Cover photo: This product was made using VIIRS Nighttime Light (VNL) data produced by the Earth Observation Group, Payne Institute for Public Policy, Colorado School of Mines.

ILLUMINATING RESEARCH

Examining night light satellite imagery as a tool for analysis and aid response

NOVEMBER 2024

MERCY CORPS

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Overview

Humanitarian and development organizations face mounting barriers to assessing needs. Traditional data collection methods are often insufficient in fast-moving and chronically insecure contexts. Local governing actors often view humanitarian and development actors with hostility and suspicion, and increasingly limit field data collection. Traditional assessment methodologies are also expensive, cumbersome, and susceptible to manipulation. While not a panacea, remotely sensed data is one potential solution to access and capacity constraints. Nighttime light emissions have become a broadly accepted proxy for economic and other human activity, especially in places where reliable data is otherwise unavailable. So-called Nighttime Light Reflectance (NLR) data gathered by satellites is not only being used to analyze economic growth. It is also deployed in studies on light pollution, illegal fishing, fires, natural disasters, human settlements (including refugee camps), and energy production, among other applications. Some researchers use NLR data to identify human activity in remote areas and to generate near-real-time measurements and inferences on economic developments.

> *"In places as distinct as Puerto Rico, Libya, Lebanon, Sudan, Syria, and Türkiye, humanitarian and development organizations have used NLR to rapidly assess damage and recovery after natural disasters, trade patterns, urban inequality, and economic vulnerability."*

Humanitarian and development organizations working in, or planning to work in, countries and regions where economic and other data is scarce stand to benefit from NLR analysis in assessing needs, trends, and evaluating the impact of interventions. In places as distinct as Puerto Rico, Libya, Lebanon, Sudan, Syria, and Türkiye, humanitarian and development organizations have used NLR to rapidly assess damage and recovery after natural disasters, trade patterns, urban inequality, and economic vulnerability.

Yet to date, the adoption of NLR and other remotely sensed data is limited. Humanitarian- and development-focused analysts and operational leaders hesitate to use NLR because they are familiar with criticisms of the way NLR research is sometimes used, its limitations, or because they are deterred by perceived technical barriers. Mercy Corps is becoming a leader in deploying NLR analysis as part of its analytical and operational work. Yet its use of NLR and other so-called "Earth Observation" tools is limited to a few country contexts where technical specialists work closely with analysts and operational leaders.

This note, researched and written in June 2024 by Mercy Corps' Crisis Analysis Team,[1] draws on a literature review; interviews with expert practitioners in economics, data science, and humanitarian operations; as well as Mercy Corps researchers and analysts who use NLR and other remote sensing techniques. It assesses the potential of NLR analysis for humanitarian organizations and reviews NLR-related research already conducted by Mercy Corps. This note proposes several potential use cases for NLR, including:

- Analyzing economic growth and activity patterns, especially in regions with scarce data
- Conducting rapid assessments of localized impacts of natural disasters, such as tracking power outages and restoration post-disaster, enabling better emergency response and recovery efforts

1 This study was led by Peter Salisbury, in collaboration with Michael Chohaney and Alexander Harper from the Mercy Corps' Crisis Analysis MENA - Europe team. The report benefited from review and input by Mercy Corps' MENA - Europe, Global Crisis Analysis, and Technology for Development teams.

- Highlighting the impact of natural disasters and conflicts on areas in need of intervention, influencing policy decisions and humanitarian aid distribution
- Detecting human settlements, including refugee camps, and monitoring of activity levels in remote or inaccessible areas, informing in resource allocation and planning
- Validating incomplete or anecdotal data from the field
- Monitoring and analyzing patterns in energy production and consumption, particularly in urban areas. Also, relatedly, assessing urban growth, land use, and spatial inequalities within cities, providing insights for humanitarian and development projects
- Identifying areas of activity (and inactivity) before entering new operational spaces, facilitating strategic planning and risk assessment for humanitarian organizations
- Comparing activity patterns across similar contexts, such as different urban centers, to help identify anomalies and target interventions more effectively
- Assisting in the detection of illicit activities such as illegal fishing or logging and monitoring environmental changes such as forest fires and light pollution, supporting conservation and regulatory efforts

This note proposes several steps Mercy Corps and other aid organizations can take to mainstream the use of NLR and other forms of Earth Observation or remote sensing analysis into their analytical and operational work. These include developing user-friendly guides and tools, including an automated user interface that allows non-experts to perform simple visual analysis of NLR data, paired with cutting-edge techniques to identify NLR patterns that indicate humanitarian circumstances. Such a platform would enable humanitarian and development organizations to integrate NLR – and eventually other Earth Observation tools – more effectively into humanitarian and development programs.

This note also stresses that remotely sensed data should complement, not replace, ground-truthing. Mercy Corps' and other organizations' experiences with NLR also points to the limitations and potential for misuse. Ideally, NLR analysis should better equip expert operational and analytical staff to test theories, and help them identify areas of interest for on-the-ground validation.

Analysis of night lights reflectance data can measure the impact of natural disasters and conflicts on areas in need of intervention, influencing policy decisions and humanitarian aid distribution

Photo credit. Earthquake responders, Bsenaih village Syria, Mercy Corps Syria, 2023

Abbreviations

DMSP	Defense Meteorological Satellite Program (United States Air Force)
EVS	Economic Vulnerability Score
FCV	Fragile, Conflict, and Violence
GDP	Gross Domestic Product
IMF	International Monetary Fund
ISIL	Islamic State of Iraq and the Levant
LED	Light Emitting Diode
NLR	Nighttime Light Reflectance
VIIRS	Visible Infrared Imaging Radiometer Suite

About Crisis Analysis at Mercy Corps

Crisis Analysis Teams sit alongside broader Mercy Corps humanitarian, development, and peacebuilding portfolios at a global, regional, and country level, providing evidence and analysis in support of our programming and the aid community. Crisis Analysis Teams provide rapid, dynamic, and targeted analysis in the most hard-to-reach, data-poor, and complex contexts requiring assistance, to support more effective responses.

Crisis Analysis Research Series

This note is the first in a planned series outlining innovative methodological approaches used by Mercy Corps' Crisis Analysis Teams in pursuit of more contextually informed and efficient international aid responses to conflict and crisis.

Nighttime Light Reflectance

For six decades, humans have been able to see and photograph the Earth from space. For much of this time, it has been possible to capture and transmit low-light images of the surface.[2] These kinds of images, gathered by the United States Air Force's Defense Meteorological Satellite Program (DMSP), were first made publicly available in 1973. Yet, only relatively recently has nighttime imagery been put to use.[3] Over the past 15 years, satellite and NLR technology have improved significantly. In 2011, new satellites equipped with Visible Infrared Imaging Radiometer Suite (VIIRS) sensors,[4] specifically designed to produce high-resolution imagery during both day and night, were launched to replace older systems. DMSP and VIIRS images are now freely available to the public.[5] They enable data scientists to analyze luminosity – that is, light emissions – at the global, regional, country, and subnational level.[6]

Light emission patterns are a useful, if imprecise and sometimes erratic, proxy for human activity. Economists and data scientists were among the earliest and most enthusiastic adopters of NLR pattern analysis. Since the publication of a 2012 *American Economic Review* study arguing that NLR data could be used in place of, or to augment, conventional measures of economic growth – specifically Gross Domestic Product (GDP) – at the national and subnational level, economic papers and studies on the subject have proliferated.[7]

Economists have a growing interest in NLR because it offers a readily available, near-real-time, and low-cost measure of human activity. Economists are also mistrustful of data from countries with limited or weak statistical capacity and poor governance. NLR analysis is most often used in areas and countries where data is either unavailable or hard to gather. A growing number of World Bank reports, particularly on Fragile, Conflict, and Violence (FCV)-affected countries make use of NLR data. In a 2023 World Bank paper, *Nowcasting Economic Activity Using Night-Time Lights*, the authors argue that "[NLR] benefits from data insulated from human error or malfeasance. Especially in a conflict-affected setting, NTL (sic) provides more reliable information than official national accounts data, which can prove susceptible to bias, manipulation, and measurement error."[8,9]

Critiques and caveats

NLR analysis is not a like-for-like replacement of conventional economic data gathering. NLR imagery is sensitive to several factors including the time of day, the angle at which it is captured, cloud cover, and other seasonal

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2 Croft, Thomas. "Nighttime Images of the Earth from Space." Scientific American, July 1978.

3 Nighttime pictures of Earth were largely seen as incidental to high altitude image-gathering efforts. But in 1978, Scientific American reported that "Nighttime Images of the Earth from Space" allowed United States military and NASA observers to study cities, forest fires, and gas flaring at oil and gas fields. An archive of nighttime light images was not established until the 1990s, and only more recently has data from nighttime light imagery been produced and studied as part of a standalone, concerted effort.

4 VIIRS imagery is available at about 500 square meters per-pixel.

5 New VIIRS imagery is produced by the 2011 Suomi National Polar-orbiting Partnership (S-NPP) satellite and systems launched in 2017 under the banner of the Joint Polar Satellite System (JPSS) network. There are two main sources for the higher-resolution VIIRS data: the Colorado School of Mines, which is available in its raw form via Google Earth Engine, and NASA's daily pre-processed Black Marble initiative (See below for an explanation of why data needs to be processed). (1) World Bank. "Introduction to Nighttime Light Data." Accessed June 2, 2024; (2) Earth Observation Group (EOG). "See the World at Night."

6 The Chinese government launched an even higher resolution satellite, the Luojia 1-01, with NLR capabilities in June 2018. Several commercial entities have begun to offer high-resolution NLR from private satellites, most prominently via Israel's Israel's EROS-B satellite (launched in April 2006), which offers NLR imagery up to 70 centimeters (cm) per pixel, and effectively replicates daytime optical imagery. BlackSky, an American satellite data firm, sells high-resolution nighttime light imagery with a 1m2 per-pixel resolution to private clients. VIIRS NLR satellite images are the most widely used in applied analyses. Though newer satellites that produce higher spatial resolution images have been launched, they are less accessible or must be purchased.

7 The authors proposed that "...lights growth gives a very useful proxy for GDP growth over the long term and also tracks short-term fluctuations in growth" at both the national and subnational level, providing the example of NLR emissions in sub-Saharan Africa. Henderson, J. Vernon, Adam Storeygard, and David N. Weil. "Measuring Economic Growth from Outer Space." The American Economic Review 102, no. 2 (2012): 994–1028.

8 The World Bank and other organizations use the abbreviation "NTL" to refer to nighttime light reflectance. For the purposes of this paper, "NTL" is synonymous with "NLR". The

9 authors note, however, that the subject of their case study – Libya – may represent a unique use case for NLR analysis because so much of the country's economy relies on oil and gas production, which can be relatively easily measured using NLR emissions. Al-Kadi, Dalia, and Ali Ibrahim al-Melhwm. "Nowcasting Economic Activity Using Night-Time Lights." World Bank, June 2023.

factors. Many experts are cautious about NLR's potential as a live data feed to monitor events on the ground and argue that, at a minimum, data should be used only when it is available in monthly, aggregated form.

Moreover, the claim that NLR emissions are an accurate proxy for economic activity is contested. The most common critique of using NLR as a proxy or substitute for GDP statistics is the fact its relationship is only statistically demonstrable in well-lit urban or industrial areas. In areas economically dependent on agriculture, DMSP NLR data often underrepresents economic activity, even when a relatively large population is present. Even in urban environments, NLR emissions may become a less useful proxy for economic activity in future. Yohan Iddawela, an economist and popular blogger on the subject of NLR and other forms of Earth Observation data, argues that the use of light emitting diode (LED) technology poses a dual challenge to NLR-GDP analyses. LED lights emit similar luminance levels to conventional light bulbs but only use about 10% of the energy as conventional bulbs, meaning they muddy the claim that NLR is a proxy for electricity consumption. Most satellite NLR imagery struggles to capture shorter-wavelength light emitted by LEDs,[10] which may produce unwanted bias in future analyses if LED usage is not uniformly spatially distributed over the study area.

These critiques have not prevented leading institutions from adopting NLR analysis. For example, despite publishing numerous studies questioning NLR's usefulness (and skepticism from its own economists), as noted above, the World Bank regularly uses NLR analysis. Indeed, NLR analysis represents an opportunity for actors in the humanitarian and development space, if used thoughtfully. A balanced approach to leveraging NLR data entails both recognizing its potential and its shortfalls. NLR is likely the most accessible of the suite of tools used to analyze Earth Observation data gathered from satellites, which also includes optical, radar, and infrared imagery, in addition to other climatic data on emissions like heat, moisture, and chemicals. When higher-resolution imagery (e.g. VIIRS) is bounded geographically (that is, it focuses on a particular area of interest), and compared to the same space over time, it can provide valuable insights on patterns of human habitation and activity, and the availability and accessibility of electricity supply, among other observations.

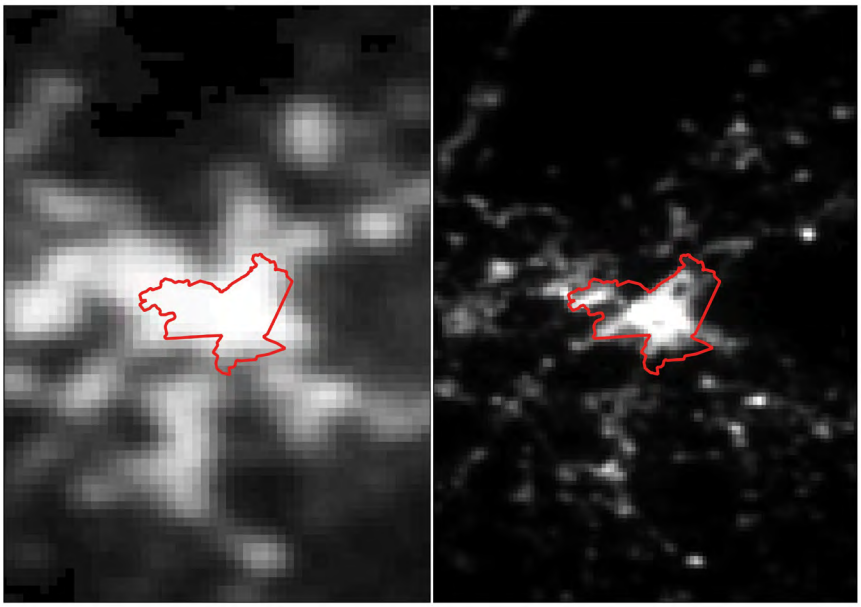

FIGURE 1. COMPARISON OF DMSP (LEFT) AND VIIRS (RIGHT) NLR IMAGES FOR DAMASCUS, SYRIA

10 Iddawela, Yohan. "The Spatial Edge." Accessed July 2024.

Use Cases

A review of existing literature on NLR and interviews with economists, data scientists, and humanitarian officials suggests several potential use cases in humanitarian and development settings. What follows is not an exhaustive list of potential applications but is instead a summary of practical uses that have been deployed and could be integrated into existing analytical and programmatic workflows. Specifically, the section highlights cutting-edge work by Mercy Corps, NASA, the RAND Corporation, and the World Bank.

Mercy Corps is arguably a leader in integrating NLR analysis into its work. In recent years, Mercy Corps' Crisis Analysis Teams have developed several innovative methodologies for the technology. This serves as an example of how country context experts, working together with technological specialists, have been able to use NLR with tangible results. Case studies of this work are also included below.

Where and how should it be used?

Before expounding on its potential, it is necessary to clarify where and how NLR analysis should (and should not) be used. First, there should be a clear rationale for deploying NLR analysis. Second, analysis based solely on remotely sensed data should be used sparingly and only where absolutely necessary. In all cases, NLR analysis should be paired with expert local knowledge and, where possible, field research. For example, NLR emissions can be used as a proxy for electricity consumption but these patterns must be linked to broader economic developments or political events identified by context experts.

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The following are simplified examples of ways in which NLR data can be quantitatively analyzed:

- Visual analysis of geospatial NLR imagery – nighttime pictures of the earth, overlaid on a satellite map – by looking for high-luminance spots in unexpected areas or comparing light emissions over time using multiple NLR images

- Aggregating NLR data at the national or subnational level and converting luminance data into time series, for visual inspection in the form of a line or bar chart by a subject matter expert who can narrativize change over time after correcting for seasonal developments

- Performing statistical analysis on quantified luminance data, including regression analyses, with the goal of identifying a statistical relationship between the level or change in light emission and other available data, such as humanitarian need

A. Economic growth and patterns of human activity

NLR analysis is most commonly used to study economic activity. As noted above, the World Bank, the International Monetary Fund (IMF), and to a lesser extent the United Nations all use NLR analyses to "nowcast" economic activity in contexts where data is poor or unavailable. The World Bank publishes regular economic "Monitors" on developments in FCV countries including Libya, Syria, and Yemen that often include sections estimating economic activity at the national level using NLR data. In the Libyan context, where the economy is heavily reliant on oil production and export and conflict has been sporadic, this makes a great deal of sense. A 2023 World Bank report showed a strong statistical correlation between oil output, measured by studying luminance around gas flares at oil producing sites, and economic output.[11]

Importantly, context matters. Syria, for example, has been at war for more than a decade and the informal economy accounts for a sizable percentage of the overall economy. For this reason, NLR analysis does not always make intuitive sense. Since civil war broke out in 2011, the country has been divided into rival zones of control and oil and gas output has fallen significantly. Economic activities related to the "war economy", particularly the production and illicit export of the drug Captagon, have flourished. In the World Bank's most recent Syria Economic Monitor, NLR analysis showed a significant decline in economic activity over the course of the war.[12] The same edition of the Monitor estimated that the Captagon industry may generate up to 1.8 billion US dollars a year, double the value of all officially recorded Syrian exports for 2023. Captagon is reportedly produced in isolated facilities by a relatively small number of people, with its benefits accruing to armed groups and regime insiders. This income is unlikely to be captured by a GDP model predicated on "licit" economic patterns like NLR analysis.

NLR analysis has, however, proven useful in tracking human activity related to the informal economy. In the March edition of the World Bank's Syria Economic Monitor, NLR analysis was used to verify claims that economic activity increased in towns along the Syrian-Lebanese border when fuel smuggling profit margins reached a

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11 Al-Kadi, Dalia, and Ali Ibrahim al-Melhwm. "Nowcasting Economic Activity Using Night-Time Lights." World Bank, June 2023.
12 World Bank. "Syria Economic Monitor: Conflict, Crises, and the Collapse of Household Welfare." May 2024.

certain level.[13] The RAND Corporation, a think tank used NLR data to analyze economic conditions in parts of Iraq under the control of the Islamic State of Iraq and the Levant (ISIL, also known as ISIS). The authors of the RAND study noted that ISIL sought to prove its governance *bona fides* by prioritizing electricity supply for hospitals and key infrastructure in the face of larger electricity shortages. The study also found that electricity shortages lingered after ISIL was defeated in Iraq, possibly as part of a state-led strategy to punish areas where ISIL had held sway.[14]

Mercy Corps' Crisis Analysis–Syria (CA–SYR) team has also measured regional GDP using NLR data[15] to analyze subnational GDP growth. The team's analysis highlighted the economic pre-eminence of Damascus in the national economy and the significant economic growth of sub-districts in northwest Syria along the Turkish border. This illustrated the unequal nature of economic growth and decline across different regions of Syria, in turn dispelling assumptions that "things are going well" for Syrians in areas where economic growth is relatively high. The research also provided a more nuanced look at economic activity across the country – a useful tool for targeting interventions and evaluating needs. However, as discussed elsewhere in this note, using NLR as a proxy for macroeconomic indicators requires careful data analysis. CA–SYR is currently developing an updated regional GDP estimation methodology.

> *"Analysis from nighttime light emissions suggests that towns and regions adjacent to smuggling routes in Syria experienced a short-lived economic boom when the profit margin for smuggling Lebanese diesel into Syria increased notably from early 2020 to the summer of 2021…Nighttime light emissions in Syrian villages near Lebanon's border declined significantly since the summer of 2021, which appears to be linked to the narrowed gap in fuel prices between Lebanon and Syria after the Lebanese subsidies ended. Smuggling activity does not appear to bypass official checkpoints, as indicated by both the nighttime light emissions and the observed mobile devices data."*
>
> World Bank, March 2023.

Elsewhere, a recent Mercy Corps Crisis Analysis report produced for an institutional aid donor studied NLR emissions in four cities in a Middle East and North Africa (MENA) region country. While working on the report, the authors learned that analyzing local light emission dynamics required a deep understanding of local electricity supply; seasonal issues, particularly in areas where solar power is common; and broader political economy dynamics that affect electricity availability and access. The authors of the report combined pattern analysis with interviews, an open-source literature review, and regression analysis, to describe trends that can be observed using NLR data, but can only be explained through local expertise. Regression analysis – using computer models to calculate statistical relationships between different patterns – indicated hyper-local patterns of income inequality and population movement dynamics that other datasets and research approaches were unable to distinguish. The team plans to expand on its research to support humanitarian programming in areas with a high concentration of needs. These findings provided a useful basis for better understanding local economies, and projecting potential economic trajectories – a critical requirement of humanitarian and development actors and policymakers seeking to respond to evolving needs.

13 World Bank. "Syria Economic Monitor: Syria's Economy in Ruins After a Decade-long War." March 17, 2023.
14 Robinson, Eric, Daniel Egel, Patrick B. Johnston, Sean Mann, Alexander D. Rothenberg, and David Stebbins. "When the Islamic State Comes to Town: The Economic Impact of Islamic State Governance in Iraq and Syria." RAND Corporation, 2017.
15 Crisis Analysis–Syria. "Using Night Light Reflectance to Measure Economic Output." 2022.

Another Crisis Analysis Team experimented with using NLR analysis as a proxy for trade data in a MENA region country. Media reports suggested that, after a series of regional events, traffic to a major port in the country had slowed. However, this could not be corroborated using traditional means and due to rival claims about trade flows. The Crisis Analysis Team's ad hoc analysis indicated what ports data would later confirm: that trade flows had been sustained, for the time being at least.

In a conflict-affected country in the MENA region, another Crisis Analysis Team performed an initial analysis of urban inequality. The team broke a major city down into grids, and studied the growth in NLR emissions over time as well as total light emissions. This analysis allowed the team to identify areas where NLR emissions were both lower than average and growing at a slower pace than other parts of the city, and where total emissions and NLR growth were higher than average.

These use cases demonstrate the broad utility of NLR analysis for humanitarian and development actors, namely when trying to answer both real time and time sensitive questions and when analyzing economic growth/decline, especially as the capacity to collect this information through traditional means can be limited.

B. In disaster response and recovery

A more direct operational use case for NLR analysis is in disaster response and recovery. NLR analysis has been used in several contexts to quickly identify areas affected by natural disasters and conflict, and those where recovery has lagged in the wake of these disasters. In the absence of other data, this type of analysis could be critical to identifying not just the hardest-hit areas during disasters, but also those which recover the slowest in the wake of a crisis. An economist who has worked with major international institutions and has used NLR analysis in his work noted that NLR is particularly useful as a "blunt tool" in disaster response.

> *"Night lights are a bit rudimentary and unreliable. But they are useful when you want to see where the lights have gone out, particularly if there was a lot of luminance a few days or weeks before. We have really clever machine learning models for assessing damage after disasters, but that can take months. This is good for quickly visualizing the effects. Sometimes dark spots just mean the whole area has been destroyed, but they can also help show an area where there aren't resources or the government isn't interested in restoring power, which usually means that other infrastructure isn't present."*
>
> Author interview, World Bank economist, Washington DC, June 2024.

In 2017 and 2018, in the wake of Hurricane Maria, NASA tracked the restoration of electricity supply in Puerto Rico. NASA data scientists combined NLR data with daylight satellite imagery to monitor where and when electricity access was restored. They also analyzed the demographics and other attributes of neighborhoods affected by the power outages. They found that "a disproportionate share of the long-duration power failures occurred in rural communities."[16]

16 NASA Earth Observatory. "Night Lights Show Slow Recovery from Maria." March 2018.

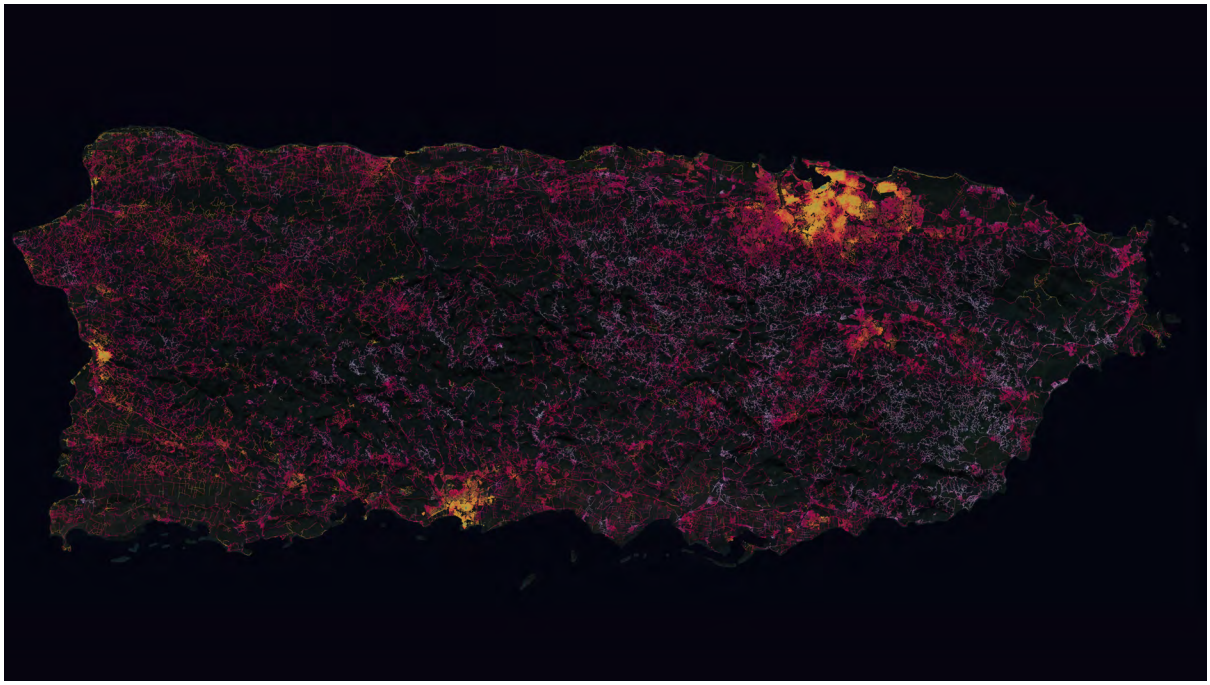

FIGURE 2. COMPOSITE MAP, SHOWING NLR EMISSIONS IN MARCH 2018, AND DAYS WITHOUT POWER IN KEY AREAS OF PUERTO RICO. SOURCE: NASA, 2024

In 2023, data scientists at NASA used satellite imagery to gauge the impact of two earthquakes that caused extensive damage across southern Türkiye and Northern Syria. Using NLR data, NASA was able to determine that much of the Turkish city of Antakya had lost access to power during the earthquake. Data scientists were also able to track in which parts of the city electricity was restored in the following days.[17]

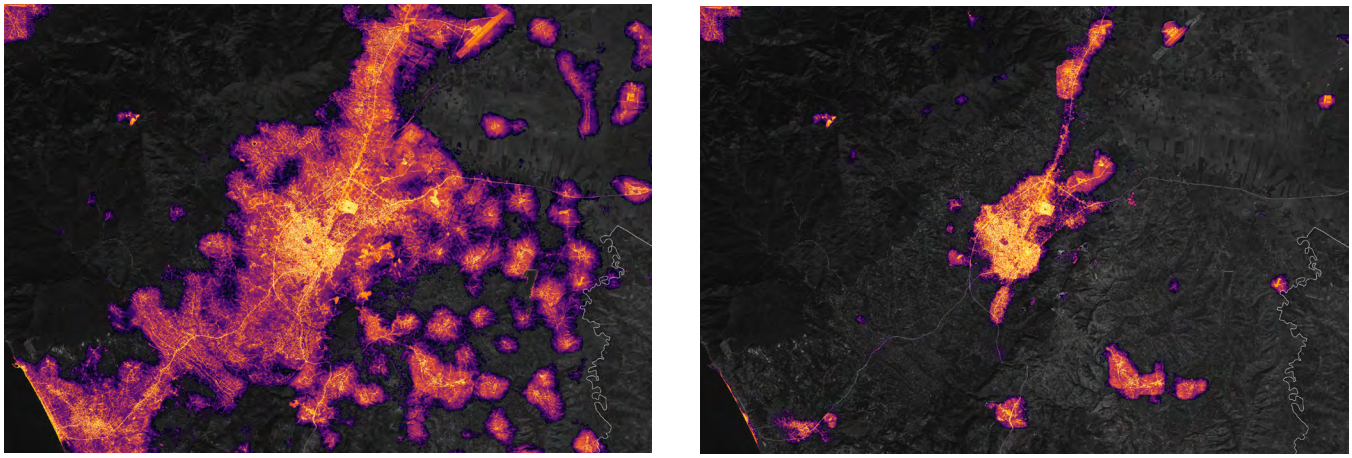

FIGURE 3.1 AND 3.2. NASA BLACK MARBLE IMAGERY OF ANTAKYA, FEBRUARY 4 AND FEBRUARY 8, 2023. SOURCE: NASA, 2024

17 NASA Earth Observatory. "Brighter Nights in Antakya." April 30, 2023.

Mercy Corps' CA–SYR team also used NLR emission patterns to assess the post-earthquake electricity recovery in northwest Syria after major earthquakes there and in Türkiye in 2023.[18] The team found that electricity supply in Idlib City was restored relatively quickly when compared to other populated areas near a major highway that crosses the broader governorate. The team also examined potential statistical links between electricity restoration and humanitarian needs, but found no significant correlation.[19]

Elsewhere, Mercy Corps used NLR to assess damage to human settlements following the Kakhovka dam break in Ukraine and the Derna dam collapse in Libya. Figure (4) displays the latter analysis, namely the variation in post-disaster recovery after the dam collapse in Derna.

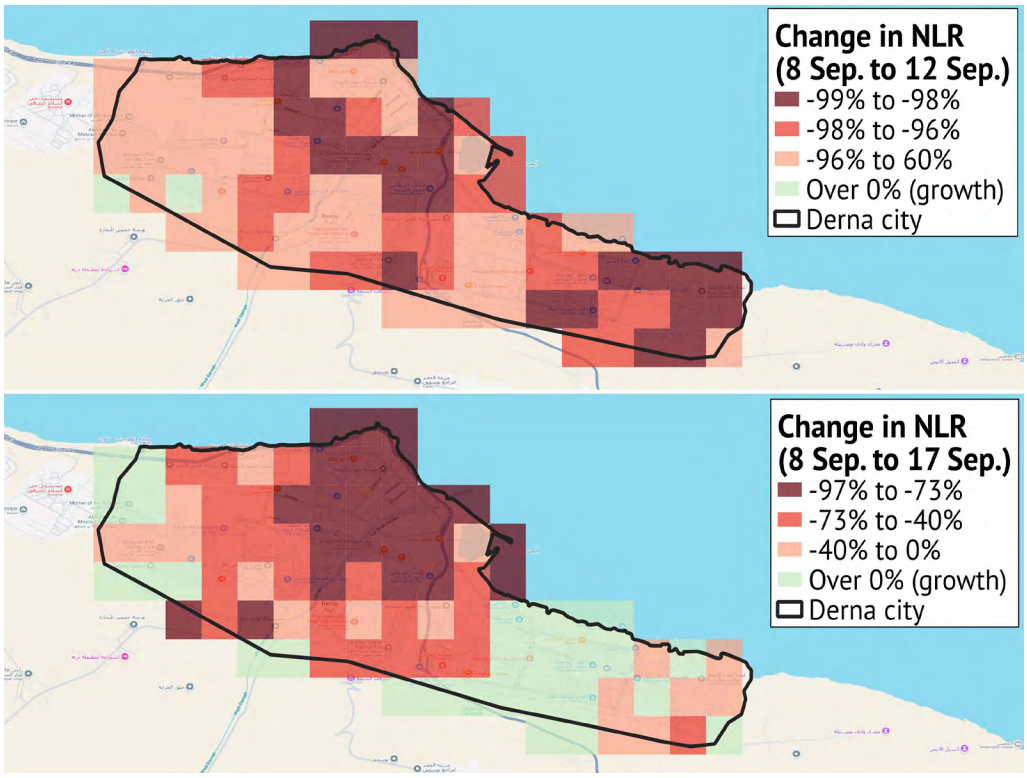

FIGURE 4. CHANGE IN NLR EMITTED FROM DERNA BEFORE (SEPTEMBER 8) THE SEPTEMBER 10, 2023 DAM COLLAPSE AND TWO AND SEVEN DAYS AFTER (SEP 12 AND SEPTEMBER 17)

Mercy Corps is currently developing a suite of post-disaster recovery indicators based on inferential statistical analysis – looking for statistical patterns that suggest a particular humanitarian outcome in a given area – for advocacy and to inform program area targeting; for example, by calculating a linear regression of NLR growth rates on baseline NLR levels to measure how equitably electricity consumption is recovering, and using the model's residuals to identify areas of unusually high or low rates of recovery.

NLR images have also been used to identify conflict-affected areas and refugee trends, and as an advocacy tool in Ukraine since the full-scale Russian invasion of the country in 2022.

18 Crisis Analysis–Syria. "Northwest Syria series: Post-earthquake electricity recovery." May 2023.
19 Crisis Analysis–Syria. "Humanitarian need and the re-electrification of northwest Syria" January 2022.

C. Identifying human settlements and activity

Proposed applications for NLR analysis include measuring population and migration patterns. For instance, Worldpop uses a machine learning model trained with census data and a variety of geospatial indicators, including NLR data, to estimate national and subnational populations worldwide.[20] Academic studies suggest that NLR analysis alone has limited utility in demonstrating population outflows, and that NLR is particularly ineffective in rural areas.[21]

Researchers have nevertheless found NLR to be a useful tool for identifying some patterns of human activity, including refugee movement and informal settlement formation. In 2023, Chinese economists published a paper that described a new methodology for identifying informal settlements around major Chinese cities using a mixture of high-resolution satellite imagery produced using China's Luojia 1-01 satellite system, including NLR data and machine learning tools.[22] Similar approaches have been used to identify and quantify activity at informal settlements and refugee camps in Bangladesh and forced labor camps in China.[23] While such research is still in its infancy, it is likely to become more prevalent and more effective over time, including for identifying and roughly quantifying the size of camps for internally displaced people and refugees.

Researchers have also used NLR imagery to geolocate human activity in remote areas of conflict-affected countries. In doing so, they have found that isolated clusters of NLR emissions in remote areas are often linked to the presence of solar panels. Researchers studying informal trade in Yemen have used NLR to identify critical informal meeting points in transportation networks.[24] In 2023, as mentioned above, researchers working for the World Bank examined purported fuel smuggling sites along the Syria-Lebanon border, and found that NLR emissions increased during (what were understood to be) particularly busy periods for smugglers. Passing trade attracted vendors and other businesses to illicit trade hubs/distribution sites, and likely worked through the night.[25] These analyses were predicated on both a thesis developed using qualitative and quantitative data (locally collected fuel price data and key-informant interviews) and validation via remotely-sensed data (NLR imagery).

NLR data could prove useful to humanitarian organizations working to identify and support informal settlements, and to estimate refugee and IDP populations, when analyzed in conjunction with local knowledge. NLR analysis may also help humanitarian program teams and security focal points identify settlements or the presence of armed and political actors in areas where they are conducting operations or risk assessments, by indicating areas of unusual activity. Other potential uses are evaluative, as NLR data, satellite imagery, and machine learning could aid in assessing solar power penetration in rural areas, or measuring the impact of solar power projects.

D. Determining economic relationships and targeting interventions

NLR data can be compared with other data sources to establish statistical relationships that inform operational planning including humanitarian interventions. In 2023, Mercy Corps evaluated household vulnerability in Lebanon[26] at a subnational level by measuring the relationship between changes in NLR and diesel prices. An

20 WorldPop. "WorldPop Methods." Accessed June 28, 2024.
21 Martinez, J.F., K. MacManus, E.C. Stokes, Z. Wang, and A. de Sherbinin. "Suitability of NASA's Black Marble Daily Nighttime Lights for Population Studies at Varying Spatial and Temporal Scales." Remote Sensing, May 17, 2023.
22 Peng, Q., S. Ge, W. Li, L. Xiao, J. Fu, Q. Yu, and J. Gao. "Identification of Densely Populated-Informal Settlements and Their Role in Chinese Urban Sustainability Assessment." GIScience & Remote Sensing 60, no. 1 (2023).
23 Robinson, Eric, Maggie Habib, Sean Mann, and Ed Burke. "Tracking the Relocation of Rohingya Refugees in Bangladesh: A Nighttime Lighting Approach." Tearline.mil, January 13, 2022; Robinson, Eric, and Sean Mann. "Investigating the Growth of Detention Facilities in Xinjiang Using Nighttime Lighting." Tearline, February 26, 2021. (Both notes summarize the findings of RAND research).
24 Author interview, June 2024.
25 World Bank. "Syria Economic Monitor: Syria's Economy in Ruins After a Decade-long War." March 17, 2023.
26 Mercy Corps Lebanon. "Night-Time Light Reflectance: A New Economic Vulnerability Score (EVS) for Lebanon." Mercy Corps, April 25, 2022.

initial study found a strong connection between NLR emissions and diesel prices, with municipalities receiving electricity from a hydroelectric power plant experiencing a noticeably less severe decline in NLR than other comparable areas. Other parts of Lebanon favored by political elites also exhibited less drastic NLR declines during this period.

The study also established a statistical relationship between the growth of NLR emissions (as a proxy for electricity consumption), diesel prices, and household poverty and food security. Wealthier homes, in other words, were better able to cope with the fuel/electricity crisis (in some cases because they had already installed solar power), and as such incurred less intense losses of NLR emissions than worse-off households. The two most significant relationships were those between the growth rate of diesel prices and NLR in a given geographic area (Figure 5), and the change in the distribution of NLR, particularly an increased uniformity of NLR values in a geographic area, compared to the pre-crisis period. These findings, quantified as an economic vulnerability score (EVS), facilitate the creation of a high-level vulnerability indicator at the municipality level not publicly available in Lebanon. The EVS, which was used to support Mercy Corps' cash program targeting, is specific to the Lebanon context, but is applicable where electricity generation is decentralized and reliant on diesel generators.

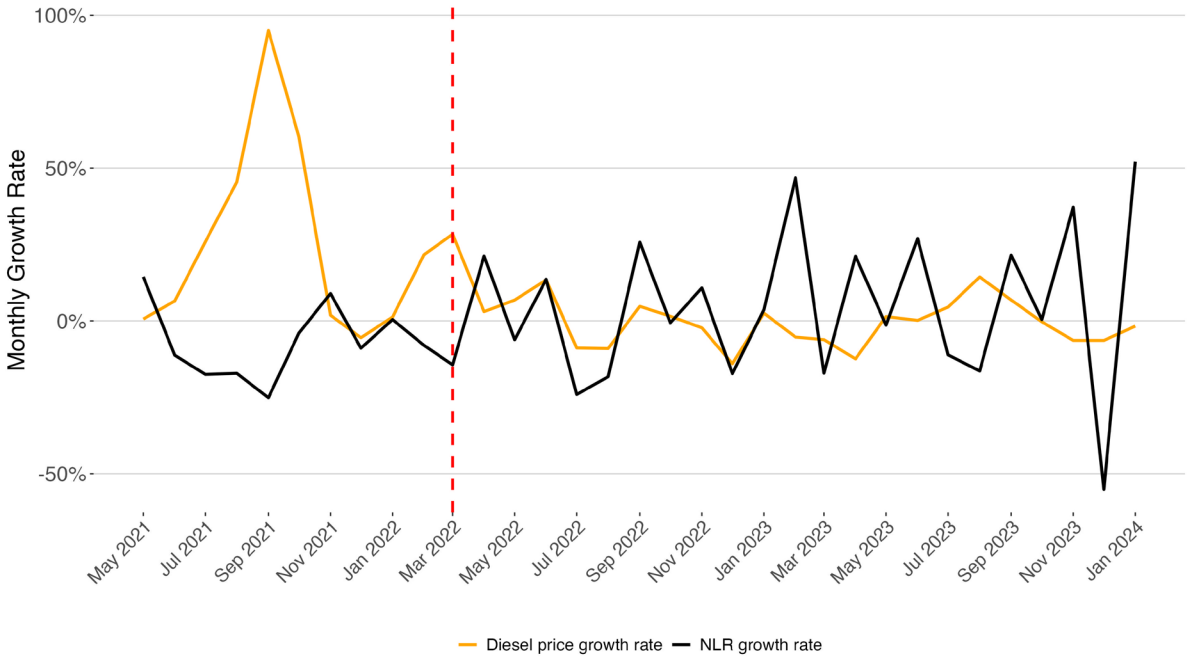

FIGURE 5. NLR AND DIESEL PRICE GROWTH RATES IN A HIGHLY ECONOMICALLY VULNERABLE MUNICIPALITY IN LEBANON. THE DOTTED RED LINE INDICATES THE MINIMUM CORRELATION BETWEEN THE TWO INDICATORS. LOWER CORRELATIONS INDICATE ECONOMIC VULNERABILITY.

NLR dynamics are also being explored by CA–SYR to compare different areas of the country. Proximate locations that share very similar NLR patterns likely share electricity providers and are possibly linked by economic trade and a common labor market. By defining inter-community linkages according to proximity and highly correlated NLR dynamics, CA–SYR is exploring the utility of using such networks to identify distinct economic regions in Syria. This data may help Mercy Corps and other organizations plan future humanitarian and development interventions.

E. As an advocacy tool

NLR imagery can also be used as an advocacy tool. It is often difficult for humanitarian organizations to explain the cumulative impact of disasters, conflicts, and economic crises in a way that a general audience finds compelling. Static and animated images of lights disappearing in major urban centers and across entire countries can illustrate the magnitude of a crisis. Figure (6) shows two such images of Kyiv taken in January and November 2022, before and after Russia's offensive on the city from February to April 2022. NLR data can now be combined with high-resolution satellite imagery to produce detailed city maps showing light loss.[27]

Humanitarian organizations can produce these kinds of visuals relatively easily, and provide them to fundraisers, senior officials, and media outlets to quickly and simply illustrate talking points on the scale of destruction and/or crisis in a given context.

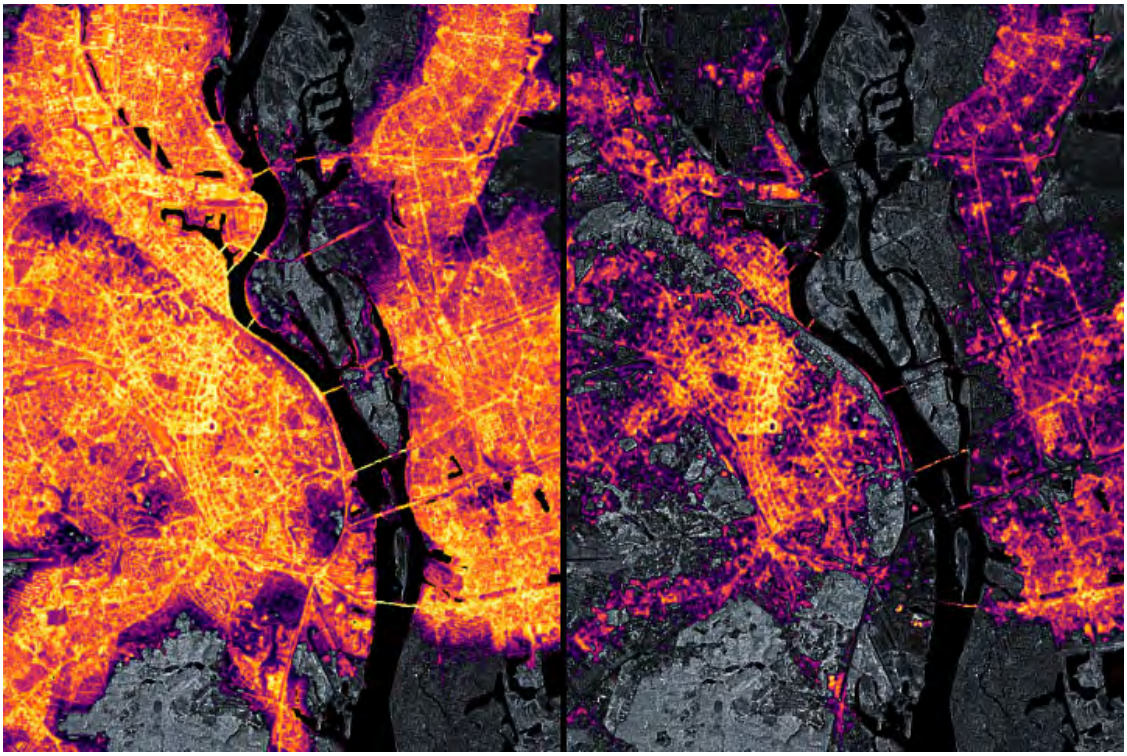

FIGURE 6. KYIV NLR EMISSIONS BEFORE AND AFTER RUSSIAN INVASION OF KYIV. SOURCE: NASA EARTH OBSERVATORY, 2022

27 Iddawela, Yohan. "Tutorial: How to Increase the Resolution of Nightlights Data." The Spatial Edge, March 13, 2024.

Charting a Way Forward: Toward a Crisis Analysis Approach and Overcoming Barriers to Entry for the Aid Community

NLR imagery and other forms of Earth Observation have the potential to become a valuable part of humanitarian agencies' operational, research, and advocacy work, as part of a wider push toward integrating remotely sensed and other forms of unconventional data into analytical and programmatic work.

Drawing on a literature review and a series of case studies, this note argues that NLR analysis can help humanitarian organizations develop a better understanding of local economic and humanitarian dynamics and target areas that had not previously been considered vulnerable, particularly in data-poor contexts where recent crises have created programmatic time pressure. NLR data may also prove useful for organizations entering spaces in which they have not previously operated. Case studies from Puerto Rico, Syria, Sudan, Libya, Lebanon, and Türkiye described in this note underscore the technology's potential, including:

Photo: Earth Observation Group, Payne Institute for Public Policy, Colorado School of Mines.

- Rapid assessment of the localized impacts of natural disasters
- Identifying anomalous trade and activity patterns in comparable contexts like cities
- Identifying areas of activity (and inactivity) before entering new operational spaces
- Assessing humanitarian vulnerabilities and spatial inequality

This note has also made the case that NLR analysis should not be used as a definitive, generalized measure of national or subnational economic activity. Rather, it should be used to track trends in bounded areas over time and identify anomalous patterns in comparable contexts, like urban centers. Identifying these areas for analysis, and interpreting the data, should be the work of expert researchers and analysts who can provide much-needed local context and develop feedback loops between quantitative and qualitative research methods, with each helping direct and shape the other. Researchers and operational leaders should consider the benefits of using NLR data to test their theories about economic and other developments, then "ground truth" the data, before using more advanced techniques to again test the narrative that emerges.

A valuable part of humanitarian work

NLR imagery and other forms of Earth Observation have the potential to become a valuable part of humanitarian agencies' operational, research, and advocacy work, as part of a broader push toward integrating remotely sensed and other forms of unconventional data into analytical and programmatic work.

Operationalizing this approach will take time, resources, and institutional buy-in. While the data and analytical tools needed to interpret it are generally available, the primary challenge may be promoting use by non-expert staff. NLR analysis is still used by a relatively small number of expert practitioners who can process raw data and analyze it visually or using computer programming techniques.

One useful step would be the development of a curated suite of resources and tools including user guides and tutorials from expert analysts, and pre-programmed use case-specific analysis workflows. These types of online tools would only require basic parameter definitions (e.g., study area, time periods, analysis type) and therefore allow non-expert staff to easily generate maps, charts, and run proven analysis routines. In time, artificial intelligence may be integrated into such a platform so that users can type a simple set of commands to produce up-to-the-minute analyses and visualizations for programmatic and advocacy work.

Such a suite of tools could include analytical approaches already used by Mercy Corps and others that are outlined in this note. To do this, the organization could commit to developing an NLR or Earth Observation platform as described above in cooperation with other major international organizations, for instance the World Bank, NASA, or USAID. The fact that VIIRS NLR images are publicly available for download and use on Google Earth Engine is a major advantage for the development of an NLR analytics platform, as it enables developers to forgo engagement with private satellite imagery providers, whose services often prove prohibitively costly and less geographically and temporally comprehensive.

In the longer term, Earth Observation data could allow humanitarian organizations to anticipate developments using remotely sensed data rather than just tracking them, using deep learning techniques. Once the organization has socialized the use of NLR technology and established methodologies for studying specific humanitarian issues, it may be possible to use machine learning to identify specific areas of interest without human input. For example, machine learning could help identify rising urban inequality or a slowdown in activity at major trade centers that are an important source of basic goods for vulnerable populations.

Conclusions

At first glance, integrating NLR into humanitarian and development work may seem like a hugely demanding task. However, it could prove to be a gateway to broader uptake of other Earth Observation and data-led tools that would enrich internal analysis capabilities and allow senior leaders to make quicker, more targeted decisions and communicate their thinking more easily. The analytical approaches developed by Mercy Corps may serve as a proven starting point for analyzing NLR for humanitarian purposes, which could be integrated into an online NLR analysis platform designed for the humanitarian and development sectors.

To donors: Support projects employing NLR analysis and initiatives that seek to centralize proven NLR analysis approaches by creating user-friendly tools on publicly available platforms. Build understanding of existing NLR analysis and suggest its application among recipient agencies, when appropriate. Recognise that in the absence, or partial absence, of traditional aid sector data sources, NLR and other remote sensing tools are a valuable tool to help prioritize and justify funding allocations and program design.

To implementing actors: Introduce proven NLR methodologies to a given organization to raise awareness of the utility of NLR and advise on how to replicate it in different contexts. Request funding for technical training and (ideally) additional internal resources to integrate NLR analysis into analytical and operational programming, particularly in data-poor environments. Pursue collaboration or capacity sharing with other organizations (including researchers and think tanks), and inform context analysts about NLR to ensure that statistical or geospatial NLR analysis is matched with local field research and knowledge. Ensure that the organization's geospatial researcher(s) use NLR to produce research or indicators that are immediately applicable for team members who directly implement programming to maximize the utility of research effort. For example, Mercy Corps' developed the EVS to fill a data gap in subnational vulnerability indicators in Lebanon and was used as a primary selection criteria for the area of intervention.

To researchers: Continue to innovate and expand upon the growing number of studies using NLR to measure social, economic, and natural phenomena while maintaining focus on applicability. Similar to recommendations provided to implementing actors, research institutions not already working with NLR data should build internal capacity by dedicating working hours to learning and perhaps collaborating with other research institutions or humanitarian or development research units.

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About Mercy Corps

Mercy Corps is a leading global organization powered by the belief that a better world is possible. In disaster, in hardship, in more than 40 countries around the world, we partner to put bold solutions into action — helping people triumph over adversity and build stronger communities from within. Now, and for the future.

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