MDP TRINITY|UCD Masters in Development Practice

Food for Thought on Metric Determination for the SDGs at the Water-Food-Agriculture Nexus in Northern Senegal

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Abstract

The Sustainable Development Goals (SDGs) were adopted in 2015 to mobilize efforts to terminate poverty, challenge inequalities, and combat climate change. To this end, the seventeen goals of the agenda set an indicator framework covering a range of topics including energy, water, agriculture, and governance. There has been increasing research linking the food, water, agriculture, nutrition, and energy aspects of the Millennium Development Goals (MDGs), and SDGs into the water-energy-food (WEF) nexus discussion following the 2011 Bonn Conference. However, research is lacking on how to monitor and assess nexus discussions at the regional and household level.

While the SDGs are determined at the international level, they require local implementation given the SDGs' call to 'Leave no one behind.' Context-based, regionally adapted agricultural, food, and water security indicators are a crucial element in discussions of achievement at the food-agriculture-water nexus as a subset of the larger WEF nexus. Metrics play a role within monitoring and evaluation, which in turn influences implementation, policy and strategy formulation. While metrics are rarely all-inclusive, they can provide a starting point for discussing needs to foster dialogue, promote inclusiveness, stimulate transparency and, increase awareness, to bridge SDG implementation gaps.

While agricultural and food security metrics have been more extensively developed in the literature, to date most scales examining water security at the household level do not demonstrate the true extent of local water security. Thus, poor understanding of household dynamics at the food –agriculture-water nexus provides a weak basis for policy at the international level. Specifically, there has been a call in the literature across the food, agriculture, and water sectors to further develop localized metrics evaluations which are informed by qualitative data collection to take into consideration the scientific inquiry through social and political frameworks which nexus discussions are inherently embedded. Applying more integrative approaches which use qualitative and quantitative methods to understand conjoint household agricultural practices alongside food and water security is a novel approach, and applying these newly developed metrics more broadly seeks to more accurately inform nexus discussions.

This research undertaken in 2018 employed quantitative data collection methods (i.e. household structured questionnaires (n=360)) and qualitative data collection methods (i.e. key informant interviews (n=27)), to understand the food-agriculture-water nexus at the household and community level within the Leona region of Northern Senegal. Ultimately with the newly developed metrics, a significant effect emerged between different facets of agriculture and water security on household food security (i.e. region, household diet diversity, and secondary water source type). The significance of these variables signals a need for experts to work horizontally and vertically within the agriculture, water and energy fields to collaboratively formulate accurate determinants for the nexus discussion from the household level. Creating a strong evaluative framework at the household level ensures that the achievement of the SDGs goes beyond a box-ticking exercise. By starting with the foundation of household surveying, nexus discussions can be localized, providing a template for future operationalization of the nexus across the global ecosystem.

I. Introduction

i. Background

The global population is expected to reach almost 10 billion by 2050.[1] In anticipation of the simultaneous challenges of this growth alongside climate change, it is estimated that agricultural production will need to expand 70%.[2] Agricultural systems – including resource-efficient, resilient food systems, and value chains – must become stronger, more sustainable, and better linked to nutrition, and health.[3] Moreover, productive agriculture and nutritious food depend on clean and freshwater. Water is an essential component of all aspects of social, economic and environmental development, including poverty eradication, food security, and resilience to natural and human-induced disasters, while also playing a key role in climate change adaptation. The agriculture sector – particularly crops and livestock – on average accounts for 70% of all water withdrawals globally, and up to 95% in some developing countries. Further withdrawal increases for irrigation and livestock are expected to meet the growing global food demand, which is often a limiting factor for food production.[4]

The SDGs aspire for universal application and are thus global in nature. Yet they are also expected to be adapted to the national and local context by taking into account several factors, such as the level of development and existing national and local policies.[5] Household surveys provide the foundation for rigorous and transparent monitoring, given their potential to cover multiple aspects of development, to review large sample sizes accurately, and clarify effects of exclusion by demographic disaggregation. While the water-food-agriculture nexus is widely discussed in the literature at global and basin scales, mainstreaming, and evaluating the nexus with improved metrics at national and sub-national levels is not. Nevertheless, food, water, and energy system interactions are determined regionally and locally. Thus, interaction across the nexus are rarely well captured in most global frameworks for integrated assessment.[6]

This project seeks to explore the relationship between agriculture, food and water security to inform nexus discussions. Specifically, it highlights the role that improved metrics can have in these areas at the national and sub-national levels. The structure of this paper is four-fold. It first situates accurate metric evaluation of agriculture, food and water security from the literature. It then provides mixed-methodologies used to evaluate the food-agriculture-water nexus in Northern Senegal. Thirdly, it evaluates this nexus at the subnational level. Lastly, it provides recommendations for future research and policy to inform nexus discussions.

ii. Research Aim

As developed in the previous section, this project seeks to explore the relationship between agricultural practices, food security and water security, and the role that metrics can have in these areas to inform wider nexus discussions through the lens of a case study in Northern Senegal.

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[1] "World Population Projected to Reach 9.8 Billion in 2050, and 11.2 Billion in 2100 | UN DESA Department of Economic and Social Affairs." United Nations. Accessed July 01, 2019. https://www.un.org/development/desa/en/news/population/world-population-prospects-2017.html.

[2] "Water in Agriculture." World Bank. Accessed July 01, 2019. https://www.worldbank.org/en/topic/water-in-agriculture.

[3] Fresco, Louise O. "Challenges for food system adaptation today and tomorrow." *Environmental science & policy* 12, no. 4 (2009): 378-385.

[4] Abraham, Mathew, and Prabhu Pingali. "Transforming smallholder agriculture to achieve the SDGs." *The role of small farms in food and nutrition security. Springer* (2017).

[5] Biermann, Frank, Norichika Kanie, and Rakhyun E. Kim. "Global governance by goal-setting: the novel approach of the UN Sustainable Development Goals." *Current Opinion in Environmental Sustainability* 26 (2017): 26-31.

[6] Loring, Philip A., S. Craig Gerlach, and Henry P. Huntington. "The new environmental security: Linking food, water, and energy for integrative and diagnostic social-ecological research." *Journal of Agriculture, Food Systems, and Community Development* 3, no. 4 (2013): 55-61.

II. Literature Review

i. Defining Food Security

At the 1996 World Food Summit, food security (at the individual, household, national, regional and global levels) was defined as, when "all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life."[7] Food security is closely related to, but not synonymous with, nutrition security and optimal health outcomes.[8] For food security to be a reality, households need to have unrestricted access to a healthy and nutritious diet. Access to healthy diets depends on having adequate economic resources and readily available foods within the household's community.[9]

Food security is a necessary but insufficient condition for ensuring nutrition security,[10] which considers care, health, and hygiene practices in addition to food security. Nutrition security is defined as "a situation that exists when secure access to an appropriately nutritious diet is coupled with a sanitary environment, adequate health services and care, to ensure a healthy and active life for all household members."[11]

ii. Food Security Metrics

A plethora of food security metrics currently exists and are implemented widely across a variety of scales ranging from national to individual.[12] The following examples represent just a fraction of those available. SDG2 (Zero Hunger) Indicator 2.1.2 recommends the utilization of the Food Insecurity Experience Scale (FIES) to measure national food insecurity over a 12-month period (see Box 1). A more appropriate and accurate instrument for sub-national (and particularly household) data collection is the Household Food Insecurity Access Scale (HFIAS), which also measures seasonal variation, since it adopts a 4-week rather than 12-month recall period.[13] [14]

Box 1: SDG Target 2.1

"By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round."

- **Indicator 2.1.1:** Prevalence of undernourishment
- **Indicator 2.1.2:** Prevalence of moderate or severe food insecurity in the population, based on the Food Insecurity Experience Scale (FIES)

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[7] FAO. Rome declaration on world food security and world food summit plan of action. Rome: FAO; 1996.

[8] Perez-Escamilla, R. and Segall-Correa, A.M. (2008) Food insecurity measurement and indicators. Revista de Nutriçao, 21, 15–26.

[9] Perez-Escamilla, R. (2017) Food Security and the 2015–2030 Sustainable Development Goals: From Human to Planetary Health, Department of Social and Behavioral Sciences and Global Health Concentration, Yale School of Public Health, New Haven, CT.

[10] Food and Agriculture Organisation of the United Nations (2011) Towards a Food Insecurity Multidimensional Index (FIMI), available: http://www.fao.org/fileadmin/templates/ERP/uni/FIMI.pdf.

[11] Food and Agriculture Organisation of the United Nations. Rome declaration on world food security and world food summit plan of action. Rome: FAO; (1996).

[12] Jones, Andrew D., Francis M. Ngure, Gretel Pelto, and Sera L. Young. "What are we assessing when we measure food security? A compendium and review of current metrics." *Advances in Nutrition* 4, no. 5 (2013): 481-505.

[13] *Ibid*.

[14] Swindale, Anne, and Paula Bilinsky. "Household dietary diversity score (HDDS) for measurement of household food access: indicator guide." *Washington, DC: Food and Nutrition Technical Assistance Project, Academy for Educational Development* (2006).

Dietary diversity, meanwhile, is the number of food groups consumed over a given reference period, typically 24-hours, and is often used as a proxy for nutrition intake. The Household Dietary Diversity Score (HDDS) is a particularly useful (and easy-to-administer) tool for measuring household socio-economic access to food, and associations between diverse dietary food group consumption and nutrient quality of diets as well as child anthropometry.[15] The HDDS is also useful for ensuring that agricultural development, food security, and nutrition education programmes effectively lead to more nutritious diets.[16] The HDDS has been positively associated with household food security in some cases, and similar tools (e.g. DDS) have been developed to measure the nutritional quality of individual diets.[17] The HDDS does not measure dietary diversity (or nutritional quality) at the individual level, nor does it account for the quantity of a particular food group that was consumed.

iii. Defining Agricultural Productivity

The definition of agricultural productivity based on outputs produced for a given set of inputs. In international development surveying, two measures of productivity are used: total factor productivity and partial factor productivity. Partial factor productivity is more commonly used, and it is composed of partial measures including land productivity, state the amount of output per unit of a particular input like land or labor.[18]

iv. Agricultural Productivity Metrics

Core agricultural metrics in household surveying are based on FAO recommendations. They take into consideration national conditions and considerations. Thus they include but are not limited to the area of land used for agricultural purposes, the types and quantities of crops grown, along with additional measures of productivity at the household level, such as ownership of livestock or engagement in fishing. Metrics for agriculture productivity are still underdeveloped within the SDG framework, however, SDG Target 2.3 alludes to the measure.

Box 2: SDG Target 2.3

"By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment."

- **Indicator 2.3.1:** Volume of production per labour unit by classes of farming/pastoral/forestry enterprise size

v. Defining Water Security

Currently, the most cited definition of water security is "the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments, and economies."[19] Unlike the widely accepted food security definition, this definition takes the reductionist approach to water

[15] Jones, Andrew D., Francis M. Ngure, Gretel Pelto, and Sera L. Young. "What are we assessing when we measure food security? A compendium and review of current metrics." *Advances in Nutrition* 4, no. 5 (2013): 481-505.

[16] Food and Agriculture Organisation of the United Nations (2010) Nutrition assessment, available: http://www.fao.org/ag/agn/nutrition/assessment_en.stm.

[17] Jones, Andrew D., Francis M. Ngure, Gretel Pelto, and Sera L. Young. "What are we assessing when we measure food security? A compendium and review of current metrics." *Advances in Nutrition* 4, no. 5 (2013): 481-505.

[18] Zepeda, Lydia, ed. *Agricultural investment and productivity in developing countries*. No. 148. Food & Agriculture Org., 2001.

[19] Grey, David, and Claudia W. Sadoff. "Sink or swim? Water security for growth and development." *Water policy* 9.6 (2007): 545-571.

security, examining security against a predetermined acceptable level of risk which water insecurity would present to a community. Policymakers generally also use this approach to water security, using quantitative risk analysis to make decisions through "science-based" decisions.[20] While allowing for rapid needs assessments it is likely, however, to suffer from oversimplification of the complex regional challenges which are underpinning water security.

The UN system relies on the definition of water security provided by UN-Water which states "the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability."[21] This definition takes an integrated approach to water security, examining the water needs of a community more holistically, thus requiring more complex metrics.

vi. Water Security Metrics

SDG 6 calls for access to water and sanitation for all.[22] Specifically for potable water, Target 6.1, aims to "By 2030, achieve universal and equitable access to safe and affordable drinking water for all."

Box 3: SDG Target 6.1

"By 2030, achieve universal and equitable access to safe and affordable drinking water for all"

- **Indicator 6.1.1:** Proportion of population using safely managed drinking water services

The UNICEF/WHO Joint Monitoring Program, has since elaborated on Target 6.1 (Box 2) to include the following three criteria for people using an improved water source. It should be available on premises, available when needed, and free from contamination (Although the technical determination for free from contamination has yet to be specifically addressed). However, there is consensus, that these methods can rarely capture critical dimensions of water security such as political, socio-cultural, and gendered dynamics of household water provision.[23]

Applying more integrative approaches which use qualitative and quantitative methods to understand household water insecurity is still a novel approach, with new methods being tested in a handful of studies previously including pilot studies with varying methodologies in Bolivia,[24]

[20] Zeitoun, Mark, Bruce Lankford, Tobias Krueger, Tim Forsyth, Richard Carter, Arjen Y. Hoekstra, Richard Taylor et al. "Reductionist and integrative research approaches to complex water security policy challenges." *Global Environmental Change* 39 (2016): 143-154.

[21] Water, U. N. "Status report on the application of integrated approaches to water resources management." *United Nations Environment Programme: Nairobi, Kenya* (2012).

[22] Griggs, David, Mark Stafford-Smith, Owen Gaffney, Johan Rockström, Marcus C. Öhman, Priya Shyamsundar, Will Steffen, Gisbert Glaser, Norichika Kanie, and Ian Noble. "Policy: Sustainable development goals for people and planet." *Nature* 495, no. 7441 (2013): 305.

[23] Boateng, Godfred O., Shalean M. Collins, Patrick Mbullo, Pauline Wekesa, Maricianah Onono, Torsten B. Neilands, and Sera L. Young. "A novel household water insecurity scale: Procedures and psychometric analysis among postpartum women in western Kenya." *PloS one* 13, no. 6 (2018): e0198591.

[24] Wutich, Amber, and Kathleen Ragsdale. "Water insecurity and emotional distress: coping with supply, access, and seasonal variability of water in a Bolivian squatter settlement." *Social science & medicine* 67, no. 12 (2008): 2116-2125.

and the United States.[25] In sub-Saharan Africa, research in assessing integrative water security has been done in Ethiopia,[26] and Uganda.[27] In Uganda, metrics developed from food insecurity scales were adapted to water systems, thus creating the Household Water Insecurity Access Scale (HWIAS) which requires monthly recall.

vii. Localizing Nexus Discussion with Improved Food, Agricultural, and Water Security Metrics

While new methods examining food and water security separately have been implemented across sub-Saharan Africa, most studies investigating the nexus to date have been at the international and national scale (i.e. initiatives such as the Food Sustainability Index (FSI),[28] the Adjusted Food Sustainability Index (AFSI),[29] and the Sustainable Nutrition Security[30]). However, given the various scales and actors of the nexus, many discussions have been simply a 'paper exercise.' To date, operationalization has largely been stagnant. [31]

While the nexus discussion provides strong frameworks for discussions, there is little understanding of the interactions between the different aspects at the household level. One study in Iraq analysed the nexus at the household scale. However, this study took a reductionist lens and focused largely on consumption rather than insecurity. [32] No published studies have yet taken place to regionally compare advanced methods for holistic household water security determination links with food security, agricultural and diet diversity in Senegal. While there is a variety of data on SDG achievement within Senegal collected across the national statistics department and various UN organizations in the food, agricultural, and water, comparing these more integrative metrics in each sector across household provides valuable insights to the nexus discussions, both for the local context and more broadly.

[25] Jepson, Wendy. "Measuring 'no-win' waterscapes: Experience-based scales and classification approaches to assess household water security in colonias on the US–Mexico border." *Geoforum* 51 (2014): 107-120.

[26] Hadley, Craig, and Matthew C. Freeman. "Assessing reliability, change after intervention, and performance of a water insecurity scale in rural Ethiopia." *Food Security* 8, no. 4 (2016): 855-864.

[27] Tsai, Alexander C., Bernard Kakuhikire, Rumbidzai Mushavi, Dagmar Vořechovská, Jessica M. Perkins, Amy Q. McDonough, and David R. Bangsberg. "Population-based study of intra-household gender differences in water insecurity: reliability and validity of a survey instrument for use in rural Uganda." *Journal of Water and Health* 14, no. 2 (2016): 280-292.

[28] The Economist Intelligence Unit. Fixing Food: towards a More Sustainable Food System (2016)

[29] Agovino, Massimiliano, Massimiliano Cerciello, and Andrea Gatto. "Policy efficiency in the field of food sustainability. The adjusted food agriculture and nutrition index." *Journal of environmental management* 218 (2018): 220-233.

[30] Gustafson, David, Alona Gutman, Whitney Leet, Adam Drewnowski, Jessica Fanzo, and John Ingram. "Seven food system metrics of sustainable nutrition security." *Sustainability*8, no. 3 (2016): 196.

[31] Leck, Hayley, Declan Conway, Michael Bradshaw, and Judith Rees. "Tracing the water–energy–food nexus: Description, theory and practice." Geography Compass 9, no. 8 (2015): 445-460.

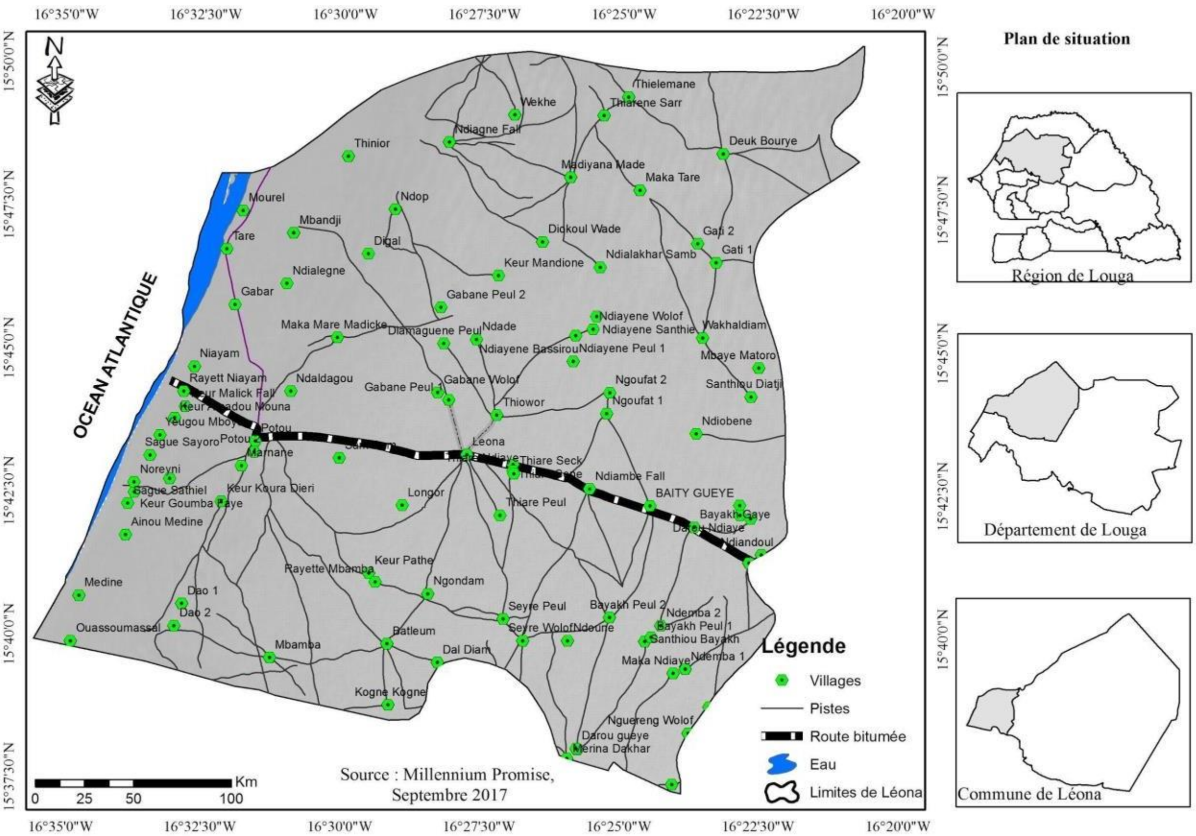
[32] Wa'el A, Hussien, Fayyaz A. Memon, and Dragan A. Savic. "An integrated model to evaluate water-energy-food nexus at a household scale." *Environmental modelling & software* 93 (2017): 366-380.

III. Methodology

i. Study Site

The study comprises the Leona community, Senegal (16°3'26"N, 16°15'19"W; 415 km²) located in the Louga region, 190 km north-east of Dakar. The population is just over 38,000 consisting of 6 health districts, divided into 127 villages with 3,485 households.[33] The mean annual temperature ranges between 24°C and 35°C and the rainy season is from July-October.[34] The Leona region crosses the Niayes and the Dieri ecological zones of Senegal and most residents engage in economic activities, including agriculture, pastoralism, and fishing.[35]

Figure 1: Study Region Map.



Targeted MDG specific intervention in Leona began in August 2007 as part of the Millennium Villages Project (MVP). Clusters were selected based on their site's high prevalence of hunger and poverty (i.e. >20% of children <5 years are underweight), their country's governmental stability and support, as well as their diverse farming systems and agro-ecology zones.[36] During the MVP in Potou, agriculture interventions were designed and implemented in two

[33]"Senegal Census Data, 2013 - Senegal Data Portal." Senegal Data Portal. Accessed May 10, 2018. http://senegal.opendataforafrica.org/SNCD2015/senegal-census-data-2013?location=1000000-senegal&indicator=1000010-total-population.

[34] Trape, Jean-Francois, Evelyne Lefebvre-Zante, Fabrice Legros, Gora Ndiaye, Hilaire Bouganali, Pierre Druilhe, and Gerard Salem. "Vector density gradients and the epidemiology of urban malaria in Dakar, Senegal." *The American journal of tropical medicine and hygiene* 47, no. 2 (1992): 181-189.

[35] "Potou, Senegal." Millennium Villages. Accessed September 10, 2018. http://millenniumvillages.org/the-villages/potou-senegal/.

[36]Nziguheba, Generose, Cheryl A. Palm, Tadesse Berhe, Glenn Denning, Ahmed Dicko, Omar Diouf, Willy Diru et al. "The African green revolution: Results from the millennium villages project." In *Advances in agronomy*, vol. 109, pp. 75-115. Academic Press, 2010.

phases: Phase 1 (2006-2010) intended to boost agricultural productivity and food security in addition to strengthening farmer-based organisations (i.e. cooperatives and unions, initially called ‘associations’) and delivering of quality extension services. Phase 2 (2011-2015) added profitability and sustainability by incubating and officially registering cooperatives as business entities (organised into two distinct unions; the Niayes and the Dieri), creating niche opportunities for private sector engagement (e.g. agro-dealers, financial institutions and buyers), and transforming food crops into cash crops to increase producers’ yields and incomes. Throughout Phase 1 and Phase 2, agricultural interventions focused on improvements in irrigation, (agronomic) extension services, livestock and dairy production to achieve the intended outcomes.[37] Prior to intervention 29.1% of the population had access to drinking water from an improved source (i.e. protected from outside contamination). By 2015, access to improved drinking water sources in the region had reportedly reached 91%.[38]

ii. Quantitative Methods

i. Sampling

The sampling unit for this research was the household. The household was defined for the purpose of this study as a group of people that live together in a dwelling and share domestic resources. Slovin’s formula was used to determine the sample size necessary to be representative of the designated region:

Equation 1:

$$n = \frac{N}{1 + (N\,x\,e^2)}$$

In Slovin’s formula, n is the number of samples, N is the total population, and e is the selected error margin. Because selection was done at the household level, N was chosen to be the total number of households within the study region (n=3,485).[39] The selected error margin was 0.05, resulting in a 95% confidence interval of the ability of the sample to represent the Leona population. The number of households representative of the region at a 95% confidence interval was given as 358.8. Thus, this number was rounded up, and the number of households to be surveyed was determined to be 360.

To avoid bias, the household selections (n=360; 95% CI; p=0.05) was then randomized in Stata 15.1 over the sampling frame of 3,485 households in the Leona region based on the latest available census data which listed village and household number. The randomization selected individual intervals between households across the 3,485 total households. This household randomization resulted in households selected in 82 villages across the region.

The survey instruments were administered by two trained male research assistants in a language chosen by respondents (French, Peuhlar, or Wolof). The questionnaire was first translated into French, and then administered in the local language (Wolof or Peuhlar) by the local research assistants. Key informants including Agriculture Specialists and WASH staff also shared their views on appropriate translation of key aspects of the questionnaire with the survey team.

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[37] Millennium Promise (2016) 2015 Millennium Promise Annual Report on the Millennium Villages Project, available: http://www.millenniumpromise.org/sites/default/files/2017-06/MP%202015%20Annual%20Report-21-12-2016.pdf

[38] Mitchell, Shira, Andrew Gelman, Rebecca Ross, Joyce Chen, Sehrish Bari, Uyen Kim Huynh, Matthew W. Harris et al. "The Millennium Villages Project: a retrospective, observational, endline evaluation." *The Lancet Global Health* 6, no. 5 (2018): e500-e513.

[39] "Senegal Census Data, 2013 - Senegal Data Portal." Senegal Data Portal. Accessed May 10, 2018. http://senegal.opendataforafrica.org/SNCD2015/senegal-census-data-2013?location=1000000-senegal&indicator=1000010-total-population.

ii. Instrument Development

The household questionnaire assessed food insecurity, water insecurity, and agricultural involvement. Metrics used in household surveys were synthesized and adapted from a variety of household food and water insecurity scales including methods outlined by FAO/UNFPA, USAID/FANTA, WHO/UNICEF JMP, MVP previous food and water security determination, and academic literature examining household food, agricultural, and water insecurity cited in the literature review.

iii. Qualitative methods

i. Key-Informant Interviews

To inform the food security and agricultural adherence discussions, all cooperative and union leaders, as well as 2 agricultural specialists with an in-depth knowledge of the study site (and not based in the commune), were invited to participate in the key informant interviews. 8 leaders (including 4 from each subzone) and both specialists agreed. Interviews consisted of fifteen questions related to the agricultural production methods and (sustainable) farming practices. All health posts were informed about the study and 2 agreed to participate (one from each subzone). Cases of malnutrition were recorded at both health posts, according to standard protocols.[40]

To inform the water security discussion, key informant interviews were conducted with each of the 4 borehole managers, the Louga local water utility manager, the WASH specialist at Millennium Promise, the regional district health head, the head of each of the six health posts in the region, and the headmasters of six schools within the region.

ii. Qualitative Analysis

Themes were coded in household observations and key informant interviews using NVivo 12 Pro software. Themes included codes such as ‘short-term/long-term mechanical water utility failure,’ ‘failure/success of community managed system,’ and ‘negative health outcome’ as well as ‘successes,’ ‘challenges,’ and ‘opportunities’ for the agricultural cooperatives and unions, ‘sustainable agriculture’ and ‘nutrition-sensitive agriculture.’ Qualitative data was used within the results narrative to support quantitative findings.

iv. Ethical Considerations

This project was conducted in line with the ESRC standards for research. Ethics review and approval was obtained from the Trinity College Dublin Geography Ethics Review Board.

[40] Mitchell, S., Gelman, A., Ross, R., Chen, J., Bari, S., Huynh, U.K., Harris, M.W., Sachs, S.E., Stuart, E.A., Feller, A., Makela S., Zaslavsky, A.M., McClellan, L. Ohemeng-Dapaah, S., Namakula, P., Palm, C.A., Sachs, J.D. (2018) The Millennium Villages Project: a retrospective, observational, endline evaluation, The Lancet.

IV. Results

i. Model 1: Variables affecting total HFIAS score

A multiple linear regression model was run to see the effects of the updated variables on food security – determined by the HFIAS score. The higher the HFIAS score, the higher the household food insecurity. The dependent variable was HFIAS score, and the independent variables were agricultural (region, area, household food acquisition practice), dietary (diet diversity score), and metrics of water security (improved primary and secondary source, and yearly assessment of water security).

Table 1: *Regression Model of Agricultural, Dietary, and Water Metric Significance in Household Food Insecurity Scale*

Variables	Effect on HFIAS score
Household Diet Diversity Scale (0-12)	-1.03894*** (-7.22)
Region (Dieri= 0 Niayes=1)	0.9899511* (2.40)
Total Farming Area (Ha)	0.0893716 (0.169)
Grow Crops	2.081367 (0.138)
Sale of Crops	-0.1996382 (-0.14)
Food Exchange	1.962593*** (3.15)
1st Water Source Improved	-0.5865921 (-0.16)
2nd Water Source Improved	-0.7327401** (-1.71)
Not Enough Water in Past 12 Months	1.164039** (3.75)
Constant	10.74043* (2.55)
Observations	360
R-Squared	0.3043
Adjusted R-Squared	0.286
F-Test	16.62***

t statistics in parentheses

*p< 0.05,** p<0.01, ***p<0.001

Five variables were significant in understanding the total household food insecurity: household diet diversity, and type of secondary water source (Negative and significant) and region, inter-familial food exchange, and annual water security (Positive and significant).

The adjusted R-squared for the model one is 0.286 which means that the regression model explains 28.6% of the variability of the response data surrounding the mean. Given the "large" dataset (n=360), a t-statistic greater than 2 (or less than -2) indicates the coefficient is significant with greater than 95% confidence. The F-statistic, however, was significant (F-stat=16.62, $p<0.05$) thus verifying the overall significance of the regression model.

Qualitative interviews conducted also underscored the interlinked relationship between agricultural practices, food and water security in the region and the need for further development of metrics across the nexus. For example, in regard to the effects of water security on agriculture and food security, an agricultural specialist in the area noted that there were a number of challenges facing the Leona commune. Firstly, he highlighted the variability in climate as a hindering factor to agricultural productivity. Secondly, he highlighted the salinization of agricultural water sources in the Niayes region (this was triangulated with electric conductivity water quality testing of wells across both regions). He noted: "because of erosion and everything, the bottom land [i.e. Niayes] is already reducing in size, and the rainfed agriculture [i.e. Dieri] is also very affected by climate change." He concluded, noting that "There is a lot of irrigation happening, and the water may be exhausted… and in 15 years, 20 years, 30 years, I don't think that what we are doing [i.e. agriculture] is going to increase. It is going to decrease because of climate change, salinization, erosion, [and] urbanisation." A decrease in agriculture in the already food insecure area which relies on farming for subsistence and livelihoods would likely negatively affect food and dietary diversity in the region.

ii. Monthly effects of Water Security on Food Security

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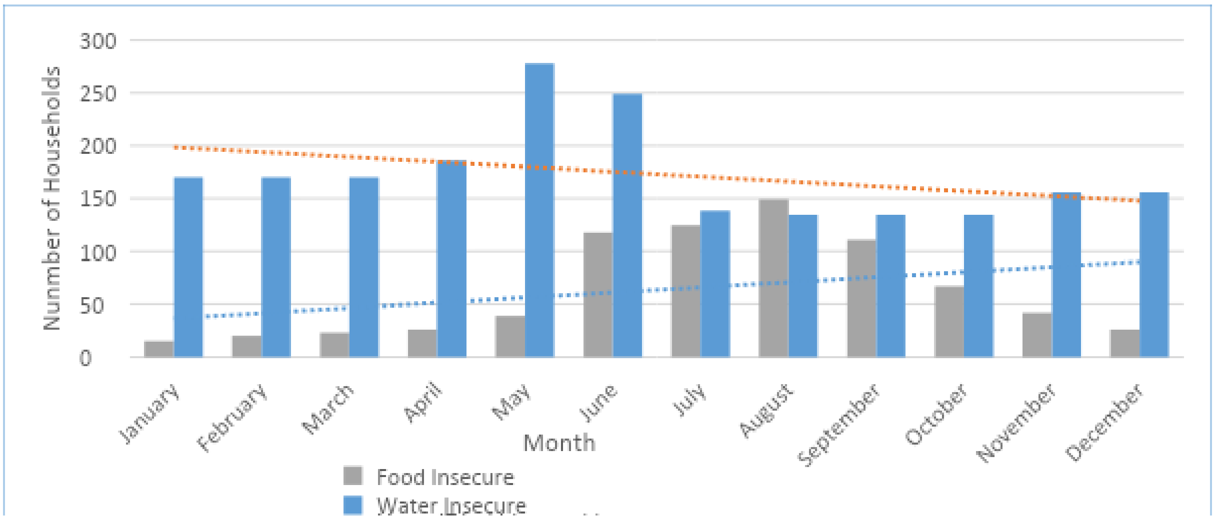
Furthermore, a monthly breakdown of food security and water security was done to analyse the relationship between the two variables, as water insecurity usually acts as a precedent for food insecurity given the agricultural need for water to raise crops.

Figure 2: Household incidence reporting food and water insecurity by month (2018).



There were major technical problems with two of the boreholes in the region in May and June, causing a high number of outages across the region and pressuring people to rely heavily on their secondary source of water (where the secondary source type was significant within the regression model). These problems occurred during the lean season which accounts for the end of the dry season with the lowest agricultural productivity (May-Sept) in advance of the rainy season (typically July-Sept in the evaluated region).

V. Discussion

i. Implications for Research

Focusing on further developing the five significant metrics should be a priority for SDG implementers. The significance of these regression coefficients underscores that when examining food security specifically, household diet diversity, regional agricultural differences, varying household social food sharing practices, and a variety of water security metrics beyond improved and unimproved source should be examined to more accurately inform nexus discussions.

Condiering new potential indicators at the household level to create a strong foundation for examining security at the nexus will require harnessing specialist knowledge with each nexus-dimension to critically think of how new household metrics could aid the nexus discussion. Oftentimes this discussion will require contextualization, given that many factors affecting the nexus are place-specific (i.e. agricultural zones vary by soil type, composition and rain levels). When input into heterogeneous landscape of systems and metrics, key place-based components of food, agricultural, and water security are obfuscated. Developing localized household metrics beyond SDG indicators will improve validity of scale and ensure true achievement of Agenda 2030.

Moreover, this research highlights the need to enable more granular data disaggregation including using intra-household and gender lens in future research to ensure that we "leave no one behind." This study did not disaggregate at the household level and, since all community-level key informants were men, the representation of women is limited.

The inter-temporal data trends highlight that having increased time series data on these metrics will also improve development specialist's ability to quantify the effects of long term changes in the region. Qualitative analysis from the region suggests a focus on the potential effects of climate change in the area, which can be analyzed with time-series data. Climate change and increasing water withdrawals are lowering the water table in the area, causing increased salinization in key sources. This is causing direct and indirect health impacts (i.e. poor availability or access to quality water may lead to water-borne diseases from direct consumption; and also affect agricultural practices and productivity, food security and nutrition). Frequently collected data can work to monitor seasonality and climate shocks, to determine the robustness of the nexus, and to anticipate future disturbances or changes. In collecting inter-temporal data, however, it is crucial to consider accuracy and recall time.

Increasingly, researchers should also consider the use of secondary data coupled with household surveying to improve metrics at the nexus. Recent technological advancements (i.e. satellite imagery, remote sensor monitoring, ICT, and citizen science techniques) are changing the data landscape and creating innovative options for collecting data needed for measurement of outcomes. Coupling big data technologies with household monitoring allows the nexus discussion to be further operationalized across scales.

ii. Implications for Policy

A cornerstone to achieving the SDGs will be building an accurate indicator framework, coupled with new and effective ways of collecting data, monitoring targets and measuring progress, to ultimately build accountability. Improved indicators and metrics pave the road for supporting evidence-based policy-making.

Localizing not only metric determinations, but policy nexus discussions from the international level to the national and sub-national level is critical to increasing accuracy as local governments have different tools to adapt policy to their regions. This localization allows for national officials and development programmers to ensure that the "leave no one behind" policy priority is achieved by developing needs assessments, and monitoring strategies.

Engaging in horizontal inclusion to this end by pairing together national statistics agencies with ministries of health, agriculture, water and economic and social affairs to examine opportunities, priorities, and trade-offs across the nexus would benefit effective data collection. Given the multifaceted nature of nexus discussion, including relevant stakeholders at the table will improve cohesion. National authorities will also have some necessary contextual knowledge to inform local implementation, and national nexus knowledge to prompt donors to engage in more targeted projects at the nexus. This discussion at the national level can help reduce duplicate costs, and streamline programming.

Beyond horizontal inclusion mechanisms within government, it is key to horizontally engage across sectors. While the national statistical office is the main actor in generating data, national statistical offices receive metric inputs from potential data contributors such local and regional governments, academia, civil society and private companies. Ultimately, the national statistical office seeks to coordinate and manage data inputs from various actors to ensure data quality, and comparability, before reporting internationally.

Furthermore, funding research and technologies for improved metrics across the nexus using vertical inclusion methodology is crucial for effective policy. Due to limited, and inconsistent data, particularly in least developed countries, significant investment will be needed to improve the data landscape, both in terms of collection and collation. There are many opportunities for investment beyond traditional data channels, to open data platforms and technologies given higher productivity and cost-efficiency of many new data tools. Furthermore, promoting open data could aid in supporting newly developed effective metrics that can be shared across regional peer-learning platforms to further engage in food-agriculture-water nexus discussions.

Ultimately, the goal is to develop better understandings of the linked social and ecological dynamics of at the nexus, to ensure that SDG achievement is not a box-ticking exercise, but a valiant effort to improve agriculture, food and water security for individuals. By starting with the basic building blocks of household surveying, nexus discussions can be localized, and work can move beyond academic discussions to operationalizing the nexus in practice.

Works Cited

Abraham, Mathew, and Prabhu Pingali. "Transforming smallholder agriculture to achieve the SDGs." *The role of small farms in food and nutrition security. Springer* (2017).

Alaofè, H., Burney, J., Naylor, R., Taren, D., 2016. Solar-powered drip irrigation impacts on crops production diversity and dietary diversity in Northern Benin. Food Nutr. Bull. 37, 164–175. http://dx.doi.org/10.1177/0379572116639710.

Agovino, Massimiliano, Massimiliano Cerciello, and Andrea Gatto. "Policy efficiency in the field of food sustainability. The adjusted food agriculture and nutrition index." *Journal of environmental management* 218 (2018): 220-233.

Biermann, Frank, Norichika Kanie, and Rakhyun E. Kim. "Global governance by goal-setting: the novel approach of the UN Sustainable Development Goals." *Current Opinion in Environmental Sustainability* 26 (2017): 26-31.

Boateng, Godfred O., Shalean M. Collins, Patrick Mbullo, Pauline Wekesa, Maricianah Onono, Torsten B. Neilands, and Sera L. Young. "A novel household water insecurity scale: Procedures and psychometric analysis among postpartum women in western Kenya." *PloS one* 13, no. 6 (2018): e0198591.

Food and Agriculture Organisation of the United Nations. Rome declaration on world food security and world food summit plan of action. Rome: FAO; (1996).

Food and Agriculture Organisation of the United Nations Nutrition assessment, available: http://www.fao.org/ag/agn/nutrition/assessment_en.stm. (2010)

Food and Agriculture Organisation of the United Nations Towards a Food Insecurity Multidimensional Index (FIMI), available: http://www.fao.org/fileadmin/templates/ERP/uni/FIMI.pdf. (2011)

Fresco, Louise O. "Challenges for food system adaptation today and tomorrow." *Environmental science & policy* 12, no. 4 (2009): 378-385.

Grey, David, and Claudia W. Sadoff. "Sink or swim? Water security for growth and development." *Water policy* 9.6 (2007): 545-571.

Griggs, David, Mark Stafford-Smith, Owen Gaffney, Johan Rockström, Marcus C. Öhman, Priya Shyamsundar, Will Steffen, Gisbert Glaser, Norichika Kanie, and Ian Noble. "Policy: Sustainable development goals for people and planet." *Nature* 495, no. 7441 (2013): 305.

Gustafson, David, Alona Gutman, Whitney Leet, Adam Drewnowski, Jessica Fanzo, and Ingram. "Seven food system metrics of sustainable nutrition security." *Sustainability*8, no. 3 (2016): 196.

Hadley, Craig, and Matthew C. Freeman. "Assessing reliability, change after intervention, and performance of a water insecurity scale in rural Ethiopia." *Food Security* 8, no. 4 (2016): 855-864.

Jepson, Wendy. "Measuring 'no-win' waterscapes: Experience-based scales and classification approaches to assess household water security in colonias on the US–Mexico border." *Geoforum* 51 (2014): 107-120.

Jones, Andrew D., Francis M. Ngure, Gretel Pelto, and Sera L. Young. "What are we assessing when we measure food security? A compendium and review of current metrics." *Advances in Nutrition* 4, no. 5 (2013): 481-505.

Leck, Hayley, Declan Conway, Michael Bradshaw, and Judith Rees. "Tracing the water–energy–food nexus: Description, theory and practice." Geography Compass 9, no. 8 (2015): 445-460.

Loring, Philip A., S. Craig Gerlach, and Henry P. Huntington. "The new environmental security: Linking food, water, and energy for integrative and diagnostic social-ecological research." *Journal of Agriculture, Food Systems, and Community Development* 3, no. 4 (2013): 55-61.

Millennium Promise (2016) 2015 Millennium Promise Annual Report on the Millennium Villages Project, available: http://www.millenniumpromise.org/sites/default/files/2017-06/MP%202015%20Annual%20Report-21-12-2016.pdf

Mitchell, Shira, Andrew Gelman, Rebecca Ross, Joyce Chen, Sehrish Bari, Uyen Kim Huynh, Matthew W. Harris et al. "The Millennium Villages Project: a retrospective, observational, endline evaluation." *The Lancet Global Health* 6, no. 5 (2018): e500-e513.

Nziguheba, Generose, Cheryl A. Palm, Tadesse Berhe, Glenn Denning, Ahmed Dicko, Omar
Diouf, Willy Diru et al. "The African green revolution: Results from the millennium villages project." In *Advances in agronomy*, vol. 109, pp. 75-115. Academic Press, 2010.

Olney, D.K., Bliznashka, L., Pedehombga, A., Dillon, A., Ruel, M.T., Heckert, J., 2016. A 2-year integrated agriculture and nutrition program targeted to mothers of young children in Burkina Faso reduces underweight among mothers and increases their empowerment: a cluster-randomized controlled trial. J. Nutr. 146, 1109–1117. http://dx.doi.org/10.3945/jn.115.224261.

Perez-Escamilla, R. (2017) Food Security and the 2015–2030 Sustainable Development Goals: From Human to Planetary Health, Department of Social and Behavioral Sciences and Global Health Concentration, Yale School of Public Health, New Haven, CT.

Perez-Escamilla, R. and Segall-Correa, A.M. (2008) Food insecurity measurement and indicators. Revista de Nutriçao, 21, 15–26.

"Potou, Senegal." Millennium Villages. Accessed September 10, 2018. http://millenniumvillages.org/the-villages/potou-senegal/.

"Senegal Census Data, 2013 - Senegal Data Portal." Senegal Data Portal. Accessed May 10, 2018. http://senegal.opendataforafrica.org/SNCD2015/senegal-census-data-2013?location=1000000-senegal&indicator=1000010-total-population.

Swindale, Anne, and Paula Bilinsky. "Household dietary diversity score (HDDS) for measurement of household food access: indicator guide." *Washington, DC: Food and Nutrition Technical Assistance Project, Academy for Educational Development* (2006).

The Economist Intelligence Unit. Fixing Food: towards a More Sustainable Food System (2016)

Trape, Jean-Francois, Evelyne Lefebvre-Zante, Fabrice Legros, Gora Ndiaye, Hilaire Bouganali, Pierre Druilhe, and Gerard Salem. "Vector density gradients and the epidemiology of urban malaria in Dakar, Senegal." *The American journal of tropical medicine and hygiene* 47, no. 2 (1992): 181-189.

Tsai, Alexander C., Bernard Kakuhikire, Rumbidzai Mushavi, Dagmar Vořechovská, Jessica M. Perkins, Amy Q. McDonough, and David R. Bangsberg. "Population-based study of intra-household gender differences in water insecurity: reliability and validity of a survey instrument for use in rural Uganda." *Journal of Water and Health* 14, no. 2 (2016): 280-292.

van den Bold, M., Dillon, A., Olney, D., Ouedraogo, M., Pedehombga, A., Quisumbing, A., 2015. Can integrated agriculture-nutrition programmes change gender norms on land and asset ownership? Evidence from Burkina Faso (IFPRI Discussion Paper 51). J. Dev. Stud. 1155–1174. http://dx.doi.org/10.1080/00220388.2015.1036036.

Wa'el A, Hussien, Fayyaz A. Memon, and Dragan A. Savic. "An integrated model to evaluate water-energy-food nexus at a household scale." *Environmental modelling & software* 93 (2017): 366-380.

"Water in Agriculture." World Bank. Accessed July 01, 2019. https://www.worldbank.org/en/topic/water-in-agriculture.

Water, U. N. "Status report on the application of integrated approaches to water resources management." *United Nations Environment Programme: Nairobi, Kenya* (2012).

"World Population Projected to Reach 9.8 Billion in 2050, and 11.2 Billion in 2100 | UN DESA
Department of Economic and Social Affairs." United Nations. Accessed July 01, 2019. https://www.un.org/development/desa/en/news/population/world-population-prospects-2017.html.

Wutich, Amber, and Kathleen Ragsdale. "Water insecurity and emotional distress: coping with supply, access, and seasonal variability of water in a Bolivian squatter settlement." *Social science & medicine* 67, no. 12 (2008): 2116-2125.

Zeitoun, Mark, Bruce Lankford, Tobias Krueger, Tim Forsyth, Richard Carter, Arjen Y. Hoekstra, Richard Taylor et al. "Reductionist and integrative research approaches to complex water security policy challenges." *Global Environmental Change* 39 (2016): 143-154.

Zepeda, Lydia, ed. *Agricultural investment and productivity in developing countries*. No. 148. Food & Agriculture Org., 2001.