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Parts Unmapped: Linear Multi-variate Analysis of Food, Water, and Temperature Requirements for Regional Stability

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INTRODUCTION: This Geospatial Research Laboratory (GRL) technical note (TN) explores the potential to forecast incidences of destabilizing violence based upon the availability of food, water resources, and temperature. The algorithm *Livability Index* will be used to measure these dynamics, as food, water, and temperature are the basic components of an ecosystem that can support human life. Food, energy, and water are at the core of human needs, and there are many complex relationships and interactions among these three elements. The elements are considered "the pillars on which global security, prosperity, and equity stand" (Hague 2010). Impacts of the loss of critical ecosystem services can be far-reaching, but certain impacts are more acutely felt, possibly leading to the destabilization of the population. Recent conflicts in Syria, Egypt, and the existence of large militant groups (i.e., ISIS and Boko Haram), have been driven into existence, in part, by the loss of water and food resources, thus, providing a controlling interest in the water and food that remain within a population (Gleick 2012; King 2015). The rate of change to these systems is expected to increase, with significant impacts to coupled human systems. To date, long term challenges resulting from loss of critical water infrastructure include employment reduction, loss of basic income and economic security, large scale migration, violence and famine, all existing within known conflict areas (Kloos et al. 2013). The military views climate change and human insecurity as *network threats*, similar to international terrorism. Understanding and assuaging network threats is especially difficult because community and regional characteristics determine the relative importance of each condition, driver, or mediating factor (Butzer 2012; Redclift and Grasso 2015).

In order to assess the potential for conflict based upon loss of food and water resources and identify regions that may jeopardize mission security, an accessible and versatile framework that can be applied to existing programmatic infrastructure was created.

Water. Water supports the ecosystems on which stable and productive societies exist (Mason and Calow 2012), but any form of water scarcity can become a significant security risk. Loss of water resources can occur from droughts, flooding, or unanticipated storm events, degrading basic living conditions and increasing vulnerability to resultant violence (Cook and Bakker 2012; Kloos et al. 2013). Even without the risk of climate variability, transferring water between drainage basins, particularly those with multinational governance and boundaries, can trigger conflict among users. As climate variability decreases water availability, inter-basin movement and transfers may increase, leading to conflict (Bogardi et al. 2012).

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By 2025, two-thirds of the global population will be living in areas that are experiencing water stress (United Nations Environment Program (UNEP) 2012). Agriculture, already the largest consumer of freshwater resources, will further stress water resources as it expands to feed growing populations.

Food. Water security is necessary to ensure food availability, which supports the functioning of civil society. Even without considering climate impacts and increased risks to global food systems (IPCC Working Group 1 2014), over 840 million people worldwide suffered from undernourishment, 100 million children under the age of five are underweight, and malnutrition is a cause of death for more than 2.5 million children every year (World Health Organization 2018; Willis et al. 2016). Additionally, global food production must double to meet the demands of the world population by 2050 (Chakraborty and Newton 2011). The growing risk to global food systems from climate driven disasters and loss of ecosystem resources was already a mounting concern at the 1996 World Food Summit, and has grown in the last twenty-plus years.

Temperature. An increase in the number of heat waves, including a decrease in frequency and an increase in the amount of precipitation per event, has been forecast by numerous climate models (IPCC Working Group 1 2014; Kloos et al. 2013). Extreme precipitation events significantly increase the chance of flood occurrence, in addition to increases in local humidity and wet bulb temperatures. In the Persian Gulf, temperatures have already exceeded the wet bulb temperature for the last two years, resulting in over 800 deaths in 2015 alone (Krajick 2017).

DATA AND METHODS: A warming climate will contribute to extremes in both precipitation and drought, leading to insecurity in water and food availability. A linear expression to quantify the interplay of factors impacted by cascading climate destabilization is described in Equation 1. The *Livability index* quantifies conflict indicators within food and water support systems.

$$\text{Livability Index} = \left(\frac{W_a}{W_I} * 70\right) + \left(\frac{F_a}{F_I} * 30\right) + (T_I - T_R) \tag{1}$$

Where W_a is the accessibility/availability of water and W_I is the ideal uptake of water per day per capita in liters (Gorchev and Ozolins 2011; World Health Organization 2013). For the Wa parameter, the baseline value for consumption and basic use recommended by the World Health Organization of 7.5 L/day is utilized (World Health Organization 2013). F_a is the accessibility/availability of food, and F_I is the ideal intake of food per day per capita in kilocalories. The recommended baseline calorie consumption is 2100 calories/day, this is the recommended consumption for men, (2400) and women (1800), averaged (USDA 2002). Due to the necessity for regular water intake for human survival, the water factor is weighted at 70%, with the weight for food a corresponding 30%. T_I is the maximum wet bulb temperature under which humans can perform normal activities outdoors for multiple hours, is baselined at 78 degrees Fahrenheit (DoA 2016). T_R is the corresponding real wet bulb temperature on the ground that incorporates both temperature and humidity. The resultant calculation provides a scaled understanding of the availability of necessary resources and temperature impact to identify regions of increased civilian stress or deployment strain.

To demonstrate the applicability of the livability index, the country of Jordan was selected as the first case study area. First-level administrative boundaries, called Governorates, provided ideal constrained geographic regions with available data provided by the Kingdom of Jordan (Ministry of Water and Irrigation 2015, 2016). Depending on data accessibility, the *Livability Index* can be calculated and applied to multiple spatial levels (e.g., state, province, county, census tract). For each of the twelve governorates of Jordan, the amounts of available water (W_a), food (F_a), and average summer temperature (June–September) (T_R) were identified.

A linear, multivariate model has been developed in ArcGIS's ArcMap ModelBuilder (Figure 1), allowing users to alter the geographical region of interest while keeping the same model framework. For this case study, a recent shapefile of the Jordan Governorates was retrieved from ArcGIS.com, water supply data were obtained from the Jordan Water Sector Facts and Figures (2013) report (Ministry of Water and Irrigation 2015). Water data was well above the minimum daily liters, so to standardize the data within the scope of the model, any values above 7.5 L/day were considered to meet 100% of daily water needs. Daily caloric intake averages for Jordan in 2013 were obtained from the Food and Agriculture Organization (FAO) of the United Nations (FAO 2011). Average monthly temperatures for June through September were downscaled from the 30-year running average, data provided by WeatherBase.[1] The WeatherBase program sources from the National Oceanic and Atmospheric Administration (NOAA) and local weather stations. Where temperature data was not available for a Governorate, the nearest-neighbor interpolation, utilizing temperature from surrounding Governorates to average local temperature was applied. The final step in temperature interpolation utilized zonal statistics to find the majority value average daily temperature for the Governorate. These data were added as attribute fields in the Governorates shapefile (Figure 2) and automatically integrated into the shapefile's attribute table. The linear framework outlined in ModelBuilder then performs the *Livability Index* expression calculation to arrive at the *Livability Index* score (Figure 2). The Jenks natural breaks classification method was selected to divide the *Livability Index* scores into three classes. A score of 100 indicates that the geographic region has the ideal quantities of food and water, and moderate temperature variations, necessary for sustainment. A score less than 100 indicates that the region does not have the ideal quantity of food, water, or livable temperature, with graduated amounts below 100 indicating the level of strain.

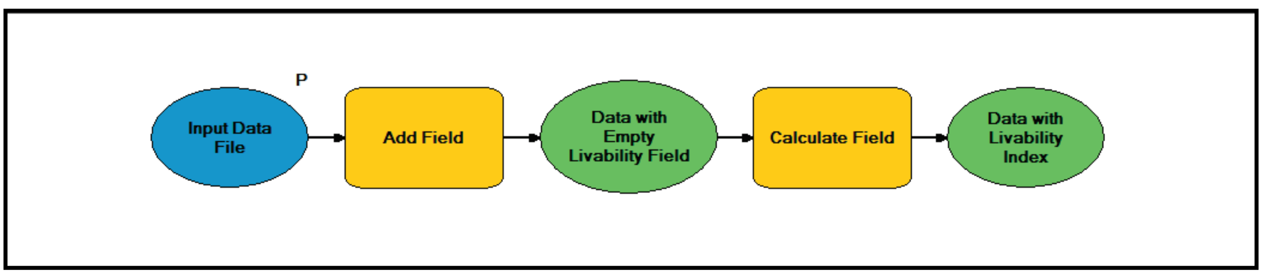

Figure 1. ModelBuilder layout with inputs demarcated by circles and Arc GIS automatic computational functions demarcated as squares.

[1] WeatherBase (https://www.weatherbase.com/weather/city.php3?c=JO&countryname=Jordan)).

FID	Shape *	NIC_NAME_	Pop_2014	Pop_km^2_14	Pop_Percen	Ho_beds_14	Refugees	H2O_L_Day	FoodCalDay	AvgTemp	Livability
0	Polygon	Aqaba	145500	21.1	2.2	263	3138	7.5	2100	87	91
8	Polygon	Balqa	447200	399.1	6.7	388	19963	7.5	2100	84	94
4	Polygon	Mafraq	313700	11.8	4.7	243	156564	7.5	2100	82	96
10	Polygon	Zarqa	994500	208.9	14.9	940	86196	7.5	2100	81	97
3	Polygon	Madaba	166900	177.6	2.5	188	10721	7.5	2100	80	98
7	Polygon	Ajloun	153500	365.8	2.3	130	8745	7.5	2100	80	98
2	Polygon	Ma'an	126900	3.9	1.9	203	7136	7.5	2100	78	100
5	Polygon	Jerash	200300	488.8	3	171	10247	7.5	2100	78	100
6	Polygon	Karak	260400	74.5	3.9	432	8633	7.5	2100	78	100
9	Polygon	Amman	2584600	341	38.7	6453	171787	7.5	2100	78	100
11	Polygon	Tafilah	93400	42.3	1.4	106	1554	7.5	2100	78	100
1	Polygon	Irbid	1188100	755.9	17.8	1959	139860	7.5	2100	76	102

Figure 2. Attribute table for Jordan Case Study model including Livability Index.

RESULTS: For this first case study, the Jordan Governorates presented a regional-scale application of the model utilizing the data records mentioned above as a proof of concept. The results of the calculation identified regions of resource depletion and strain on a 0–100 scale, illuminating potential priorities for conflict monitoring in a deployment situation. As shown in Figure 3, green denotes the governorates with the most access to resources and moderate temperatures, and orange denotes those with lowered access to resources, or increased temperature stress, quickly providing an idea of the potential resource-driven impacts on stability throughout the country of Jordan.

Utilizing the Jordanian Governorates *Livability Index*, an operationally relevant and timely case study as migration from Syria into the region was developed. Data regarding the per capita availability of food and water resources were difficult to obtain. The Kingdom of Jordan provides some resource-specific data at varying scales, but additional data management will need to be accomplished to downscale some variables to the local or per capita level. Though the country is surrounded by desert, conservation, reuse, and desalination plants are reported to have generated sufficient water for the current resident population (Carr et al. 2010; Center 2006). This important and surprising information is illuminated clearly by the livability model and is an example of real-world data that can be gathered from the regional mapping platform. Though the data for Jordan was accessible, it reflected minimal regional and per capita variability. In this case, the strong availability of food and water resources implemented by the Jordanian government makes temperature the constraining variable within the livability equation. It is likely that with other case studies, a single constraining variable may again be present, illustrating the need for deployed troops to focus on a mitigating or replenishing a specific resource for themselves or the civilian population. Increasing the flexibility of equation terms to incorporate data relating to food security or scarcity, as opposed to caloric intake, will allow for future applications in spare data regions. Next steps in refining and applying the model include expanding the datasets and creating new case studies, increasing the opportunity for variability within the terms based on available data, and creating a map overlay that can be exploited by existing Army applications.

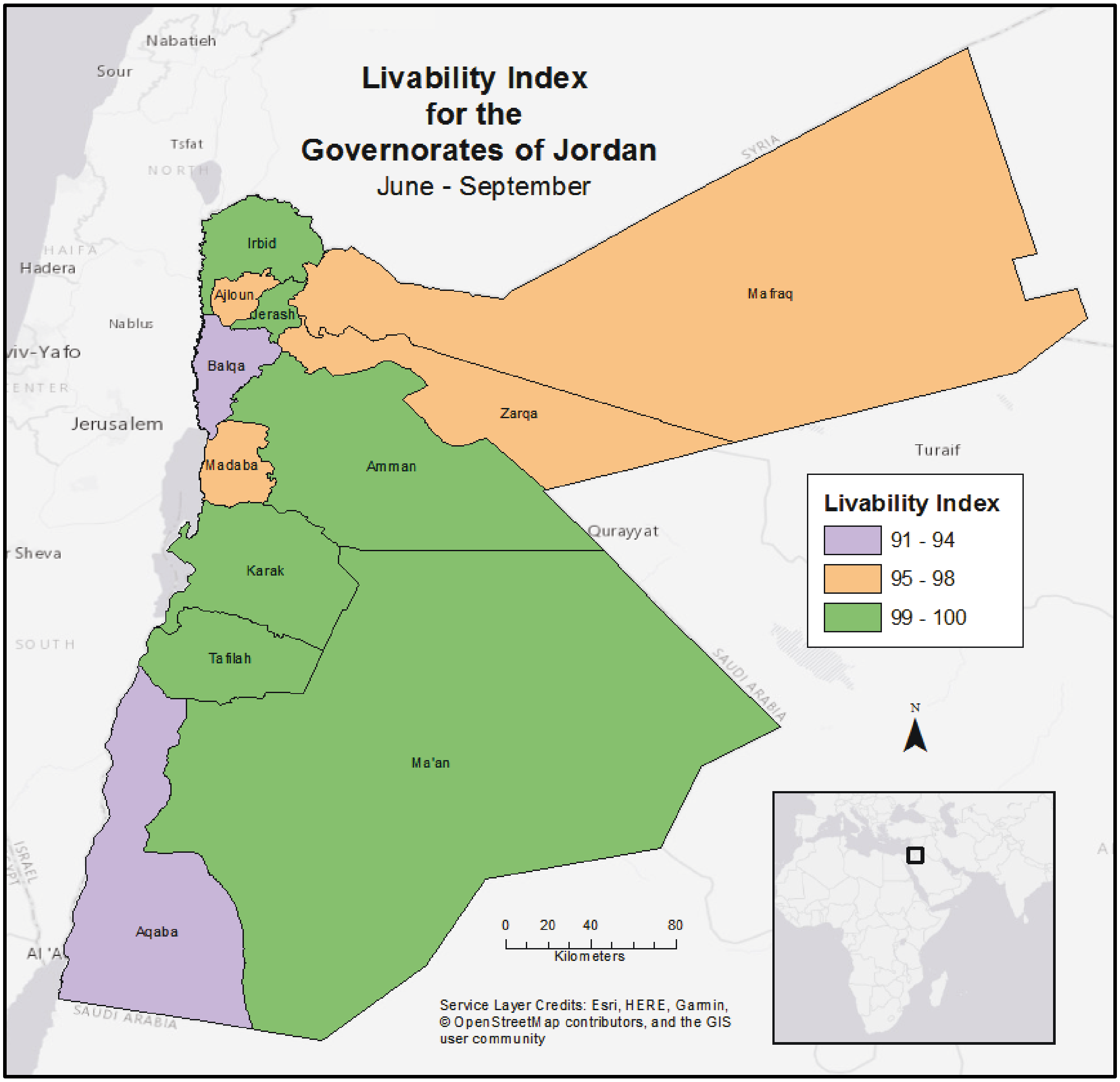

Figure 3. Livability Index map layer for Jordan Governorates.

SUMMARY: In the United States, universities, nongovernmental organizations, and federal agencies are actively collaborating to develop and apply food and water resource concepts to further national environmental and economic objectives. Numerous federal agencies have begun incorporating these concepts into land use planning, water resources management, and preparations for, and responses to, climate change (Schäfer and Schlichting 2014). This technical note presents the first proof-of-concept study utilizing food, water, and temperature to identify regions of potential conflict that can be used in tandem with current map-based GIS platforms. Moving forward, well-defined policy will be necessary to institutionalize ecosystem services approaches in federal agencies, including to guide multi-sector, interdisciplinary collaborative research and development efforts. To meet this goal, it is crucial to understand the interlinked impacts of climate variability that lead to human crises and the potential implications to national security.

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