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Estimating District GDP in Uganda

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Executive Summary

This brief introduces district-level GDP and GDP per capita estimates for Uganda's 116 districts[1] utilizing a method based on models using imagery of nighttime lights and agricultural data. Several approaches for estimating grid-level GDP were tested. After comparing model outputs across methods, the **Enhanced Light Intensity Model** was chosen as the best performing model by analysts at the Frederick S. Pardee Center for International Futures at the University of Denver.[2]

Key takeaways from the Enhanced Light Intensity Model:

Results related to Gross Domestic Production (GDP) per capita:

- The distribution of GDP per capita in Uganda is heavily skewed. Only 14 districts have GDP per capita values above the population-weighted national average ($580) and 102 are below the average. This equates to roughly 4 in 5 people (or 29 million) living in districts with GDP per capita estimates below the national average. [3]
- Wakiso has the largest GDP per capita in Uganda ($3,250), followed by Kampala ($2,655) and Mukono ($1,738). Kagadi ($56), Alebtong ($64), and Otuke ($66) are the three poorest districts based on this model.
- 6 of the 10 poorest districts per capita are in Northern Uganda. Kalangala and Buvuma -- island districts in Lake Victoria -- are also among the 10 poorest districts in Uganda.

Results related to GDP:

- The top 19 economies in Uganda make up 75% of the total GDP of Uganda, leaving the remaining 25% of the national economy coming from 97 districts.
- Karamoja's collective GDP accounts for less than 1% of Uganda's total GDP.
- GDP is heavily concentrated in Central Uganda. Kampala (22.5%), Wakiso (20.8%), and Mukono (5.3%) account for nearly half of Uganda's total GDP (20.8 billion US$ in 2014), while comprising only about 10% of Uganda's population.
- Kampala and the South Central region account for an outsized proportion of Uganda's GDP relative to its population size, meaning that it is a significantly more productive region in Uganda. Kampala is roughly 5% of Uganda's population, but it generates 22.5% of its GDP; the South Central region comprises 11.4% of Uganda's population and produces 27.5% of the country's GDP.
- Of the ten largest district economies, seven are in Central Uganda.

[1] This analysis is based on 115 districts plus Uganda's capital city, Kampala, as of 30 June 2017.

[2] To see this comparative analysis, please refer to Uganda Subnational GDP Estimation: Final Report.

[3] All estimates in this analysis are for 2014, and the unit is 2011 US$ at Market Exchange Rates.

Section 1: Motivation

Why are GDP estimates for Uganda's districts important?

Gross Domestic Product, or GDP, is a measure of the total goods and services produced in a country annually. GDP has been the most widely used metric of national economic progress for over a half century. Only data measuring national-level GDP and GDP per capita exist for Uganda.

These estimates were not developed to serve as a thought exercise. Rather, there is a clear interest in understanding how GDP and GDP per capita are distributed throughout Uganda to target poverty interventions and bring greater prosperity to more people. These estimates can also shed light on how human development is distributed throughout Uganda.[4,5] GDP per capita has a very strong correlation with the Human Development Index, particularly for low-income countries.[6]

Why use spatial modeling to generate these estimates?

There are many challenges to the collection of data measuring GDP. Cross-country measurements of GDP lack standardized accounting methods and have inconsistent data collection methodologies.[7,8] As a result, many researchers have used satellite imagery to develop globally-consistent proxies to understand and evaluate the relationship between human activity and the environment.

Nighttime light intensity has emerged as a key dataset for understanding human activity from a distance. Nighttime lights have been used as a proxy for subnational GDP in a variety of African contexts, including South Africa[9], Nigeria[10], Kenya[11], and Rwanda[12]. In a metaanalysis of its

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[4] Ebener, S., Murray, C., Tandon, A., & Elvidge, C. (2005). From wealth to health: modelling the distribution of income per capita at the sub-national level using night-time light imagery. International Journal of Health Geographics 4(5).

[5] Ghosh, T., Anderson, S., Elvidge, C., Sutton, P. (2013). Using nighttime satellite imagery as a proxy measure of human well-being. Sustainability (5), 4688-4717.

[6] Deb, Surajit. (2015). Gap between HDI and GDP: are the rich country experiences different from the poor? IARIW-OECD Special Conference Paper.

[7] Henderson, J. V., Storeygard, A., & Weil, D. N. (2012). Measuring economic growth from outer space. The American Economic Review, 102(2), 994-1028.

[8] Min, B. (2008). Democracy and light: Electoral accountability and the provision of public goods. Annual Meeting of the Midwest Political Science Association.

[9] Ghosh, T., Anderson, S., Elvidge, C., Sutton, P. (2013). Using nighttime satellite imagery as a proxy measure of human well-being. Sustainability (5), 4688-4717.

[10] Obikili, Nonso. (2015). An examination of subnational growth in Nigeria: 1999-2012. South African Journal of Economics, 83(3), 335-356.

applications, Huang et al. (2014) concluded that nighttime light images could help measure and monitor human settlements, urban population, energy and electricity consumption, gas emission, forest fires, and the impacts of military actions and natural disasters.[13]

Section 2: Data

Spatial data

The Enhanced Light Intensity Model makes use of remote sensing data from the Defense Meteorological Satellite Program-Operational Line Scanner (**DMSP-OLS**) and the LandScan Global Population Project (**LandScan**).

DMSP-OLS contains stable, cloud-free coverage light emissions data, and it has been widely used for socioeconomic analysis because it contains consistent, longitudinal, and global data with high resolution (per km^2).[14] Each square kilometer grid contains relative digital number (DN) values from 0 to 63, which indicates the intensity of nighttime lights. The light intensity dataset is based on an average annual value for light intensity per km^2. One critical benefit to the use of nighttime lights is its resolution; nighttime lights data offer a glimpse at human activity at the km^2 level – far lower than GDP data tend to exist.

The LandScan Project produces worldwide estimates of grid-level, "ambient" population density. Ambient population is a temporally-averaged notion of population tallying, which takes into account the mobility of population (where individuals work, eat, shop, travel, etc.). National censuses are conducted residentially, and they do not attempt to capture the mobility or activity of populations. Additionally, national censuses often release their results with limited resolution below the national level, as is the case with Uganda.[15,16]

Agricultural data

The Enhanced Light Intensity Model uses district-level agricultural data to supplement the spatial data in the model. This is because agricultural activity is not as light intense as commercial activities, so it is underrepresented in a model based solely on nighttime lights.

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[11] Bundervoet, T., Maiyo, L., & Sanghi, A. (2015). Bright lights, big cities: measuring national and subnational economic growth in Africa from outer space, with an application to Kenya and Rwanda. World Bank Policy Research Working Paper 7461.

[12] Ibid.

[13] Huang, Q., Yang, X., Bin, G. l., Yang, Y., & Zhao, Y. (2014). Application of DMSP/OLS nighttime light images: A meta-analysis and a systematic literature review. Remote Sensing, 6(8), 6844-6866.

[14] Image and Data processing by NOAA's National Geophysical Data Center. DMSP data collected by the US Air Force Weather Agency.

[15] Rose, A. & Bright E. (2014). The LandScan Global Population Distribution Project: current state of the art and prospective innovation. Oak Ridge National Laboratory.

[16] Sutton, P., Elvidge, C., Obremski, T. (2003). Building and evaluating models to estimate ambient population density. Photogrammetric Engineering and Remote Sensing, 69(5), 545-553.

Agricultural production in Uganda represents around 25 percent of total economic output.[17] Taken together, nighttime lights (representing higher value-add economic activity) and agricultural production (an important aspect of Uganda's economy) provide a broad-based estimate of economic activity at the subnational level. This forms the conceptual foundation for the Enhanced Light Intensity Model.

Section 3: Method

The Enhanced Light Intensity Model is based on the following assumptions:

- Nighttime light intensity is positively correlated with industrial and commercial activity.
- Productivity is non-uniform across locations, and the degree of light intensity is correlated with the level of productivity in urban areas.
- All non-agricultural GDP (or GDP not generated from agriculture, livestock, forestry, and fishing) is coming from pixels that generate a minimum of 1 on the digital number threshold from DMSP-OLS.
- Rural pixels, which register a 0 digital number from DMSP-OLS, produce the agricultural GDP of Uganda's districts.

A common method for estimating the value of agriculture is taking the production of each crop and multiplying by its respective market price. Rather than analyzing data for all crops in Uganda (which only exist to an extent), a representative subset of crops was chosen to estimate the relative agricultural value of each district. A mix of annual crops, perennial crops, and livestock were measured, including: coffee, cotton, tobacco, cattle, maize, millet, sorghum, rice, beans, cow peas, soya beans, groundnuts, sim sim, banana (food), cassava, sweet potatoes, and Irish potatoes.

Each district's agricultural GDP contribution – or agricultural value ratio – is determined by the ratio of a district's agricultural value (production * price) over the total national agricultural GDP.

EQUATION 1. AGRICULTURAL VALUE RATIO

$$DistrictAgriculturalValueRatio = \frac{\sum_{i=1}^{17} X_i * Y_i}{NationalTotalAgriculturalGDP}$$

where: $X = crop\ production\ by\ type\ (17\ types\ included)$

$Y = average\ crop\ price\ by\ type$

Enhanced Light Intensity Model estimates were produced for 2014 based on the following steps:

[17] The World Bank Group. (2016). World Development Indicators. Washington, D.C.

1. Classified the nighttime light pixels of Uganda from the DMSP-OLS dataset by their digital number (DN) into urban (DN > 0) or rural (DN=0).
2. Used the urban/rural pixel categorization to extract the rural population data from LandScan data.
3. Separated the GDP data into agricultural and non-agricultural categories, based on the value added from agriculture in Uganda nationally.
4. Applied the agricultural value ratios of each district to the rural pixels found in its corresponding district boundary.
5. With a GDP estimate derived for every pixel in Uganda, the urban and rural regions pixels were merged. Estimates were then aggregated into Uganda district shapefiles for district-level estimates. All results were normalized based on Uganda national GDP data for 2014.

Equations 2 and 3 demonstrate how the pixel-level estimates were generated.

EQUATION 2. URBAN PIXEL VALUE

$$NonAgriculturalGDPperGrid = \frac{DMSPDigitalNumberPerGrid}{TotalNighttimeUrbanLightIntensity} * UgandaNationalNonAgriculturalGDP$$

EQUATION 3. RURAL PIXEL VALUE

$$AgriculturalGDPperGrid = \frac{LandScanPopulationPerGrid}{TotalNationalRuralPopulation} * UgandaNationalAgriculturalGDP * DistrictAgricultureValueRatio$$

It is critical to highlight that these estimates have been normalized based on Uganda's total GDP value from 2014. By definition, GDP excludes the informal sector, so this approach does not account for informal economic activity, which is a key source of primary and supplemental income for many Ugandans.

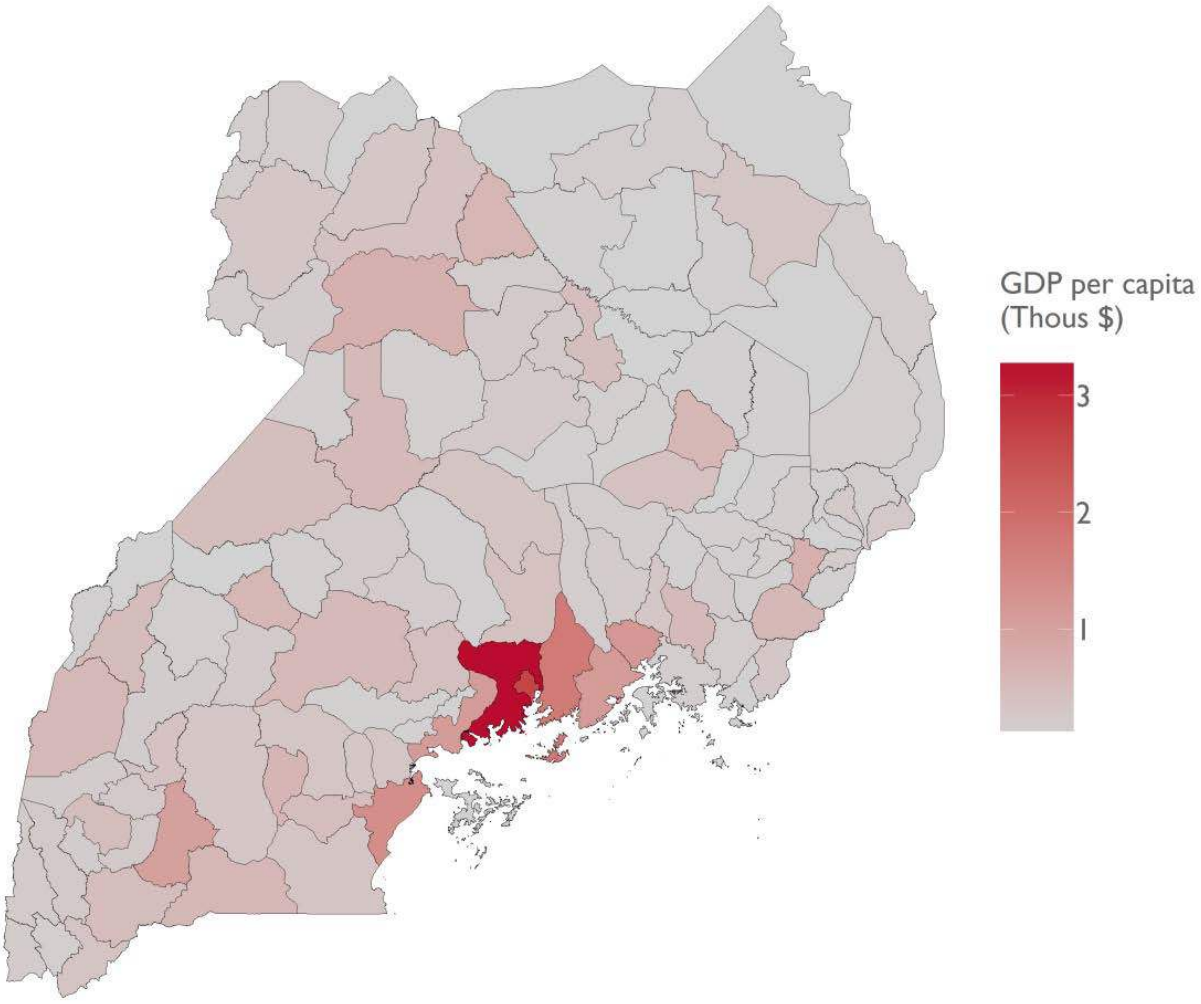
Section 4: Results

GDP per capita results

In per capita terms, the distribution of GDP in Uganda is heavily skewed. Only 14 districts have GDP per capita values above the national average. This equates to roughly 4 in 5 people (or 29 million) living in districts with GDP per capita estimates below the national average.[18]

[18] The estimates from this work do not reflect the intra-district GDP per capita distribution, so this should be interpreted as the number of individuals living in districts which have an average GDP per capita estimate below the national average.

FIGURE 1. MAP OF GDP PER CAPITA ESTIMATES FOR DISTRICTS



Source: Enhanced Light Intensity Model

Wakiso has the largest GDP per capita ($3,250), followed by Kampala ($2,655) and Mukono ($1,738). Central and Western Uganda tend to have larger per capita GDP estimates than Eastern and Northern Uganda.

FIGURE 2. TOP 10 DISTRICTS BY GDP PER CAPITA ESTIMATES

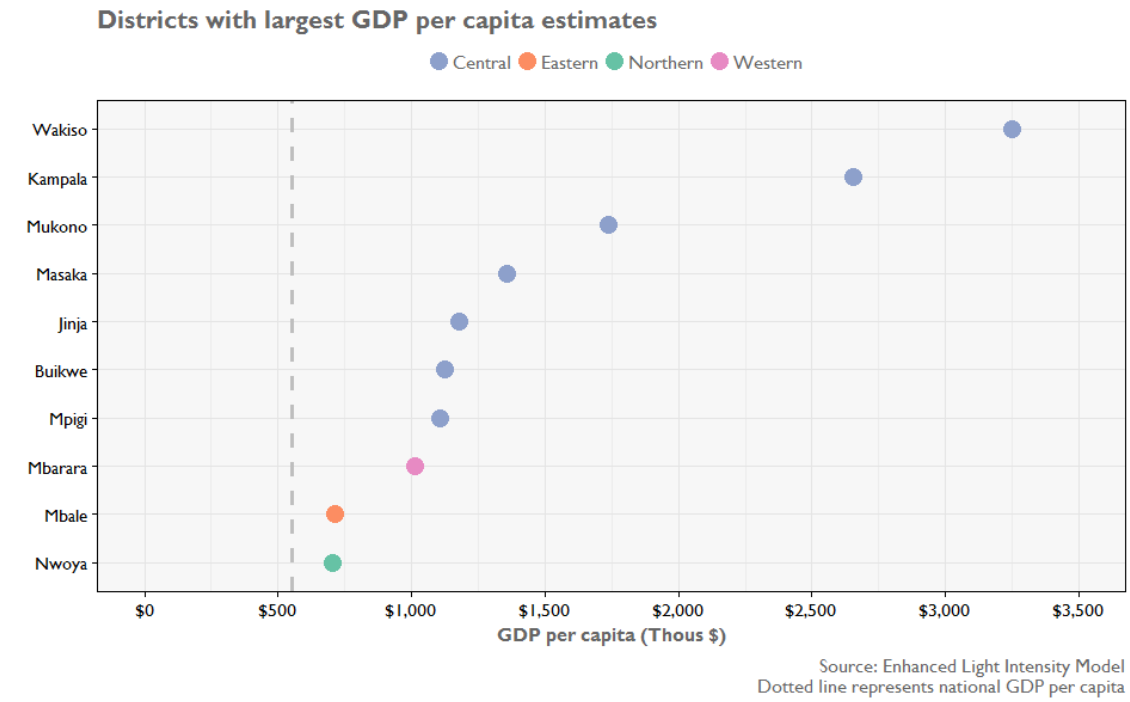
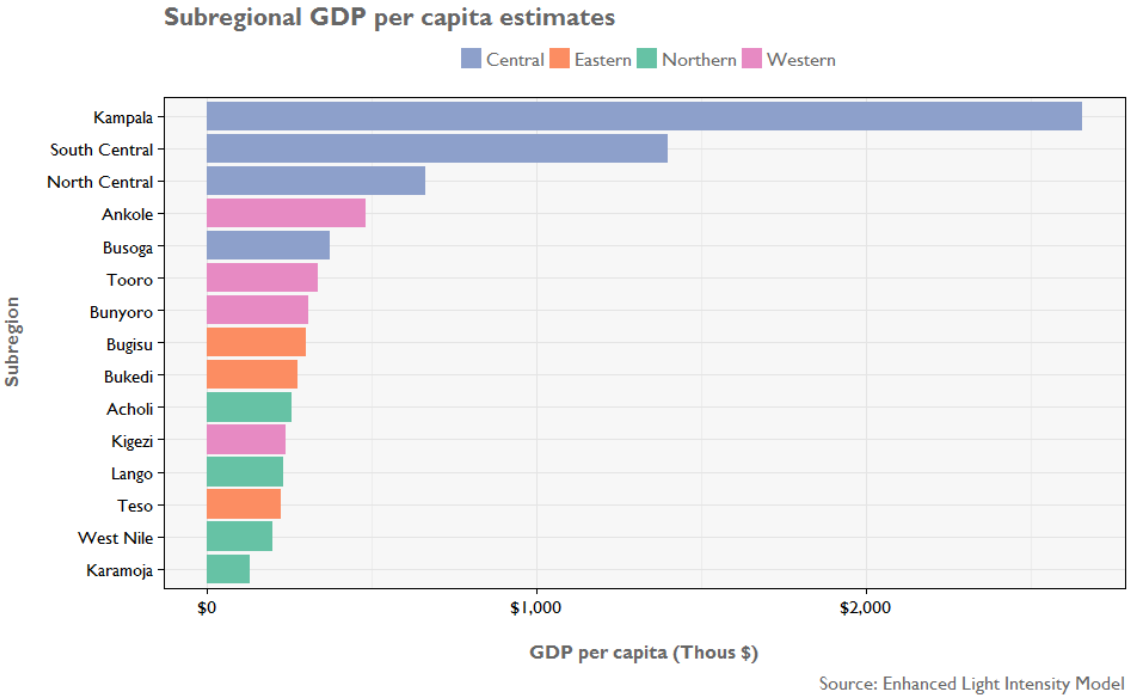


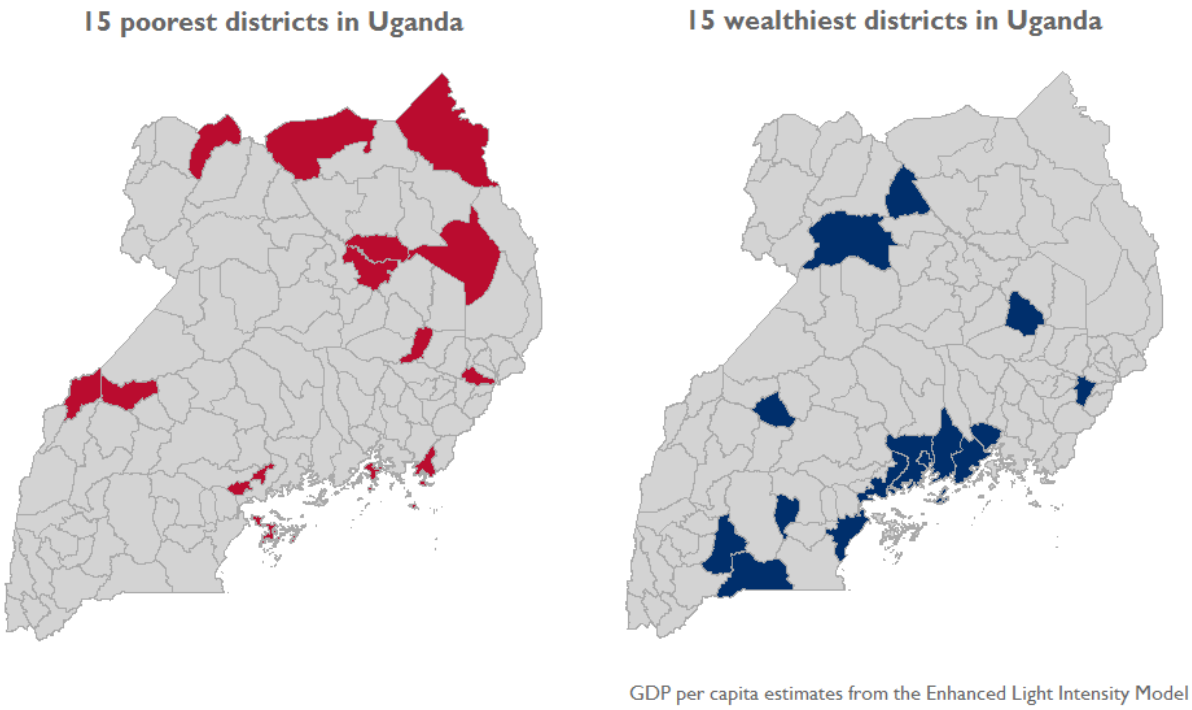
FIGURE 3. SUBREGIONAL GDP PER CAPITA ESTIMATES



Six of the ten poorest districts per capita are in Northern Uganda. Kalangala and Buvuma -- island districts in Lake Victoria -- are also among the 10 poorest districts in Uganda.

This model suggests that, on average, 19 districts have people living on less than $10 per month and in some places just $5 per month.

FIGURE 4. MAPS OF POOREST AND WEALTHIEST DISTRICTS BY GDP PER CAPITA

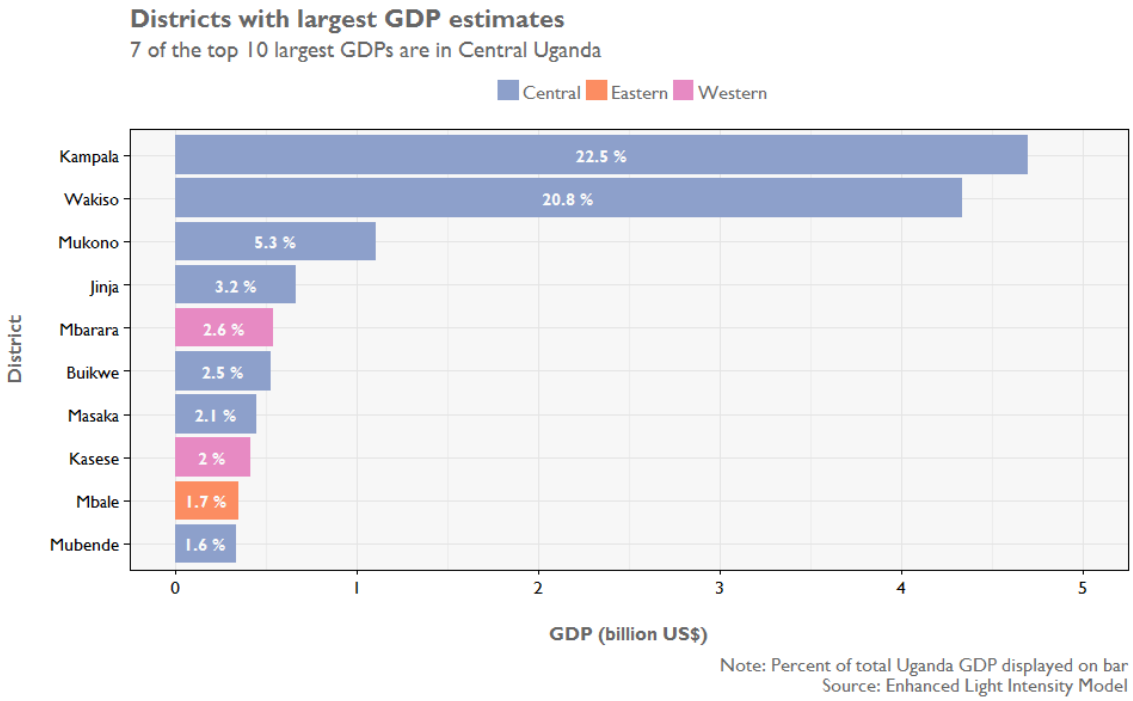


GDP per capita estimates from the Enhanced Light Intensity Model

GDP results

GDP is heavily concentrated in Central Uganda. The Enhanced Light Intensity Model estimates that Kampala (22.5%), Wakiso (20.8%), and Mukono (5.3%) account for nearly half of Uganda's total GDP. Of the ten largest district economies, seven are in Central Uganda.

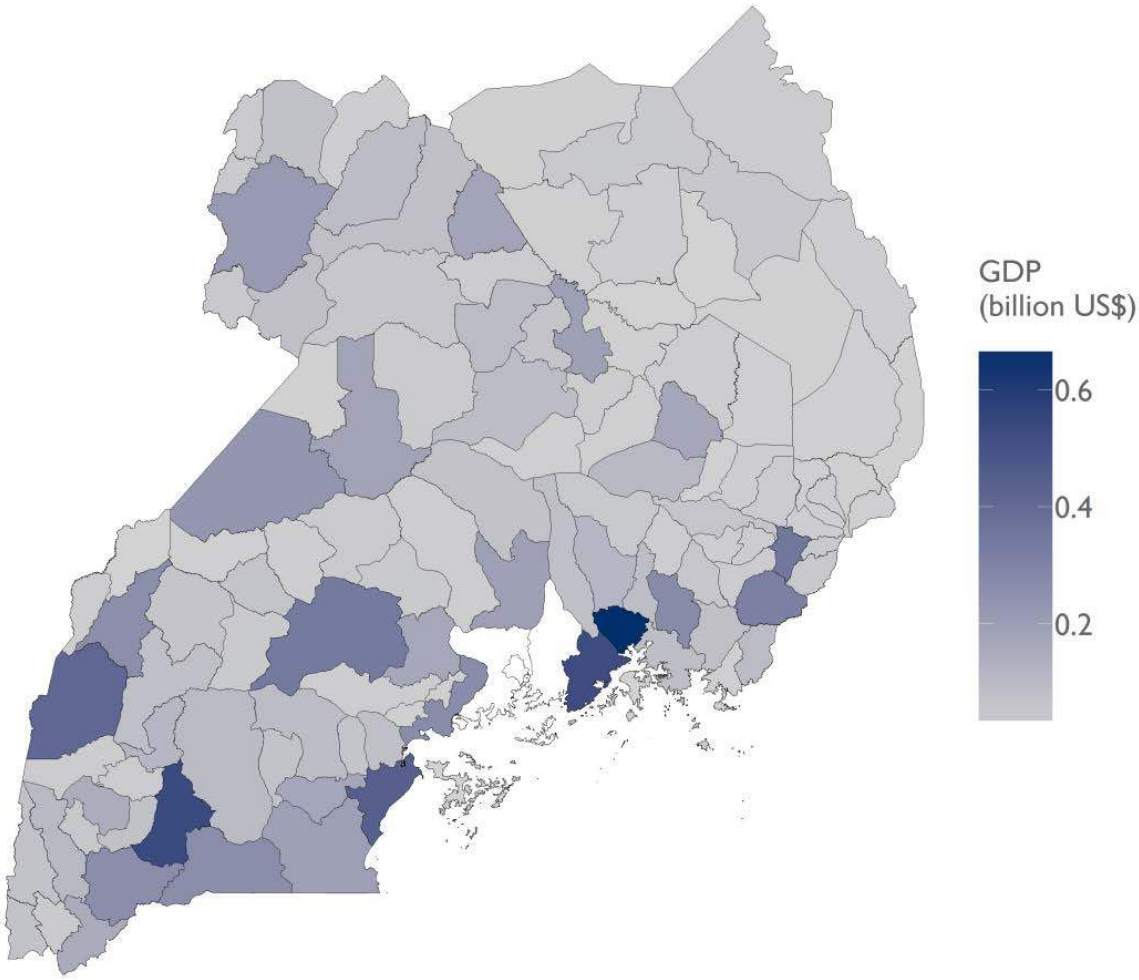
FIGURE 5. TOP 10 LARGEST ECONOMIES IN UGANDA



Subregionally, **Kampala and South Central subregion account for an outsized proportion of Uganda's GDP relative to its population size**, meaning that they are significantly more productive subregions in Uganda. Kampala is roughly 5% of Uganda's population, but it generates 22.5% of its GDP; the South Central region comprises 11.4% of Uganda's population and produces 27.5% of the country's GDP.

The top 19 district economies in Uganda make up 75% of the total GDP of Uganda, with the remaining 25% of the national economy coming from 97 districts. Put another way, these 19 districts have roughly one-third of the total population and generate three-quarters of the total GDP.

FIGURE 6. MAP OF DISTRICT GDP ESTIMATES IN 2014, EXCLUDING KAMPALA, WAKISO, & MUKONO



Note: Removing districts with more than $1 billion annually
Source: Enhanced Light Intensity Model

Outside of Central Uganda, regional economies emerge. Mbarara (Western/Ankole), Kasese (Western/Tooro), and Mbale (Eastern/Bugisu) each have top 10 economies and are the largest economies in their respective subregions. Arua (West Nile), Lira (Lango), and Gulu (Acholi) all emerge as district hubs in Northern Uganda. Collectively, these districts make up roughly one-third of Northern Uganda's economy.

Regionally, Northern Uganda makes up slightly more GDP than Eastern Uganda (7.7% and 6.9%, respectively), but Eastern Uganda is more productive based on its population size. Karamoja's collective GDP accounts for less than 1% of Uganda's total GDP.

TABLE 1. REGIONAL AND SUBREGIONAL SHARES OF GDP AND POPULATION

Region / Subregion	Total GDP (billion US$)	Total Population (millions)	% of GDP	% of Population
Central	**14.4**	**13.511**	**69.1**	**37.6**
Busoga	1.409	3.769	6.8	10.5
Kampala	4.695	1.769	22.5	4.9
North Central	2.569	3.877	12.3	10.8
South Central	5.726	4.096	27.5	11.4
Eastern	**1.443**	**5.426**	**6.9**	**15.1**
Bugisu	0.528	1.764	2.5	4.9
Bukedi	0.525	1.906	2.5	5.3
Teso	0.39	1.756	1.9	4.9
Northern	**1.602**	**7.641**	**7.7**	**21.3**
Acholi	0.414	1.614	2	4.5
Karamoja	0.138	1.076	0.7	3
Lango	0.486	2.12	2.3	5.9
West Nile	0.565	2.832	2.7	7.9
Western	**3.403**	**9.341**	**16.3**	**26**
Ankole	1.574	3.26	7.5	9.1
Bunyoro	0.553	1.794	2.7	5
Kigezi	0.408	1.716	2	4.8
Tooro	0.869	2.571	4.2	7.2

Conclusion

The results of the Enhanced Light Intensity Model indicate some emerging themes for those interested in district-level policy in Uganda:

- **The distribution of GDP per capita in Uganda is heavily skewed:**
  - Only 14 districts have GDP per capita values above the national average. Six of the ten poorest districts are in Northern Uganda.
- **GDP is concentrated in Central Uganda:**

    - Kampala, Wakiso, and Mukono account for nearly half of Uganda's total GDP, while comprising only about 10% of Uganda's population.
- **The top 19 economies in Uganda make up 75% of the total GDP of Uganda**, leaving the remaining 25% of the national economy coming from 97 districts.
- **Outside of Central Uganda, regional economies emerge:**
    - Mbarara (Ankole), Kasese (Tooro), and Mbale (Bugisu) each have top 10 economies and are the largest economies in their respective subregions. Arua, Lira, and Gulu collectively produce roughly one-third of Northern Uganda's GDP.

These results can help us understand how GDP and per capita GDP are distributed throughout Uganda to target poverty interventions and bring greater prosperity to more people.

Annex A: Results Tables

TABLE 2. RESULTS OF ENHANCED LIGHT INTENSITY MODEL, ARRANGED BY GDP PER CAPITA

District	GDP (million US$)	GDP per Capita (US$)
Wakiso	4,335.30	$3,250
Kampala	4,695.50	$2,655
Mukono	1,106.30	$1,738
Masaka	446.9	$1,360
Jinja	669.2	$1,180
Buikwe	529.1	$1,124
Mpigi	266.9	$1,109
Mbarara	540.1	$1,013
Mbale	351.8	$712
Nwoya	45.4	$704
Lyantonde	61.8	$614
Gulu	173.3	$599
Kibaale	59.3	$587
Soroti	167.9	$586
Isingiro	263.4	$568
Tororo	312.9	$558
Mubende	339.1	$546
Kasese	415.9	$540
Masindi	178.8	$514
Iganga	271.9	$511
Kabarole	257.5	$486
Ntungamo	260.6	$463
Bushenyi	143.2	$457
Lwengo	165.3	$455
Hoima	229.6	$449
Lira	190.9	$449
Mityana	163.8	$419
Luwero	193.2	$385
Serere	99.4	$382
Ibanda	105.9	$359

District	GDP (million US$)	GDP per Capita (US$)
Amuru	71.4	$356
Kabale	148.9	$347
Nakasongola	63.8	$334
Rakai	193.5	$325
Ssembabule	84.6	$314
Kalungu	74.6	$313
Kotido	43.8	$300
Luuka	81.9	$290
Kiruhura	91.1	$289
Adjumani	83.4	$277
Busia	88.3	$266
Bukomansimbi	55.6	$265
Arua	214.8	$261
Sheema	66.8	$258
Bukwo	18.6	$250
Rukungiri	100.6	$244
Buhweju	29.7	$241
Kapchorwa	25.3	$236
Kole	56.5	$230
Apac	83.9	$228
Oyam	88.8	$223
Kyegegwa	37.4	$223
Kyankwanzi	35.7	$216
Kanungu	62.5	$210
Kiboga	37.3	$206
Bududa	37.2	$199
Kamuli	105.3	$194
Kisoro	62.6	$192
Namutumba	47.3	$188
Kamwenge	73.1	$186
Mitooma	44.9	$186
Rubirizi	28.3	$186

District	GDP (million US$)	GDP per Capita (US$)
Nebbi	71.5	$183
Bugiri	71.1	$181
Yumbe	67.1	$181
Omoro	27.4	$179
Moroto	20.3	$177
Maracha	36.4	$169
Mayuge	77.3	$168
Kayunga	72.8	$165
Kitgum	40.9	$165
Koboko	31.2	$162
Zombo	39.4	$159
Bukedea	27.4	$146
Buyende	41.5	$145
Kween	14.3	$144
Kiryandongo	33.8	$142
Dokolo	26.8	$141
Kyenjojo	53.9	$137
Nakapiripirit	18.7	$137
Rubanda	33.9	$136
Pallisa	51.1	$134
Kakumiro	20.3	$126
Buliisa	12	$125
Budaka	24.6	$124
Gomba	24.3	$121
Butaleja	28	$117
Amolatar	16.9	$117
Amudat	11.2	$117
Bulambuli	17.2	$116
Nakaseke	23.4	$112
Manafwa	40.8	$111
Bundibugyo	25.4	$109
Kaliro	25.1	$108

District	GDP (million US$)	GDP per Capita (US$)
Kibuku	20.5	$107
Abim	5.4	$107
Kaberamaido	19.7	$104
Amuria	24.8	$97
Katakwi	16.6	$94
Pader	19.6	$92
Kumi	22	$90
Namayingo	19.1	$89
Butambala	14.3	$88
Agago	23	$85
Ngora	12.8	$84
Sironko	22.9	$81
Buvuma	4.9	$77
Moyo	21.9	$76
Kaabong	27.2	$75
Lamwo	13	$75
Ntoroko	5.7	$71
Napak	11.3	$68
Kalangala	3.5	$67
Otuke	7	$66
Alebtong	15.5	$64
Kagadi	19	$57