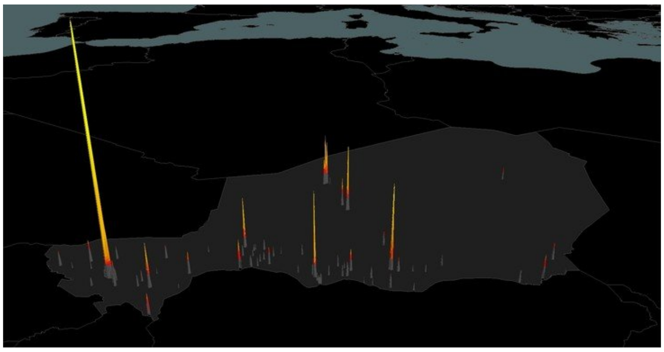
Remote technologies help biologists predict disease outbreaks, vaccinate kids in Africa

20 February 2018, by John Tibbetts



On this image of Niger, size and brightness of the glow of cities at night, photographed by orbiting satellites, has been converted into colored spikes indicating the approximate human population of those sites. Niger's capital, Niamey, is represented by the tall spike at left. Seasonal changes in the size of the spike indicate movement of thousands of people into or out of the city. The blue-gray shape across the top of the image is the Mediterranean Sea. Credit: Andrew Tatem

Each autumn in the Sahel, a vast band of grasslands just south of the Sahara desert, seasonal farmers and their families move from their farms when the long dry season begins. Many travel long distances to large towns and cities where they squeeze into already crowded districts, finding spaces in extended family compounds or temporary sites on the city's edges.

In places like Niamey, capital of the West African nation of Niger, the dry season also brings measles. Every autumn, a fresh outbreak. When the rains come in spring and the people return to their farms, measles cases drop off abruptly.

Was the virus itself affected by weather? Or, as researchers suspected, were the outbreaks related to the influx of seasonal migrants? Measles, after all, is highly infectious; it flourishes under crowded conditions. But with no good way to track the changing population in a densely populated place like Niamey, they had little chance to test their hypothesis.

Nita Bharti, now an assistant professor of biology at Penn State, began working on this problem as a postdoc at Princeton. "We knew these places had very important and predictable fluxes in population," she says, "but no one had ever found a way to measure those changes."

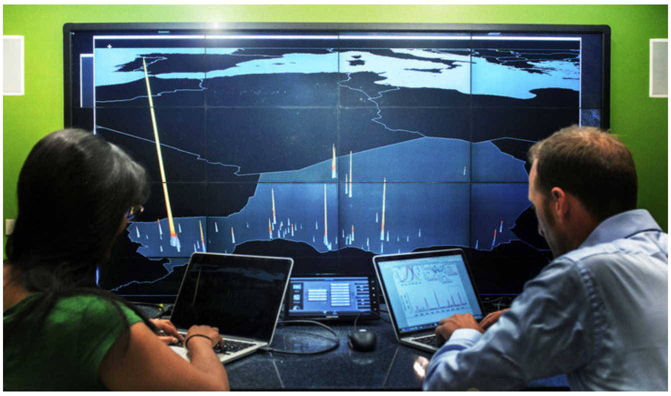
Bharti first looked at infectious disease as an anthropologist, with a focus on the role of behavior on epidemiology. When she began her Ph.D. research in biology at Penn State, she found that human behavior, especially long-distance movements, had been somewhat neglected as an important driver of infectious diseases.

She and geographer Andrew Tatem, who was then at the University of Florida, devised a novel method to measure fluctuating populations. They used satellite images of nighttime lights, a data source that had been previously used to create composite images over large periods of time in order to study urbanization and economic development, but had never been analyzed across shorter time scales or applied to predicting disease outbreaks.

When large numbers of migrants moved into Niamey, they reasoned, the nighttime city would appear both brighter and larger in satellite imagery, reflecting the increased number of cooking fires and electric lights associated with a swollen population. When seasonal migrants left the city to return to agricultural areas, the nighttime images of the city would dim to reflect a reduced population size. By comparing satellite images over time, they were able to estimate population changes, and then correlate those changes with public-health records of measles outbreaks. This provided a more precise understanding of the links between human movement and disease, and could in turn help them to more accurately predict future outbreaks.

As a graduate student, Bharti had begun collaborating with fellow biologist, Matthew Ferrari, who was then a post doc and is now an associate professor at Penn State. Ferrari, a specialist in quantitative epidemiology, developed a way to estimate transmission rates of measles at different times, including during the spikes in urban populations which Bharti could now measure.

"I count things—that's what I do," says Ferrari. "I count people because we need to know where populations are, how large those populations are, how often they move, and where they are going. When are places experiencing high population density, at which times? These factors not only influence the incidence of infectious disease but also the effective functioning of the health system."



Biologists Nita Bharti and Matt Ferrari are using satellite images to track seasonal changes in population in African cities, in order to predict outbreaks of measles and estimate how many children will need to be vaccinated in particular areas. Bharti wrote a program to convert the brightness of nighttime lights, as recorded by satellite, into population density, shown here as spikes above cities and towns in Niger. The tallest spike is over the capital, Niamey. Credit: Patrick Mansell

Populations at risk

"Because measles is so infectious and potentially deadly, it's an important disease for aid and development organizations to study," he adds. "Measles is relatively easy to diagnose, and easy to see in health surveillance data. Because it's so transmissible and visible, it is a bit of a 'canary in the coal mine'— if you see a place that is having measles outbreaks, then you know their immunization system is not working."

Migrant families frequently live beyond the reach of conventional health care; the Sahel is no exception. Many children are malnourished, unvaccinated, and suffering from weakened immune systems. When these families move into the cities, public health authorities often don't know how many have come and which urban districts they are staying in.

Migrant families are also often overlooked by population censuses, health surveys, and vaccination campaigns. The small villages where they spend the growing season can be difficult to reach and sparsely populated, making them strategically low risk or low priority. However, these families may, for at least part of the year, constitute a significant portion of the population in nearby cities. "These are the kinds of places where vaccine-preventable diseases such as measles persist. They are also places where well-timed interventions may do the most good," says Bharti.

In a 2016 study, Bharti, with Ferrari and other colleagues, developed a model that combined the population estimates they derived from satellite imagery with health care data—such as the timing of measles cases, deaths, and vaccinations—from three municipal districts of Niamey in the winter of 2003-2004. During that outbreak the city experienced 10,880 measles cases and 397 deaths from the disease.

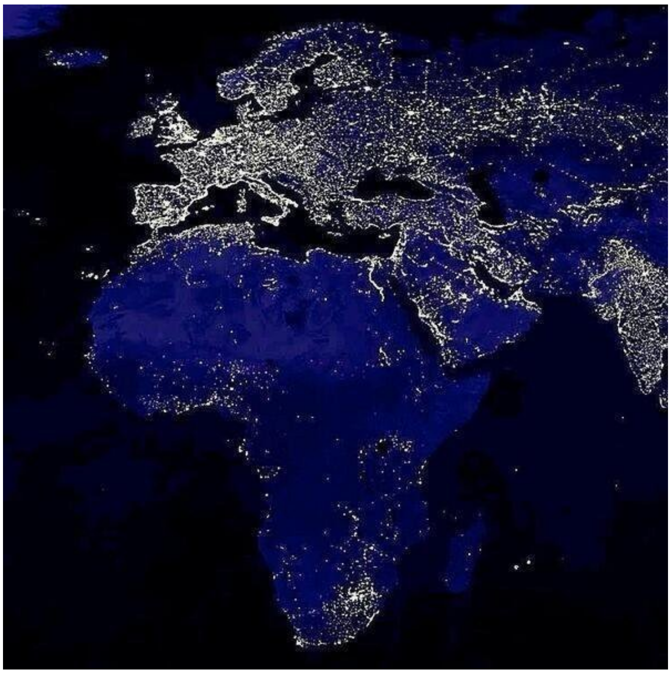
Bharti's previous work using satellite imagery had conclusively shown that measles outbreaks in Niger's big cities were not driven by some characteristic of the measles virus itself or some other physical or biological cause. Instead, outbreaks spread rapidly because of those predictable seasonal spikes in population.

In the 2003-04 event, Niamey's public health authorities had undertaken a vaccine campaign during the dry season, when measles cases typically take off. But the campaign did not work as effectively as expected. Public health officials had calculated that the vaccination effort, together with existing measles immunity, would reach 57 percent of the combined seasonal and resident population of children under five, a high enough coverage to halt the outbreak. But they had underestimated the total size of the target population.

Reviewing the satellite data, the research team found that there were 11,000 to 17,000 more young children present in the city during the outbreak than had originally been estimated—a result of the influx of migrant families. That meant only 50 percent coverage—too few children vaccinated to effectively slow the spread of disease. The team's retrospective estimates matched actual measurements of campaign coverage made following the outbreak.

Now that they've proven their method works, they are eager to use it to better target public health interventions for other highly communicable diseases where fluctuating populations play a role. Rather than seeing times of high population density only as a time of high risk, Bharti suggests, public health officials could take advantage of them.

"We could use migrants' time in the city as an opportunity," she says. "That's when immunization and health care are most accessible to them and easier for governments to provide."



Africa and Europe at night, as seen from an orbiting observatory. Sizeable towns and cities emit enough light to be visible from space, and the bigger the city, the larger and brighter the spot of light. Credit: NASA Earth Observatory/NOAA NGDC

A phone call away?

Satellites are an established technology, and satellite images are especially good at offering insights from the past to predict large-scale population movements. Bharti and other researchers are also exploring a much newer technology—mobile phones —to track finer-scale movements of small groups of people across remote regions in order to be able to reach them with vaccines and other health care interventions.

In sub-Saharan Africa, many people carry cell phones. Each time an individual places a call or text, that usage, along with the location of the routing tower, is recorded by network operators for billing purposes. Researchers can analyze sequences of calls or texts and their locations for large numbers of individuals with their identities concealed.

Phone data are great for big cities, Bharti says. But will they work in underserved, under- resourced areas where data and health care are scarce? That's why she is studying pastoral villages in the desert of Namibia, whose inhabitants migrate with their herds of livestock in pursuit of suitable grazing land. These pastoralists live and roam across vast desert areas beyond the reach of government health services.

Mobile call traces could be useful to track this population, but phone data have inherent biases, Bharti says, and these must be factored in.

"We've found that less than one third of the adult population in these villages has ever used a phone, and far fewer own a phone. Additionally, very few locations in the large desert have network coverage," she says. Moreover, "Men are far more likely to own and use phones, and they are more likely to be the herders. Women are more likely to work near their homes."

In other words, "Mobile phone usage data do not provide an accurate picture of this population, so we can't use them assuming that they're representative. But they're a great resource and we don't want to throw out a data source that we could use if we could simply interpret it better."

Bharti is currently using video footage shot by drone and household survey data she has collected to compare against phone records, in order to account for the biases in the phone data and interpret it accurately.

As researchers like Bharti and Ferrari work towards the global elimination of measles and other scourges, they rely on remote technologies to pinpoint the last stubborn reservoirs of disease, the areas that are the most difficult and expensive to reach. These reservoirs, says Bharti, "persist in populations that we're not measuring accurately, or where we're using remote technologies without understanding their biases.

"We need to develop better tools and better understanding of these cultures to learn what we're missing."

Provided by Pennsylvania State University