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Mobility analysis to support the Government of Ghana in responding to the COVID-19 outbreak

Insights into the effect of mobility restrictions in Ghana using anonymised and aggregated mobile phone data

Report #3

27 April 2021

Flowminder Foundation
Ghana Statistical Service
Vodafone Foundation

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Overview

Anonymised and aggregated data from Mobile Network Operators (MNOs) is a key data source for understanding the mobility patterns of populations, and improving decision-making and scenario planning during the COVID-19 epidemic. This data can be analysed in near real-time and provide an overview of mobility patterns across all of Ghana. Flowminder is working with Ghana Statistical Service (GSS) to produce mobility indicators from aggregated and anonymised data provided by Vodafone Ghana. These indicators can be used by the government and public health experts to inform response efforts.

We published a first report with initial insights on 03 April 2020, showing how population movements had been affected by nationwide school closures and a nationwide ban on public gatherings, and then by a lockdown in parts of the Greater Accra Metropolitan Area and the Greater Kumasi Metropolitan Area. We followed this with a subsequent report on 15 May 2020, extending the analyses to show how population movements changed after the lockdown measures were lifted. In this third report, we extend the analyses to show how population movements were impacted during the second wave of the pandemic in the remainder of 2020, into early 2021.

We first provide a description of results and show changes in mobility within each region, and then changes in subscriber presence in each region. Then we look at changes of travel between regions and changes in the distance travelled nationwide. After this description of results, we discuss limitations of the data source for mobility analysis and offer possible interpretations for the changes observed.

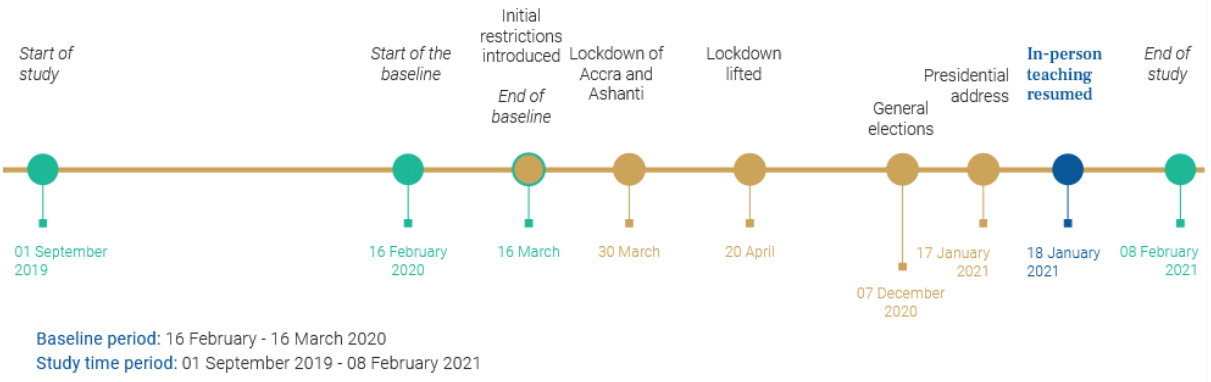
Details of the analysis methods are included in the Annexes at the end of this report.

As of the date of publication (27 April 2021), Ghana Health Service reports the number of confirmed COVID-19 cases in Ghana to be 91,709.

Timeline of COVID-19 interventions in Ghana

The timeline of events in Ghana is as follows:

Monday 16 March 2020	Initial restrictions - school closures and bans on public gatherings - introduced nationwide.
Friday 27 March	President announces that lockdown measures will be introduced in parts of the Greater Accra Metropolitan Area and the Greater Kumasi Metropolitan Area the following Monday.
Monday 30 March	Lockdown measures are imposed in parts of the Greater Accra Metropolitan Area and the Greater Kumasi Metropolitan Area.
Sunday 19 April	President announces that lockdown measures will be lifted the following day, although nationwide school closures and bans on public gatherings will continue.
Monday 20 April	Lockdown measures lifted, nationwide school closures and bans on public gatherings still in place.
Monday 07 December	General elections held in Ghana.
Sunday 17 January 2021	Presidential address about Ghana experiencing a second wave of COVID-19.
Monday 18 January	In-person teaching resumed in schools and universities.



Understanding the graphs

In all of the figures in this report, we show the time period from 01 September 2019 to 08 February 2021. This encompasses the period where restrictions were in force, and includes the previous year to contextualise the recovery period. We also denote weekends by a filled white circle, mark public holidays with a yellow dot, and indicate the period used for the baseline with a shaded region in each graph.

The values for all metrics are displayed as change relative to the baseline value. The baseline value is calculated as the median value of the metric between 16 February and 16 March 2020 inclusive, i.e. during the four weeks prior to the introduction of the first restrictions. We refer to this four-week period as the 'baseline period'. We use the median to define the average, rather than the mean, as the median is not strongly affected by outliers. For line graphs, we display percentage change from the baseline. For maps, we display a qualitative scale over the median absolute change from the baseline.

For context, we have included below a map showing the regions of Ghana.

Changes in travel within regions

We analyse travel within each region by counting the number of trips that are made between each pair of districts in that region. These trips will mainly comprise short-distance, routine daily trips that correspond to activities such as commuting to work, shopping, and entertainment. The method used to count these trips is described in Annex 1.

The number of trips between any two districts in Greater Accra:

- Increased significantly, relative to the lockdown period, immediately after lockdown measures were lifted.
- Continued to increase over the remainder of the year, but remained below levels from the comparable period September 2019 - February 2020.
- Began to fall following a small spike prior to the state funeral for former president Rawlings on 27 January 2021.

Key events: 1) Initial restrictions nationwide (school closures, bans on public gatherings), 2) Lockdowns imposed for parts of greater Accra metropolitan area, greater Kumasi metropolitan area, 3) Lockdown lifted, 4) Election, 5) Presidential address

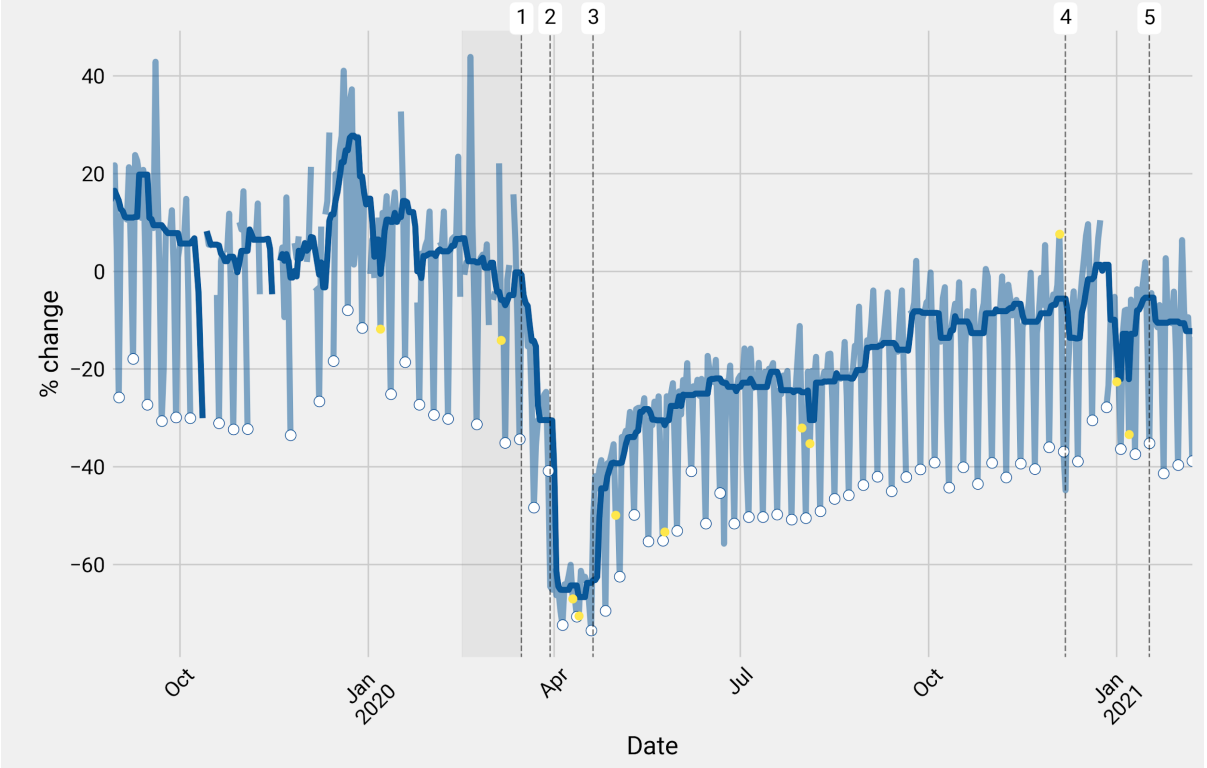


Figure 1: Percentage change in the number of trips between any two districts in Greater Accra, each day, relative to the baseline value overlaid with a seven day rolling median. Yellow and white dots denote public holidays and weekends respectively, with the baseline period indicated by a shaded region.

The number of trips between any two districts in Ashanti Region:

- Increased immediately by 20%, relative to the lockdown period, after lockdown measures were lifted. However, this level was still 30% below the baseline level although some part of this decrease may be due to a decrease in phone activity relative to the baseline period (see Annex 2 for details of the median travelled distance which somewhat ameliorates this ambiguity).

- Continued to increase up to the beginning of August, stabilising at 20% below the baseline level through July-September, before gradually increasing over the remainder of the year, but remaining 21-25% lower than the previous year.
- Low levels in September are notable in contrast to levels during September 2019 (32% lower).
- Low levels in December–January 2021 are notable in contrast to the same period the previous year (21-25% lower than 2019/20).

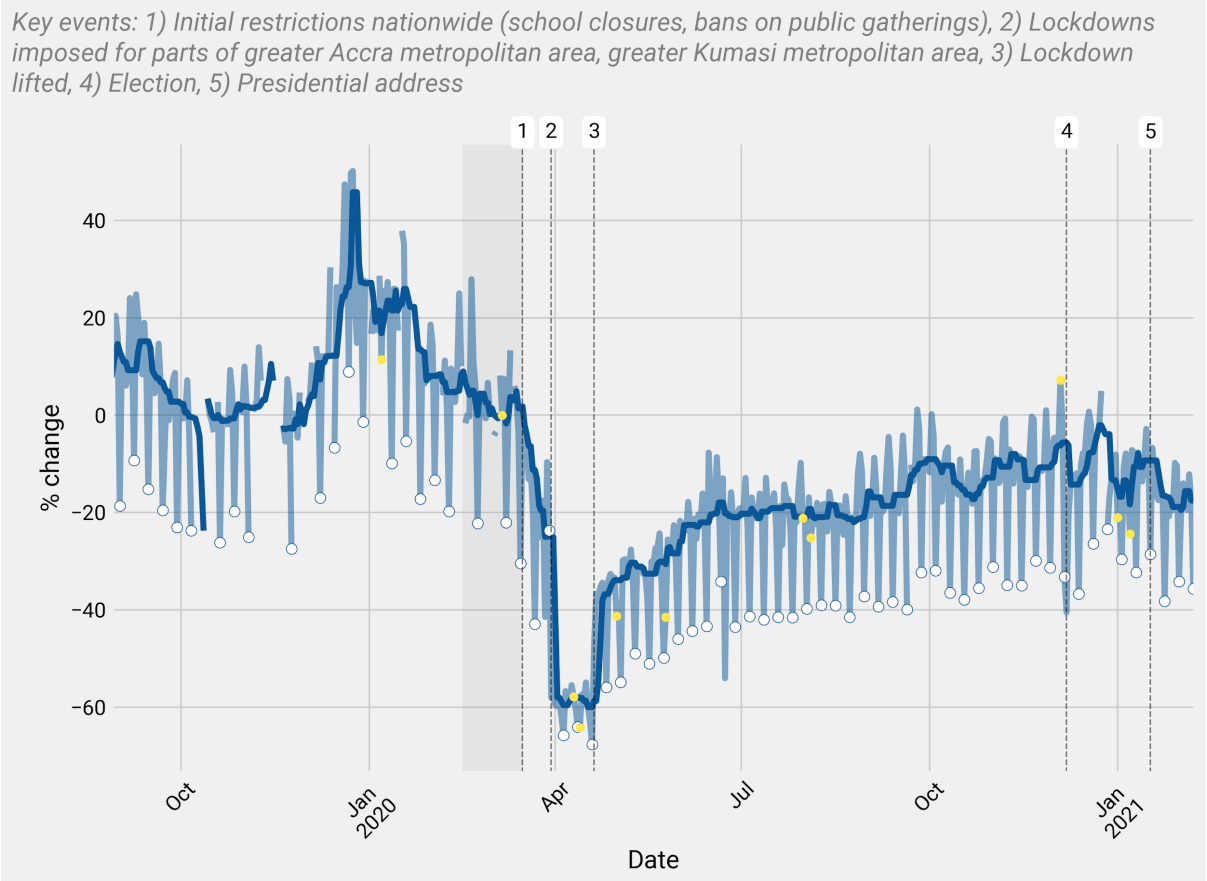


Figure 2: Percentage change in the number of trips between any two districts in Ashanti Region, each day, relative to the baseline value overlaid with a seven day rolling median. Yellow and white dots denote public holidays and weekends respectively, with the baseline period indicated by a shaded region.

The number of trips between any two districts within each region, excluding Greater Accra and Ashanti Regions:

- Increased in all regions, relative to the lockdown period, once lockdown measures were lifted. These levels were below the baseline levels for all regions at the time of the last report on 15 May 2020. The exception is a spike to above the baseline level in the Oti region, on 22 April, which may have been a response to the first case in Oti being confirmed on 21 April. The level in the Savannah region reached a few percent below its baseline level on 24 April.
- Most regions had returned to baseline levels as of September 2020.

- North East showed a sustained increase relative to baseline from September 2020, reaching 50% above baseline (30-36% higher than the previous year) in December 2020–January 2021. Several factors could have contributed to this effect, including internal displacement following the heavy flooding in September 2020; the Damba (Dumma) festival in November and the final funeral rites are observed for all deceased persons across several areas in the North East Region annually in November.
- Sustained decrease in Upper East compared to baseline and corresponding months the previous year.

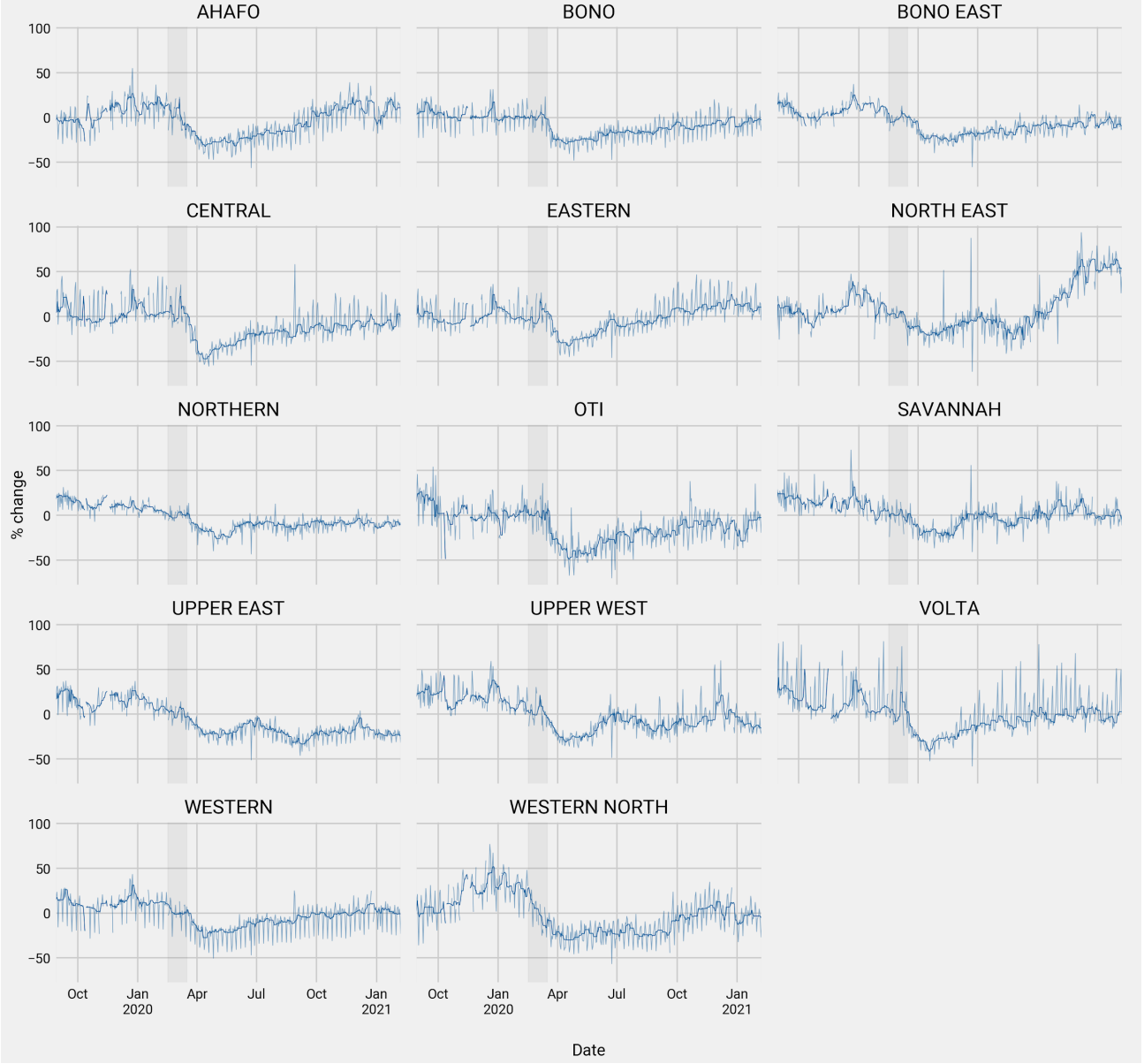


Figure 3: Percentage change in the number of trips between any two districts in each region, each day, relative to the baseline value for each region overlaid with a seven day rolling median.

- Central region[1] saw a decrease of ~50% compared to baseline in April 2020, this will capture the effect of Kasoa being included in the partial lockdown. Mobility recovered somewhat but remained 10-13% below the corresponding months from the previous year for December 2020 –January 2021.
- Despite fears of an *election-effect* on mobility which would have led in turn to increased COVID-19 infections, Figure 3 does not reflect a sharp increase in intra-regional trips during the campaigning season of September - December 2020, rather a continued gradual recovery following the trend of previous months. A spike in trips within regions can be seen during election week itself in Savannah, Upper West, Upper East with dips in Oti, Bono East and Ahafo.

The average number of regions visited by each subscriber:

See Annex 2 for details of how this indicator is calculated.

- Decreased to 40% below the baseline as restrictions were introduced, although we note that the average number of regions is relatively low (median 1.05 during the baseline, suggesting most subscribers rarely travel out of the region within a day).
- Gradual recovery over the remainder of the year, reaching baseline levels from the start of 2021.

[1] Note that the Central Region experienced the third highest COVID-19 infection rate and was prioritised alongside Ashanti and Greater Accra regions for vaccinations.

Key events: 1) Initial restrictions nationwide (school closures, bans on public gatherings), 2) Lockdowns imposed for parts of greater Accra metropolitan area, greater Kumasi metropolitan area, 3) Lockdown lifted, 4) Election, 5) Presidential address

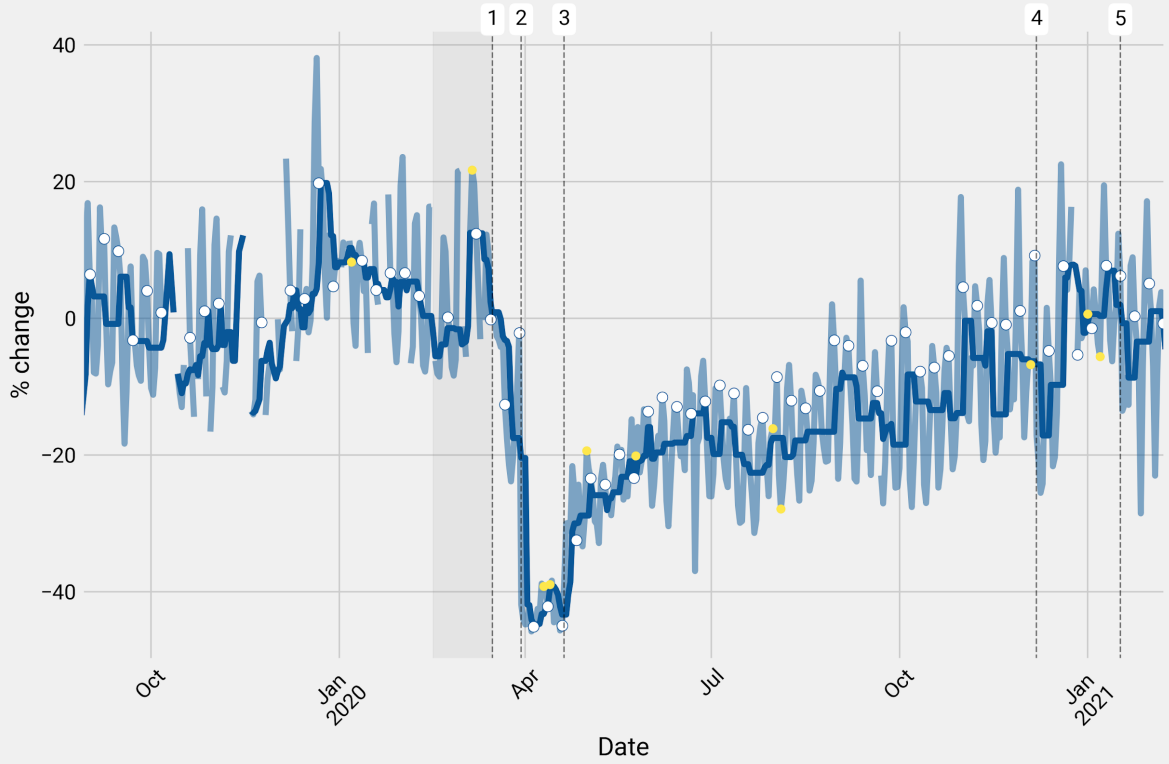


Figure 4: Percentage change in the average number of regions visited by each subscriber, each day, relative to the baseline value overlaid with a seven day rolling median. Yellow and white dots denote public holidays and weekends respectively, with the baseline period indicated by a shaded region.

Changes in presence

We analyse presence in an area by counting the number of unique subscribers who are observed in a region each day as a proportion of the total number of unique subscribers observed in the country.

Presence in Greater Accra and Ashanti Regions:

- Increase in presence in December 2019 - February 2020 in both Ashanti Region and Greater Accra, which coincided with an increase in calls per subscriber (Annex 4) (and an increase in events in December 2019, Annex 3). The apparent increase in presence could be mostly due to increased activity by subscribers during this period making them more likely to be observed, rather than more subscribers actually being *present* in the area.
- Decreased during the lockdown by ~5% in Greater Accra, and ~7.5% in Ashanti Region.
- Increased significantly, relative to the lockdown period, immediately after lockdown measures were lifted.
- Sharp increase during late December and January would be expected based on 2019–2020, but evident only in Greater Accra in 2020–2021.

- Remains 5-8% below baseline levels in Ashanti Region (~10% below the equivalent time period the previous year).
- In this instance the baseline period coincided with large changes of the quantity being measured (here presence), which may make the y-axis less readable on this graph, but changes can still be compared to different previous periods. We have maintained the baseline used in previous reports, and kept it consistent for all graphs for comparability purposes, in this instance it happened to coincide with a period of rapid change for these two regions.

Key events: 1) Initial restrictions nationwide (school closures, bans on public gatherings), 2) Lockdowns imposed for parts of greater Accra metropolitan area, greater Kumasi metropolitan area, 3) Lockdown lifted, 4) Election, 5) Presidential address

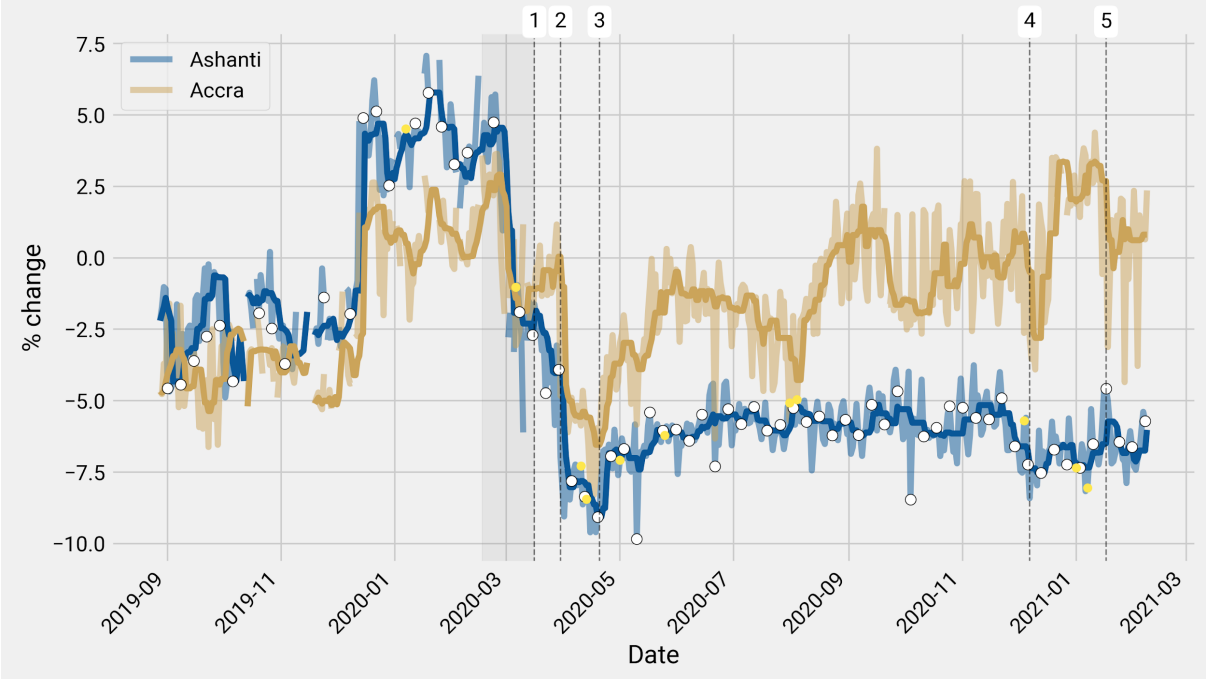


Figure 5: Percentage change in the presence of subscribers in Greater Accra and Ashanti regions, each day, relative to the baseline value overlaid with a seven day rolling median. Yellow and white dots denote public holidays and weekends respectively, with the baseline period indicated by a shaded region.

Average presence across districts in Metro, Municipal and Ordinary districts[2] nationally:

- Limited change in District and Municipal districts, slightly reduced by 5% relative to the baseline during the lockdown.
- Large fall in presence in Metro districts during lockdown (20%), recovering to 10% below baseline by July. Because our historical data does not cover this period in 2019, it is difficult to assess the extent to which this reflects normal seasonal variation, a change in phone usage patterns, or an ongoing impact of restrictions.

[2] **Ordinary Districts** have a minimum population of seventy-five thousand people; **Municipal Districts** have a minimum population of ninety-five thousand people; **Metropolitan Districts** have a minimum population of two hundred and fifty thousand people.

- Metro districts in September to November 2020 continue to show presence 5% lower than the same period in 2019, falling to 15% lower for December.

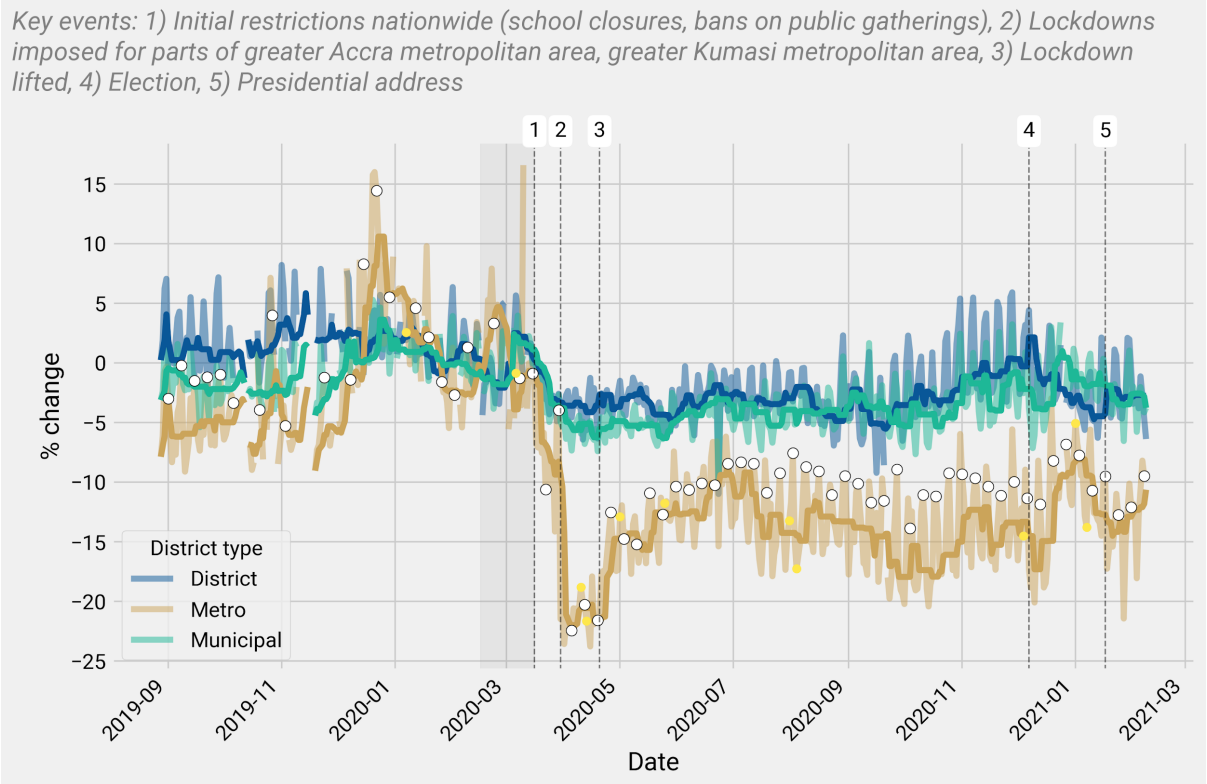


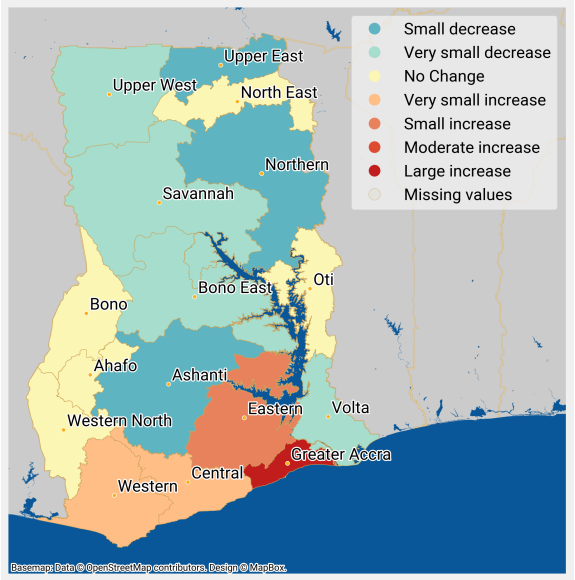
Figure 6: Percentage change in the presence of subscribers in districts by urbanisation, each day, relative to the baseline value. Yellow and white dots denote public holidays and weekends respectively, with the baseline period indicated by a shaded region.

Presence per region (maps):

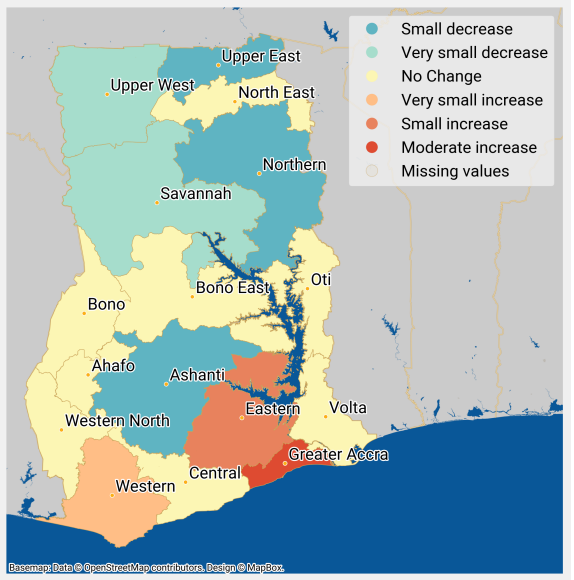
- Across 2020, the overall picture is of a small but sustained decrease in year on year presence in northern regions, with a larger fall in Ashanti Region. Presence in Ashanti Region actually remained relatively stable after the initial recovery from restrictions, not showing the increased December-January presence seen in 2019. Western, Greater Accra and Eastern regions had increased presence in the latter part of 2020 as compared to 2019, although in percentage change terms this increase was small in Greater Accra and largely represents a return to normal levels. Eastern region shows an increasing trend across the latter part of 2020, although this could also be a result of increased market share in the region.
- January 2021 shows a small to moderate increase in presence concentrated in the south when compared to the previous year, but similar levels of presence in Greater Accra. Presence was sharply reduced in the Ashanti Region in January 2021 compared to January 2020.
- In most northern regions, presence was lower in 2020 than it was in the same month in 2019. While this may indicate an ongoing effect from restrictions, it is also likely to reflect

the impact of significant flooding during September 2020, which may have had a knock on effect in reducing presence.

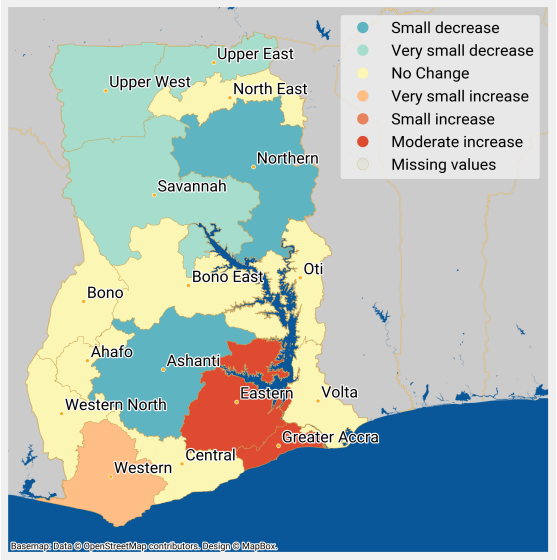
- Time series of presence changes in all regions are shown in Annex 5.



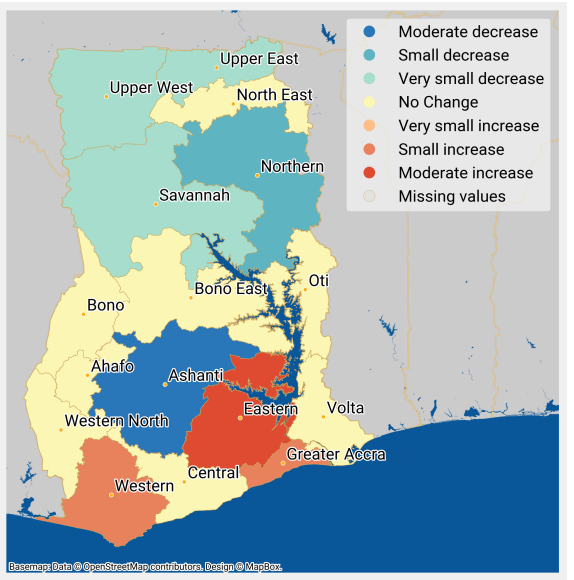
September 2020 vs September 2019: Observed presence was slightly lower in most northern and central regions in September 2020 as compared to 2019, but was higher in Greater Accra, Eastern, Central and Western regions with Greater Accra seeing the largest increases.



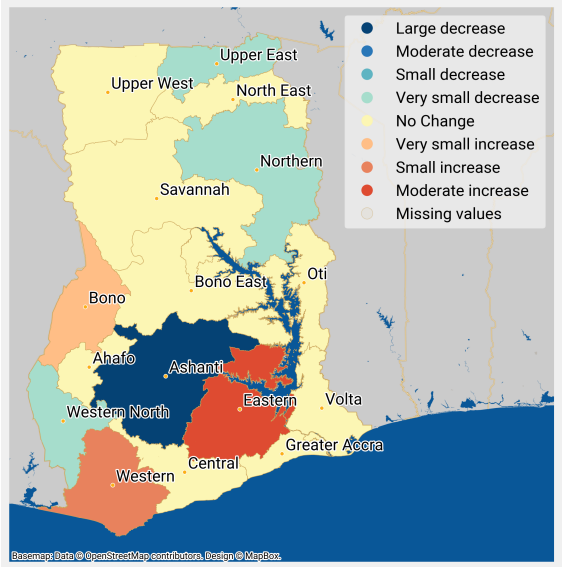
October 2020 vs October 2019: Compared with 2019, October 2020 continued to show reduced presence in Ashanti Region and most northern regions, but with moderately increased presence in Greater Accra, Eastern and Western regions.



November 2020 vs November 2019: Compared with 2019, November 2020 continued to show reduced presence in Ashanti Region and most northern regions, but with increased presence in Greater Accra, Eastern and Western regions.



December 2020 vs December 2019: The contrast between December 2019 and December 2020 is similar to November, with the differences in Ashanti and Western regions becoming more pronounced



January 2021 vs January 2020: Compared with 2020, January 2021 there was a large decrease in presence in Ashanti Region, and some smaller decreases in presence in the Northern, Upper East and Western North Regions. Presence in Greater Accra was similar, but higher in Eastern, Western, and Bono regions.

Figure 7: Five maps presenting the qualitative change in median daily regional subscriber presence relative to the same month in the previous year for September 2020–January 2021.

Changes in travel between regions

Journeys between regions comprise a mixture of long-distance, and short-distance trips, including routine daily trips made, for example, by people who live or work near a regional border. The method used to count these trips is described in Annex 1.

The number of trips between districts in Greater Accra and those in any other region:

- Immediately increased, relative to the lockdown period, by around 15% after the lockdown was lifted. However, this was still below the baseline level, and the number of trips remained consistently 25-30% below the baseline value in June through August 2020, although some part of this decrease may be due to a decrease in phone activity relative to the baseline period, and normal seasonal variation.
- Recovered in December–January 2021 to 17-19% below levels in the same period the previous year. before falling back slightly following the presidential address.

- Trips ending in Greater Accra follow largely the same pattern as those beginning there, and both are shown combined in figure 8 below.

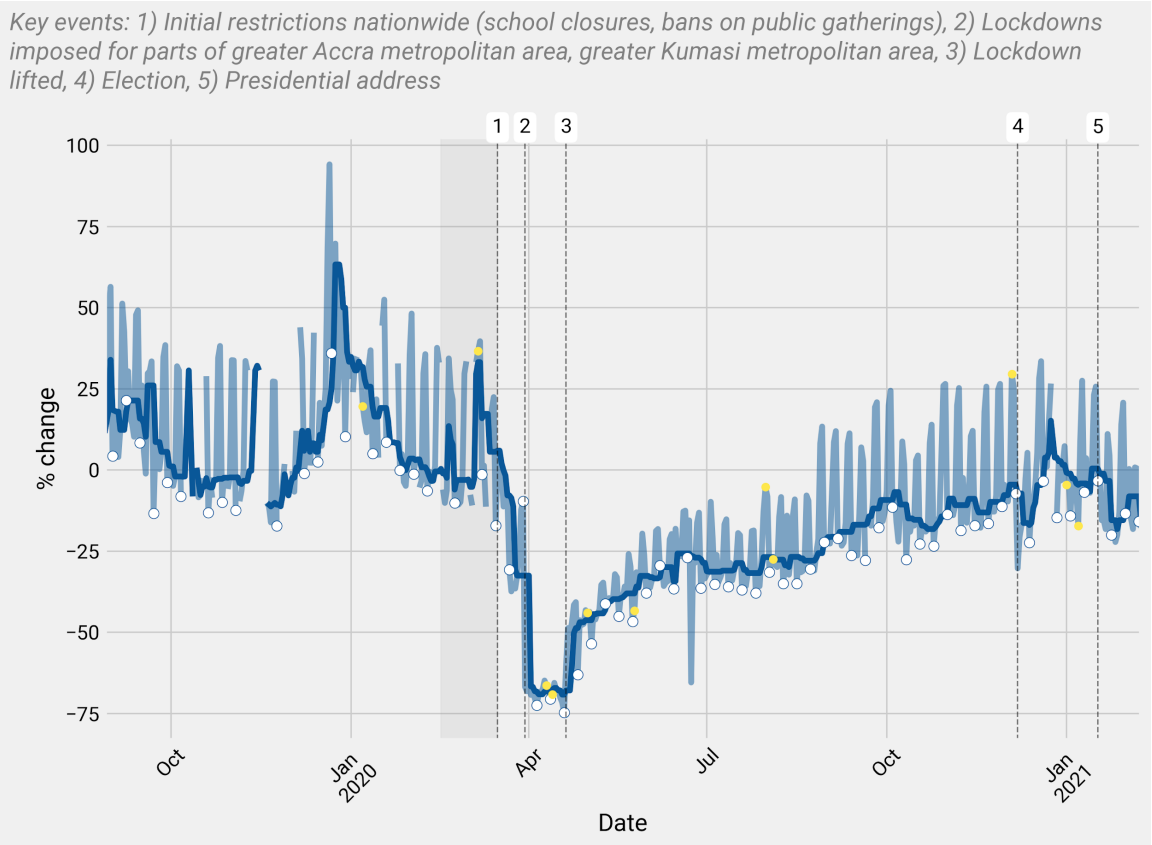


Figure 8: Percentage change in the number of trips starting or finishing in Greater Accra but beginning or ending in another region, each day overlaid with a seven day rolling median. Yellow and white dots denote public holidays and weekends respectively, with the baseline period indicated by a shaded region.

The number of trips between districts in Ashanti Region and those in any other region:

- Immediately increased, relative to the lockdown period, by around 15% after the lockdown was lifted. This was still below the baseline level, and the number of trips remained 25-30% below the baseline value until mid August, although some part of this decrease may be due to a decrease in phone activity relative to the baseline period.
- Gradual recovery over the latter part of the year, falling back to 26-31% below levels for the same period in the previous year following the presidential address.
- These trends are very similar to the ones we observe for Greater Accra, and as in Greater Accra, trips to Ashanti Region decline and recover in parallel with those outward.

Key events: 1) Initial restrictions nationwide (school closures, bans on public gatherings), 2) Lockdowns imposed for parts of greater Accra metropolitan area, greater Kumasi metropolitan area, 3) Lockdown lifted, 4) Election, 5) Presidential address

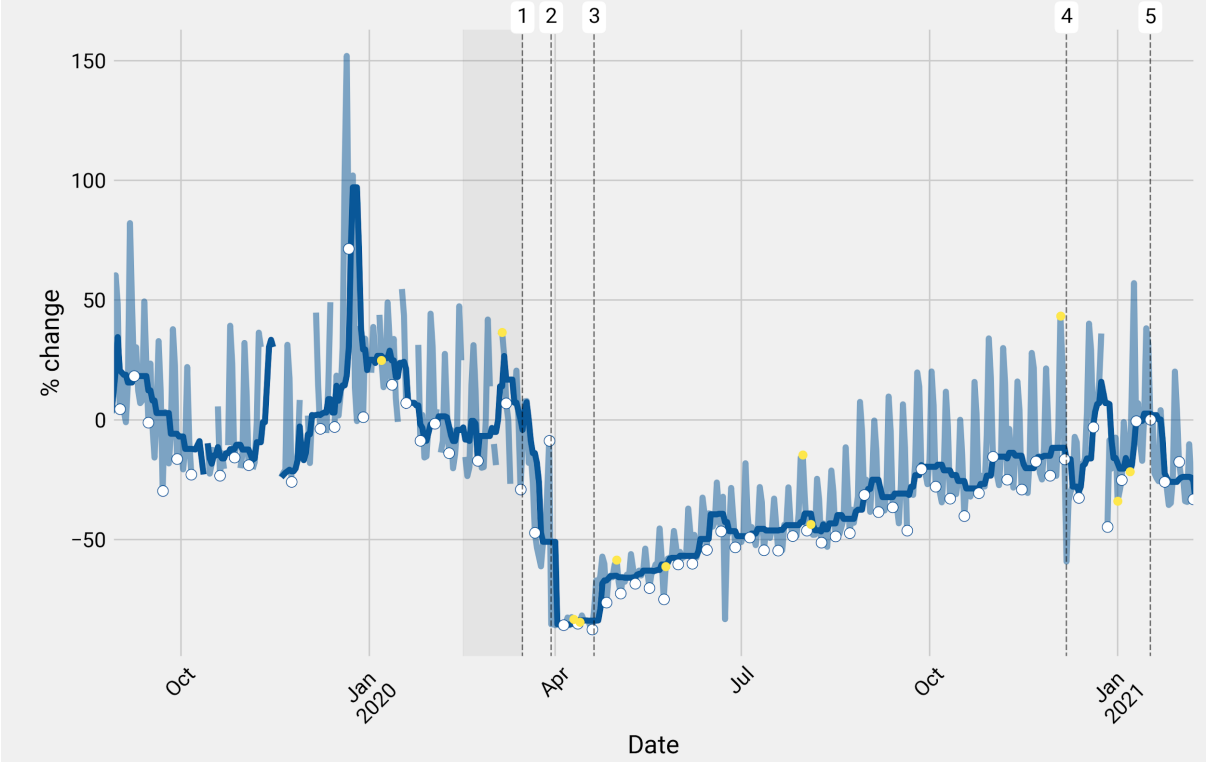


Figure 6: Percentage change in the number of trips starting and ending in Ashanti Region but beginning or ending in another region, each day overlaid with a seven day rolling median. Yellow and white dots denote public holidays and weekends respectively, with the baseline period indicated by a shaded region.

Median travelled distance nationally:

This is the median of the distances between each unique pair of locations visited each day, if further away locations are visited on one day (by any number of subscribers but above 15) the median distance travelled increases, and if distant locations are not visited on the same day but were before then the median decreases. This can be a more robust indicator in the face of varying phone usage because it doesn't rely on all subscribers maintaining their usage pattern, but only that a portion maintains their usage frequency. We describe the method used to calculate the median travelled distance in Annex 2.

- Slight trend downwards from September 2019 to March 2020, as seen in other mobility indicators particularly in Greater Accra and Ashanti regions.
- Decreased by ~20%, relative to the baseline value, during the period when initial restrictions were in place.
- Decreased to around 45% less than the baseline value during the lockdown period.
- Slow and sustained increase after an immediate recovery to 20% below the baseline after lockdown was released.
- Close to the baseline in December–January 2021, falling back to 5% below following the presidential address.

Key events: 1) Initial restrictions nationwide (school closures, bans on public gatherings), 2) Lockdowns imposed for parts of greater Accra metropolitan area, greater Kumasi metropolitan area, 3) Lockdown lifted, 4) Election, 5) Presidential address

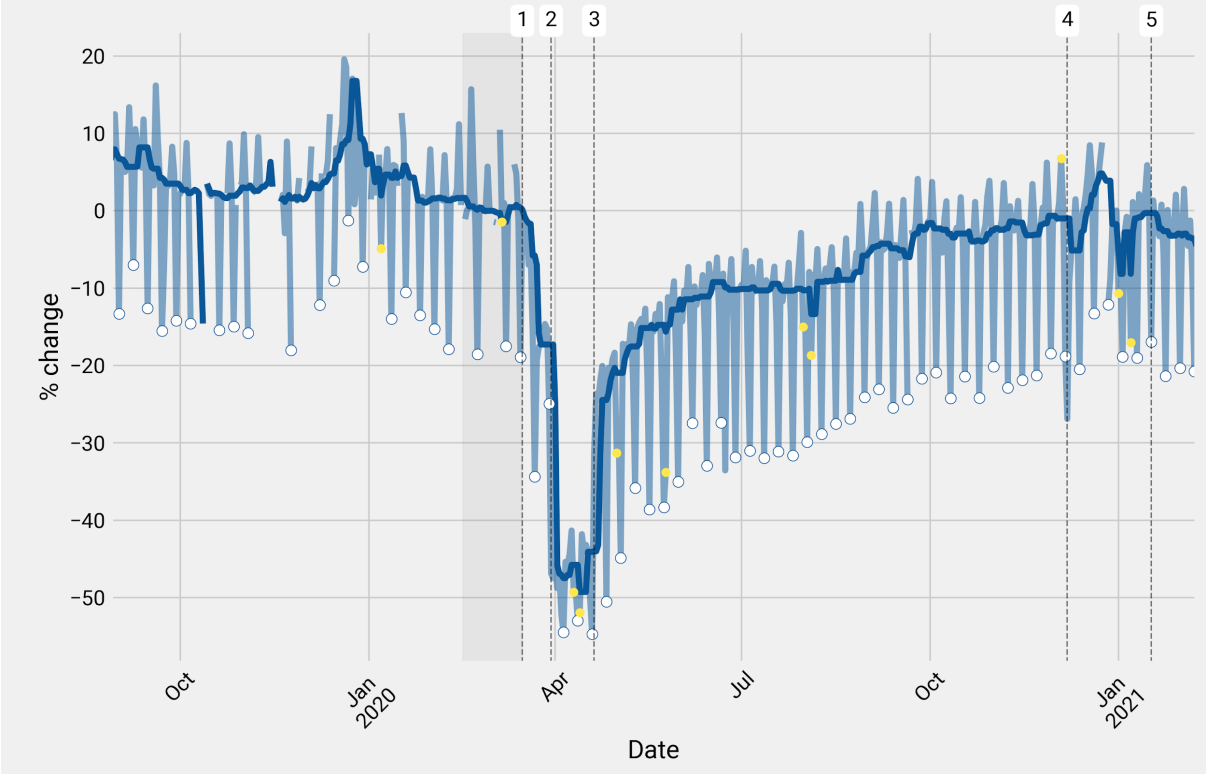


Figure 7: Percentage change in the median distance travelled, each day, relative to the baseline overlaid with seven day rolling median. Yellow and white dots denote public holidays and weekends respectively, with the baseline period indicated by a shaded region.

Analysis limitations

The anonymised and aggregated data used in this report was sourced by Vodafone Ghana. This dataset is unlikely to be perfectly representative of the entire population of Ghana, due to demographics and ownership differences across the country. In spite of these limitations, the dataset still provides a good indicator of changes in a population's movements as a significant proportion of the population is included in the dataset (74% of those aged over 5 had at least some phone usage in the three months prior to survey according to the GSS ICT survey 2019, p7), although the proportion of those who were Vodafone users is substantially lower). Whilst further work is needed to understand the extent to which analyses of telecommunications datasets result in biased estimates of population movements, the existing studies[3] have shown that such

[3] Wesolowski, A., Eagle, N., Noor, A. M., Snow, R. W., & Buckee, C. O. (2012). Heterogeneous mobile phone ownership and usage patterns in Kenya. *PloS One*. https://doi.org/10.1371/journal.pone.0035319

Wesolowski, A., Eagle, N., Noor, A. M., Snow, R. W., & Buckee, C. O. (2013). The impact of biases in mobile phone ownership on estimates of human mobility. *Journal of the Royal Society Interface*, *10*(81).

analyses have a high degree of validity. In this case we note that the major changes to mobility correspond with changes to the number of telecommunication events (see Annex 3), and a shift in the number of calls per subscriber (Annex 4) which followed the relaxation of lockdown, although the average number of calls does not show a trend after that time. This may indicate that some of the observed changes in mobility are in fact changes to phone usage behaviours. To address this, we also make use of the median travelled distance metric, which is thought to be less sensitive to changes in the number of events.

Interpretation of results

Relative changes in mobility (travel within regions, distance travelled, number of locations visited) were generally of larger magnitude than changes in presence, indicating that subscribers altered their daily mobility but did not necessarily relocate as the result of the lockdown and subsequent recovery. However, there appear to have been some relocations (migrations) related to seasonal cyclical patterns and perhaps other factors, with regions appearing to gradually gain or lose subscribers from September 2019 to January 2021 (cf. Annex 5). This could be a result of other factors, such as extensive flooding in northern regions, rather than a result of the COVID-19 crisis.

In terms of mobility trends, the main observations were: (i) a decrease during lockdown; (ii) recovery from June to December 2020; and (iii) a possible decrease from mid-January 2021 in response to the presidential address,

However, as observed changes in mobility and presence may be reflecting changes in phone use (frequency and/or regularity, cf previous section), they need to be interpreted alongside observed changes in the number of calls, sms and data sessions (termed 'events'). The total number of events (Annex 3) and average number of events per subscriber (Annex 4), both decreased sharply in April 2020 shortly before measures were lifted, they remain stable and slowly recover from September-October 2020. Before this, they had also both increased in December 2019, with the number of events going back down to its previous level before the 2020 `baseline' period, while the events per subscriber remained higher than before December 2019. These are statistics of phone usage nationally, which are likely to represent those regions with the most subscribers, while other regions may have had different patterns of phone usage. However, from these observations in national phone usage we can make the following interpretation of changes in mobility and presence indicators:

1) Mobility reductions observed during the 2020 lockdown (especially the first part) are likely to reflect real changes in mobility (as phone use was stable then);
2) Mobility reduction observed since the January 2021 presidential address is likely to be real (as phone use is increasing over this period);

https://doi.org/10.1098/rsif.2012.0986

Jahani, E., Sundsøy, P., Bjelland, J., Bengtsson, L., Pentland, A., de Montjoye, Y.A. (2017) "Improving official statistics in emerging markets using machine learning and mobile phone data" EPJ Data Science, 6:3 DOI 10.1140/epjds/s13688-017-0099-3

3) Recovery trend post-lockdown (May to December 2020) is also likely to be real but may have been underestimated due to decreased phone usage in some regions: most indicators show a near recovery compared to baseline and levels seen in the previous year, but this could in fact correspond to a full recovery to pre-lockdown mobility combined with reduced voice and sms usage or Vodafone market share.
4) Disparities in seasonal presence in Greater Accra and Ashanti regions between years may not be as they first appear. The increased presence from December 19 to March 2020 could be overestimated due to the effect of increased caller activity. However, a seasonal increase in the number of trips in December 2020 to January 2021 (figures 8 and 6) is only seen in Greater Accra meaning further examination would be useful to better understand the situation in the Ashanti Region.

An implication of the observed sharp decline of mobility which coincides with local lockdowns is that it likely slowed the rate of COVID-19 infections in those areas.

Whilst we expect some of this observed travel reduction to be due to public health messaging on COVID prevention measures, we do not know the extent to which it contributed to this effect. Other factors driving the mobility reduction could be around the schools closure; pandemic-related unemployment and businesses electing to work-from-home or use a shift system reducing the volume of commuters.

As mobility recovers, the risk of COVID-19 transmission also increases with larger volumes of people moving from their homes to other districts and regions, making any outbreaks of COVID-19 infections harder to contain. Meanwhile, a recovery to normal mobility levels underscores the urgency for an effective vaccination campaign to prevent future peaks in COVID-19 infections.

Whilst the gradual recovery in mobility may translate into further recovery in the economy, the effect on the local economy of reduced number of customers may be felt most keenly in those areas with a sustained mobility reduction.

Key messages

1. Following an initial reduction in travels, by February 2021 people in half of the regions are now moving within and between regions as much as they were before the beginning of the pandemic. However, the two most populous regions Greater Accra and Ashanti Region seem to be experiencing a slower recovery.

2. As people begin to return to their pre-pandemic movement patterns, the increased exposure raises challenges in containing the pandemic. This increased risk of infection reinforces the urgency of a successful vaccination campaign and for the public to continue to follow the COVID-19 protocols.

About the authors

This analysis was performed by the Flowminder Foundation, in partnership with Ghana Statistical Service (GSS). Access to anonymised mobile telecommunications network data is being provided by Vodafone Ghana. Flowminder, GSS, and Vodafone Ghana have been working together, since 2018, on a Data For Good project that aims to strengthen capacity within GSS in order to enable the types of analysis described in this report to be performed more routinely and easily. The work is funded by the William and Flora Hewlett Foundation and Vodafone Foundation.
www.flowminder.org | www.statsghana.gov.gh | www.vodafonefoundation.org

Annexes

Annex 1: Origin-destination matrices and 'trip' definitions

All the analyses in this report are based on an 'origin-destination matrix' (OD matrix). An OD matrix is an anonymised, aggregated data structure that is produced by counting the number of subscribers that have made a trip between any two localities - the first locality being the 'origin' and the second the 'destination'. In this report, we have used either districts or regions as the 'localities'.

A 'trip' can be defined in many different ways, and the OD matrices that result from using different definitions therefore encapsulate different aspects of mobility behaviour. The analyses in this report are based on the following definition:

'Directed all pairs' OD matrix: Definition

In this matrix, a 'trip' is defined to be an event where a subscriber is recorded to have used their phone sequentially in two different localities, within a single day. For example, if a subscriber uses their phone in District A and they next use their phone in District B, and then in District C, a trip is recorded for the pair [A, B], one for the pair [B, C], and one for the pair [A, C]. This is different from the intuitive definition of a 'trip', where only the start and final destination (but not any intermediate 'stops') would be counted.

The majority of trips that are included in this matrix will be routine, short-distance trips, since there are many more of these types of trips than there are long-distance trips each day. In order to remove high-frequency 'oscillatory' movements, which are movements of subscribers that seem to be moving rapidly and frequently between a pair of localities, when in actual fact they are situated close to the border of those localities but are not moving, we only count one trip per subscriber for each pair of localities. So a subscriber who moves in the sequence A -> B -> A -> B -> A -> C will be counted *once*, for each of the pairs [A, B], [B, A], and [A, C].

Annex 2: Calculation of indicators

Median travelled distance

We include in this report median distance travelled, an indicator derived from the 'trip' OD matrix, which is more resistant to fluctuations in numbers of subscribers and event patterns.

The median distance travelled is calculated by taking the unique origin destination pairs observed each day, and then taking the median of the (straight line) distance between them. This captures changes in the large scale pattern of mobility, rather than a detailed view on journeys between particular places.

Average number of regions visited

We calculate the nationwide average number of regions visited per subscriber by the sum of the count of unique subscribers observed in each region, divided by the number of unique subscribers observed in the country as a whole.

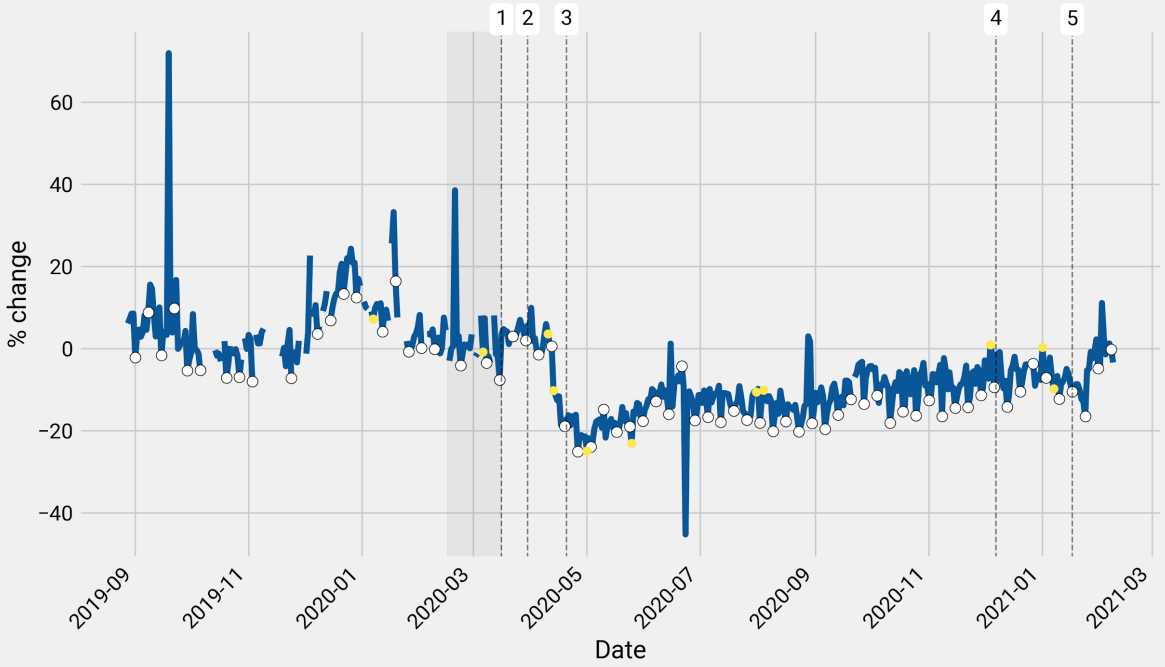
Subscriber presence

Subscriber presence in each area is calculated by taking the count of unique subscribers observed in that area divided by the number of subscribers observed in the country as a whole.

Annex 3: Event counts

Change from baseline to the total number of telecommunication events (initiating or receiving a text or call) nationally each day.

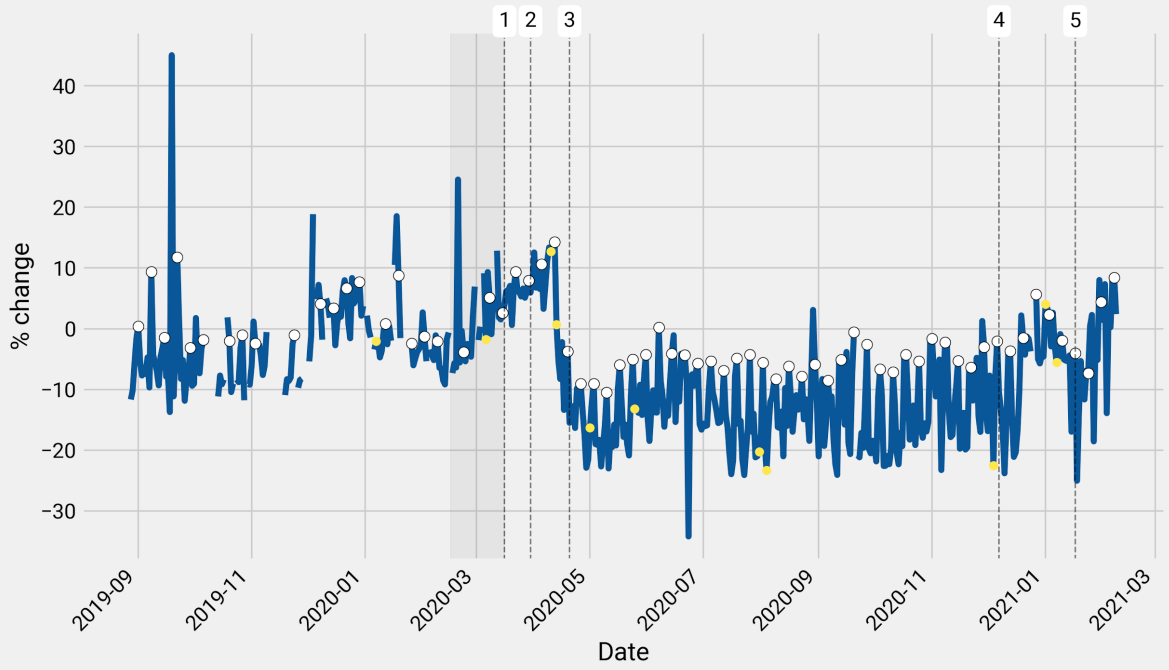
Key events: 1) Initial restrictions nationwide (school closures, bans on public gatherings), 2) Lockdowns imposed for parts of greater Accra metropolitan area, greater Kumasi metropolitan area, 3) Lockdown lifted, 4) Election, 5) Presidential address



Annex 4: Average number of events per subscriber

Change from baseline to the average number of telecommunication events per subscriber nationally each day.

Key events: 1) Initial restrictions nationwide (school closures, bans on public gatherings), 2) Lockdowns imposed for parts of greater Accra metropolitan area, greater Kumasi metropolitan area, 3) Lockdown lifted, 4) Election, 5) Presidential address



Annex 5: Regional subscriber presence outside Greater Accra and Ashanti Regions

Change from baseline to subscriber presence for regions outside Greater Accra and Ashanti regions overlaid with seven day rolling median.