The Picture from Above: Using Satellite Imagery to Overcome Methodological Challenges in Studying Environmental Displacement

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In today's global climate crisis, extreme weather events, such as droughts and floods and forced migration are becoming a norm. As a more extreme and uncertain climate continues to adversely affect people around the world, it is critical to have a range of tools available to measure and address the scale and drivers of forced migration. Inclusive development and the provision of time-effective humanitarian aid to those displaced requires real-time information on displacement, information that can be difficult to fully obtain through data collection on the ground. Satellite data offers an opportunity to supplement ground-level data collection for targeted intervention in areas most at-risk of displacement. The starting point of this paper is the discourse on environmental displacement, the challenges of studying this type of displacement and the opportunities information from remote sensing provide. We then showcase the applicability of such data in an embedded case study on Somalia, a country with a longstanding history of forced migration, drought and conflict.

Introduction

We find ourselves in the midst of a warming world with intensifying climate and conflict shocks. Studying forced migration in the context of environmental change and extreme weather events has gained prominence with the climate emergency being discussed in the media and among policymakers worldwide (McLeman and Gemenne 2018; Ponserre and Ginnetti 2019). The effects of climate change on rainfall patterns and storm severity will continue to threaten populations in coastal, low-lying, agricultural and pastoral communities (IPCC 2012). Additionally, their economic livelihoods are at risk as weather events jeopardize natural resources on which many of these 'climate change hotspot' communities depend. Intervention into areas at risk of environmental degradation and extreme weather as well as providing early response in the wake of displacement, possibly at a large scale, are critical in addressing forced migration.

Interventions into areas at risk of displacement and areas receiving displaced persons require a thorough understanding of the mechanisms and processes driving the timing of people's decisions to move and their selection of destination locations. In turn, understanding the displacement process requires data on a range of topics as the movement of populations is highly complex and motivated by interrelated sets of factors (see, for example, Heslin et al. 2019; Marsh 2015). Studies of displacement, in general, can face difficulty in obtaining data which predate the displacement event of interest. In particular, studies of environmental displacement may require data both preceding and following natural disasters, which alter the landscape, infrastructure and communities and can therefore disrupt any existing and ongoing data collection efforts.

In the context of environmental displacement, satellite imagery offers an opportunity to supplement information collected on the ground with environmental data that covers large geographic areas and time frames. To exemplify, using satellites, one can measure land use, vegetation, soil moisture, and other environmental variables at fine time scales and varying spatial resolutions. Through platforms such as Google Earth Engine, these data sets are publicly available and frequently updated, providing near-real time information to monitor displacement events as they unfold. In addition to environment-specific data, satellite imagery can be applied to measure the growth of cities, refugee camps, and informal settlements, adding to data on destination locations. In this paper, we discuss the scale of environmental displacement, the need for quality data to inform our understanding of this process and provide an example of the potential use of satellite imagery in the case of internal displacement in Somalia.

Environmental Displacement

Projections of displacement[1] in general and environmental displacement, specifically, vary widely across studies using differing data and methodologies (Gemenne 2011). Based on reliable sources, natural disasters resulted in 227 million internal displacements from 2009 to 2018; a number nearly three times greater than conflict-related internal displacement over the same time period (IDMC 2018a) (Figure 1). The first half of 2019 saw 10.8 million new internal displacements, with seven million of these triggered by natural disasters, a new record high mid-year displacement by natural disasters (IDMC 2019a). In addition to sudden onset natural disasters, environmental displacement can occur through longer term, gradual onset changes that affect livelihoods, fuel conflict, and drive internal migration to urban centres (Heslin et al. 2019). While the majority of displacements occur internally, disasters and conflict also drive populations across borders–most often into neighbouring countries, which host four in five refugees (UNHCR, 2019).

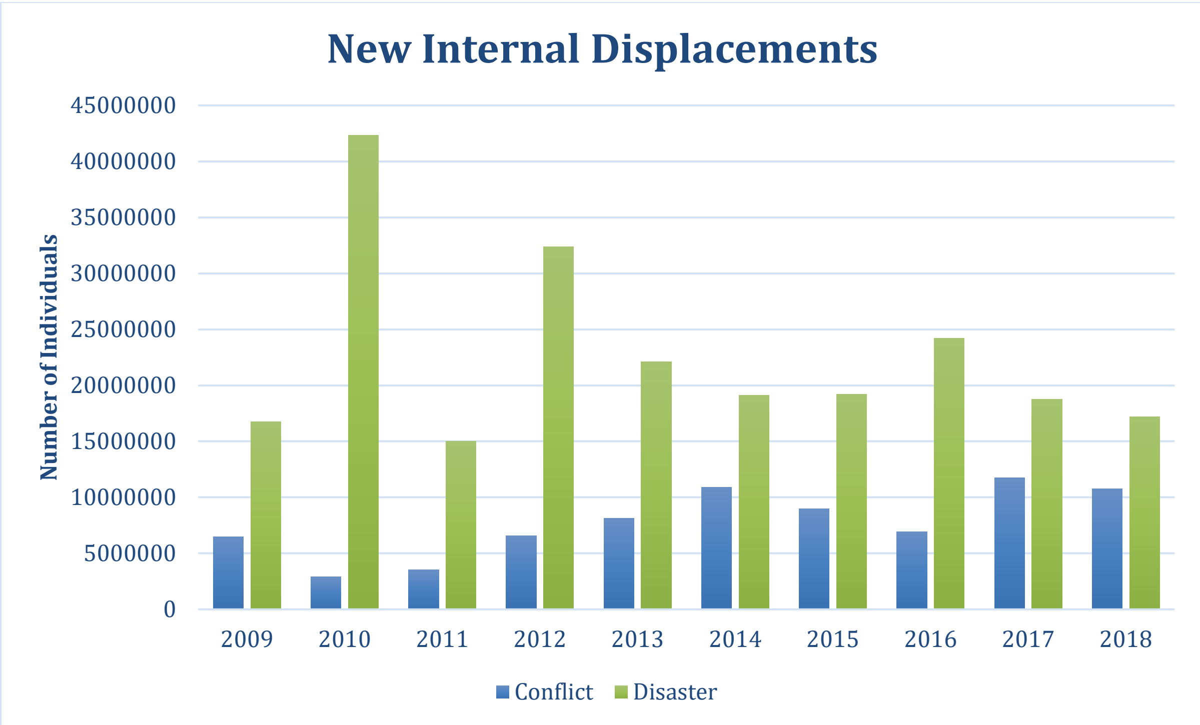

Figure 1: New Internal Displacements 2009-2018
Source: Internal Displacement Monitoring Centre, Global Internal Displacement Database

[1] In the migration literature, typically the terms displacement and forced migration can be used interchangeably. Throughout the remainder of the paper, we use the former.

With climate change adversely affecting sea-level, storm severity, and weather patterns (IPCC 2018), environmental displacement is likely to continue as a major humanitarian issue into the future. During extreme weather events and humanitarian emergencies, health, safety and shelter are the most prevalent priority needs for displaced people. In addition, displaced persons face disruptions in education and livelihoods when leaving home, which can have lasting impacts (Bessler 2019; Cazabat 2018). Differences in disaster-preparedness, geographic location, and societal context also create context-specific challenges for displaced people. Ayeb-Karlsson et al., for instance, investigate early warning system (EWS) effectiveness, finding social determinates of EWS failure in some cases (e.g. mistrust of authorities) and cultural determinants (e.g. religious understandings of disasters as God's will) in others (2019).

Environmental displacement is complex, and our understanding of associated mechanisms is limited. Examining the causes and mechanisms of environmental displacement can help in designing effective policies and processes influencing people's exposure and vulnerability to extreme weather events (sudden) or climate change (slow onset). It is widely accepted that drivers are multi-causal, meaning they range from non-environmental issues such as the political economy, demographic change and conflict conditions to environmental changes and climatic shocks resulting in floods, storms or heat waves (Black et al. 2011). Thus, the study of environmental displacement requires a range of data sources to model these complex dynamics.

Data Limitations

When studying displacement in general, and environmental displacement specifically, several data challenges emerge. First, ground-collected data for determining underlying drivers of migration decisions may not exist or may be incomplete if collection begins only after an event has occurred or only in locations where formal programmes of assistance exist. Within the context of disasters reported in the IDMC database, Ponserre and Ginnetti (2019) report that only 130 of 7,000 events reported since 2008 have time-series data displacement numbers and flows. Second, in the case of regularly collected data–the type that could be used to determine the initial characteristics or vulnerability of a region, community, or household–sudden onset extreme weather events can disrupt their collection. Such gaps in data collection result in missing data during a critical time frame for fully understanding a displacement process. For monitoring unfolding humanitarian emergencies, delays in data access between its collection and public availability can impede research and hold up activities aimed at assisting relief efforts. Lastly, in addition to delays in the public availability of data, data collected by government agencies and aid organizations may not ever be made accessible due to either explicit intentions to keep information internal or simply from lack of capacity or resources to enter and host data in an accessible server.

Opportunities in using satellite data

The IDMC, among others, has highlighted the potential role of satellite data as a tool in addressing displacement (IDMC 2019b). While remote sensing, or collecting data about an area from a distance, cannot replace the breadth of information gained from on-the-ground knowledge and experience—for instance from in-depth interviews, household surveys, or ethnographies—it can supplement such information in many ways. Addressing the above listed data limitations, one advantage of satellites is that they consistently record data at equal intervals around the world. A prominent example are Landsat satellites, which have been collecting imagery of the Earth's surface since the 1970s. The intervals of image collection for the numerous open source satellite data sources are uninterrupted by natural disasters (with the exception of cloud obstruction) or conflicts. This historical depth and contemporary consistency offer major advantages (Witmer 2015).

Satellite imagery can be used in many different ways in the study of environmental displacement, both in terms of gaining a better understanding of the drivers of migration and in measuring actual displacement numbers. Imagery can be used to track changes in landcover or land use type, surface water extent or infrastructure locations at high spatial and temporal resolutions, with open source satellite imagery from sources such as the Sentinel 2 satellite, which collects high-resolution imagery in five day intervals at a 10-meter spatial resolution, meaning any location will have imagery data collected by the satellite every five days. In addition to such imagery, georeferenced climate data provides information on rainfall, temperature, drought indices and soil moisture at daily or near daily timescales as well as climate projections of temperature and rainfall under different climate change scenarios. Radar data, which measures physical properties of the earth's surface, is available for a given location every three days and can be used to gauge expansions of settlements, measuring increases in built structures such as houses, tents, buildings, or roads. Such geographic data are particularly useful due to the near immediacy with which they are publicly accessible, providing near real-time information on the state of the landscape in any given location.

Targeting interventions and building resilience

Researchers and practitioners have used remote sensing in post-natural disaster and large-scale displacement contexts to aid in addressing ongoing crises. In the event of a natural disaster, satellite imagery can provide information on the extent of damage and displacement. For instance, imagery of flood extent, destroyed structures, or burned areas can be compared with pre-disaster imagery to provide governments and aid organizations estimations of the land area and number of people affected (Boccardo and Giulio Tonolo 2015). In addition, studies have used satellite imagery to estimate the size of displaced populations at points of destination. Such studies use imagery to count tents and buildings as well as to measure night time lights to estimate the number of people in a given location (Bharti et al. 2015; Bjorgo 2000; Checchi et al. 2013; Lang et al. 2010; Wang et al. 2015).

These remote sensing data can be combined with ground data and applied in collaboration with organizations working on the ground. In the Northwest Himalaya mountain region, Bharti et al. (2015), for instance, combine anonymized mobile phone data with satellite imagery of night time lights to estimate population movements to improve in the delivery of aid and rebuilding. With information on the approximate number of people in a location, governments and aid organizations can better allocate food and other supplies and estimate requirements for supporting these displaced populations. In the context of targeting interventions displacement need not be strictly environmentally motivated to benefit from satellite data, as determining the size and location of populations can direct aid and resources those displaced from any driver.

During humanitarian emergencies, knowledge of the most affected regions may come after displacement has begun when livelihoods and social structures are already severely damaged. Anticipating who is affected and likely to be displaced can allow for intervention in situ, reducing challenges of assisting already displaced populations and allows for work to build resilience in vulnerable populations. Creating resilience to environmental hazards requires building and strengthening the capacity of vulnerable populations to quickly and effectively recover from disasters and anticipate and reduce future risks (Hallegatte et al. 2017). Satellite imagery, along with georeferenced climate projections, can help identify areas at risk in order to build resilience and intervention strategies in advance of a crisis. The information available through remote sensing from satellites includes climate and land cover, such as vegetation and road surfaces, among many others. Such information can be used to assess the vulnerability of regions to environment displacement. In identifying factors that may cause displacement, such as unusual drops in vegetation or projections of crop failure based on rainfall anomalies, one is also less limited by the spatial resolution of data than in identifying the size the already displaced populations. In measuring already displaced populations, studies like those outlined above counting tents and buildings, require high-resolution imagery whereas in identifying potential environmental hazards for populations, high resolution imagery increases precision, but lower resolution imagery of land-use type or geographic data on climate variables can still offer insight into regions at-risk of displacement.

Critical to using such a vast resource of information for locally applied interventions, however, is ensuring that the data is relevant to the specific context of interest. Knowledge on the region of interest is important for first identifying the primary livelihood source of the population and the livelihood-specific vulnerabilities. Once these specific stressors are identified, it is possible to map vulnerabilities in near real-time or based on future climate projections to identify areas likely to face threats to their well-being. Increased temperature or decreased rainfall, for instance, will be acutely experienced by those dependent on rain-fed agriculture, specifically drought sensitive crops. For example, with remote sensing, one can first identify agricultural regions, then use historical data to locate areas, which regions have experienced decreases in vegetation during periods of below average rainfall. Knowing these areas are vulnerable to rainfall variability and knowing the values of precipitation at which the cropped area historically decreased allows for the use of either contemporary rainfall or rainfall projections to identify locations for intervention. By mapping future rainfall projections over the same regions, we can begin identifying areas likely vulnerable to droughts as climate change progresses.

Such measurements have most potential when applied in tandem with data collected on the ground or in-depth familiarity with the region, as they identify potential environmental drivers of displacement, a process that is multi-causal and context-specific. Satellite data offers the opportunity to fill gaps in knowledge of real-time conditions over large areas for practitioners working in the field. Already existing knowledge of the conditions which have driven displacement events in the past should guide data collection efforts to identify the current state of those factors in inaccessible regions or time intervals.

Potential for satellite data: the case of Somalia

For over two decades, Somalia has been a prominent humanitarian crisis in Africa, presenting a challenging landscape for aid agencies. The case of Somalia presents an example of the highly complex nature of protracted displacement crises in which conflict, environmental disasters, and political and economic instability drive internal and international displacement while disrupting aid flows and data collection (Thalheimer and Webersik 2020). Somalis have faced seven drought events from 2000 to 2017, including the severe drought in East African drought from 2011 to 2012 (Gebremeskel Haile et al. 2019). Despite the number of new drought-related displacements abating, drought-related internal displacements continue and many people have been unable to achieve durable solutions in terms of their health, safety, shelter (Figure 2).

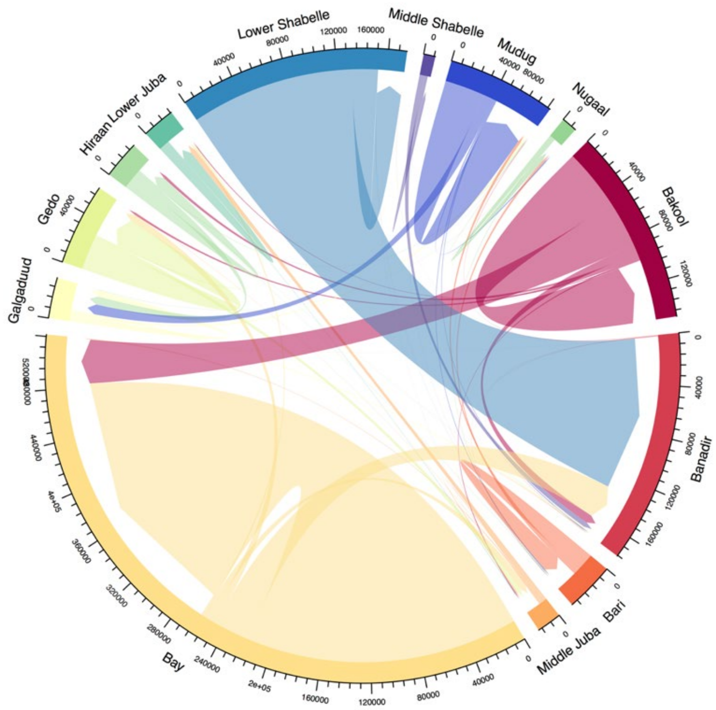

Figure 2: Drought-Related Internal Displacement 2017, Somalia (excluding Somaliland)
Data Source: UNHCR PRMN Somalia Internal Displacement, 2017

The 2011 East African Drought

The 2011 drought in East Africa offers a sobering example of the role of the environment in displacement. Well below average rains in the fall of 2010 and spring 2011 devastated livestock and crop production, causing an increase in food prices and worsening humanitarian situation in East Africa. The humanitarian emergency in Somalia was further exacerbated by a combination of generalized violence and conflict between the Federal Government of Somalia (FGS) and its allies fighting rebel groups. By summer 2011, the UN declared famine conditions in south and central Somalia as refugees fled into neighbouring Kenya and Ethiopia and internally displaced persons (IDPs) numbered over one million (Norwegian Refugee Council/Internal Displacement Monitoring Centre, 2012). As the drought destroyed crops, reduced livestock levels and exhausted people's resources, much of the food assistance allowed into the country was diverted by different parties to the conflict (Seal and Bailey 2013). Although the Federal Government of Somalia (FGS) recognized the severity of the food crisis, it was unable to react *ex-ante*, as little had been invested in anticipating and preventing the vulnerabilities, thus addressing root causes of this kind of displacement. Somalia's capital Mogadishu, for example, is an urban centre, which receives IDPs without the capacity to provide adequate safety, healthcare, housing, education and sanitation to arrivals, resulting in evictions, illness and gender-based violence (IDMC, 2018b). Due in part to limited state capacity as well as delayed humanitarian response, the 2011 drought resulted in widespread famine in Somalia, killing approximately 258,000 people (Checchi and Robinson, 2013).

The need for pre-emptive action

While Somalia represents a particularly challenging case for intervention, it encapsulates many aspects leading to forced displacement more broadly, including ongoing conflict and limited state capacity. In such circumstances, the combination of an environmental event, moving populations and fragility presents substantial challenges for directing timely intervention. Indeed, once displacement begins, many intervention opportunities have already passed. In addition, ground-level data collection, if it existed prior to the crisis, will likely be disrupted, adding further obstacles to identifying intervention locations and solutions. In a real time evaluation report of the 2011 drought in the Horn of Africa commissioned by the UN Office for the Coordination of Humanitarian Affairs, the authors highlight uncertainty regarding the severity of the crisis as a factor, which limited early responses (Darcy et al. 2012). For example, the report notes scepticism and uncertainty surrounding anecdotal evidence reported from various agencies and villages to central officials.

The presence of additional data to confirm or expand upon reports from more remote areas of Somalia could have expedited the identification of those at risk of hunger and displacement This could have allowed for aid interventions in place, thereby protecting populations from many additional dangers that accompany displacement.

Following the 2011 East Africa drought, Save the Children and Oxfam issued a joint report outlining insufficiencies in the response that accounted for the prolonged and devastating food crisis and famine. Of particular note in their report is the call for a stronger focus on data to identify risks and investment in preventative interventions based on those assessments of risk (Save the Children and Oxfam, 2012). What both organizations highlight in the report regarding the famine applies more broadly to addressing forced migration elsewhere–that the best strategy to deal with a crisis is by intervening before it can become one through building resilience and reducing vulnerability to droughts, floods, storms and other risks.

To locate populations most vulnerable to climate extremes requires data on their location and surrounding environment, livelihoods, infrastructure and topography. For example, a qualitative assessment of existing road conditions through satellite-derived images are crucial for determining the feasibility and type of humanitarian aid delivery. Combining these data with that of local climate conditions and projections can target intervention before situations deteriorate into displacement-driving humanitarian emergencies. Such advanced action faces fewer obstacles on the ground as it could occur prior to disaster-induced conflict and instability and infrastructure and housing damage.

During the 2017 Somalia drought, after almost half of the Somali population was already on the brink of yet another humanitarian crisis, the World Bank supported the Food and Agriculture Organization (FAO) and the FGS with a $50 million emergency funding package for drought relief, addressing deteriorating food security levels. While the response in 2017 helped to avert a repeat of the famine conditions of 2011, forecasts of soil moisture, temperature, and precipitation could be used to direct aid to areas at risk of future extreme events before populations are so severely affected. Whereas satellite imagery has been used in the context of mapping Somali road networks and population distribution in the absence of a humanitarian crisis (World Bank Group 2018), we argue that such data could have been used for a timelier intervention in 2017 (and 2011) to ensure disaster preparedness and build resilience in the face of a changing climate. Practitioners like the Red Cross Climate Centre (RCCC), for instance, have been starting to apply tests of forecast-based financing (FbF) approaches to inform short-term humanitarian assistance based on disaster warnings from scientific forecasts (Coughlan de Perez et al. 2015). For example, FbF was applied during the 2015/16 El Niño event in Peru and helped reduce impacts from heavy rainfalls and floods by protecting houses, providing safe drinking water and first-aid training to affected populations (Red Cross EU Office 2019). To enable anticipatory humanitarian action, the use of satellite data helps to develop early warning systems, providing funding before an extreme weather event strikes. Ultimately, such ex-ante finance mechanisms support disaster-preparedness, reducing risks and strengthening resilience of vulnerable populations through an integrated framework.

The applicability of satellite data could have averted a humanitarian emergency during Somalia's 2011 drought. Satellite imagery could have offered an opportunity to locate vulnerable populations when regular data collection was obstructed by violent conflict or limited resources. One could, for example, combine data on rainfall, temperature and land use to identify areas facing most extreme weather anomalies, use satellite imagery to measure the size of displaced-persons camps and assess the environmental vulnerability of those in refugee or IDP camps. In the context of food security, the Famine Early Warning Systems Network (FEWS NET) incorporates data from partner organisations such as National Oceanic and Atmospheric Administration (NOAA) and remote sensing climate products, like the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) in analyses for food security outlooks in selected regions in Africa, Central Asia and Central America (FEWS NET 2019a). Such a system could be applied to populations' vulnerability to extreme weather and displacement.

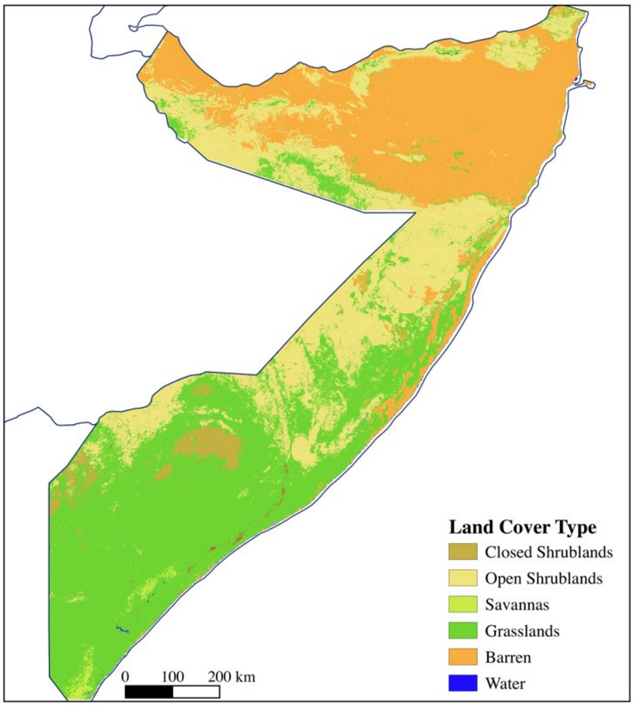

Figure 3: Land Use Type Somalia
Data Source: MODIS Land Cover Type 2016

To identify at-risk areas to target aid intervention, one can use existing land cover maps (Figure 3) or create more detailed supervised classifications of remote sensing data to locate land use types throughout the country and to identify regions vulnerable to climatic changes like decreases in rainfall, for instance agricultural or pastoral communities. Historical data can identify regions that experienced vegetation loss in previous drought events using numerical indicators, including the Normalized Difference Vegetation Index (NDVI) and the Standardized Precipitation Evapotranspiration Index (SPEI). NVDI provides a measurement of the amount of vegetation, which can be used to identify regions showing a marked decrease in vegetation during previous years. The possible influence of drought can then be assessed using SPEI, which combines measures of precipitation with evapotranspiration to identify drought conditions. This combination of NDVI, SPEI, and landcover data can allow for distinguishing the role of human and conflict-driven land degradation from drought-induced vegetation declines. Following the identification of regions with high levels of vegetation and land-based livelihoods, which were historically drought-sensitive, remote sensing can further be used to plan aid shipment routes or identify infrastructure damage that may impede intervention.

In the context of disasters such as severe droughts, having up-to-date information as well as historical data for comparison is critical to anticipate resource needs and high-risk locations before situations rapidly deteriorate into displacement and famine, as occurred in Somalia in 2011. Having access to additional types of data beyond that which can be collected on the ground is vital to pre-empt disasters and inform humanitarian responses in unstable and quickly changing environments.

Way forward

Satellite data can provide important opportunities to strengthen estimates of populations at risk of forced migration, particularly in the context of disasters and degrading environments. Remote sensing data has been used in limited contexts to enhance the timeliness of knowledge on displaced persons' destination localities. We suggest additional applications to address environmental displacement, including identifying vulnerable communities to support pre-disaster resilience-building interventions. Regarding Somalia, these methods are applicable to inform life-saving early warnings, especially given existing conflict conditions and associated risks in on-the-ground data collection and field visits. Satellite data of conditions of land areas must be guided by knowledge of the populations and their prior experiences under different environmental conditions. For this reason, the data from satellites would be best obtained and analysed in close collaboration between geographic and remote sensing experts and those by government and humanitarian actors working in early response and risk mitigation.

While these data sources are publicly available online, expertise is required to obtain, analyse and interpret data in a way that can inform decision makers and, ultimately, policy. For example, satellite information on the location, frequency and intensity of affected areas will be crucial to address priority needs and to design adaptation measures, but requires merging data from multiple satellites, resolutions, and time scales. The existence of the data does not guarantee its accessibility by those who could best interpret and apply the information available. In such cases, capacity building needs to be a priority to equip actors with the tools needed to take advantage of this vast data resource satellite imagery offers. Maps of displacement outlooks could make the information quickly accessible through an easy to grasp visual method, similar to maps showing priority areas of future food insecurity (FEWS NET 2019b). In addition, collaborations between researchers and practitioners to create early warning systems for displacement and emergency aid needs is crucial to better address displacement in the context of environmental disasters.

Acknowledgement

The work reported here was funded in part by the Army Research Office under the Multidisciplinary University Research Initiative (Grant #W911NF1810267). The views and interpretations expressed in this document are those of the authors and should not be attributed to the US Army. Additionally, financial support from the Robertson Foundation, United States (Award 9907422) is gratefully acknowledged.

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