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Vegetation changes attributable to refugees in Africa coincide with agricultural deforestation

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Abstract
The recent adoption of the Global Compact on Refugees formally recognizes not only the importance of supporting the nearly 26 million people who have sought asylum from conflict and persecution but also of easing the pressures on receiving areas and host countries. However, few countries may enforce the Compact out of concern over the economic or environmental repercussions of hosting refugees. We examine whether narratives of refugee-driven landscape change are empirically generalizable to continental Africa, which fosters 34% of all refugees. Estimates of the causal effects of the number of refugees—located in 493 camps distributed across 49 African countries—on vegetation from 2000 to 2016 are provided. Using a quasi-experimental design, we find refugees bear a small increase in vegetation condition while contributing to increased deforestation. Such a combination is mainly explained not by land clearance and massive biomass extraction but by agricultural expansion in refugee-hosting areas. A one percent increase in the number of refugees amplifies the transition from dominant forested areas to cropland by 1.4 percentage points. These findings suggest that changes in vegetation condition may ensue with the elevation of population-based constraints on food security.

Introduction

International migration, driven by economic reasons, to avoid conflict and persecution, or even in response to climate change, is receiving greater attention in policy circles given the increased responsibility of host countries to provide goods and services for a growing, diversified population [1]. Considerable headway has been made in establishing the Global Compact on Migration and the Global Compact on Refugees out of the recognition that additional resources will be required from the international community to broadly foster the economic and social integration of immigrants [1, 2]. These agreements are nonetheless not legally binding or enforceable [1]. The inertia of creating new migration policy instruments at the local level can be hindered by perceptions regarding the burden migrants may pose on the economy and environment of receiving areas.

Concerns over the environment in part may be rooted from the messaging of previous reports and academic studies [3–7]. Refugees have been purported to leave their ecological footprint through the permanent clearance of land and extraction of resources for cooking, heating, and building their homes [6–10]. Scholars have since challenged the thesis of refugees acting as *exceptional resource degraders* [11]. They highlight the importance of context, in terms of the policy and conditions in countries hosting refugees. For example, camps with exceptional degradation, such as Darfur in Sudan, are commonly placed in areas facing increasing population pressure combined with an absence of regulations restricting extractive practices [11–13]. Similarly, in these locations, indefinite moratoriums are placed on the movement of refugees, limiting their options for employment and their space to farm [14]. Overall, there is scant systematic, quantitative evidence regarding changes in physical landscape or resource deterioration to corroborate the Malthusian view of refugees' environmental impact.

We therefore combine a unique dataset of geo-referenced refugee camps in 49 African countries over 2000–2016 with multiple satellite datasets on contemporary vegetation condition and change to test our main hypothesis that refugees are unlikely to render significant change to landscape condition in hosting areas. A related literature which focuses on quantifying the effects of internally displaced peoples (IDPs) on local land cover produces a range of results. While some studies point to losses in forested land from forced displacement [15, 16], others find evidence of increased vegetation due to the replanting of trees, and the resurgence of vegetation from the suspension of previous grazing routes [17].

In addition to testing the refugee effect on the condition of natural vegetation, we test a second hypothesis: refugee camps lead to the expansion of agricultural land [18–20]. Refugee camps offer additional sources of cheap labor and attract capital investment, such as the expansion of road networks [21–27]. Both features can strengthen farmers' access to cheaper inputs and auxiliary output markets reinforcing incentives to cultivate more land [28–30]. However, refugees themselves have at times been responsible for the conversion of forest to agriculture due to their volition to continue farming in host regions [28]. Qualitative studies identify the use of unsustainable, customary practices and shortened fallowing cycles as a means of compensation for meager land allotments through existing programs initiated within camps [8, 10]. Such behavior highlights the importance of not only evaluating the causal effect of refugees on vegetation condition, but also potential effects on conversion between forest and agriculture [15].

Data and methodology

Definition of key variables

Our main unit of analysis is a 1° grid-cell, which has a length and width of roughly 111 kilometers at the equator. We use the grid-cell unit over subnational administrative boundaries, such as a province, as the size of the latter differs from country to country. Hence, by using a grid, each geographic unit is comparable in size across countries. Our main dataset uses 2767 grid-cells, covering 49 African countries, save the island states. The details of the following data sources used to create our main dataset are summarized in supplementary table S1 is available online at stacks.iop.org/ERL/15/044008/mmedia.

Geo-referenced data on 810 refugee camps in Africa and their number of residents are provided by the United Nations High Commissioner for Refugees (UNHCR) over the period of 2000–2016 (supplementary figure 1). Although this dataset currently provides the most comprehensive view of camp locations, the reported numbers of refugees are limited to those residing in camps. Therefore, we will be unable to extrapolate the environmental effects of refugees integrated in rural communities or cities. Furthermore, the reported number of refugees likely underestimates the true refugee population in Africa given that the dataset only includes information on camps monitored by the UNHCR.

The main challenge in using this dataset is that location information is only available for 61% (493) of the camps. To address the error in measuring exposure to the Universe of refugee camps (supplementary Information), we apply an instrumental variables (IV) approach. We additionally, display estimates from specifications that aggregate vegetation, refugee populations, and other explanatory factors at the province level, a geographic unit in which we can identify most camps. Such an aggregation allows us to account for a greater percentage of camps (36%) in our analysis and evaluate how sensitive our main estimates are to the incomplete representation of the distribution of refugees (supplementary Information). According to our sample, on average, there are 2000 refugees per grid-cell (supplementary table 2).

We measure a suite of remote sensing-derived indicators of vegetation condition and land cover extent across Africa, all of which are spatially aggregated to our 1° grid-cell. Landscape condition is quantified using the annual average enhanced vegetation index (EVI) from the MODIS MOD13C2.006 product from 2000 to 2016 [31]. Change in forested area is captured by subtracting the total area of tree cover loss from gain with the Landsat-based Hansen product from 2000 to 2012 [32] (supplementary figure 2). We add two more metrics to examine the validity of our second hypothesis. Agricultural expansion with contemporary forest contraction per grid-cell is based on International Geosphere-Biosphere Program land cover data using the MODIS MCD12Q1 product from 2001 to 2012 [33]. Our first metric is an indicator variable that holds a value of one per grid-cell if the percentage of cropland increased and the percentage of forested areas decreased between 2001 and 2012 (supplementary figure 3). Average annual net primary productivity (NPP) is based on the MODIS MOD17A3H.006 product [34], which measures vegetative biomass accumulation.

To rule out competing hypotheses on refugee contributions to changes in vegetation condition, such as through their resource-extractive activities or through their effect on native displacement from camp locations, we provide analysis applying three auxiliary outcomes: burn area index (BAI), changes in built-up area, and changes in population. The BAI is constructed using the MODIS MCD43A4 product [35]. BAI is sensitive to charcoal signals following the burning of vegetation, and, thus, relevant for monitoring land clearing associated with informal settlement establishment, conversion to pasture, or charcoal production. Change in built-up area between 2000 and 2014 is created using the Landsat-derived Global Human Settlement Layer [36]. Finally, change in population between 2000 and 2015 is computed using data from the Gridded Population of the World [37].

Given that fluctuations in vegetation are also linked to climatic conditions and conflict, we integrate local climate variation and conflict as explanatory variables in our preferred specifications. We include the contemporaneous average annual monthly temperature (in Kelvin) and average daily precipitation (in millimeters) [38, 39]. We also add the total number of reported annual conflict events within the grid-cell as an explanatory variable, using the UCDP Georeferenced Event Dataset [40]. A conflict event incorporates events related to civil conflicts, violence between different groups (e.g. ethnic violence), and repression in the form of violence against civilians by parties engaged in civil conflict. The average monthly temperature is 298 Kelvin (or 25° Celsius) in our sample (supplementary table 2). Precipitation averages 2 millimeters per day. Finally, a grid-cell experiences 0.4 conflict events per year on average.

Statistical models

To formalize the relationship between the EVI and the number of refugees, *Refugees,* in a cell c at time t, we estimate the following linear regression model:

$$EVI_{ct} = \alpha + \delta_c + \delta_t + \delta_t \times Lat_c + \delta_t \times Lon_c + \beta Refugees_{ct} + \gamma X_{ct} + \theta Con_{ct} + \varepsilon_{ct}. \quad (1)$$

The number of refugees is transformed by the inverse hyperbolic sine (IHS), as it approximates the natural logarithm transformation while including zero-valued observations [25, 41]. Our first hypothesis contends that refugee presence does not negatively affect vegetation, or $\beta \geqslant 0$. To explore whether changes in vegetation result from the expansion of agricultural land (our second hypothesis), we apply model (1) with the NPP as an alternative dependent variable. Our second hypothesis explicitly suggests $\beta > 0$. In (1), the grid-cell fixed effect δ_c controls for unobserved, location-specific factors that are likely to influence vegetation, such as the location's agro-ecological zone. The inclusion of a time fixed effect δ_t is meant to capture the role of inter-annual trends on vegetation such as the phenological cycle. The natural induced time-varying factors that influence vegetation are implicitly accounted for in X, which includes the average temperature measured in degrees Kelvin, the average level of precipitation measured in millimeters, and *Con*, the number of conflict events. Our inferences rely on standard errors clustered at the cell level, but conclusions remain similar when based on standard errors adjusted for spatial and time dependency of an unknown form [42] (supplementary table 3).

We also aim to shed light on the mechanisms underlying refugees' contributions to changes in landscape condition and composition. We estimate (1) replacing EVI with BAI to validate refugees are not responsible for land clearing due to resource-extractive activities. The following model is also estimated using outcomes which reflect changes in vegetation condition over the long term:

$$\Delta Y_c = \alpha + \beta \, Refugees_c + \gamma \Delta X_c + \theta Con_c + \varepsilon_c. \quad (2)$$

In (2), *Refugees* signifies the average number of refugees in cell c over the period under study. The relationship between refugee presence and a variety of other outcomes are explored applying (2), such as the long-term change in tree cover area, the tendency of a cell to be converted from forested land to cropland, and changes in population and built up area. ΔX includes the change in temperature and precipitation, and *Con*, the cumulative number of conflict events over the period of study. The duration of the differences for the outcomes and climate variables and the period over which we take the cumulative conflict events is consistent in each specification. However, given variation in temporal coverage across data products, the period under investigation in each specification varies by outcome.

There are three classical challenges highlighted in the economic literature on refugees which warrant the application of an IV strategy to identify β in both specifications [43]. First, our main analysis focuses on refugee camps whose location has been estimated within 50 kilometers (supplementary information). Exposure to refugee camps may therefore suffer from measurement error. Second, bias can arise from omitted time-varying variables that determine vegetation condition. For example, the cultivation practices of native populations may be driven by factors unrelated to climate, e.g. localized policies or investments implemented in a given year, or aspects of climate unaccounted for in the model, e.g. wind. These are omitted in (1) and (2). Adding latitude-specific, $\delta_t \times Lat_c$, and longitude-specific, $\delta_t \times Lon_c$, time fixed effects in (1) alleviates this second concern. Third, the locations of refugee camps are unlikely to be exogenous. They may be instead situated in highly marginalized or otherwise degraded regions, leading to erroneous conclusions that refugee populations contribute to environmental deterioration.

IV approaches are typically used to address each of the econometric issues articulated above. We therefore employ an IV model (rather than a standard ordinary least squares model) when estimating (1) and (2) [43]. Before estimating (1) and (2), however, we first verify the conditions required for the application of the model. The first condition is that the outcomes and refugee population are stationary [44] (supplementary table 2). The second condition is that we substitute actual refugee camps with an exogenous measure of refugee presence in (1) and (2). In practice, we can construct such an exogenous variable from a first stage regression. In the first stage regression, the number of refugees is the dependent variable and the explanatory variables in (1) and (2) as well as the IV are the independent variables. The requirements of a strong IV are that it effectively predicts the number of refugees *and* satisfies the exclusion restriction. In this case, we must identify an instrument that only affects vegetation (and other outcomes) through the presence of refugees at the destination area.

We utilize an instrument that has been applied in numerous migration studies [27, 45, 46]:

$$IV_{c(D)k(O)t} = \sum_{k \neq c} Refugee_{ODt} \times \left(\frac{1}{Distance_{ck}}\right) \times Q_{kt-1}. \quad (3)$$

The first term represents the number of refugees moving from country O to country D at time t. The IV utilizes the UNHCR Population Statistics time-series data on the number of refugees in a destination country in a given year from a particular origin country [47]. The second and third terms serve to exogenously allocate a greater number of refugees from a given origin to destinations based on existing pull and push factors. The second term presumes spatial proximity, intrinsic in the measure of the inverse distance between location k in origin country O and location p in destination country D, pulls refugees to destinations relatively close to their origin. The third term suggests a greater number of refugees will come from locations exposed to higher levels of conflict Q_{kt-1} in the preceding year, where conflict levels are measured by the number of conflict events in the cell. The strength of the instrument is apparent from the first stage regression estimates: the coefficient on the instrument is positive in the first stage of the preferred specification and statistically significant ($P < 0.01$), and other standard diagnostics are satisfied (the Kleibergen-Paap rk Wald F statistic exceeds > 10). Several tests of the validity of the models' assumptions are described in the supplementary Information.

Results

The precise relationship between vegetation and refugee presence is shown in table 1. Estimates of the parameters for all control variables and for alternate standard errors in the second stage regressions are reported in supplementary table 3. Coefficient estimates are converted into elasticities to facilitate interpretation of the size of the effect of our explanatory variables on vegetation [41]. Our preferred model suggests that precipitation positively and temperature negatively influence the EVI, confirming established linkages between inter-annual weather anomalies and vegetation [48–51]. While conflict events negatively affect vegetation, the magnitude of the effect is quite small after considering refugee presence. For example, the conflict elasticity suggests that doubling the number of conflict events in a given location would affect vegetation by less than 1%. These findings are consistent with earlier global analysis which suggest that there are small associations between conflict and environmental degradation after controlling for population growth [52, 53]. We also plot the value of the change in the root mean squared error and t statistic representing statistical significance in the regression for each variable in supplementary figure 4 to further gauge the explanatory power of each factor on changes in vegetation. The results indicate that refugee presence offers the highest degree of explanatory power for the variation in vegetation among the control variables after conditioning on location and time-specific occurrences.

Turning to the validity of our first hypothesis, we first display the precise estimated relationship between vegetation and refugee presence in table 1. The elasticities indicate that refugees are positively associated with vegetation condition. Based on our IV approach, doubling the number of refugees increases the EVI by 3%.

We additionally create 95% confidence intervals of the calculated elasticities from the coefficients produced by the main model (specification A) and alternative models (specifications B-H, supplementary table 4) in figure 1. Transforming distance by the square root and square in (3) slightly increases and decreases the values of the elasticities (specifications B and C). Removing conflict in the IV (specification D) or adding a measure of conflict spillovers (specification E) in the second stage regression to address concerns over the exclusion restriction produce fairly similar results. Dropping years with high serial correlation of refugee inflows and including a lagged refugee variable corroborate the presence of refugees has minimal impact on vegetation (specifications F and G). The refugee effect also remains the same when adding a control for the presence of IDP (specification H). The vegetation effects are also uninfluenced by whether we restrict the sample to cells whose distance to the closest refugee camp is below 200 kilometers (supplementary table 5), or whether we change the vegetation outcome (supplementary table 6) and underlying specification of the treatment or model (supplementary tables 7 and 8). The magnitude of the effect declines when evaluating the relationship at the province level to include the Universe of camps in the analysis (supplementary table 9).

Additional support for the first hypothesis is corroborated upon examining the refugee effect on other outcomes in table 1. For example, there is no statistical evidence that the BAI is affected by refugee presence.

Table 1. Effects of refugee intensity on landscape change.

	Model 1							
Dependent variable	Enhanced vegetation index 2000–2016		Burn area index 2000–2016		Net primary productivity 2000–2016			
	OLS	IV	OLS	IV	OLS	IV		
Number of refugees (IHS)	0.00006	0.00586	−0.38158	7.77362	−7.23825	476.58792		
	(0.00006)	(0.00194)***	(0.20774)*	(5.24677)	(9.98791)	(215.78907)**		
Elasticity	3×10^{-4}	0.027	−0.012	0.256	−0.001	0.095		
Observations	45101	45050	45101	45050	32775	32730		
Root MSE	0.01	0.01	48.71	46.64	1391.49	1391.00		
Kleibergen-Paap rk Wald F		12.37		12.37		12.17		
	Model 2							
Dependent variable	△ Forestland, 2000–2012		△ Population, 2000–2015		△ Built-up area, 2000–2014		Forest to Cropland Indicator, 2001–2012	
	OLS	IV	OLS	IV	OLS	IV	OLS	IV
Number of refugees (IHS)	−0.05375	−0.63372	0.00630	0.18749	0.73687	−0.16594	0.01585	0.23119
	(0.01293)***	(0.09165)***	(0.002 44)***	(0.025 94)***	(0.38154)*	(1.12395)	(0.00443)***	(0.03121)***
Elasticity	−0.139	−1.641	4×10^{-4}	0.013	0.053	−0.012	0.095	1.391
Observations	2658	2654	2559	2558	2658	2654	2658	2654
Root MSE	0.96	1.51	0.35	0.53	31.08	31.13	0.36	0.57
Kleibergen-Paap rk Wald F		74.00		78.22		83.19		74.00

Notes. Number of refugees transformed using the inverse-hyperbolic sine (IHS). Elasticity provides the percentage point change for a one-percentage point increase in the number of refugees. Model 1 also includes location, year, longitude by year, and latitude by year fixed effects, as well as conflict, temperature, and rainfall explanatory variables. Model 2 also includes the change in conflict, temperature, and rainfall explanatory variables. Standard errors are clustered at the cell level. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

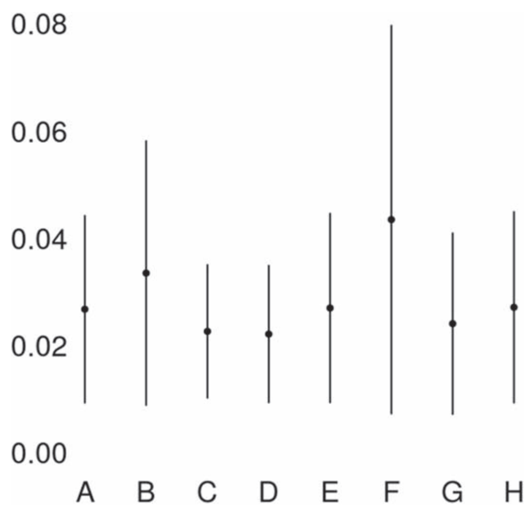

Figure 1. 95% confidence intervals of refugee elasticities calculated from second stage estimates presented in supplementary table 3. A: Baseline, B: Square-root of Distance in IV, C: Square of Distance in IV, D: Remove Conflict from IV, E: Controlling for Conflict Spillovers, F: Dropping 2000–2003 data, G: Including lagged IV, H: Controlling for the presence of internally displaced people. The motivation for estimating each of these specifications is described in the supplementary information.

This offers an alternative perspective to the vegetation variable, as it demonstrates that refugees are not extracting biomass for fuel or other purposes at a massive scale in the long term. One possible explanation for vegetation improvements is that native populations may decide to move once refugee camps arrive lowering the demand for forest resources or cropland. The literature suggests that, if anything, refugee camps reduce out-migration [21, 25, 26, 29]. Nevertheless, in order to rule out native displacement as an underlying driver of the refugee effect on vegetation, we also evaluate how refugees may change population and built-up area. Analysis of both outcomes suggest that the out-migration of natives is not responsible for improvements in vegetation.

We next test our second hypothesis by applying model (2) using alternative land cover measures. The refugee-induced vegetation change seems to be associated with a small, increase in agricultural production, as reflected by the estimated effects on NPP (table 1). We similarly investigate the refugee effects on other aspects of land cover, such as deforestation. Refugee presence exacerbates deforestation. Our empirical model predicts that the conversion from forest-dominant to crop-dominant land accrues by 1.4% with a 1% increase in the number of refugees.

Discussion

The analysis above provides a more nuanced view of how refugees affect the African landscape. Refugee-hosting areas experience a slight increase in vegetation condition. There is no systematic evidence that refugees contribute to deforestation due to their engagement in resource-extractive activities. Instead, we find there is increased risk of forested areas being converted to cropland. Local farmers may be responding to incentives to expand agricultural production and intensify crop production with potentially higher yields. Alternatively, this may be in result of refugees' desire to remain self-employed in the agricultural sector in receiving areas.

While our data allow for a comprehensive assessment over continental Africa, the level of spatial aggregation in our analysis may mask the magnitude of the degradative processes that occur within closer proximity to the refugee camps. For example, an evaluation of the changes in landscape within 90 km of Darfur camps in 2001–2007 illustrated a regeneration of vegetation in the rural residences of the displaced while an intensification of agricultural practices in the urban periphery [15]. Extending the temporal coverage to 2010 and refining the spatial resolution to 250 m indicates that the deleterious impacts on vegetation are quite concentrated in the areas surrounding the camps [18]. In utilizing data at a greater spatial resolution, our study may underestimate the scale of agricultural deforestation induced by refugees.

An additional limitation of the analysis is our inability to obtain outcomes over one uniform time frame. As the Model 1 outcomes are available annually, we can check the sensitivity of the refugee effects on EVI, BAI, and NPP, when restricting the time frames to periods covered by the Model 2 outcomes. The analysis presented in supplementary figure 5 corroborates our earlier conclusions. There is still a slight positive effect of the number of refugees on EVI and NPP, and a null effect of the number of refugees on BAI. However, we lose precision on the estimates due to the reductions in the sizes of the samples.

Our findings may also be sensitive to the age of the refugee camp, as well as the timeframe in which we conduct the investigation. With respect to the latter, figure 2 demonstrates that there were marked positive shifts in vegetation in areas neighboring refugee camps following 2007. Although we are unable to attribute these differences to a specific policy, the positive effects observed at the end of our event study coincide with rhetoric in policy documents expressing urgency over mitigating the environmental degradation in areas surrounding refugee camps [54]. International initiatives, like the Global Alliance for Clean Cookstoves in 2010, have since targeted refugee camps to reduce health risks associated with indoor air pollution as well as deforestation rates triggered by biomass fuel consumption [55]. At the same time, local reforms that facilitate economic integration, such as the provision of work permits in Djibouti, may also be responsible for alleviating the pressure for refugees to extract forest resources or convert land for agricultural purposes [56]. Finally, the results in figure 2 may also be explained by local government actions in host

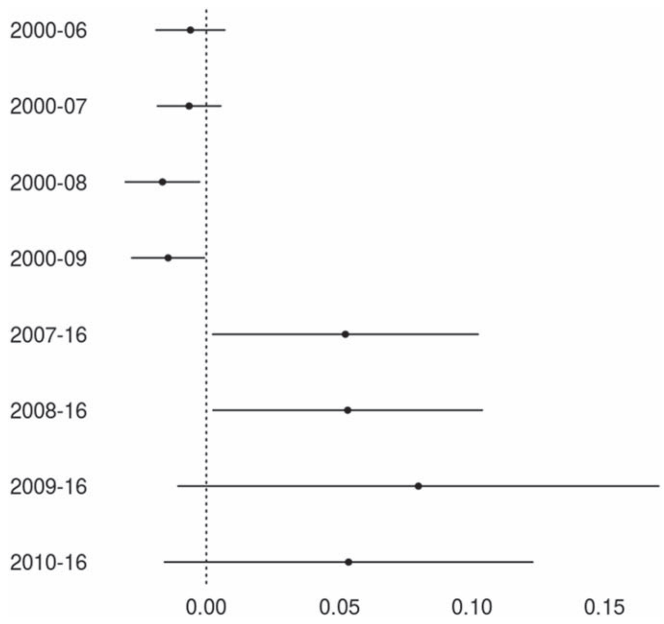

Figure 2. 95% confidence intervals of refugee elasticities differentiated by time.

countries to address the growing deforestation problem. The Government of Uganda, in particular, has increased tree planting investments in communities surrounding camps [57].

Population pressure and a number of unsustainable practices including over-cultivation, overgrazing, and deforestation will continue to be an underlying source of land degradation in many hosting countries [7]. Governments are exploring various cost-effective programs to diffuse sustainable land management [56, 58–60]. As refugee camps contribute to growing population densities in host countries, further research is necessary to examine how natural vegetation losses attributable to the growing demand for agricultural land may be remedied. For example, an objective of the Global Compact on Refugees is to ease pressures on host countries. One potential way of satisfying this goal is to financially support employment programs for refugees or programs that target conservation in areas surrounding camps [54, 61]. However, there is limited research that quantifies which of the current programs effectively mitigate environmental degradation in these specific contexts. Further exploration of the successful initiatives would greatly inform high-level discussions taking place among international stakeholders on international migration.

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Author contributions

JM, VM, and SvW designed the evaluation, analyzed the data, and wrote the paper. JVDH processed the remote sensing data used in the analysis, made the maps, and contributed to writing the paper.

Competing interests

The authors declare no competing interests.

Data availability

The data that support the findings of this study are available from the corresponding author upon request.

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