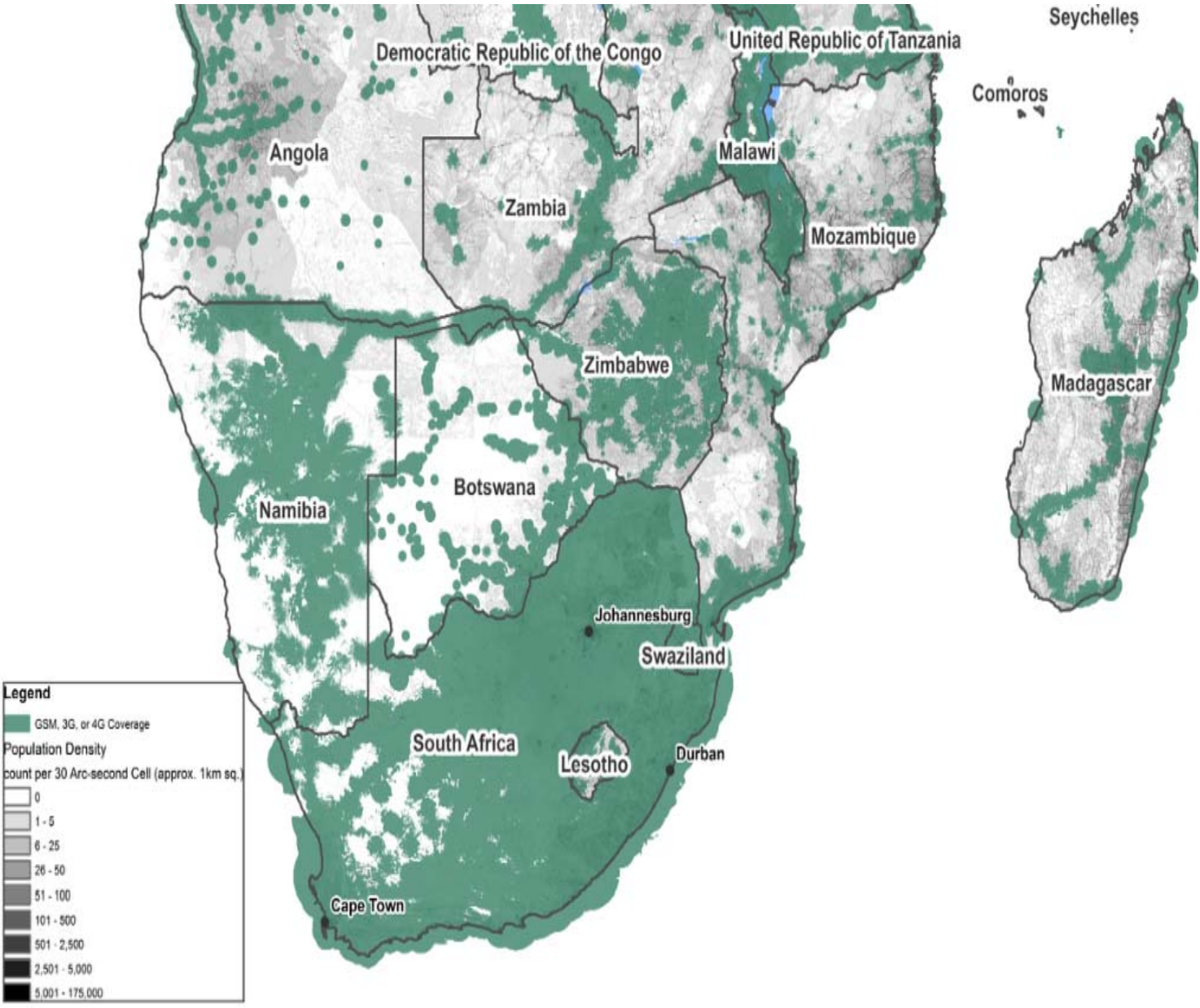
Appendix A. Coverage Maps for Selected Regions

Figure A.1. West Africa mobile coverage and population density



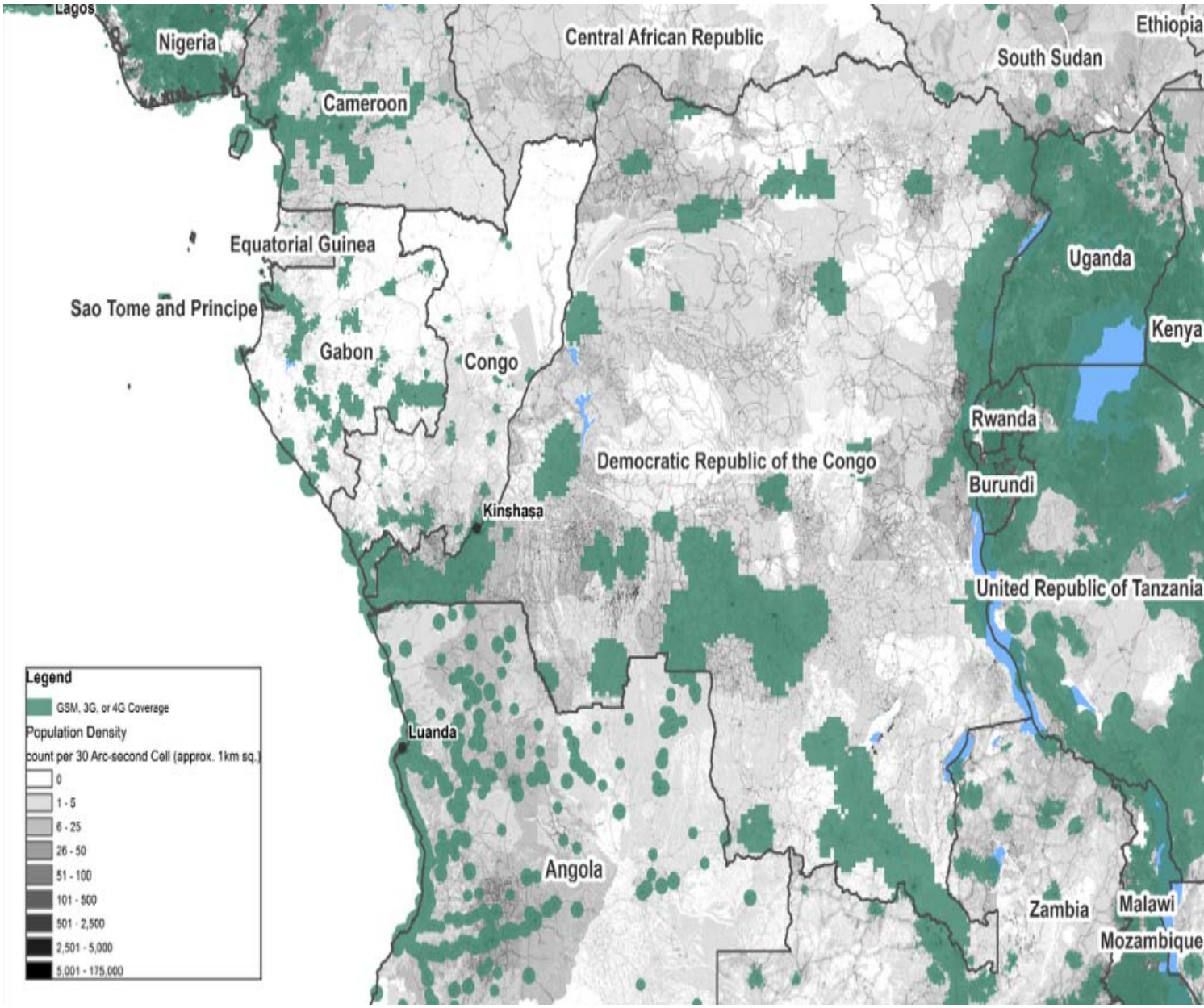
Source: SpatialDev Estimates, 2014.

Figure A.2. Southern Africa mobile coverage and population density



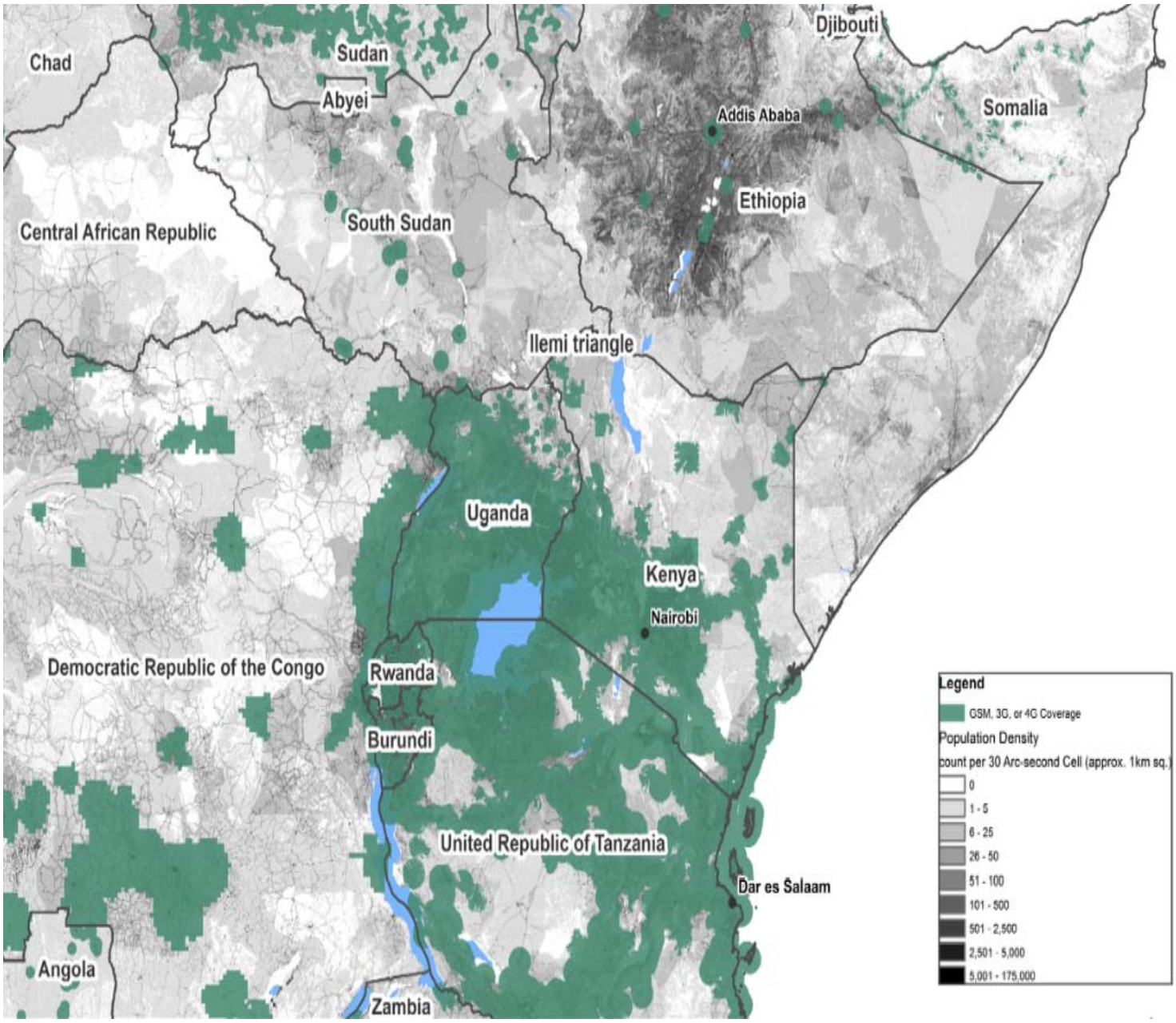
Source: SpatialDev Estimates, 2014.

Figure A.3. Central Africa mobile coverage and population density



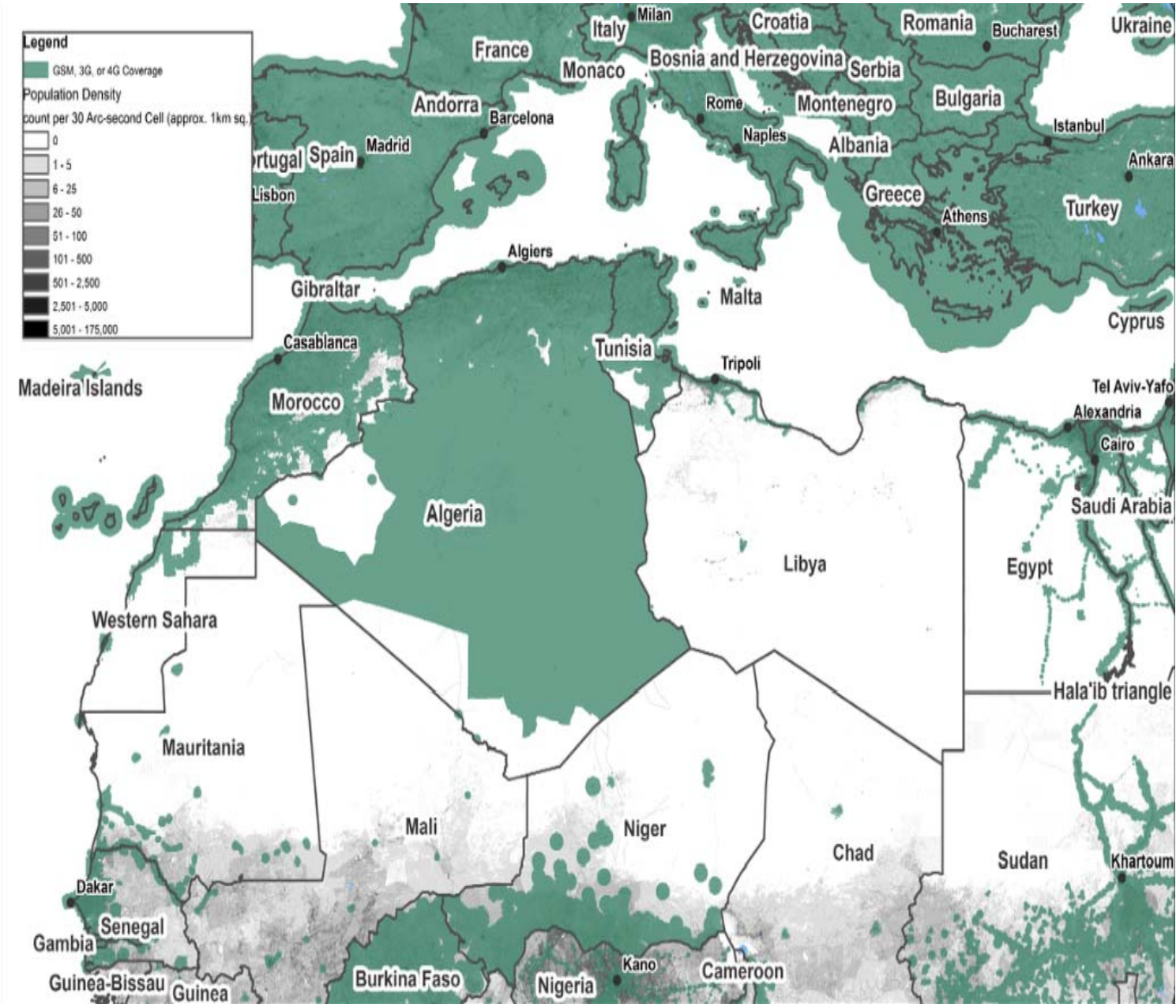
Source: SpatialDev Estimates, 2014.

Figure A.4. East Africa mobile coverage and population density



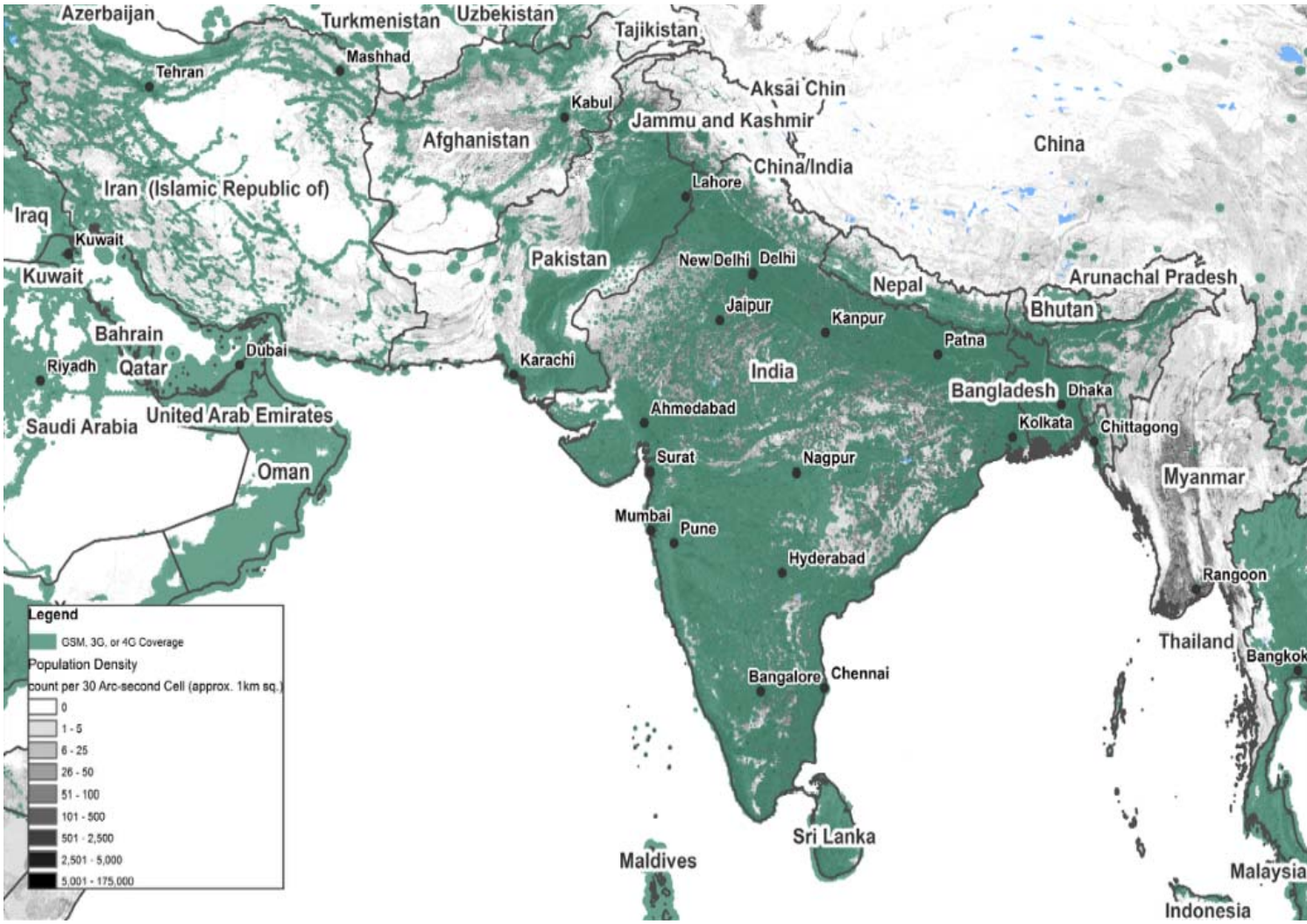
Source: SpatialDev Estimates, 2014.

Figure A.5. North Africa mobile coverage and population density



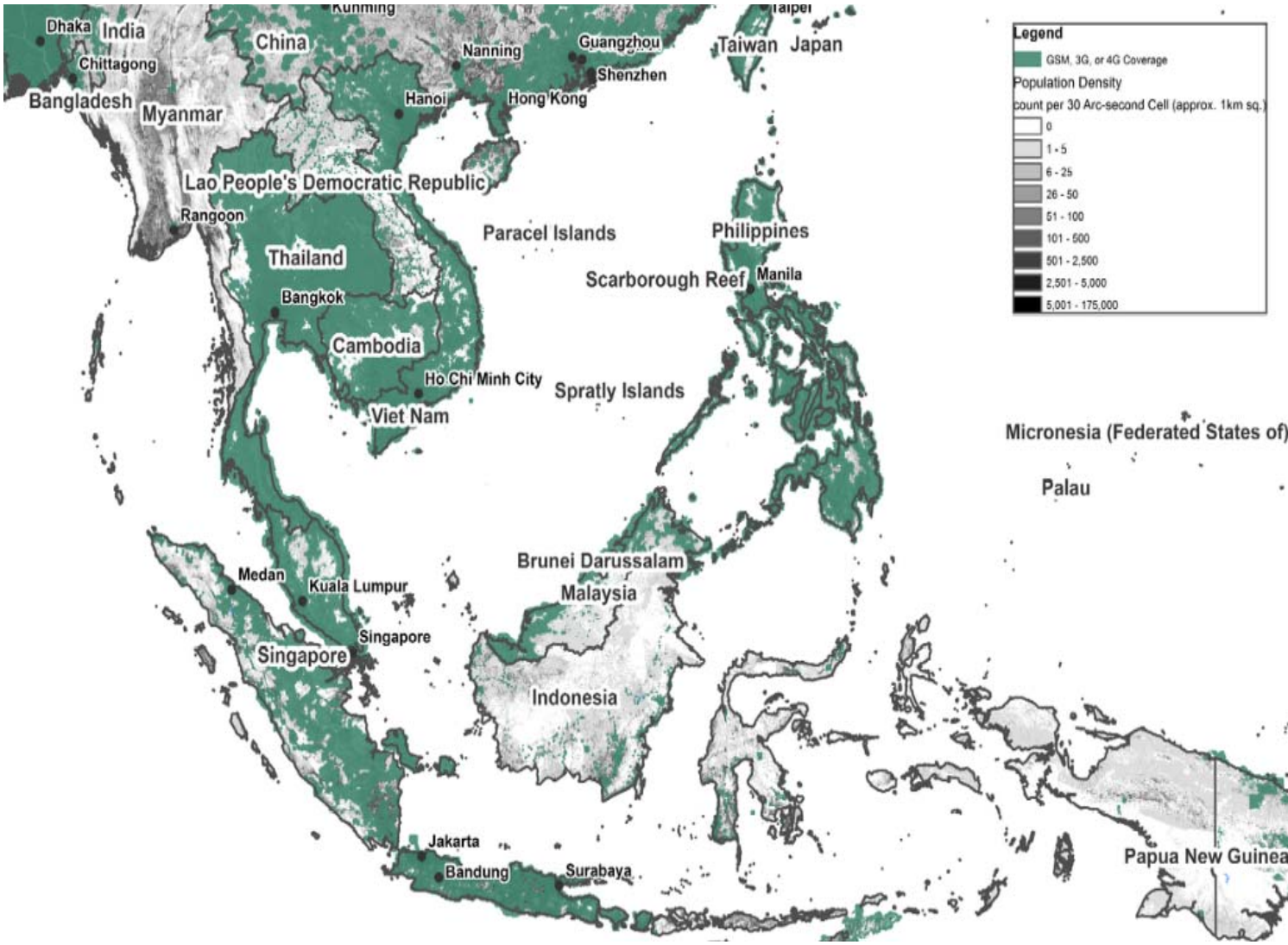
Source: SpatialDev Estimates, 2014.

Figure A.6. South Asia mobile coverage and population density



Source: SpatialDev Estimates, 2014.

Figure A.7. Southeast Asia mobile coverage and population density



Source: SpatialDev Estimates, 2014.