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Research paper

Introducing the Local Agricultural Potential Index: An approach to understand local agricultural extension impact for farmer adaptive capacity and gender equity

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ABSTRACT

Despite significant work to enhance women's empowerment in agriculture, women remain marginalized across the globe. This includes gender gaps in agricultural extension and advisory service implementation that can lead to inequitable resource and knowledge access by farmers, specifically women. However, gender does not exist in isolation, it is place and time specific. This study investigated the impact of gender and geography on smallholder farmer access to and agency over resources/knowledge. The overarching question we explored was the role that extension providers might play in building farmer adaptive capacity and gender equity. To do so, a mixed-methods approach was used to develop a new multidimensional index from participant responses to 352 surveys and 44 focus groups. The index has four domains that represent farmer's access to resources, leadership opportunities, household power, and time allocation; it is called the Local Agricultural Potential Index or L-API. The index was applied to a case study setting in rural Liberia due to its designation as a USAID-Feed the future country, and national investment in gender equality and poverty alleviation through agricultural development. Statistical and spatial analysis results indicate that women in Liberia, on average, have lower access to information and communication technology, leadership opportunities, and credit; as well, when compared to their male counter parts, less agency to make decisions at home and in the community. Further, a surprising spatial finding was that rurality did not have a diminishing impact on access. We concluded that the L-API is one example of a process and the resulting tool, informed by locally relevant indicators, to help improve farmer access to and agency over extension services. The L-API is meant to provide a baseline tool to be tailored in different locations based on local needs and can be used as a measure for adaptive capacity.

1. Introduction

The agricultural sector employees an estimated 27% of the world's population and accounts for approximately 4% of global gross-domestic product (GDP) (FAO, 2017; The World Bank, 2020). However, in many least developed countries agriculture accounts for upwards of 25% of national GDP (FAO, 2017) and a much larger share of the population derive income from agriculture. For example, across sub-Saharan Africa, agriculture-related employment plays a key role in local economies and food security (Alston & Pardey, 2014; Davis, Babu, & Ragasa, 2020). As a result, the agricultural sector is frequently prioritized by national governments and international development/aid agencies in programs to reduce poverty and improve economic and social stability, especially in rural areas in low- and middle-income countries with limited job diversity. For over a century, national agricultural extension systems have played a key role in supporting farmers and farming communities.

Agricultural extension providers, sometimes termed extension officers, agents, or educators (referred to interchangeably throughout this paper), exchange knowledge with local farmers and are tasked with sharing up-to-date information and advancements related to markets, research, and new technologies and innovation (Davis et al., 2020). Extension providers may share information with farmers individually or to farmer groups through technological devices such as cell phones, radios, and websites, or by hosting face-to-face workshops and trainings. Collectively, these personnel provide what are frequently termed extension (and advisory) services (EAS); services include resources and

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knowledge intended to improve farmer livelihoods by increasing farmers' abilities to problem solve and incorporate science and technology into their practices (Davis et al., 2020; Jones & Garforth, 1997). Extension providers can affect what types of services farmers have access to, who has access, and the adoption of new practices. Due to their work in local contexts, extension providers play a key role to help farmers overcome place-specific challenges and prepare for varying future scenarios such as flooding, drought, pest infestation, or economic fluctuations. Thus, throughout this paper we focus on improvements in extension services that will build rural adaptive capacity, and in particular where attention to gender dynamics may further that goal.

Throughout this paper, we refer to adaptive capacity as the ability of farmers and farming communities to build strategies using available resources and knowledge, in order to manage and change in the face of current and future social and environmental stress while maintaining livelihoods (Engle, 2011; Folke, 2006; Holling, 2001; Siders, 2019). Adaptive capacity is impacted by salient social and geographic issues, including gender dynamics and place-specific conditions that are not normally the focus of extension agent training (Defiesta & Rapera, 2014; Engle, 2011; Siders, 2019). This paper explores the efficacy of extension services through an intersectional lens that considers how gender and setting may also affect farmer access to and agency over extension services, at the community-level.

The previous literature, specific to gender and agriculture, has shown that access and agency are essential building blocks for farmer's adaptive capacity in the face of change (Agarwal, 2011; Asare-Nuamah, Botchway, & Onumah, 2019; Caretta & Börjeson, 2015; Malapit, Kovarik, Sproule, Meinzen-Dick, & Quisumbing, 2015). For example, Caretta and Börjeson (2015) specify that a diminishment in access and/or agency contributes to increased vulnerability to climate change and will negatively impact adaptive capacity. Similarly, Malapit et al. (2015) identify agency as a key component of gender empowerment in agriculture (IFPRI, 2012). Further, Cohen et al. (2016) highlighted the importance of addressing gender dynamics in building adaptive capacity. Therefore, identifying and addressing gender gaps in EAS may help to more effectively build farmer and farming community adaptive capacity. Despite recent efforts to improve the efficacy and equity of EAS dissemination, women continue to be marginalized across the globe (Farnworth & Colverson, 2015; Huyer, 2016; Quisumbing & Pandolfelli, 2010; Trauger et al., 2008; Witinok-Huber, Radil, Sarathchandra, & Nyaplue-Daywhea, 2021)

In this paper, we explore the intersection of agricultural extension, place-based adaptation, and gender. To that end, we introduce and apply a new tool to assess farmers' access to and agency over extension services which we call the Local Agricultural Potential Index, or L-API. The following research questions were investigated to inform the overarching question of what role extension service providers might play in building farmer adaptive capacity and gender equity.

1. How does gender impact local smallholder farmer access to and agency over EAS?
2. How does access to and agency over EAS vary spatially?
3. To what extent are Liberian EAS aligned with farmer needs?

When considering gender, we hypothesized that men were more likely to have access to complementary agricultural resources and the agency to use them. When considering geography, we hypothesized that communities nearer one another would have more similar levels of access than would those further apart. Also, we hypothesized that rurality would have a diminishing impact on access.

The rest of the paper is organized as follows. First, the theoretical motivations for our approach with a discussion of adaptation in agriculture and how it varies both socially and spatially. Second, we describe the Liberian context and explain why it was selected as the study setting. Third, the L-API is introduced and applied to the Liberian case study setting. The paper concludes with the practical value of our approach in Liberia and how the L-API may be adapted to other contexts.

1.1. Multidimensional indices

Multidimensional indices have been used to create more comprehensive representations of complex issues or phenomena such as adaptive capacity (Brooks et al., 2005; Defiesta & Rapera, 2014; Siders, 2019), poverty and empowerment (Kabeer, 2005; Sen, 1976), or when intersecting factors may not be simply additive (Siders, 2019). Indices have also been used to determine latent variables and understand differences across geographies, demographics, and temporal scales (OPHI, n.d.; Sen, 1976). No matter their intended purpose, the overall utility of a multidimensional index relates to the accuracy and relevance of the inputs toward intended goals and stakeholders. For example, for an index to be useful to a community, the inputs must be specific to that community's local reality and the outputs must address context specific needs/challenges. These were motivating issues for our development of the index explained in this paper, which we call the L-API.

1.2. Why the need for something new?

In developing the L-API, insights from the International Food Policy Research Institute (IFPRI) Women's Empowerment and Agriculture Index (WEAI) and the Alkire-Foster method were incorporated. The study specifically examined the WEAI questions, underlying methods, and domain categories. The five WEAI domains are: a) decisions about agricultural production; b) access to and decision-making power about productive resources; c) control or use of income; d) leadership in the community; and e) time allocation. At the time of this study, the WEAI was primarily used to evaluate women's overall 'empowerment in agriculture' in low- and middle- income counties through survey data aggregation (Malapit et al., 2015). Prior to 2018, the WEAI was not developed for use at the project or community levels. Further, the WEAI was not developed for longitudinal data collection, but rather evaluation of the existing status of women's empowerment in agriculture and gender parity in a specific region at a specific time (IFPRI, 2012).

The Alkire-Foster method, used in the WEAI, was developed as a multidimensional method to measure poverty by incorporating different measures in relation to pre-determined nationwide deprivation cutoffs (Alkire, Foster, Seth, Santos, Roche, & Fernandez, 2015; OPHI, n.d.). For instance, indicators of national poverty may include a pre-defined value for education vs lack thereof, or other variables such as employment or living conditions (OPHI, n.d.; Sen, 1976). These values are then used to construct a multidimensional index used for comparison between countries for concepts of interest (Malapit et al., 2015).

Both the WEAI and its underlying Alkire-Foster method were important contributors to the development of the L-API. However, it was determined that the WEAI was not specific enough to the agricultural extension service access goals of in-country partners and did not include environmental or climate specific questions. Lastly, the geographic, institutional, and temporal scales were inconsistent with the objectives of this study. Locally relevant spatial variations in resource access and household agency have been found to be critical for farmer adaptive capacity and to fill gender gaps in EAS access.

Inadequate spatial and demographic information limit the ability of extension providers to adapt their services based on longitudinal data of the farmers they service, further minimizing their understanding of and ways to enhance farmers' adaptive capacity. After realizing other options were insufficient for the study specific context, a new multidimensional index was created to account for spatially (i.e., community and county) nuanced questions and locally relevant indicators for Liberia's extension officers and farmers alike. Next, we look at why the study is set in the Liberian context.

1.3. The Liberian context

The study site in north-central Liberia, situated on the west coast of sub-Saharan Africa, encompasses three counties and 22 communities that are known for their agricultural productivity (primarily subsistence) and biological diversity (Moore, 2017; Perry, 2017) (Fig. 1). The communities involved are ethnically, religiously, and economically diverse, and mostly rural (14 communities had less-than 2000 people). The study area was central to fighting during the Liberian civil wars (1989–2003) and a hotspot during the Ebola virus outbreak (2014–2016) (Gbowee, 2011; Moore, 2017).

Site map

Liberia was selected as the study area for reasons including its designation as a USAID-Feed the Future country, international support and funding for gender equality and poverty alleviation efforts post-civil conflict and Ebola, and national government prioritization of the agricultural sector. The three counties selected are known as Liberia's breadbasket (Perry, 2017) and have been predicted to experience increased environmental stress in the coming years due to climate change (Stanturf et al., 2013, 2015). Additionally, at the time of data collection, Liberia had the first female nationally elected head of an African state, Ellen Johnson-Sirleaf, and had prioritized gender equality and inclusion across the country.

The project also responds to study objectives that included both policy and locally relevant decision-making recommendations; specifically, to identify place-based gender gaps in EAS and suggest ways to address them. To identify often invisible local gender gaps in EAS, it's important to acknowledge that gender is a social construct that cannot be removed from place and time (Rubin & Manfre, 2015). Gender is rooted in individual human or collective social experiences and locally defined through a pervasive system or set of norms that describe the appropriate or accepted actions and interactions of women (feminine) and men (masculine) (Hirdman, 1991). Locally acceptable gender roles are reinforced by social norms and primarily learned by youths through socialization (Rubin & Manfre, 2015). For example, in relation to agricultural resources/knowledge, Liberia is governed through patriarchal systems where it is common to find that information and communication technology (ICT) devices are primarily owned by the male household head, increasing the difficulty for women to effectively access first-hand agricultural and emergency information (Scarborough, 2017; Witinok-Huber et al., 2021).

Liberia has approximately 60 extension field staff, primarily men over 50 years of age, for over one-million farmers (Moore, 2017; Perry, 2017). In Mozambique where the extension field is also male-dominated, Kondylis, Mueller, Sheriff, and Zhu (2016) found that this gender imbalance hinders women's awareness of certain agricultural techniques and adoption of new technologies. Other findings across Africa show that extension services focus on income generating cash-crop production and remain limited in information and opportunities related to agriculture for household nutrition and other primary activities of women farmers (Huyer, 2016; Perez et al., 2015).

Similar to other sub-Saharan African countries, Liberia has limited national temporal data on the EAS needs, challenges, and access of farmers, let alone data that is disaggregated by gender (Moore, 2017; Perry, 2017; Talery-Wiles, 2012). This lack of data is particularly relevant for the hard-to-reach rural areas that account for a substantial portion of the agricultural sector. Seventy percent of the population derive a portion of their income from agricultural activities and 49% live in rural areas (CIA, n.d.; Moore, 2017) reinforcing the crucial role of national EAS, in general, and how this effort is essential for engaging farmers in rural settings. However, poor transportation infrastructure, low resource capacity, and inequality in service dissemination are all compounding barriers that limit access by rural farmers. Women are further incombered due to their status in society including social norms that limit education and ICT access and household decision-making power (Gbowee, 2011). Extension providers' supportive role in individual and household agricultural decisions affords them a unique opportunity to influence change at the intersection of agriculture and gender. Specifically, EAS providers have a responsibility to build the overall capacity of farmers, regardless of gender, to resist or adapt to future social and environmental change.

The task of extension providers to improve agricultural productivity

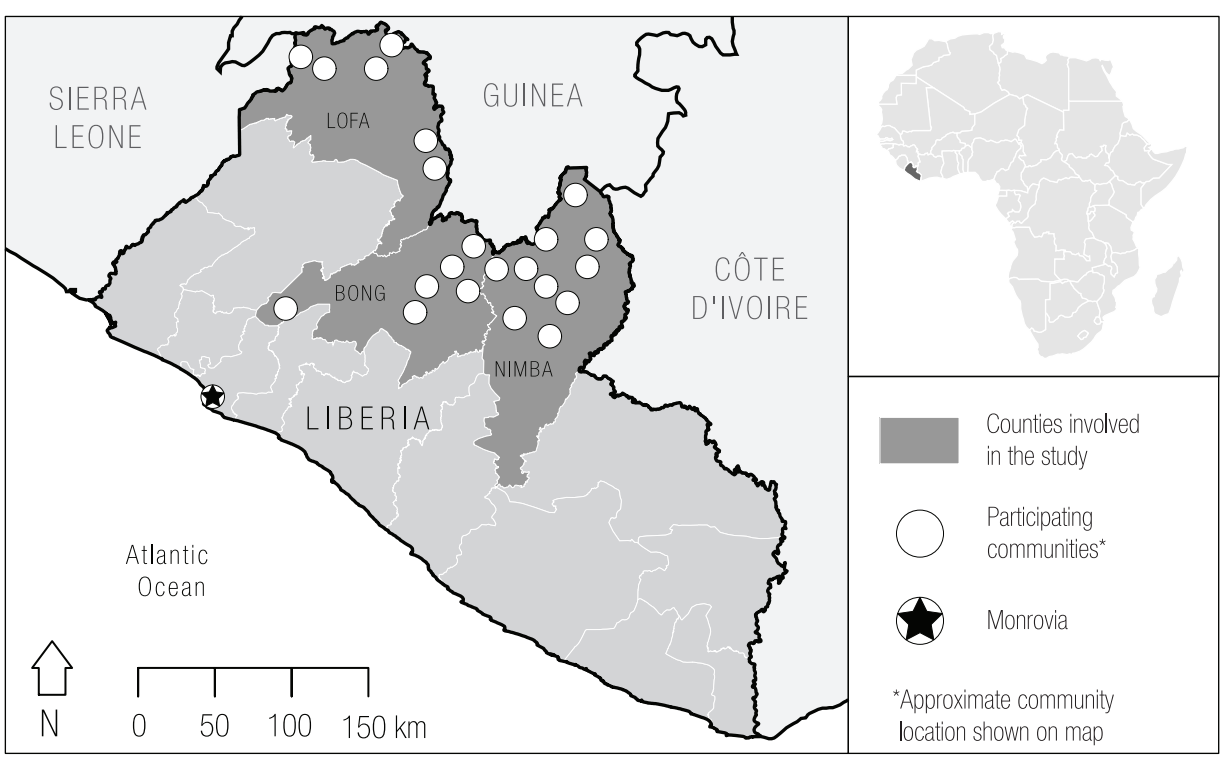

Fig. 1. Map of north-central Liberia study area including the 22 surveyed communities.

and build adaptive capacity is not simple. Farmers' challenges are diverse, and neither spatially nor gender neutral; therefore, the challenges must not be addressed through siloed approaches. For extension providers to assist in building the adaptive capacity of farmers and their communities, it is critical to understand both the endogenous and exogenous factors that influence adaptive capacity. For example, endogenous factors may reflect an individual farmer's access to resources and/or agency, i.e., decision-making power (Defiesta & Rapera, 2014; Perez et al., 2015). Whereas exogenous factors will require that extension services account for variations in the local environmental and social conditions of farmers, such as soil quality dictating locally appropriate crops or social customs that normalize gender inequalities (Moore, 2017; Stanturf et al., 2013, 2015). These factors do not exist in isolation and instead function as part of integrated systems that are rooted in particular places. In this manuscript, we specifically examine the roles of both gender (endogenous) and geography (exogenous) in relation to farmer access to EAS and the agency to effectively use EAS.

Given that farmer access and agency are contextual and dependent on the localized setting, the idea of localized places is prioritized in the study to better account for known regional and climatic variation; further, to explore spatial differences in farmer needs and challenges, agricultural potential, and adaptive capacity. Places are described as small-scale discrete and varied physical locations that are inclusive of both environmental and socio-cultural conditions, beliefs, and patterns. Therefore, it is essential that extension providers understand the experiences of farmers in relation to the immediate settings in which they live and work, and that both farmers and extension providers work to build locally relevant adaptive capacity.

1.4. Agriculture and adaptation in Liberia

Enhancing adaptive capacity in agriculture is an essential task in the face of future complex and dynamic challenges, especially for the most vulnerable populations in remote agricultural communities (Engle, 2011; Stanturf et al., 2013). Attempts to build adaptive capacity in Liberia have had to account for the shocks of civil conflict (1989–2003) and the 2014–2016 Ebola epidemic, and to prepare for future shocks such as climate change and fluctuations in aid funding or government service allocations. At the community level, Liberia's Ministry of Agriculture (Ministry) extension field staff, referred to as District Agricultural Officers (DAO), work with smallholder farmers to improve productivity and solve problems, i.e., to build adaptive capacity. While providing timely and useful agricultural information and resources is at the core of extension work, DAOs will also necessarily find themselves addressing various social and environmental changes (e.g., fuel prices, out-migration, women's land rights, and climate) that impact their efforts. Preparing for such issues now, may help move the government and agricultural development agencies away from stopgap measures and towards proactively evaluating and building adaptive capacity into extension practices for all farmers (Christoplos, 2017).

Gender-aware approaches to building adaptive capacity are also relevant due to women's often limited household agency and additional intersectional challenges. For example, gendered-intersections with race, disability, and socio-economic status further marginalize certain groups of women (Crenshaw, 1991). Additionally, deep-rooted cultural and religious beliefs of women's value and roles in the home and community further limit their opportunities to make critical decisions, own land, be educated, and involved in commercial agriculture (Coulter, Witinok-Huber, Bruyere, & Nyingi, 2019; Gbowee, 2011; Huyer, 2016; Witinok-Huber et al., 2021). Systemic social marginalization coupled with increased environmental stress such as climate change, deforestation, and shifts in precipitation contribute to the added challenges that rural women farmers experience (Perez et al., 2015). In the face of social and environmental pressures, low adaptive capacity only increases the existing struggles of rural farmers, especially for already marginalized groups of women farmers. The L-API was designed with the intersectional challenges of rural, women farmers in mind. Next, we further delve into study methods and development and validation of the index including its application.

2. Methods

2.1. Data collection

The research team worked with local agricultural extension officers in 22, purposefully and proportionally selected, communities in Bong, Lofa, and Nimba counties. Survey and focus group instruments were iteratively developed with in-country partner feedback and pre-tested in a local community akin to the study population. Surveys were conducted in February 2018 with 352 farmers, using SurveyCTO software on Android tablets, by four trained Cuttington University students. Farmers (8 women and 8 men) were randomly selected in each community by drawing folded slips of paper from a hat. Those that selected paper with an 'X' written on it were surveyed. Feedback from pilot studies led us to use an inclusive approach where everyone present on the day of field testing was invited to participate in gender-disaggregated focus groups. Every farmer randomly selected to participate in the survey voluntarily did so and the majority of farmers (surveyed or not surveyed) elected to participate in focus groups (n = 44).

Participating farmers varied by socio-economic status including land size and production types; geography, though most communities were considered rural (<2000 people) by Liberian standards; involvement in farmer groups and leadership; and demographics such as age, ethnicity, and religious affiliation. Several of Newing (2010) suggestions to minimize survey biases were used. These included:

a) developing the questions iteratively with in-country partners and agricultural extension experts;
b) for each question, including options for no response and prefer not to answer;
c) administering surveys in local languages and working with local university students to administer the surveys objectively, after a 10-day training;
d) partnering with the Ministry of Agriculture, including local extension officers for community selection and sensitization prior to data collection;
e) when possible, having females interview women, and males interview men; and
f) by working with local elders and extension officers to set up safe spaces in a central location in the community to conduct data collection.

2.2. L-API development

The index was developed after field data collection and preliminary analysis in response to in-country partners goals and questions. Specifically, to encourage local interest in a tangible product for extension officers to better understand farmer access to resources/information and needs or challenges overtime, namely, gender gaps.

The L-API incorporates local social, economic, and environmental factors that hinder farmer access to EAS and agency to use them. Survey and focus group questions were categorized into sections that relate to each overarching objective (e.g., farmer access, satisfaction and preferences; household power, decision-making, gender roles). MAXQDA (Software, 2018) was used for the coding and descriptive analysis (*results presented in* (Witinok-Huber et al., 2021)).

The four themes, referred to as domains from here forward, include: a) *resource access* with survey questions related to access to extension resources/information, loan/credit access, and land ownership; b) *leadership opportunities* inclusive of involvement and leadership roles in farmer-based and community groups; c) *household power* that looked at domestic and productive decision-making and money management and

perceived empowerment; and d) *time allocation* for domestic and productive activities. Each domain contains a number of items (i.e., survey questions) and participants responses to each item are summed for each associated domain (Appendix B). Overall, the L-API was developed to reflect a holistic representation of farmers' access and agency, referred to as agricultural potential, and a quantitative measure for adaptive capacity (Fig. 2).

2.3. L-API structure

The L-API includes 49 items (individual survey questions) totaling 56 points that make up the four L-API domains (Appendix B, Fig. 2).

L-API Score = Resource Access + Leadership + Household power − Time allocation

Scores were tallied for the overall L-API, each individual domain, and as composite domains for access (resources plus leadership) and agency (household power minus time allocation).

Access = Resource Access + Leadership

Agency = Household power − Time allocation

Within the survey, a gender matrix was used to delineate between the productive and reproductive responsibilities of all family members by product type including staple or field crop, vegetables/garden, cash crop, livestock, or poultry. The 10 possible responses included: men, women, both men and women, male children, female children, children, entire family, women and children, men and children, or not performed. To understand the daily time allocation and decision-making agency of women and men farmers, indicators were coded twice, once as '1' for women, both men and women, entire family, and women and children, all other responses were '0'; a second round of coding gave the value of '1' to men, both men and women, entire family, and men and children, and '0' for all other responses. For the final L-API, women's scores included resources and leadership along with the women's time and power scores and men's scores were the sum of resources, leadership, and men's time and power scores. Therefore, the final calculations for women and men were as follows:

Women's L-API Score = Resource Access + Leadership + Women's Household Power − Women's Time Allocation

Men's L-API Score = Resource Access + Leadership + Men's Household Power − Men's Time Allocation

2.4. Data analysis

An analysis of variance (ANOVA) was conducted to understand variation in L-API scores by gender and county for the total score and for each of the various domains of the index (the four domains of resources, leadership, power, and time, and overall access and agency). In addition, global and local tests of spatial association were performed to understand the effect of geography on the index (Anselin, 1995; Haining, 1993). Analyses were completed in RStudio (RStudio Team, 2020) and additional data preparation was performed using ArcGIS[1] (Environmental Systems Research Institute (ESRI), 2019).

Originally six domains were tested for external validity using a principal component analysis (PCA) (Wold, Esbensen, & Geladi, 1987). Based on the PCA, two domains were removed, leaving the four domains discussed previously (i.e., resource access, leadership, household power, and time allocation). The 'information and communication transfer' domain was removed from the final L-API based on significant overlap with the resource access domain. Also, the farmer 'access to Liberian Ministry extension services' domain was evaluated independently from the L-API because it was a zero-inflated variable and skewed the results with only 148 positive responses out of 352 farmers. Farmer access to Liberian Ministry extension services was analyzed and reported based on the summed score of 8 indicators (n = 148) (Appendix A).

In addition, we tested for internal consistency using Cronbach's alpha. On a scale from 0 (low) to 1 (high), $0.7 \leq \alpha \leq 0.9$ is considered to have 'good' or $0.6 \leq \alpha \leq 0.7$ 'acceptable' internal consistency (Cronbach, 1951; Tavakol & Dennick, 2011). Cronbach's alpha was 0.84 for the L-API index (Fig. 2) and all domain alpha scores had acceptable or good internal consistency ranging from 0.64 to 0.76. From the *resource access* domain, we did not remove the 'credit and loan access' and 'mechanized vs traditional farming' items even though doing so would have increased the alpha to 0.70; however, we deemed these variables important to the holistic representation of farmer extension service access.

3. Results

3.1. ANOVA

A Type II ANOVA model was used to assess the main effects of gender and county on variation in the L-API scores. The model also included an interaction term for gender*county. The model was run for the overall L-API scores, each of the domains, and access and agency. Model details and results are listed in Table 1.

As shown in Table 1, the interactions between gender and county were not significant at $p < 0.05$ (the closest was the time allocation domain). The ANOVA did reveal significant differences between women and men for the overall L-API and all domains. County location was also significant for the overall L-API but not for every domain measure (power, time, and agency were not significant). Conversely, county location and not gender was significant for Ministry access. In sum, a farmer's gender and county of residence had a more significant effect on the L-API than expected by chance, but these variables did not indicate interaction.

Least squares means were derived from the ANOVA test to explore differences across the two genders (Table 2) and three counties for the L-API and its domains (Table 3). Table 2 shows the salience of gender to farmer capacity as men's means were higher for all variables except Ministry access to services via DAOs. Further, women farmers typically reported lower access to credit/loans and on average, spent less money on agricultural information compared to their male counterparts.

3.2. Mean L-API variation by county

ANOVA results for county-based variation indicate that Nimba farmers' scores are highest for the overall L-API and access, in addition to the resource access, and leadership domains. However, Nimba farmers reported the least access to Ministry extension services. Bong and Lofa County farmers had similar L-API scores, yet Bong County was more deficient in resource access while Lofa had lower overall agency. On average, Lofa farmers had smaller farms (in acres) and spent less money each month on agricultural information. Despite having the lowest overall agricultural resource access, Bong farmers had the highest access to resources from the Ministry of Agriculture and the largest farms on average.

3.3. L-API spatial variation

The global Moran's I, a common measure of spatial autocorrelation, was used to determine the overall spatial association of L-API scores across the study area. Moran's I is a univariate spatially-weighted

[1] Geographic Positioning Systems coordinates were collected in each community during 2018 field visits. Road information was from the United National Office of the Coordination of Humanitarian Affairs' (OCHA) HOTOSM Liberia Roads dataset (United Nations, n.d.) and ArcGIS network analyst was used to develop the road distance calculations for each community (ESRI, 2019). Information about city population used 2019 population estimates by the World Population Review and the OCHA's Humanitarian Data Exchange. Additional census data was from the Liberian Institute of Statistics and Geo-Information Services.

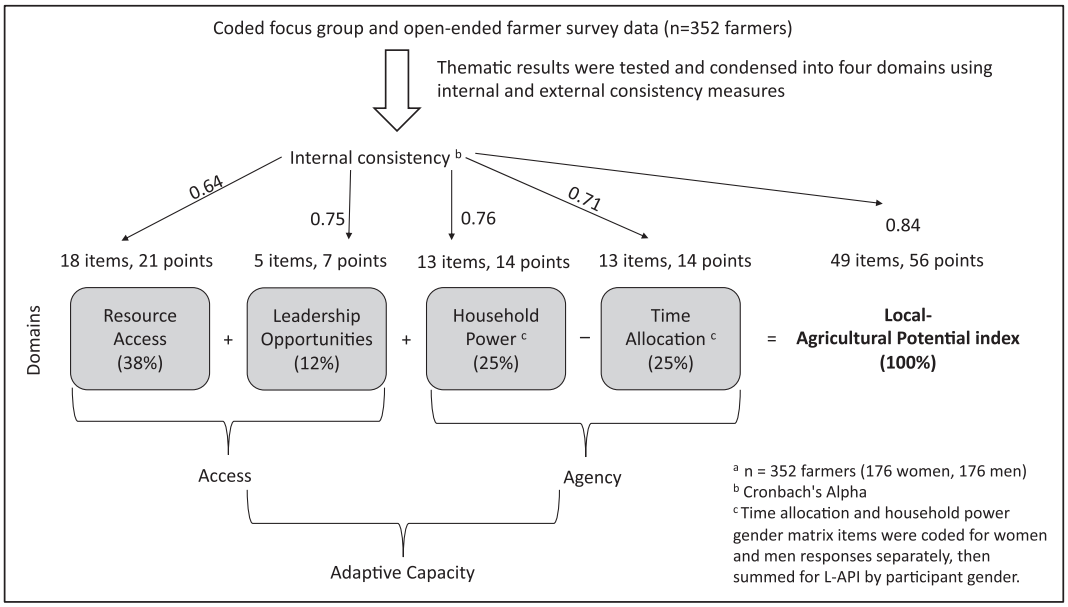

Fig. 2. L-API development and validation process.

Table 1
ANOVA (type II) results for gender, county, and gender*county interaction for L-API, its domains, access and agency.

		ANOVA Results (N=352)	
Dependent variable	Independent variable	F	*p*
L-API[a]	gender	393	<0.001***
	county	7.2	<0.001***
	gender*county	0.03	0.97
Resources	gender	55.3	< 0.001***
	county	3.9	< 0.1*
	gender*county	0.2	0.8
Leadership	gender	53.3	< 0.001***
	county	14.6	< 0.001***
	gender*county	0.96	0.4
Power	gender	99	< 0.001***
	county	0.95	0.4
	gender*county	2.1	0.1
Time	gender	290	< 0.001***
	county	0.1	0.4
	gender*county	2.8	0.06+
Access[b]	gender	77	< 0.001***
	county	10.5	< 0.001***
	gender*county	0.05	0.96
Agency[c]	gender	501	< 0.001***
	county	0.4	0.7
	gender*county	0.1	0.9
Ministry Access[d]	gender	2	0.16
	county	3.9	< 0.001***
	gender*county	1.3	0.3

Note. + = $p < 0.1$ * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$. A confidence level of 0.95 was used with degrees of freedom for gender (1), county (2), gender*county (2), and residuals (346).
[a] Resources + Leadership + Power - Time
[b] Resources + Leadership
[c] Power – Time
[d] Analyzed independent of index

adaptation of the Pearson's correlation coefficient. Like Pearson's r, Moran's I offers a single-value measure of spatial association that is centered on 0 and ranges from −1 to +1. The default null hypothesis for Moran's I is that there is no spatial autocorrelation of a variable with itself (based on a mean value of nearby locations) which occurs when the score nears 0. This is the same as saying that the values of interest are randomly spatially distributed. However, there are two alternative

Table 2
Variations by gender for L-API.

		Gender mean (standard error)		
Index	Domain	Women (n=176)	Men (n=176)	Significant[a]
L-API[b]		9.8 (0.35)	19.5 (0.35)	<.001***
	Resources	8.7 (0.19)	10.6 (0.19)	<.001***
	Leadership	2.5 (0.14)	3.9 (0.14)	<.001***
	Power	9.4 (0.18)	11.9 (0.18)	<.001***
	Time (–)	10.8 (0.16)	6.9 (0.16)	<.001***
Access[c]		11.2 (0.28)	14.5 (0.28)	<.001***
Agency[d]		−1.4 (0.20)	5.0 (0.20)	<.001***

Note. * = $p < .05$; ** = $p < .01$; *** = $p < .001$. A confidence level of 0.95 with 348 degrees of freedom was used. Cells represent the mean values for respondents by gender.
[a] Statistic from Table 1
[b] Resources + Leadership + Power - Time
[c] Resources + Leadership
[d] Power – Time

Table 3
Variations by county for L-API.

		County mean (standard error)			
Index	Domain	Bong (n=96)	Nimba (n=160)	Lofa (n=96)	Significant[a]
L-API[b]		14.1 (0.47)	15.9 (0.36)	14.0 (0.47)	<.001***
	Resources	9.3 (0.25)	10.1 (0.19)	9.6 (0.25)	<.05*
	Leadership	2.9 (0.19)	3.89 (0.14)	2.9 (0.19)	<.001***
	Power	10.9 (0.24)	10.7 (0.18)	10.4 (0.24)	
	Time (–)	8.9 (0.22)	8.8 (0.17)	8.8 (0.22)	
Access[c]		12.1 (0.34)	14.0 (0.29)	12.4 (0.34)	<.001***
Agency[d]		1.9 (0.27)	1.9 (0.21)	1.6 (0.27)	

Note. * = $p < .05$; ** = $p < .01$; *** = $p < .001$. A confidence level of 0.95 with 348 degrees of freedom was used. Cells represent the mean values for respondents by county.
[a] Statistic from Table 1
[b] Resources + Leadership + Power - Time
[c] Resources + Leadership
[d] Power – Time

outcomes to this assumption. A positive score indicates that locations near each other have similar values (a sign of clustering of like-near-like values) while a negative score indicates that dissimilar values are near each other (repulsion, or dislike-near-dislike values). This is an important issue to consider for the L-API as it provides insight into how much spatial variation is present among the domains.

The test was performed using k = 3 nearest neighbors with row standardization, which defined that the mean value of nearby locations was calculated using the nearest three other communities, each of which was weighted equally in the calculation. The results showed that the overall L-API scores and the separate scores for men and women were positively spatially autocorrelated (Table 4). However, this was not uniformly true of the separate domains. While leadership, time allocation, and overall access scores were positively spatially autocorrelated, no statistically significant spatial clustering was found for resource access, power, or overall agency (Table 4).

The Moran's I results indicated a global trend toward similar L-API scores among neighboring communities but without specification as to where such clustering is occurring in the study region or identification of the presence of sub-regional trends. For example, Fig. 3 presents the local mean L-API scores, which indicates a clear east-to-west spatial trend with lower scores in the west of the study region. To explore spatial trends at the community scale we looked at local spatial autocorrelation using a LISA test (Anselin, 1995). The LISA disaggregates the global Moran's I score by performing a test of spatial association at each location (i.e., community). Like Moran's I, LISA scores are centered on 0 with a similar interpretation for positive and negative values; however, LISA scores do not have an upper or lower bound. Statistical tests were performed for each location with p-values adjusted using the common Bonferroni correction.

Again, using a k = 3 nearest neighbor with row standardization approach, the LISA test showed statistically significant positive clustering for the overall L-API in two communities: 11 ($Ii = 1.6$, $p = 0.002^{**}$) and 19 ($Ii = 31.8$, $p = .0002^{***}$) (communities not specified for anonymity). These can be interpreted as localized 'hot spots' of similar L-API scores; in other words, these communities are far more similar to their neighbors than would be expected by chance. Therefore, they may represent ideal locations to pilot changes in agricultural extension practices or policies as they are likely to be socially and strucutrally similar to other nearby communities.

4. Discussion

4.1. Gender and geography: impacts on access to and agency over EAS

One of the main goals of this research was to develop a better understanding of gender and place-based gaps in farmer access to and agency over EAS; further, to explore measuring farmer and farming community adaptive capacity. Considering the previous use of resource access and related systems-based indicators for adaptive capacity (Siders, 2019), we discuss how our study results indicate that the L-API can be useful for more sustainable tracking of farmer access and agency to prepare farmers and their communities for change, specifically with a gender and place-based lens (Cohen et al., 2016; Engle, 2011; Stanturf et al., 2015).

Results indicate that our hypothesis that men would be more likely to have access and agency over agricultural resources was mostly correct in that gender does impact local smallholder farmer access and agency. Women in Liberia, on average, have lower index scores that reflect less access to ICT, leadership opportunities, and credit/loans, as well as agency or the social power to make decisions at home and in the community when compared to their male counterparts (Tables 1 and 2). These findings substantiate others in the literature that women's and men's needs, and challenges vary not only by gender, but also across farming communities based on varying social norms and environmental conditions (Davis et al., 2020; Lawson, Alare, Salifu, & Thompson-Hall, 2020; Tavenner & Crane, 2019). This emphasizes that women are not a homogenous group and must be understood holistically (Coulter et al., 2019; Huyer, 2016). We further analyzed the index across place, and intersections of place with gender.

When considering geography, there is a slight benefit to communities that are more distanced from populated places that are traditional centers of authority. This finding refutes our hypothesis that rurality would have a diminishing impact on access and points to the possibility of adaptive efforts happening at the local level. Hence, the *local* agricultural potential index presented provides opportunities for extension to cooperatively build adaptive capacity in communities that already show signs of self-organization.

LISA and Moran's I results indicate the importance of understanding adaptive capacity based on both internal (within the community one lives and works) and external (external to the community one lives and works) networks. Perez et al., 2015 specify that women are more likely to have internal, and men external networks. This can be a focal point for the types of services and delivery methods of EAS used. We acknowledge that additional compounding variables such as ethnicity, religion, and socio-economic status were not statistically analyzed; additionally, we bound our study to the national context and international borders may play roles not accounted for here. For instance, it is possible that cross-border flows of information or resources relevant to farmers may occur.

4.2. Adaptive Capacity, EAS, and Liberia

As discussed in the introduction, adaptive capacity is critical to managing vulnerability and building social and environmental resilience (Barrett & Constas, 2014; Engle, 2011; Quinlan, Berbés-Blázquez, Haider, Peterson, & Allen, 2016). Across the globe farmers will continue to be affected by climate change and natural disasters, though those with lower capacity to adapt to changing conditions, often in poor and post-conflict countries, are especially vulnerable (Figueiredo & Perkins, 2013; Huyer, 2016; Perez et al., 2015). Perez et al. (2015) highlights that women farmers in sub-Saharan Africa will shoulder more than their fair share of the climate change burden. The uncertainty introduced by variations in precipitation, temperature, or natural disasters will only compound the uphill battle that Liberia faces to rebuild and maintain food security and a stable economy.

The 'Liberian Climate Change Assessment' conducted by Stanturf et al. (2013) predicted that the three counties in this study, particularly Lofa and Bong, will face increased temperatures (between 1.5 and 2 deg C) and irregular precipitation patterns in the future. Shifts that are known to cause lower rice yields, one of the main subsistence and productive crops in Liberia (Stanturf et al., 2013, 2015). The prospective consequences of women's unmet farming needs coupled with the low

Table 4
Global Moran's I spatial analysis.

Moran's I Results (N=352)		
Dependent variable	*I*	*p*
L-API [a]	0.27	0.02*
Women's L-API [b]	0.25	0.03*
Men's L-API[b]	0.31	0.01**
Resources	0.06	0.45
Leadership	0.29	0.02*
Power	−0.09	0.78
Time	0.05	0.06+
Access [c]	0.23	0.06+
Agency [d]	0.07	0.42
Ministry Access	0.07	0.42

Note. + = $p < 0.1$; * = $p < .05$; ** = $p < .01$; *** = $p < .001$.
[a] Resources + Leadership + Power − Time
[b] Disaggregated by gender
[c] Resources + Leadership
[d] Power − Time

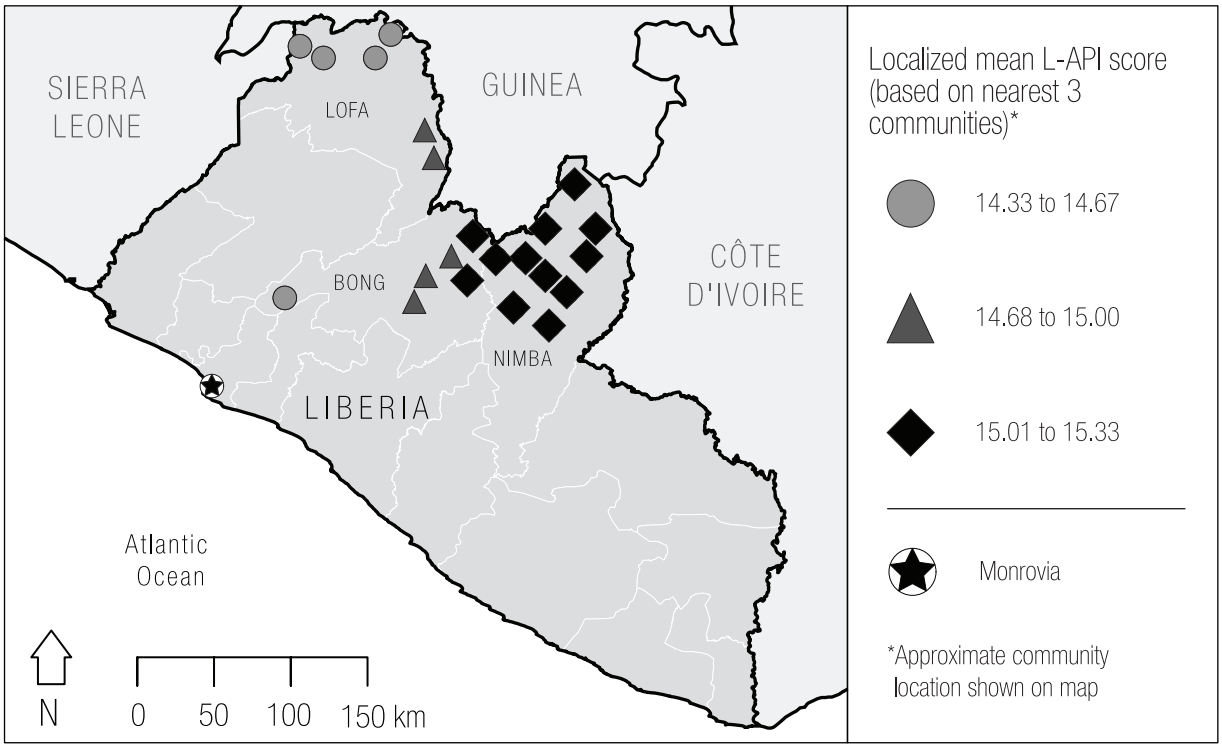

Fig. 3. Spatial trends in community L-API results.

adaptive capacity present in rural, post-conflict farming communities must be addressed through strategies that close gaps in extension reach and efficacy for farmers, especially women.

The L-API can provide a tool to track those impacts spatially and temporally. Moreover, the ability of extension officers to help build adaptive capacity requires that their knowledge and resource dissemination be adapted through a gendered lens. Because gender does not exist in isolation, extension efforts should also be aware of the potential for localized variations in the otherwise global patterns of lower female farmer access and agency. Programs can benefit from recognizing that issues are unique to individual communities including context specific compounding intersectional variables (such as age, education level, ethnicity, economic status). We used community location as a proxy to explore this variability, but more work is needed to identify the specific factors that matter most in each individual location.

4.3. Extension providers role in building adaptive capacity

Maintaining the current status quo, Liberia has insufficient agricultural resources and extension providers to effectively serve its over one-million farmers (Moore, 2017; Perry, 2017). Nor does the Ministry of Agriculture have a formal system to track who has access to what resources, and if new technologies are adopted or what is useful in terms of EAS. Conceptually and in practice, applying L-API can contribute to both a deeper understanding of farmers' place and gender-based needs and provide an adaptable tool for tracking EAS over time; opening the door — with suitable political will and collective action — for improvements to extension impact and increased adaptive capacity. Developing and delivering extension services that account for future social and environmental challenges can contribute to knowledge, skills, and innovative farmer practices that build individual and collective adaptive capacity. In the face of climate change, global disease epidemics, and political tension, adaptive capacity is more pertinent than ever.

For these reasons, we believe that a critical step in subsequent applications of the L-API, or locally-relevant adaptations of it, will be to incorporate a sixth 'climate domain'. In the face of both acute, unpredictable weather events and chronic environmental changes over time, as well as social stress such as pandemics or land-use conflict, there is apt cause to add a domain inclusive of indicators related to local physical conditions. These may include but are not limited to items such as: a) soil type and quality; b) flood, drought, or other irregular weather patterns; c) water availability; d) frequency of pest infestation; e) forest access and land cover type; f) fuel types and access (electricity and power); and g) climate predictions. The addition of a climate domain would further assist the government and local extension providers in comprehensively building local adaptive capacity with future environmental limitations in mind.

5. Conclusion

A key contribution of this study was to understand the importance of tracking and developing EAS programs from the community-level up. Previous work has shown disenfranchisement of women farmers and rural communities related to agriculture resource/information access and empowerment. However, the field lacks a locally adaptable tool for long-term tracking of farmer access and agency. The L-API is one example of a process and the resulting tool, informed by locally relevant indicators, to help improve farmer access to and agency over EAS. It is meant to provide a baseline tool to be tailored in different locations based on local needs.

As discussed, the L-API has promise as a novel, inexpensive, locally adaptable management tool to better understand farmer assess and agency of extension services, over time and space. The L-API utilizes open-source software, functions at the community-level, and is relatively simple and inexpensive to adapt to different local contexts. For these reasons, it provides a new approach to help inform future monitoring, evaluation, and provisioning toward locally relevant and more gender-equitable EAS. Where other multidimensional indices report findings at the national and regional levels to make gender comparisons, L-API allows diverse users to explore local adaptive capacity in a variety of settings at various scales. Adaptive capacity is context-specific, but the ability to understand and measure it at the local scale is an important

feature of the L-API.

The L-API is a tool to help governments (i.e., local extension providers), local research entities, and development practitioners build farmers' adaptive capacity through spatially targeted extension services. It also improves efforts to work together with communities to locally monitor and adapt EAS as social/environmental circumstances change, by focusing on community-based approaches that are participatory and inclusive. The stated access and agency barriers stem from gender norms that marginalize women in patriarchal societies across the globe. Women's compounded risks due to climate change will require holistic and innovation strategies to overcome (Perez et al., 2015). The L-API can be a tool that supports extension providers and governments in filling gender gaps in EAS delivery and adoption leading to improved national food security and gender equity. Due to its creation through an inductive approach, inclusive of community input and open-source software, the L-API may be successfully adapted to the specific needs of other locals.

Disclaimer

The views expressed are those of the authors and do not reflect the official policy or position of the U.S. Air Force, Department of Defense, or the U.S. Government.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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