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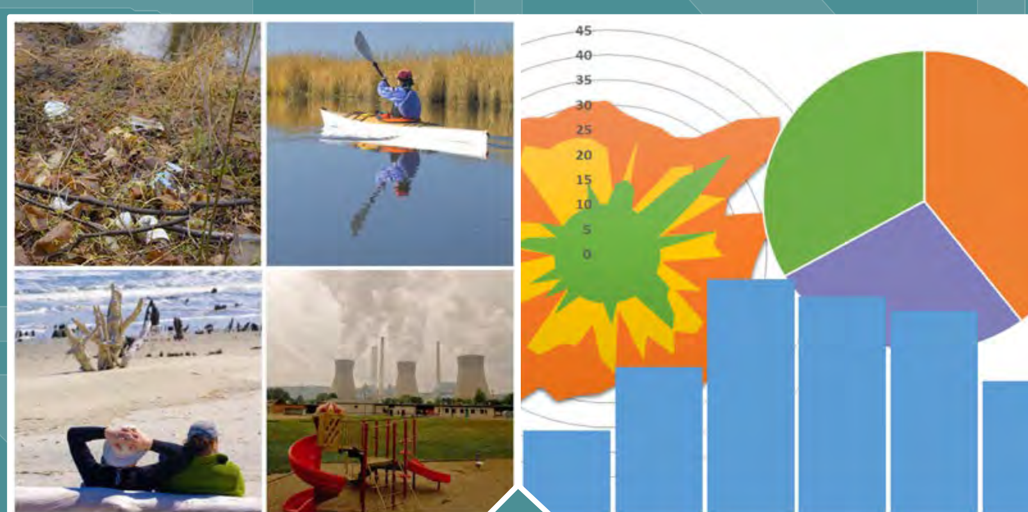
Modified HWBI Model(s) Linking Service Flows to Well-Being Endpoints:

Accounting for Environmental Quality



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NHEERL Gulf Ecology Division

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Modified HWBI Model(s) Linking Service Flows to Well-Being Endpoints:

Accounting for Environmental Quality

Technical Research Report

By

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Office of Research and Development

Notice/Disclaimer Statement

Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Health and Environmental Effects Research Laboratory (NHEERL) conducts systems-based, effects research needed to achieve sustainable health and well-being. Because they are inextricably linked, NHEERL's research encompasses both human and ecosystem health. To achieve research goals, the Laboratory research program focuses on:

- Leading innovative research and predictive modeling efforts that link environmental condition to the health and wellbeing of people and society.
- Advancing research and tools for achieving sustainable and resilient watersheds and water resources.
- Advancing systems-based research to predict the adverse effects of chemicals and other stressors across species and biological levels of organization through the development and quantification of adverse outcomes pathways across multiple scales.
- Using integrated research to identify and characterize modifiable factors that respond to environmental conditions, and through intervention, improve health and well-being.
- Translating and communicating integrated environmental and health effects science to impact decisions positively at all levels.

This report presents an approach to modify ORD's Human Well-Being Index (HWBI) relationship-function model to increase its utility. Using ORD's Environmental Quality Index (EQI), this research examines the potential for using existing indicator products in novel ways to add a new facet of interpretability regarding the linkages between socio-ecological systems and human health and well-being. The objective of this research is to demonstrate a way to combine existing composite indices for developing a new layer of information as an extended diagnostic of well-being conditions. Additionally, descriptions of population-specific HWBI adaptations are presented. These population adaptations could serve as future EQI-modified HWBI use cases.

William H. Benson, Director
National Health and Environmental Effects Research Laboratory

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Acronyms and Abbreviations

CLIM	Confidence Limits
EPA/USEPA	United States Environmental Protection Agency
EQI	Environmental Quality Index
HWBI	Human Well-Being Index
NHEERL	National Health and Environmental Effects Research Laboratory
OECD	Organisation for Economic Co-operation and Development
ORD	Office of Research and Development
PCA	Principle Components Analysis
ROE	Report on the Environment
SHC	SHC Sustainable and Healthy Research Program
U.S.	United States of America

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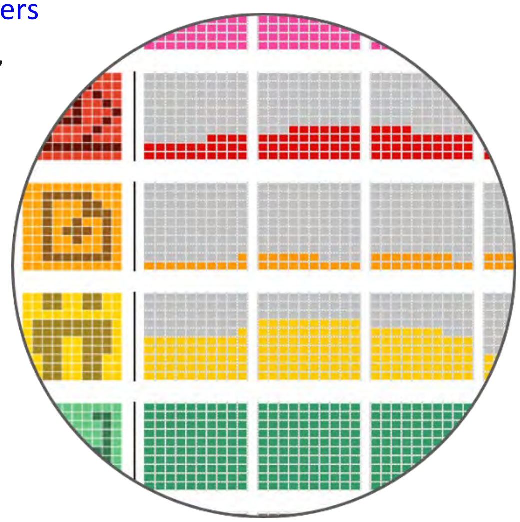
Executive Summary

The U.S. Environmental Protection Agency (EPA) Office of Research and Development's Sustainable and Healthy Communities Research Program developed the Human Well-being Index (HWBI) as an integrative measure of economic, social, and environmental contributions to well-being (Smith et al., 2014a) and the Environmental Quality Index (EQI) (Lobdell et al., 2014) as an estimate of overall environmental quality to improve our understanding of the relationship between environmental conditions and human health. The HWBI is composed of indicators and metrics representing eight domains of well-being: connection to nature, cultural fulfillment, education, health, leisure time, living standards, safety and security, and social cohesion. The domains and indicators in the HWBI were selected to provide a well-being framework that is broadly applicable to many different populations and communities (Smith et al., 2015; Buck et al., 2017; Orlando et al., 2017). Relationship function equations have been developed to link HWBI domains to the provisioning of ecosystem, social and economic services (Summers et al., 2016). The EQI uses indicators from the chemical, natural, built and social environment in the construct of five environmental domains: air, water, land, built and sociodemographic. EQI can be used as an indicator of ambient conditions/exposure in environmental health modeling and as a covariate to adjust for ambient conditions in environmental models. However, the EQI can be adapted for other uses by different end users. Both indices have been demonstrated for all U.S. counties.



This report describes an approach for modifying ORD's Human Well-Being Index (HWBI) to increase its utility by introducing a composite index developed independently of the HWBI effort. Using ORD's Environmental Quality Index (EQI), this research examines the potential for using existing indicator products in novel ways to add a new facet of interpretability regarding the linkages between socio-ecological systems and human health and well-being. This research demonstrates a way to combine existing composite indices for developing a new layer of information as an extended diagnostic of well-being conditions. HWBI adaptations and applications are also presented, highlighting population-specific HWBI research. These adaptations could serve as future EQI-modified HWBI use cases.

Analyses were completed to determine the statistical suitability of synthesizing the HWBI and EQI, to confirm variable independence and fit within the relationship-equation construct for the HWBI domain of health. A series of relationship-function equations were developed, linking aspects of the HWBI (domains) to select economic, ecosystem and social services (Summers et al., 2016). The EQI was introduced as a modifier within the HWBI health model structure which served as the conduit to affect an overall EQI-adjusted HWBI. A standard transformation of the modeled HWBI health values made combining the two indices relatively simple, requiring no further adjustments to either composite measure to accommodate the integration. Standardized HWBI health values were adjusted by the EQI directly then reconstituted to provide a score comparable to the remaining HWBI domains. An adjusted overall HWBI was calculated for each county to reflect the EQI modification.

Generally, the EQI-adjusted health domain showed little impact on the overall HWBI score. However, changes in the spatial patterns of modeled health scores were clearly delineated (Figure ES - 1). Results identified approximately 28% of U.S. county HWBI health scores exhibiting significant changes as a result of the EQI modification, both positive or negative (Figure ES - 2). These results suggest that the addition of the EQI as a modifying factor to the HWBI relationship-function equation for health provides an additional layer of diagnostics for understanding well-being.

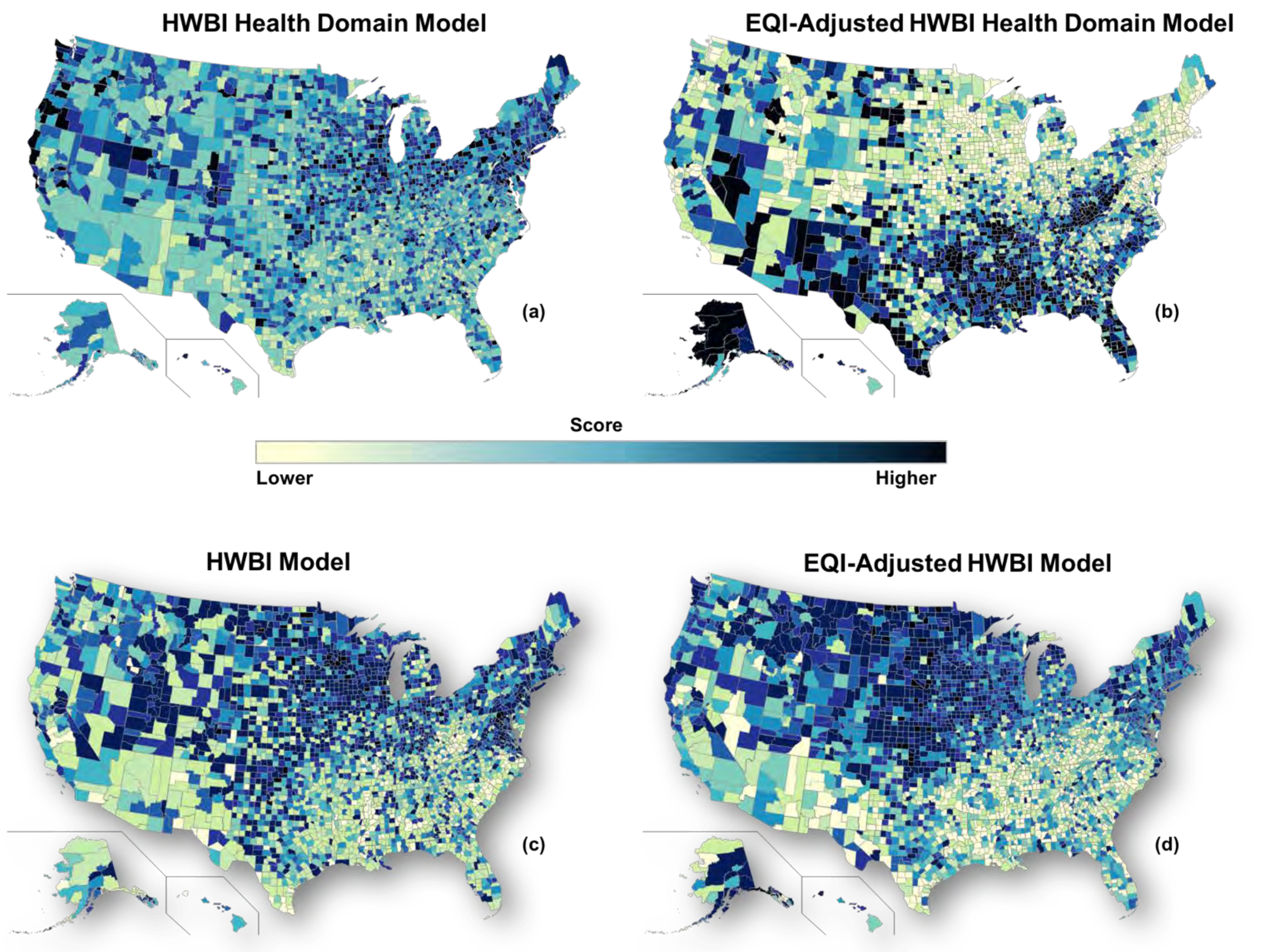


Figure ES - 1. Chloropleth maps representing un-modified and EQI-modified model scores for HWBI Health Domain (a-b) and Overall HWBI modeled scores (c-d).

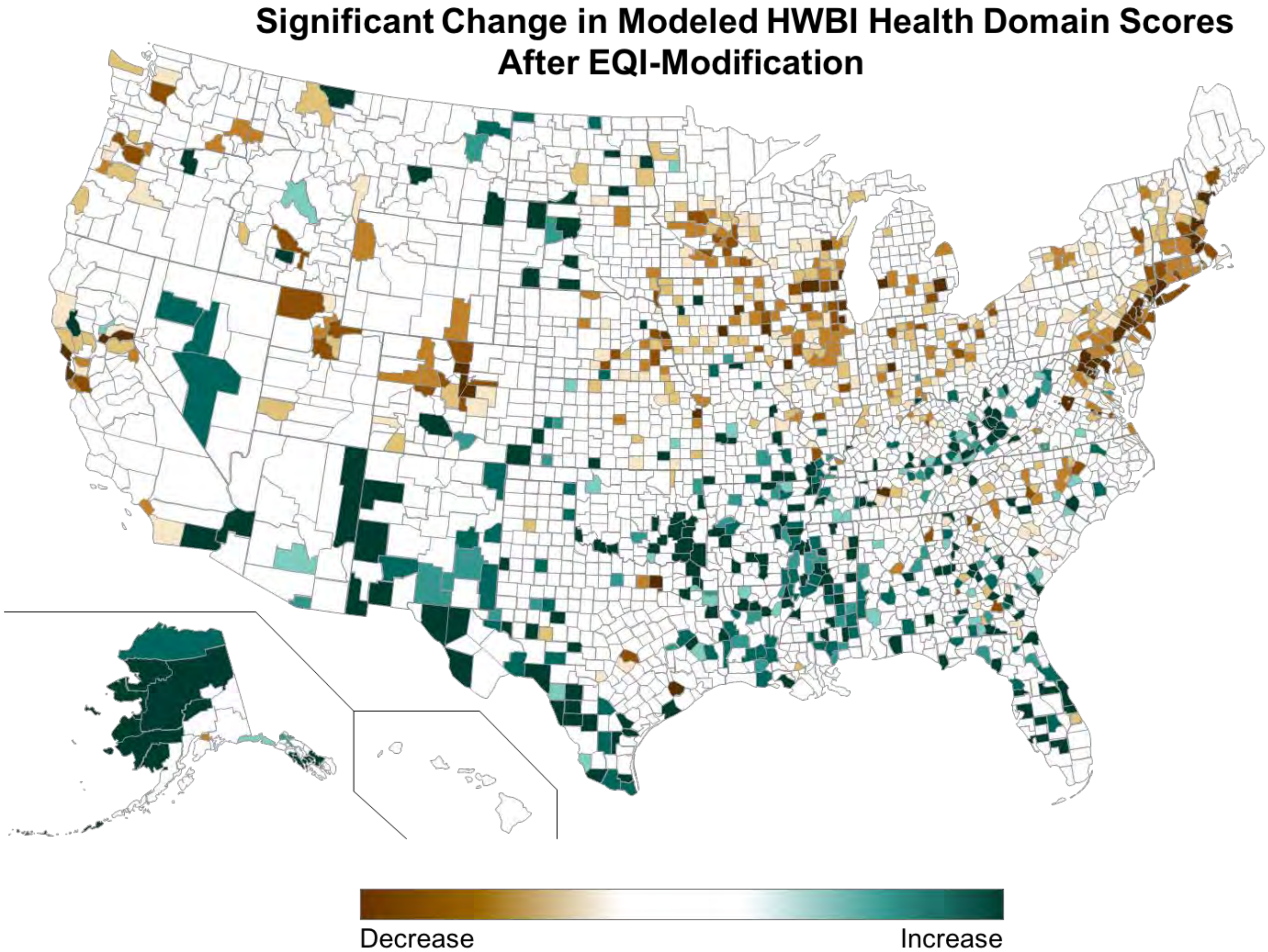


Figure ES - 2. Map depicting the degree and direction of significant change (95% CLIM) in HWBI health domain scores produced by EQI-modified relationship-function equations developed for the HWBI.

Additionally, the integration of the HWBI and EQI provides SHC with an empirical linkage between the confluence of multiple environmental quality measures and overall human health. This research contributes to EPA's Sustainable and Healthy Communities Research Program's (USEPA, 2015) objective of developing research, data, and tools to expand the capabilities of communities to consider the social, economic, and environmental impacts of decision alternatives on community well-being.

1

1.0 Introduction

Increasingly, the many valuable attributes that ecosystems provide are being recognized as important contributors to economic and social vitality. From creating jobs to building greener infrastructure, many considerations are needed to yield sustainable decision outcomes. As the needs and demands of a community change, it is often difficult for community stakeholders to consider environmental effects along with the economic and social impacts associated with development and improvement decisions, equitably. Sustainability has become a guiding principle in the pursuit of economic growth, environmental quality, and social equity across communities of all sizes. Sustainability, as a paradigm, requires finding ways for community stakeholders to assess and track it (USEPA, 2016).

Indicators offer one approach for providing meaningful sustainability measures to inform decision-making in federal, state and local governing sectors. Using indicators as a means of gauging various aspects of sustainability is a common practice, as evidenced by the plethora of published indicator efforts related to the subject (Smith et al., 2012 and 2013b).

Composite indicators, in particular, are gaining popularity as useful tools in policy analysis and public communication (USEPA, 2016). They offer simple and effective ways to describe complex, often abstract concepts across a wide-range of fields (e.g., ecology, sustainability, resilience, economy and society) (JRC, 2008). When well-constructed, composite indicators convey a synergistic message to help engage a broad spectrum of stakeholders in conversations that strengthen interpretation of indicator results.

For the United States (U.S.) Environmental Protection Agency (EPA), sustainability is one of four cross-organizational strategies which emphasizes: (1) advancing sustainability science, indicators, and tools and (2) using system-based approaches that account for linkages among different environmental systems (USEPA, 2014). One area of focus within EPA's Office of Research and Development (ORD) centers on providing data, methods, indicators, models, and tools that can be used to develop approaches for assessing aspects of community sustainability (USEPA, 2015). As part of ORD's Sustainable and Healthy Communities (SHC) Research Program, several research efforts identify and develop environmental indicators and indices to support these goals (Pickard et al., 2015; USEPA, 2008; Summers et al., 2017). Individually, indicators offer an interpretation of measures in a related scope or dimension (e.g., economics, living standards). Composite indices summarize indicators to describe a complete concept (e.g., sustainability, resilience, well-being, environmental quality), quantitatively or qualitatively. Composite indices provide context for related indicators and are typically more reflective of actual conditions associated with a concept. Additionally, constituent components of a composite index are structurally related. Categories are generally grouped together to represent a unique characteristic of the composite. The relational structure connecting indicators to an index allows for a

The Value of Composite Indices and Indicators

The power of composite indices and indicators is their ability to synthesize a large amount of information to characterize complex systems. They are multi-dimensional and independent of time and place—relevance is limited only by the availability of data.

The science of developing composite indicators and indices is rigorous. Many, sometimes hundreds, of candidate metrics represent the data foundation. At the heart of indicator research is the index framework. The framework is the roadmap for calculating an index, protecting its integrity and ensuring the reproducibility of the measures. Sensitivity, uncertainty and fidelity analyses are the proving grounds for the development approach.

From the literature review to indicator selection to calculation methods, the steps for creating an index are many. The results: composite measures that serve many roles—endpoint values, modifiers, mediators, interpreters and communicators.

deeper evaluation regarding the contributions of the various characteristics (as indicators) to composite measure (as an index) to help identify areas of potential action. Composite indices are gaining favor in community decision-making because they are easily understood by technical and non-technical audiences alike. However, these measures can be misinterpreted when viewed out of context. To be most effective, approaches that combine composite indices in meaningful ways are needed to provide more clarity for improved interpretation. However, it is critical that each index selected for integration have clearly defined purpose and development approach (JRC, 2008).

It is understood that observational data produce more precise statistical measures. However, assessing an abstract concept such as well-being, requires a large number of metrics. The trends, relationships and patterns produced by models and other statistical analyses can be lost when using a large volume of raw measurement data. In many fields, it is desirable to reduce data to include only those measures that explain the greatest proportion of observed variability. In community-focused research, measures can be sensitive to temporal and socioecological shifts on relatively small scales—what measures are not significant contributors today may be more significant tomorrow. An equally important consideration is the possibility that data reduction methods based on variance accounting alone may eliminate important indirect relationships that support community characteristics that people value (Summers et al., 2016).

Combining composite indices has the potential to produce more holistic information than a single index approach, whether a reduction or summarization calculation method is used. This practice is not new. Recognized composite indices such as the Gross National Income indicator (World Bank.org) and the Composite Leading Indicator (OECD, 2017), use at least one composite measure to inform the final index calculation. Although interpretation pitfalls exist, composite indicators and indices are still one of the more robust mechanisms for representing data to potentially influence policy (Booysen, 2002). Prospects for synthesizing composite measures to provide more contextual interpretations of the linkages across complex concepts is compelling, particularly for use in socio-ecological and sustainability fields.

The purpose of this report is to describe an approach to modify ORD’s Human Well-Being Index (HWBI), a holistic composite measure, to increase its utility by using another existing composite index, ORD’s Environmental Quality Index (EQI) (Lobdell et al., 2014). The main interest of this research was three-fold:

- Identify an approach to integrate composite measures that is simple and reproducible;
- Test the capability of the HWBI health model and overall HWBI to reflect directional changes when using EQI as a modifier; and
- Test for statistical significance should differences manifest.

The authors posit that the EQI, a composite index characterizing overall ambient environmental conditions, can effectively function as a qualifying variant within the HWBI framework to illustrate and quantify the impact of socio-ecological conditions on an indicator of overall human health and the broader measure of well-being. This report presents a brief description about the HWBI and EQI, the steps for composing a new measure from these indices and a demonstration of results. Additional published research efforts feature population-specific case studies that explore the relevance of the HWBI approach for characterizing the well-being of large tribal groups and children of the U.S. and the U.S. Commonwealth of Puerto Rico. Research highlights describing HWBI modification decisions and results for each study are available in Appendix A. These adaptations could serve as future demonstrations of the EQI-modified HWBI approach.

1.1 Intended Use

The information presented in this report represents a first-step approach intended for consideration in the development of decision-support and communication tools. The demonstration features a method for combining composite indices to introduce new topic or concept perspectives that may not be otherwise available. Demonstration results may be used as testing or baseline information for characterizing the potential influence of natural, built and socio-demographic environments on overall health and, by extension, well-being. Both the HWBI and EQI provide web-services to promote the use of these indices, related indicators and the HWBI relationship-function equations when developing mobile and desktop software applications.

2.0 The Human Well-Being Index

2.1 About the Index

Communities face multiple, often conflicting, decision priorities. Many of these priorities are abstract (e.g., sustainability, resilience) and frequently lack adequate measures to inform decision-making. To help fill this information gap, EPA developed the Human Well-being Index (HWBI) (Smith et al., 2012 and 2013a). The HWBI is an index that characterizes well-being based on metrics derived from existing cultural, economic, and social data. The index is a quantified score (0-100 scale), developed as an endpoint measure for characterizing well-being outcomes that are responsive to changes in the provisioning of economic, social and ecological services. The HWBI is part of a larger conceptual framework that serves as a roadmap for depicting the flow of a common core of community supplied services that influence the quality of people's lives (Smith et al., 2014a). The HWBI conceptual framework (Figure 1) is comprised of two groups of indicators, service and well-being, and a suite of indicator modifiers representing the linkages between services and aspects of human well-being, common across all communities (Smith et al., 2014b). A nested–indicator design guides the summarization of data to various aggregate levels until a final composite value is achieved for service categories, well-being domains and final index. Collectively, the HWBI framework and components describe an approach for calculating a holistic and quantified human well-being measure to inform policy decision-making.

COMPONENTS OF THE HUMAN WELL-BEING INDEX

An **INDEX** is an interpretable and synergistic value or category describing the nature, condition or trend of a multidimensional concept. An index can be an endpoint or final value as well as one of several values used to create what is called a composite index.

A **DOMAIN** represents a summary grouping of characteristics that is based on one or more indicators and represents a major component of a composite index. A domain and sub-index generally refer to the same level of information.

An **INDICATOR** is an interpretable value describing a trend or status for a specific feature or characteristic. An indicator may be comprised of one or more metrics.

A **METRIC** is a measurable or observable value – typically referred to as "the data".

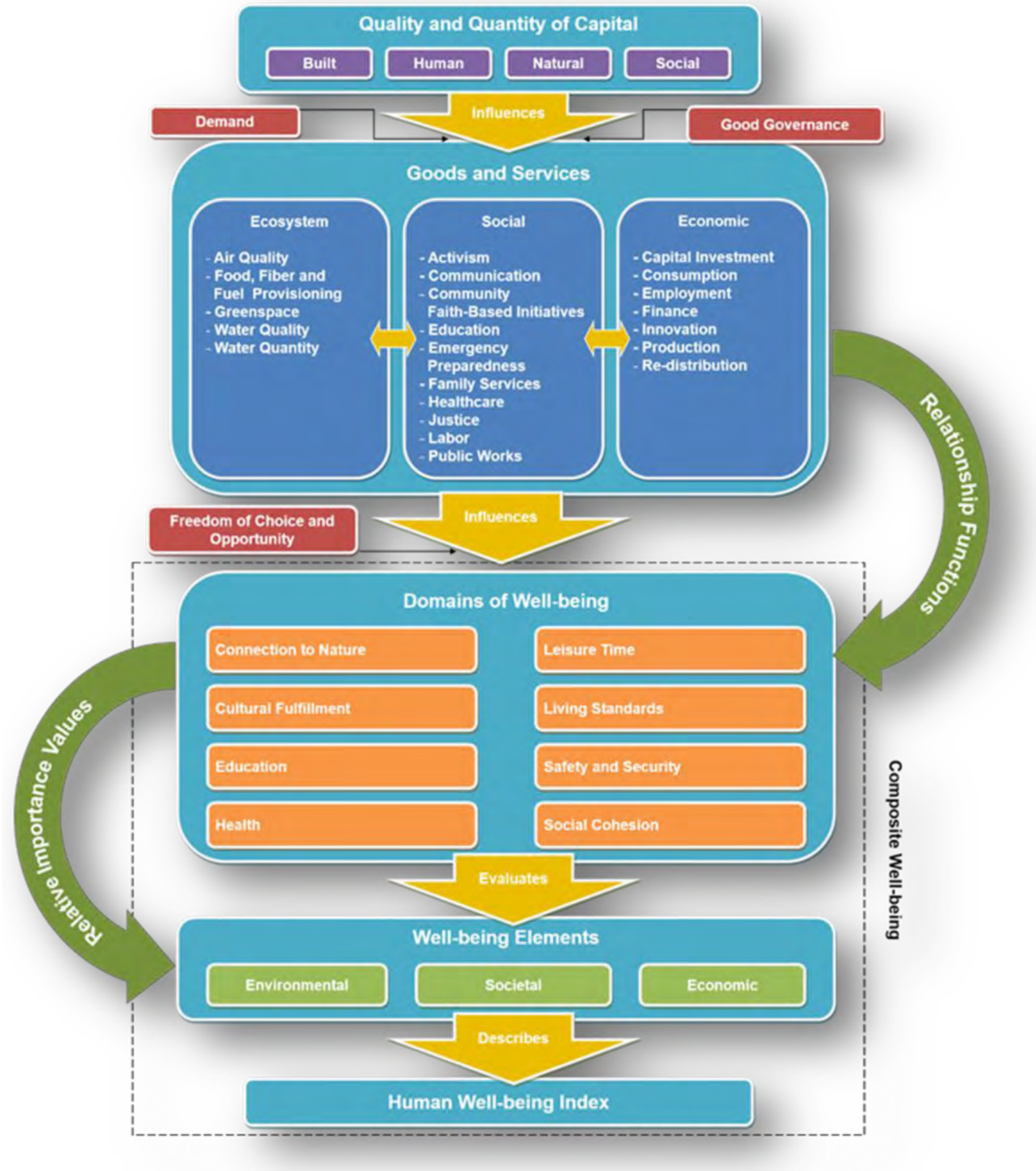


Figure 1. The Human Well-Being Index (HWBI) conceptual framework.

2.1.1 Measuring Well-Being: Domains

Domains are sub-indices that act as proxy measures representing various states of the human condition and quality of life (Table 1). Derived from indicators based on standardized data or metrics, these domain values are summarized to quantify overall well-being. The domains represent characteristics common across all communities that not only influence people's well-being, but are also tangibly sensitive to environmental change.

Smith et al. (2014b) describes the final approach for calculating the HWBI. There are four steps for calculating the HWBI:

- Indicator scores are calculated as population weighted averages of related standardized metric values.
- Domain scores are obtained by averaging indicator scores related to a specific domain.
- Relative importance values (RIVs) are optional factors that may be included in HWBI calculations to represent stakeholder priorities associated with well-being domains.
- The HWBI is calculated as the geometric mean of equally or unequally weighted domain scores.

Table 1. List of domain indices used to describe the HWBI.

Domain	Description
Connection to Nature	Describes how people feel about nature. It is measured by people's perception of nature and how it affects them.
Cultural Fulfillment	Describes people's cultural involvement. Measures include how often people participate in the arts and spiritual activities.
Education	Covers basic skills in reading, math and science. Measures of student safety and health are also included.
Health	Characterizes people's involvement in healthy behaviors, prevalence of illness, access to healthcare, mortality and life expectancy.
Leisure Time	Describes how time is spent including: employment, care for seniors and activities that people partake in for personal enjoyment. Measures represent work-life balance.
Living Standards	Contains information about lifestyles. It includes measures of basic necessities, wealth and income.
Safety and Security	Covers information about perceived safety, actual safety and potential for danger.
Social Cohesion	Describes people's connection to each other and their community through measures of involvement in family, civic engagement, and the community as a whole.

The HWBI structure allows for metric substitutions while holding the remaining parts of the framework constant. This design feature allows for the inclusion of data that more closely reflects characteristics in specific use case applications yet maintains the integrity of the index, allowing for comparisons of domain and index scores across various spatial, temporal and population scales. Smith et al. (2012 and 2013a) presents a thorough description regarding the HWBI conceptual framework, HWBI indicator selection and data sources.

Modifying the HWBI For Characterizing Well-Being in Native-American Populations

The publication, ***Evaluating the Transferability of a US Human Well-Being Index (HWBI) Framework to Native-American Populations*** (Smith et al., 2015), presents the applicability and integrity of the HWBI framework using metrics scaled to assess well-being for American Indian Alaska Native (AIAN) and large tribal populations. Potential modifications needed to produce reasonably defensible well-being assessments were identified and HWBIs were calculated for the AIAN population and large tribal groups for the time-period covering 2000–2010. Greater than 80% of the data available for a national AIAN assessment were specific to the target population, while the remaining data were derived from the general U.S. population. Despite the utilization of non-target data, the AIAN well-being signature could still be differentiated from the U.S. HWBI, indicating that the HWBI approach is transferable. As designed, the framework is intended to be used for a variety of spatial scales and demographic groups; however, the degree to which the structure can be utilized is dependent upon the availability and quantity of quality data.

See the complete research highlight (pg. 44).

2.1.2 Accounting for Community Priorities: Relative Importance Values

Well-being as a construct often reflects the collective perception of a population or community. The HWBI framework is designed to accommodate differing viewpoints about the relative importance of each of the eight domains. Externally supplied priority weighting factors can be applied across the domains before generating the final index. By weighting how domains contribute to well-being, the HWBI can better reflect community well-being priorities or values structure. This feature allows the index to show how a community perceives well-being in terms of possible magnitudes of change. Information describing the uses of RIVs and HWBI demonstration is available in Smith, et al. (2013b). Figure 2 provides an example of RIVs utilized in a real community case (Fulford, et al. 2015).

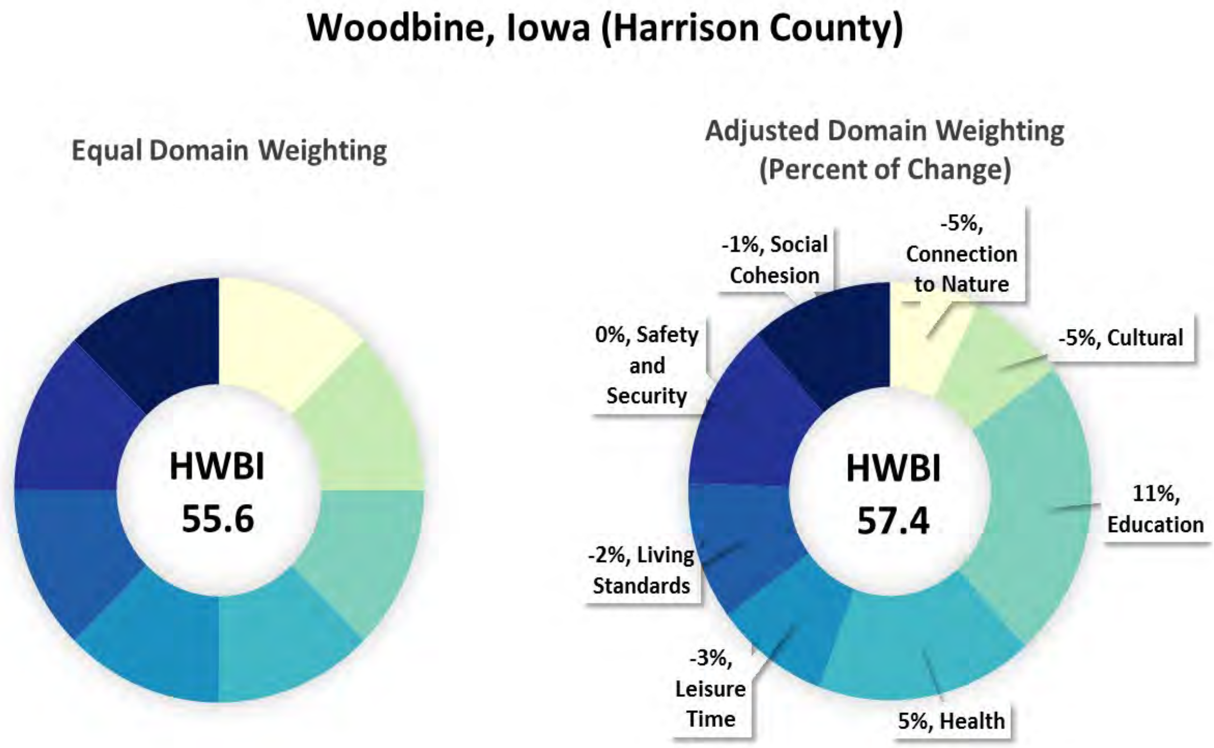


Figure 2. Illustration depicting the function of relative importance values (RIVs) within the HWBI framework. Community RIVs were contributed from Fulford, et. al., 2015.

2.1.3 Drivers of Well-Being: Services

Implementing a community decision typically requires a new investment or redistribution of available resources. The availability and flow of these resources serve many purposes in a community--everything from health to employment to clean water. This inventory of resources is often represented as economic, ecosystem and social services. Within the HWBI framework, twenty-two major service categories are used to demonstrate the relationships between ecosystem services and human well-being in the context of economic and social services (Table 2). Service indicators or categories are derived from population-weighted average metrics associated with each service and represent major endpoint service functions within communities (e.g. clean air, capital investment, access to healthcare. Details describing data sources, metric selection and indicator calculations are available in Smith, et. al., 2014b.

Table 2. List of service categories or indicators related to domains of the HWBI.

Service Group	Service Indicator	Description
Economic Services	Capital Investment	Expenditures and Activities to create new capital or to maintain the existing capital stock
	Consumption	Personal consumption of both market and non-market goods and services that directly increase utility or well-being
	Employment	Labor deployed in the production of goods and services
	Finance	Movements of financial assets and liabilities to facilitate exchange
	Innovation	Enhancing the diversity, type or quality of goods and services
	Production	Output of both market and non-market goods and services provided by business, government and households
	Redistribution	Activities undertaken to more evenly distribute wealth in society
Ecosystem Services	Air Quality	Services that remove air pollutants and control temperature
	Food, Fiber and Fuel Provisioning	Services that provide food, fiber and raw materials for energy and other uses
	Greenspace	Natural areas that allow for recreation and aesthetics (including aquatic spaces)
	Water Quality	Services that remove pollutants that enter waterways
	Water Quantity	Services that produce, preserve and renew water resources

Service Group	Service Indicator	Description (Continued)
Social Services	Activism	Services provided by individuals or groups acting to bring about social, political, economic or environmental change
	Communication	Delivery of information to promote public awareness
	Community and Faith-Based Initiatives	Spiritual and civic outreach and activities that promote the betterment of a community
	Education	Services provided to improve learning experiences and to allow for equitable educational opportunities
	Emergency Preparedness	Protective services that reduce the impact and effects of a disaster on the human population
	Family Services	Services and programs to improve household environments
	Healthcare	Goods and services that help restore or maintain individual physical and psychological health
	Justice	Services which provide ways to maintain moral rightness and penalize violators
	Labor	Law and regulations that promote fair wage practices and employment opportunities
	Public Works	Services that provide basic utilities, mass transportation, and public recreational facilities

2.1.4 Relationship-Function Equations

The intended use of the HWBI is in the development of decision-support tools. Community, policy and similar decision-making activities often require choices that change natural, built and social environments. The implementation of decision options manifests in alterations in the availability of economic, ecological and social services. To understand how these changes may influence well-being, the service indicators were created to help define relationships. Summers et al. (2016) describes the quantification of influence introduced to aspects of overall human well-being that may result from direct and indirect relationships to selected community-centric services. The approach uses multivariate relationship functions to illustrate likely positive or negative impacts on future well-being as a results of decision scenarios that disrupt the flow or inventory of select services.

The relationship-function equations are used to evaluate inherent connections between well-being and the quality and quantity of selected goods and services (Summers et al., 2014; Smith et al., 2014a). Drawing from similar approaches for developing economic and ecological production functions (Bruins et al., 2012), the HWBI relationship-function model produces forecasted direction of change in the domains related to human well-being. The functional relationship equations for each domain were determined based on results stemming from a step-wise regression process to identify main effects and primary pair-wise interactions among select economic, environmental and social service indicators quantified as scores on a 0-100 scale. A brief discussion of this stepwise method follows:

- The method used regression models to identify predictive variables based on adjusted R2 and sequenced F-tests. The initial model begins with no variables selected and candidate model variables are evaluated on a pairwise basis including those parameters already selected.
- The f-statistic significance level was the primary determinate for inclusion or exclusion in the model. After each pass in the stepwise process, the model was refitted with the held variables.
- Entry and exit criteria used for keeping or eliminating effects were based on f-value significance levels of 0.15 and 0.10, respectively.
- Main effect and two-way interaction terms selected during the step-wise process that exhibited partial R2 ≥ 0.02 were reviewed for inclusion in the final model.
- Using results from the review of the stepwise selections, a final, multivariate model was created for each well-being domain by incorporating constructed (fixed) main effects plus interaction terms identified as significantly improving the explanatory capability of the model.

For each domain, a generalized relationship function equation is as follows:

$$HW_d = ƒ(S_e, S_s, S_{ec}))$$

where a human well-being domain (HW_d) is estimated as a function (ƒ) of the combined effects of economic (S_e), social (S_s), and ecosystem (S_{ec}) services. The final HWBI can be calculated from these individual domain coefficients to present a predicted index score. The primary objective of the HWBI relationship-function equations is to demonstrate the responsive nature of the HWBI to changes in services as well as simplifying the integration of HWBI concepts and components in decision-support tools (Ignatius et al., 2016; Harwell, 2017). Complete details describing relationship-function equation development methods and demonstration results are available in Summers et al., 2016.

3.0 Modifying the HWBI: The Environmental Quality Index

Data selection, standardization methods and overall intent are decisions that dictate the viewpoint of indicators and indices. This perspective or presentation of composite measures can exacerbate the potential for misinterpretation or over-simplification of meaning (Booysen, 2002; JRC, 2008). While no single summary measure can address all possible caveats, combining composite measures can further reinforce the intended interpretation of results by accounting for effects that were originally outside the parameters of the original index. For this demonstration, a composite index qualifier was chosen to modify the HWBI relationship-function equations as a way to test the adaptability of HWBI models as well as create a new integrated measure.

The Environmental Quality Index (EQI) was developed to address a limitation inherent in current methods in environmental health research, which tend to focus on a single adverse environmental exposure at time. Well-designed environmental health studies are expensive and time consuming to conduct. This often manifests in a research trade-off dilemma—either engage only a few participants to collect high resolution data or collect data from a larger number of participants at the expense of detail. This trade-off makes it difficult to account for the plethora of co-occurring environmental conditions to which study participants may be exposed in addition to the main exposures of interest. Based on a well-defined framework, the EQI represents a more holistic way to account for overall environmental quality to inform human health and environmental effects studies. The following sections briefly describe the approach associated with calculating the EQI (Messer, 2014; Lobdell, 2014).

3.1 Characterizing Environmental Quality: Domains

The EQI is described by domains representing five environmental dimensions: air, land, water, built and socio-demographic. EPA's *Report on the Environment* (USEPA, 2008) served as the starting point for domain identification. Domain identification was further bolstered by expert consultation and a literature review on environmental exposures and adverse health outcomes. Collectively, these domains represent an overall measure of ambient environmental exposure conditions. Domain variables, or constructs, were identified to describe individual domains. These constructs provided the organizational structure for summarizing and standardizing metrics or data used to quantify the EQI. Table 3 provides a brief description of the EQI domains, attendant constructs and the primary environment-to-human health impact association.

Table 3. List of domain specific indices used to describe the EQI.

Domain	Description
Air	The air domain represents the ambient air environment. Two traditional air pollutant constructs were considered: (1) criteria air pollutants and (2) hazardous air pollutants (HAPs). Health effects linked to air pollutants include death, cancer, heart disease, respiratory disease, birth outcomes, and neurologic disorders.

Domain	Description (Continued)
Land	Represents the physical environment not covered by air or water. Five constructs were considered to represent land environmental quality: (1) agricultural environment, (2) pesticides, (3) facilities, (4) soil contaminants, and (5) radon potential. Health effects linked to land constructs include cancer, birth outcomes, birth defects, and asthma.
Water	Represents the overall water environment. Seven constructs were considered to represent water quality: (1) overall water quality, (2) general water contamination, (3) recreational water quality, (4) domestic use, (5) atmospheric deposition, (6) drought, and (7) chemical contamination. Several studies have demonstrated the association between water contaminants and pathogens and health outcomes.
Built	Contains five constructs: (1) traffic-related environment, (2) transit participation and access, (3) pedestrian safety, (4) the various business environments (such as the food, recreation, health care, and educational environments), and (5) public housing. Each of these constructs has both direct and indirect influences human health including behavioral, physiological and psychological factors.
Socio-demographic	Considers the association between socio-demographics and a broad range of human health factors which are grouped (1) socio-economic and (2) crime constructs.

3.2 Calculating the EQI

Using data from relevant existing sources, principle component analyses (PCA) were used to determine the weighting factors of metrics used to calculate the domain-specific indices and final the EQI. PCA, as a tool for indicator development, is well established in the literature (JRC, 2008; Singh et al., 2009). For the EQI, the data acquired spanned multiple years for all counties and hundreds of individual measures (e.g. air pollutants, water and land contaminants, demographics, crime statistics). Each data point was standardized to reflect the appropriate population and spatial area adjustments. The volume of metrics used to inform the construction of the EQI necessitated the use of robust methods for identifying the best information for creating variable constructs (Figure 3).

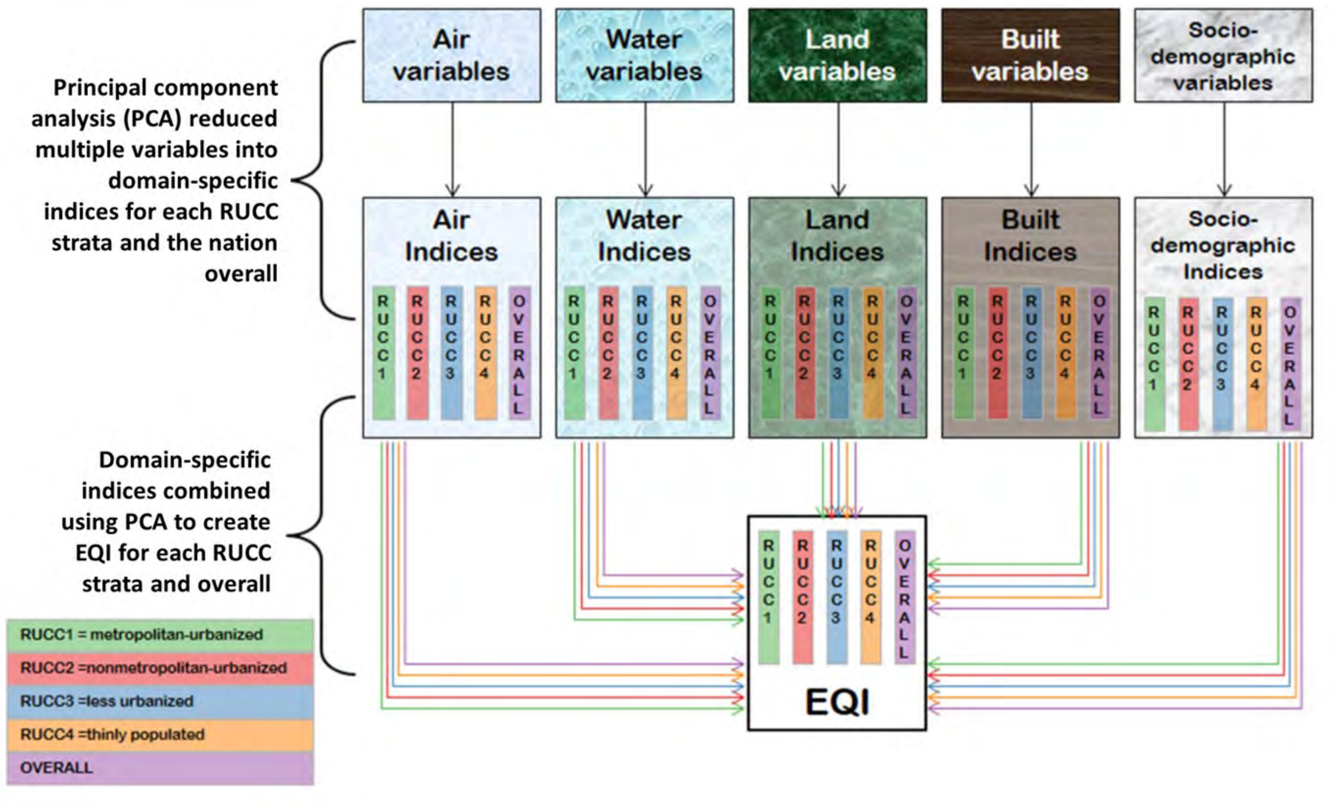


Figure 3. Principal component analysis concept for Environmental Quality Index. Analyses performed for all counties and each rural-urban continuum code (RUCC).

Domain variable constructs were identified based on the first principle component, representing the greatest accounting of the total variability in component measures. Individual variable loadings resulting from the analyses provided the variance "contribution" of each variable within a domain. The loading factor associated with each variable was multiplied by the variable mean across spatial and temporal units. Once quantified, variable constructs were summed to produce a domain-specific county-level dataset (e.g., air, land, water, built and socio-demographic). Each summed domain value was divided by the square of the PCA eigenvalue to re-scale the value on a zero-point mean distribution to create the final domain-specific index.

Each domain-specific index was subsequently included in a second PCA procedure, from which the first principal component served as the basis for the last step in the EQI calculation. Pearson's product moment correlations were used to eliminate dependent relationships within and between indices and other county-level variables based on a 0.7 cut-off threshold. The complete process, from PCAs to correlation analyses, was completed for the Nation overall and four stratified national populations based on summarized Rural-Urban Continuum Codes (USDA, 2003) groups (Table 4). The results from these activities produced two different suites of county-scale EQI measures for evaluating health outcomes. Several health studies, featuring the EQI as an independent measure of ambient conditions/exposures or as a covariate to account for ambient conditions in environmental public health models, have been published (Jagai et al., 2015; Rappazzo et al., 2015; Grabich et al., 2015). More complete details about the EQI development methods are described in (Lobdell et al., 2014).

Table 4. Rural-urban continuum code (RUCC) groups used for stratified calculations of the EQI.

RUCC Group	Description
RUCC1	Metropolitan urbanized
RUCC2	Non-metro urbanized
RUCC3	Less urbanized
RUCC4	Thinly populated

Adapting the HWBI for Use Outside the Fifty U.S. States

The publication, ***Technical Guidance for Constructing a Human Well-Being Index (HWBI): A Puerto Rico Example*** (Orlando et al., 2017), describes an approach used to adapt the US Human Well-Being Index (HWBI) to quantify human well-being for US Commonwealth of Puerto Rico. As a territory of the U.S., Puerto Rico operates simultaneously as a state-equivalent and as an independent entity. As a culturally distinct and geographically isolated population, Puerto Rico presented a unique opportunity for an HWBI application (HWBI-PR). Metric substitutions, data selection and calculated HWBI-PR measures were compared to U.S. mainland values to evaluate differences. Additionally, the published adaptation of the HWBI for Puerto Rico provides an example of how the HWBI can be adapted to different communities and technical guidance on processing data and calculating index using R.

See the complete research highlight (pg. 47).

4.0 A Case for Integrating Composite Indices

The HWBI, as an endpoint measure, is generally accepted as a robust composite measure and has informed research in fields such as ecological economics (Costanza et al., 2014; Kubiszewski, 2013), environmental policy (Breslow et al., 2016) and public health (Jennings et al., 2016). The index is reflective of a dynamic and multi-faceted environment in terms of people and environmental changes that affect their lives. HWBI demonstration results can serve as a foundation in the development of decision-support tools (Harwell, 2017). Although highly generalized in nature, the quantified relationship-function model makes the HWBI truly portable (Ignatius et al., 2016) and unique among other ORD indicator efforts. The relationship-function equations extend the life of the HWBI beyond its demonstration roots to instill new thoughts and discussions about promoting sustainable decision outcomes. The integration of the EQI potentially adds another layer of dimensionality to the modeled HWBI output. Conceptually, the introduction of an external factor to the HWBI framework introduces conditions not captured in the economic, ecological and social inputs that drive the HWBI relationship-function model. The combined effect of both indices as factors in the HWBI model could strengthen interpretation of results that paint a more complete characterization of well-being. Approaches used to quantify and calculate the two indices were similarly robust, making the HWBI and EQI good candidate indices for synthesis. Table 5 highlights the strategies or activities used for constructing the HWBI and EQI compared with the ten development considerations recommended by the Joint Research Centre-European Commission (2008):

Table 5. Comparison of the HWBI and EQI development approaches and the list of steps for creating a composite index outlined in "Handbook on constructing composite indicators: Methodology and user guide" (JRC, 2008).

Recommended Step	HWBI/EQI Activity	Variant
Develop theoretical framework	Frameworks served as roadmaps for identifying and quantifying indicators and indices.	
Select Data	Metrics and data were selected based on analytical soundness, measurability, spatial coverage, relevance and relationship to each other. Proxy measures were used when data were sparse.	
Impute Missing Data	Temporal and spatial imputation methods (e.g. spatial hierarchy, single pass forward temporal imputation, spatial interpolation) were used to fill data gaps.	The HWBI winsorized extreme outliers (4x standard deviation of interquartile range).

Recommended Step	HWBI/EQI Activity	Variant (Continued)
Perform Multivariate Analysis	For the HWBI, Cronbach's *a* and logistic, quantile and logistic regression analyses were conducted.	
Normalize	Data were standardize using the appropriate population or spatial stands. All data were normalized to create normal distribution metric base for indicators.	The HWBI used a minimum value/maximum value normalization method. The EQI domain variables were normalized to reflect a 0-mean and 1 standard deviation.
Weight and aggregate	Data were aggregated based on framework design.	The EQI used a PCA-based calculation method with loading factors as weights. The HWBI used a mean summary approach with equally weighted measures. The HWBI framework does allows for external weighting contribution (e.g., RIVs).
Determine robustness and sensitivity	For the HWBI, Monte-Carlo uncertainty and sensitivity analysis were completed to identify structural and precision strengths and weaknesses of the index	
Promote transparency	Final indices can be decomposed into contributing components	
Establish linkages	Both HWBI and EQI established linkages to highlight the relevancy and value of composite indices using a variety of methods	Fidelity and response analyses were conducted using the HWBI.
Visualize and/or Present Results	Both indices represent "characterizing" measures. HWBI and EQI are generally presented as spatial distributions (e.g. maps) or synoptic summaries such as column and pie charts or aster plots.	HWBI results are used in decision-support tools. Results are offered in dashboard format accompanied by information to put results in context.

The HWBI and EQI differ in the details of the conceptual frameworks. The HWBI and service categories represent two ends of a responsive framework design connected by statistical linkages. Based on "means-ends" heuristics (Newel and Simon, 1972; Hoppe, 2017), the HWBI framework casts services as the *means* by which change is introduced to improve or sustain aspects of well-being while the HWBI domains are the response measures or *ends* that reflect that change. The generalized relationship-function equations are constant and serve as the conduit between the two sets of measures. Indicators were chosen and sequestered as either services- or HWBI-related based on the nature of the data—influencer or responder. All values within the HWBI framework are normalized scores ranging from 0-100 that suggest better conditions when scores increase. Measures such as the HWBI tend to be easy to interpret and reproduce, making it highly suitable as an endpoint.

Where HWBI distinguishes between means and ends indicators, the EQI does not. The EQI aims to collectively represent the totality of known environmental stressors on human health. Indicators (domain variables) are organized into representative environmental dimensions to inform domain-specific and subsequent EQI calculations. EQI and associated domains values are distance-from-mean zero scores, scaled from zero to positive or negative infinity rather than 0-100. Since the EQI is a descriptor for the potential "risk" of environmental exposures, the descending sequence of scores represent increasingly better environmental conditions (less adverse exposure risk) that is inversely related to the HWBI. As a modifying value, the EQI is well-suited.

Modifying the HWBI to Characterize Children's Well-Being for the U.S.

The publication, ***Application of the Human Well-Being Index to Sensitive Population Divisions: A Children's Well-Being Index Development*** (Buck et al., 2017), presents an adaption of the HWBI for child populations to test the applicability of the index framework to specific community enclaves. First, an extensive literature review was completed to ensure the theoretical integrity of metric and indicator substitutions from the original HWBI framework. Metric data were then collected, refined, imputed where necessary and evaluated to confirm temporal and spatial availability. Using the same domains and contextually similar indicators as the original HWBI, a Children's Well-Being Index (CWBI) was calculated for the population under age 18 across all US counties for 2011. Implications of this research point to an effective, holistic and nationally consistent well-being measure for a specific population that can be tracked over time. Similarly, there is great potential for the application of the original HWBI method to other statistical population segments within the greater US population. These adaptations could help identify and close gaps in equity of resource distribution among these groups.

See the complete research highlight (pg. 51).

5.0 Approach

For this effort, both the HWBI and EQI were treated as "found" research—HWBI research supplied the service measures and relationship-function equations while the EQI results were treated as HWBI model modifiers. The relationship models for the eight HWBI domains were trained and tested using 11 years of summarized economic, social and ecosystem data and HWBI domain values (2000-2010). The EQI was derived from a weighted aggregate of pollutant, chemical, built, socio-demographic and other similar data covering the years 2000-2005. National-scale county and county-equivalent indicators were chosen as the common spatial unit for this demonstration. For the purposes of this report, the term "county" encompasses jurisdictional areas labeled county, parish or borough.

5.1 HWBI Relationship-Function Suitability and Statistical Independence of EQI

Since the HWBI relationship-function equations were originally developed using state-level indicators, observed values were fitted to model outputs to examine fit. Determination of fit was used to test suitability based on 95% confidence limits and relative percent difference estimates. Correlation and regression analyses were conducted to confirm variable independence between the EQI and the relationship-equation constructs for HWBI domain of health and overall composite index. A complete listing of all HWBI relationship-function equations are available in Appendix B.

5.2 EQI-Modified HWBI Health Domain and HWBI Calculation Method

The EQI is intended to be used as an explanatory variable in human health studies which is a characteristic more closely aligned with the HBWI service indicators. Since the objective was to introduce an HWBI modification using the relationship-function equations, the EQI was used as an adjustment factor applied to the predicted values produced from the HWBI health domain model. While several methods of EQI-integration were considered (i.e., ordinal regression and multi-level modeling using EQI as a covariate), simplicity was the final determinant of the approach selected. While other options may have offered more statistically robust solutions, an easy to understand and straightforward method will help facilitate the use of research approach on a broader scale. The EQI-modification described here required the least manipulation of the existing measures while maintaining the original intent of both indices. The HWBI modeled health domain was modified using the EQI in the following manner:

- The HWBI health score estimates stemming from the relationship equations were z-score transformed to standardized modeled output to the EQI scale (zero-mean center point).
- The EQI was subtracted from the transformed health score estimates without further transformations or modifications. Because the EQI is an inverted scale, subtraction increased a health domain z-score when the characterization of environmental conditions indicated less potential for adverse human exposures and decreased it when greater.
- The adjusted health z-scores were reverse calculated--new health value = mean of population

of original health score + (z-score * standard deviation--to provide a score comparable to the remaining HWBI domains.

- Adjusted overall HWBI values re-calculated to reflect the adjusted health domains score—geometric mean of the 7 original HWBI domain scores and new EQI-adjusted health domain value.

Where HWBI results are provided, the scores were derived using the domain value estimates from each of the HWBI services-to-domain relationship-function equations. This step ensured comparability (model output to modified model output). For this effort, HWBI domains were weighted equally to more effectively account for any differences in modeled outputs as result of the EQI modification.

5.4 Significance Testing

Patterns of significant differences between original modeled output and EQI modified outputs were identified using 95% confidence limits of new health domain measures. Z-tests were run to evaluate mean differences among original and modified health domains and HWBI.

5.5 Limitations

Error is inherent in both empirical and calculated measurements. Secondary-data were used to calculate the HWBI and EQI. Although this means most error would have been introduced from sources that are outside of our control, steps were taken to maximize the quality of the indicators produced by these research efforts. Data management strategies, data review processes, standardization and imputation methods, and model validation were some of the ways quality was maintained for HWBI and EQI indicators used this research.

The relationship-function equations used to model the health domain and the HWBI represent a generalized characterization of the directionality of change in HWBI measures (e.g. increasing or decreasing) with an overall 95% level of confidence. The model equations were not adjusted to account for the addition of the EQI as a modifier. The intent of this research was to use an existing suite of composite measures "as is" and to determine if the HWBI framework and relationship function-equations were capable of handling modifications without extensive enhancements or overhaul.

6.0 Results with Discussion

6.1 Test of Assumptions

It was important to establish that the relationship-function equations adequately represented observed measures for the HWBI and health domain endpoints at county-scale. Collectively, the weight of evidence from the following evaluations indicated a reasonable confidence in using the EQI and HWBI for this research effort. A scatter plot of observed health and HWBI values over modeled values showed good fit using 95% confidence limits (Figures 4 and 5). Observed values that fell outside the confidence limits for model health and HWBI scores were 25.4% and 14.0%, respectively.

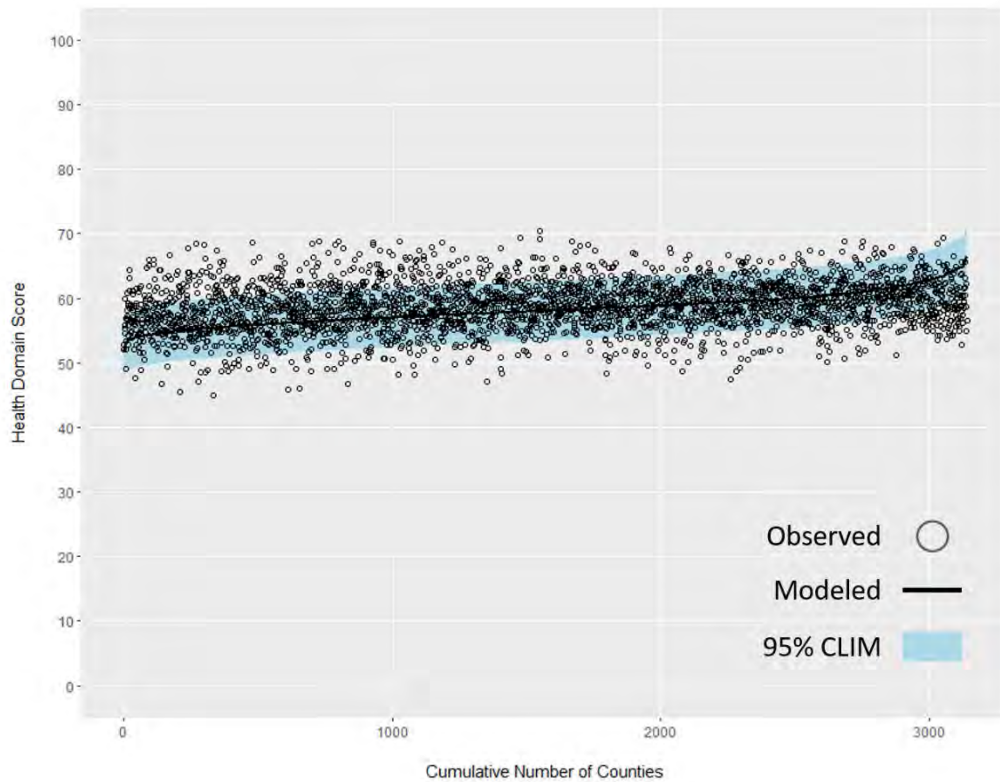


Figure 4. Observed versus modeled HWBI health domain score (95% CLIMs); based on HWBI relationship function equations.

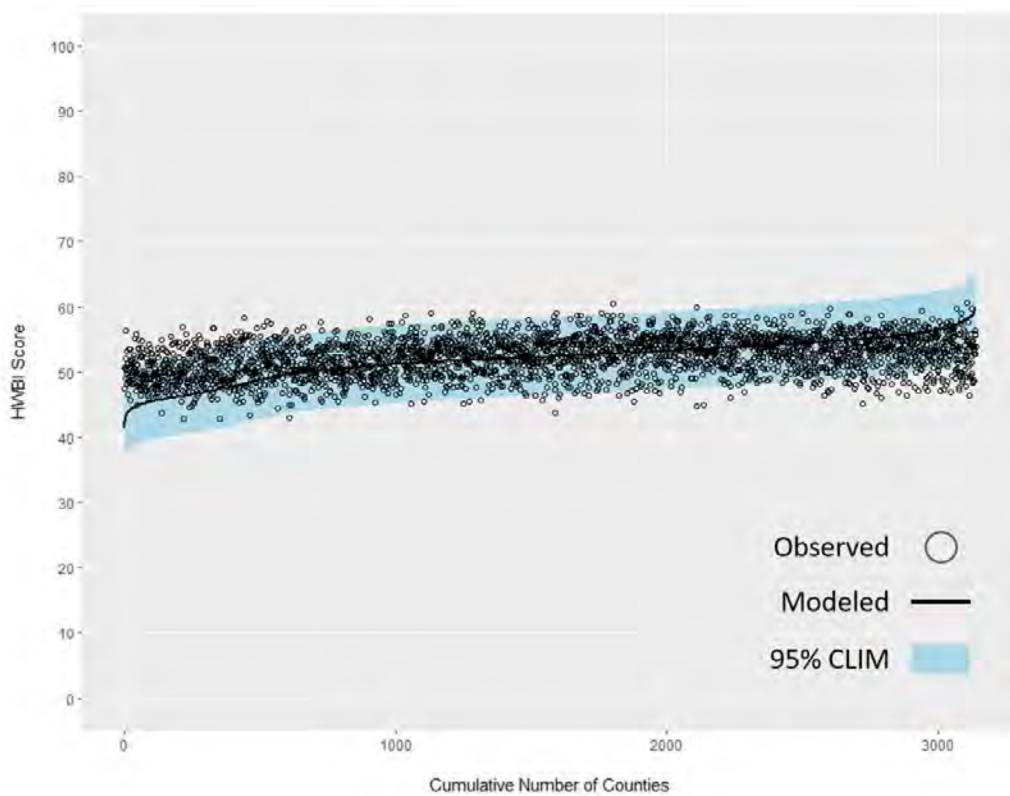


Figure 5. Observed versus modeled HWBI scores (95% CLIMs); based on HWBI relationship function equations.

Temporal scale differences associated with metric data used for the HWBI (2000-2010) and the EQI (2000-2005) were not specifically accounted for since the HWBI models served as the basis of the evaluation rather than the observed values. However, both HWBI and EQI were calculated based on metric averages for specific time spans thus reducing the impact of variability introduced by data collected in years that did not overlap. Of the 3143 counties, parishes and boroughs listed in the 2010 U.S. Census, 3139 could be matched between HWBI and EQI. Independent cities and boundary changes in Alaska contributed to the < 1% of counties not represented in this analysis.

Modeled HWBI health score and EQI values were tested for normality. Both data sets exhibited deviations from normality. The HWBI modeled health domain is slightly right skewed with light tailing while the EQI is slightly left skewed with similar tailing (Figures 6 and 7). The most likely cause of these deviations relate to imputation or interpolation processing used to fill information gaps where data were sparse, particularly in counties with low population densities. While not perfectly normal, the data sets were generally normative and suitable for this demonstration.

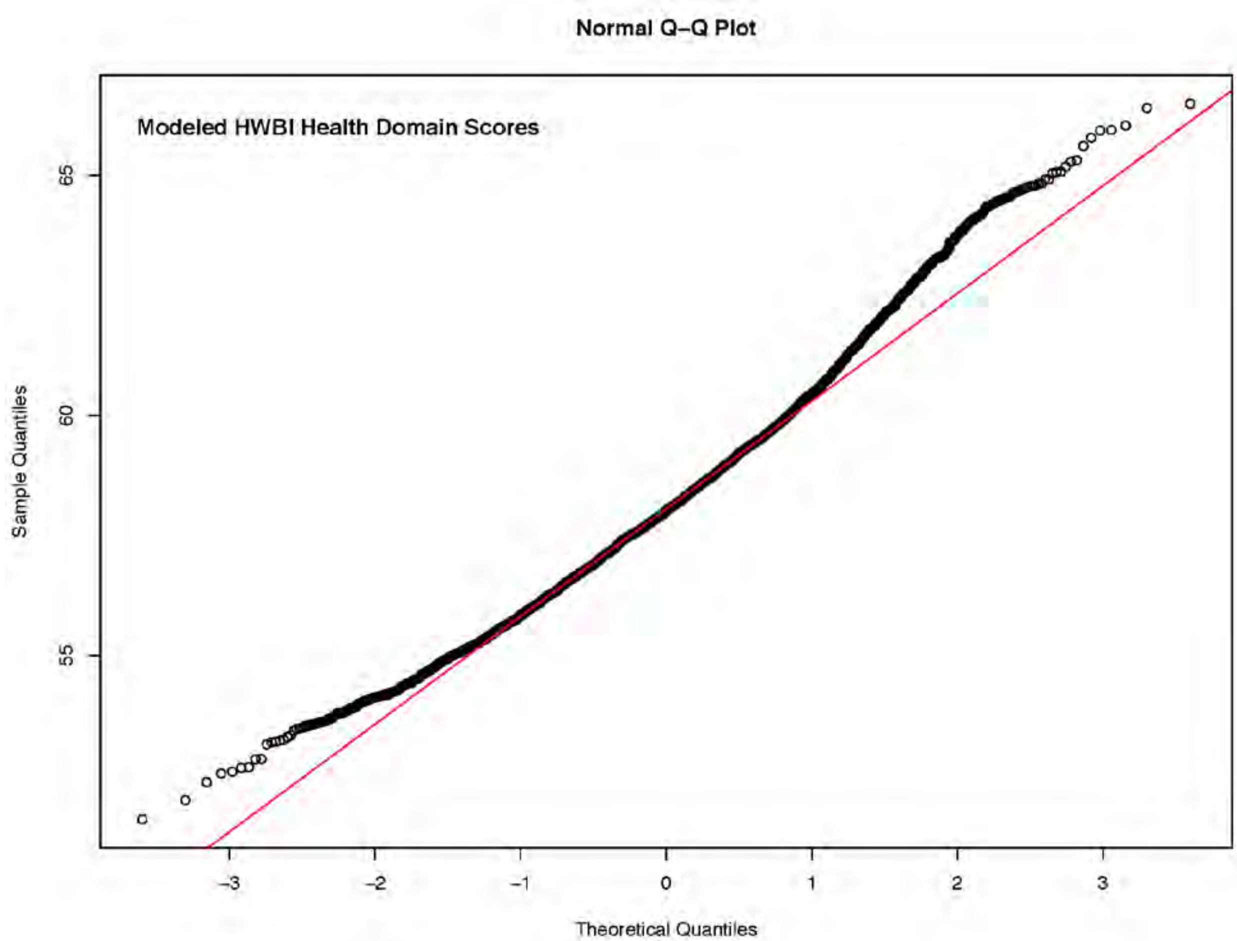


Figure 6. Normality plot for unmodified HWBI health domain modeled output.

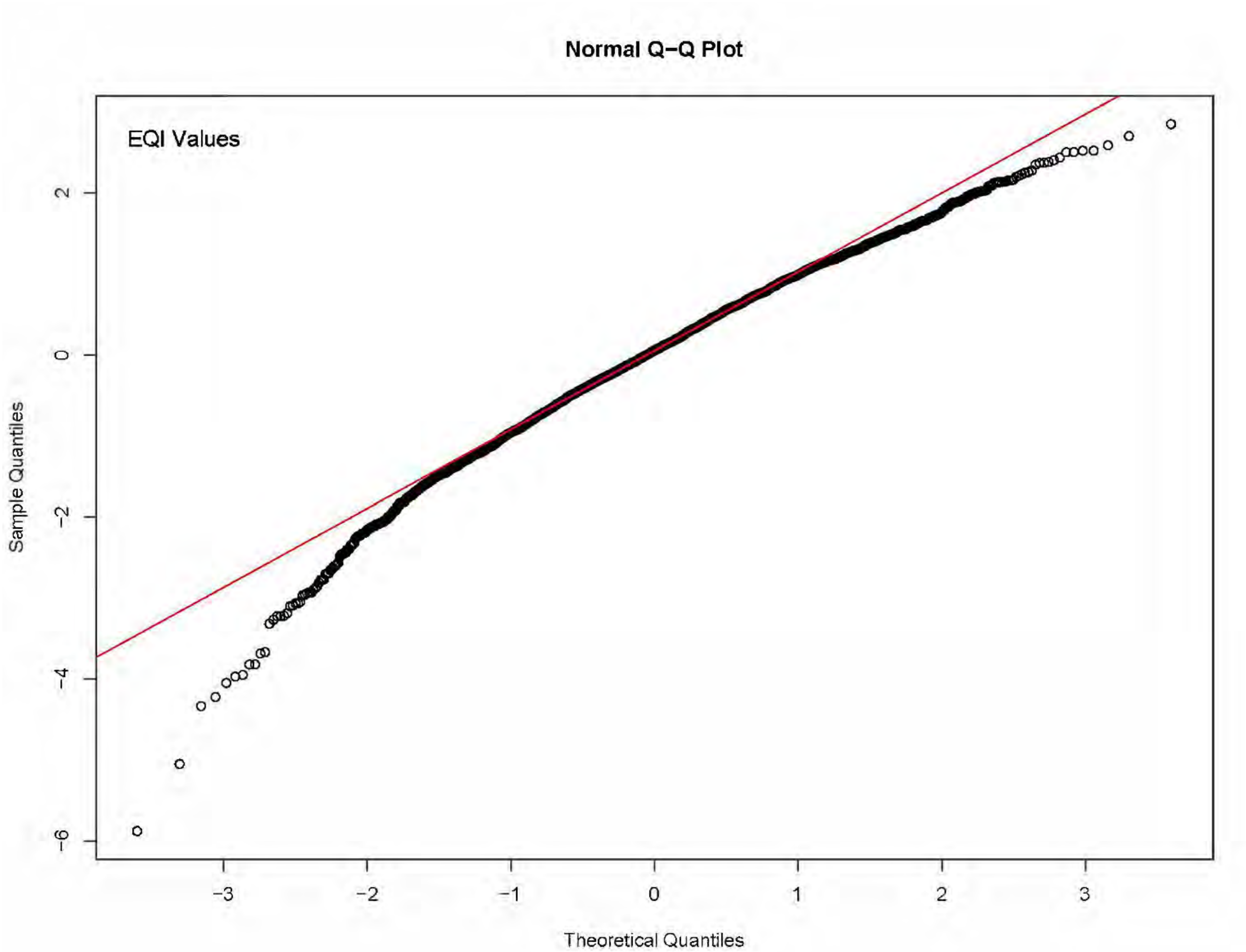


Figure 7. Normality plot for EQI values.

Since existing HWBI relationship-function equations were central to this demonstration, it was necessary to establish that the EQI, as a potential model modifier, was not a redundant characterization of either the HWBI or HWBI health domain. Pearson's Product Moment correlation analysis showed that the EQI was significantly correlated with both the unmodified, modeled HWBI health domain scores (r = .40, p < .01) and modeled HWBI scores (r = .21, p < .01). The significance of the correlations was most likely driven by the large number of observations (n=3139); however, neither correlation result showed a particularly strong relationship. In addition, regression analyses depicted the EQI as a poor predictor of the health domain and the overall HWBI with R^2 = .16 (p < .01 and R^2 = .09 (p < .01), respectively. These results showed that the EQI, HWBI and HWBI health domain scores were reasonably independent measures, suggesting that the EQI could be used as an additional factor not explicitly included in the original HWBI model considerations.

6.2 Demonstration

The most dramatic change in both HWBI health domain scores and the overall HWBI was introduced by the relationship-function equations rather than the EQI modifications. Given the model fit and data normality, these results were not unexpected. Data imputation methods used by both indices for some of the more rural counties is the probable explanation. Modeled health domain scores (mean=58.2, SD=2.4, range=51.6-66.5) exhibited a modest change in the range and mean of values after the EQI-modification (mean=57.4, SD=4.8, range=43.0-75.2). However, modeled HWBI scores (mean=51.9, SD=3.0, range=41.4 - 59.8) remained virtually unchanged (mean=51.8, SD=2.8, range=42.8 - 60.2). Observed, unmodified and EQI-modified health domain and HWBI scores were plotted in context of the remaining HWBI domain scores along a distribution gradient. Figure 8 shows how the results for all U.S. counties align with or deviate from the median (darkest color striations) of each set of scores.

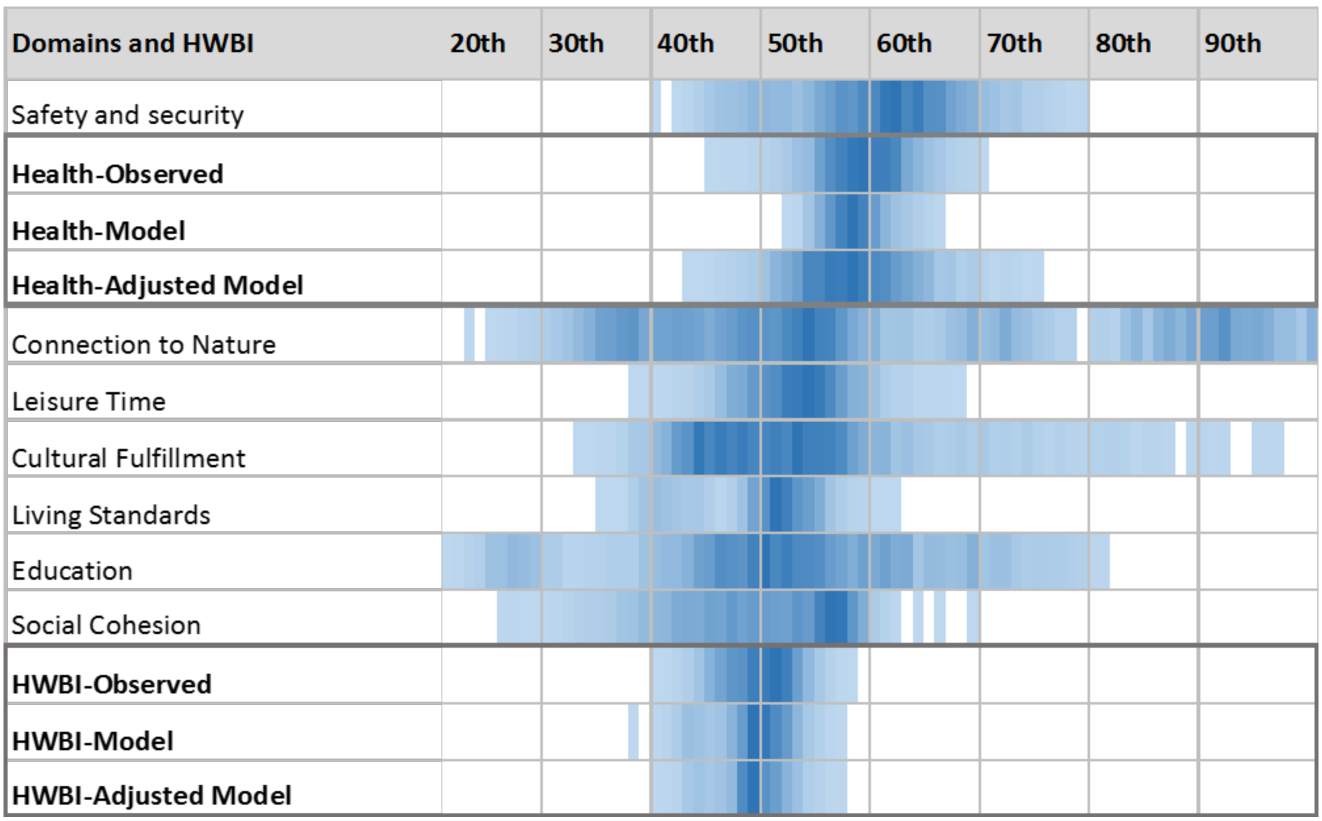


Figure 8. Observed, unmodified and EQI-modified health domain and HWBI scores plotted in context of the remaining HWBI domain scores along a distribution gradient, for all U.S. counties in relation to the median score of each domain set.

Spatial-pattern shifts occurred when the modeled health-domain scores were EQI-adjusted. The spatial distribution changes were more subtle for the overall HWBI scores, calculated using the full complement of modeled domain scores including the EQI–modified health domain (Figure 9).

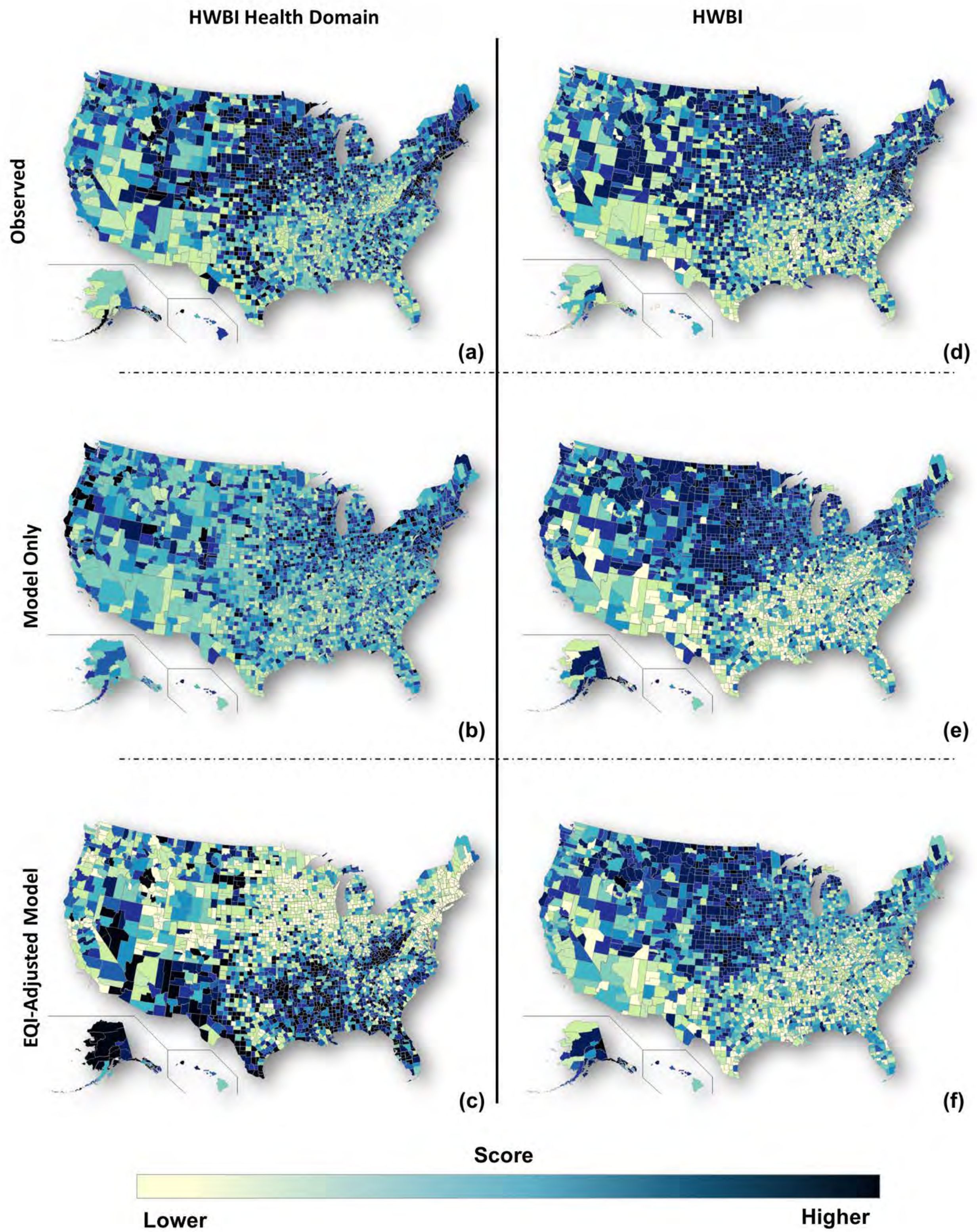


Figure 9 Spatial distribution of observed, unmodified model and EQI model results for: HWBI health domain scores (a-c) and the overall HWBI (d-f).

Z-test results showed significant differences between the unmodified and EQI-modified health domain model outputs (z=6.06, p<.001), but not for the HWBI (z=1.35, p<0.18). Differences observed between the two sets of health domain and HWBI scores were evaluated for significance based on 95% confidence limits, at ±6.77 and ±4.74, respectively. No significant difference was observed for the modified HWBI. However, the EQI modification in the health domain model produced significant changes in health scores for some counties (Figure 10).

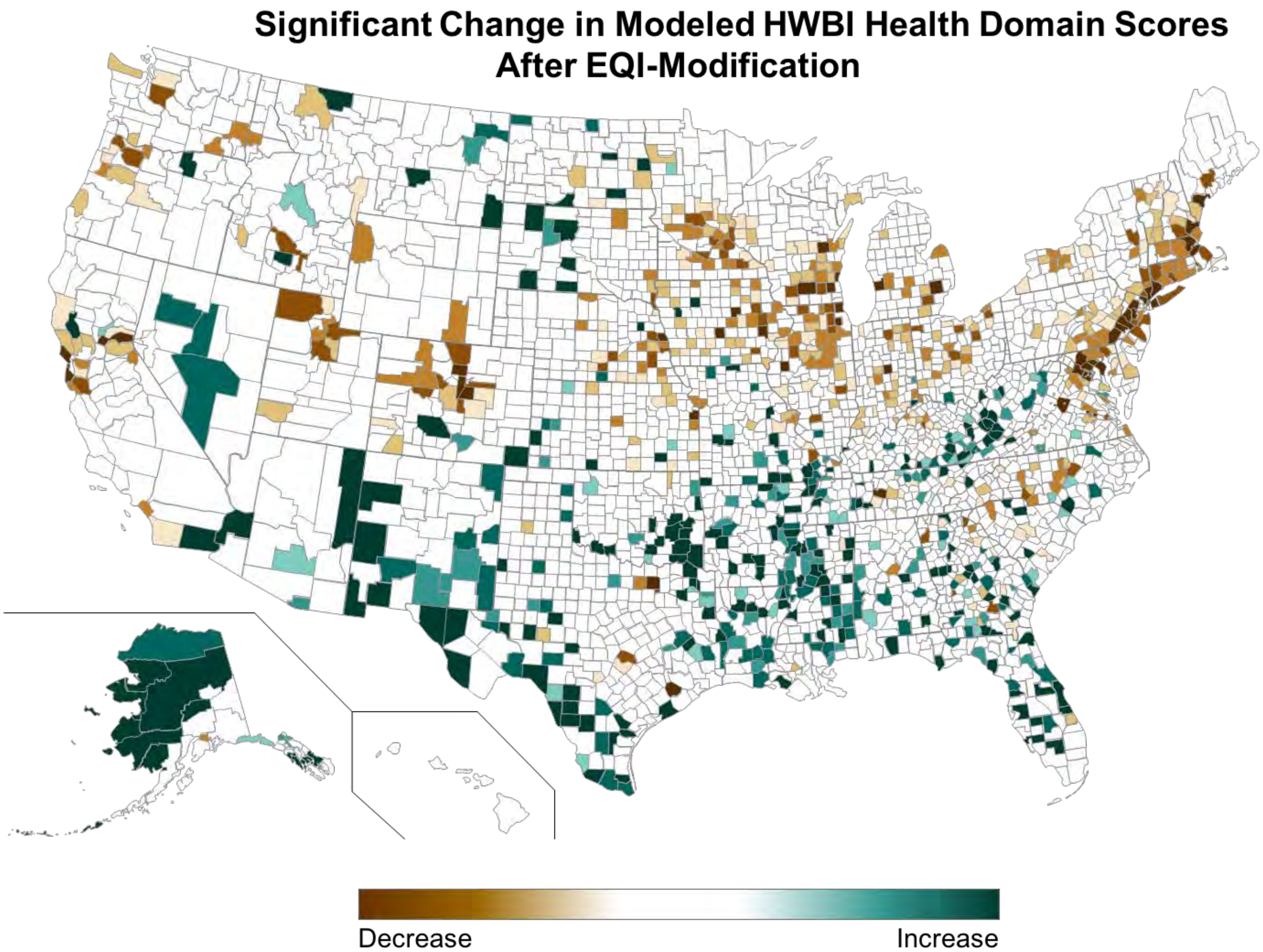


Figure 10. Bivariate chloropleth depicting county HWBI health domain scores that exceeded the 95% confidence threshold.

Approximately 28% of counties showed a significant effect in modeled HWBI health domain scores resulting from the EQI modification. While the majority of county health scores were not adjusted significantly, spatial distribution shifts were detected. As a result of the EQI modification, concentrated areas of northeastern counties exhibited lower modeled health domain scores, while discreet pockets of counties in the southeast and southwest showed higher scores.

7.0 Concluding Remarks

This demonstration illustrates that by introducing the EQI to the HWBI framework, a new sentinel indicator of change emerges. This union of indices adds value to the overall HWBI framework, generating additional drill-down layers which may be used to help identify potential areas of overall health and well-being disparities in context of economic, ecosystem and social service drivers that influence quality of life characteristics. By leveraging the HWBI relationship-function equations, the integration is simple and each index retains its original intent—a characterization of well-being and environmental quality.

The decision to use the HWBI health domain model construct as the basis for this demonstration was three-fold:

- Using the HWBI relationship-function equation models makes adapting this approach for other well-being applications fairly easy, increasing the likelihood that the method will be adopted.
- Concentrating the influence of the EQI on the health domain specifically constrained it use to the field it was originally intended to serve.
- Using the HWBI model based approach allowed the modified health domain relationship equations to continue to function in a manner consistent with the other HWBI domain relationship-function models. The observation is particularly important given the means-ends nature of the HWBI framework—the value contributed to the HWBI is dependent on the influence and response sensitivity of the two indices in context of all other HWBI-related services.

Demonstration results indicate that the EQI-modification of the HWBI model has the capacity to provide meaningful information related to modeled scores of overall health. While this demonstration shows promise, some caveats should be considered. As with many indicator-related research efforts, the lack of higher resolution data contributes to statistical noise, making it more difficult to detect true patterns. Given that the HWBI relationship function equations were developed using state-level data, the demonstration performed well but the accuracy of the HWBI domain models could be improved. These two points alone could become particularly important for using the approach at local-scales. More spatially and/or population sensitive imputation methods (e.g., Buck, 2017) might alleviate some of the uncertainty attributed to data sparsity, particularly in more rural locales. Additionally, identifying and developing easier ways to collect and synthesize existing data could help harmonize temporal scales across indices. Finer-scale and more current data could help evolve the current HWBI relationship function model which could lead to more robust and holistic tools that utilize a larger inventory of existing ORD indicator products.

Individually, both indices contribute to a “cause and effect” dialog, which work best when interpreted in terms of the characteristics of potential influence or response rather than the actual value itself. The approach described in this report potentially offers a different perspective for evaluating of overall health characteristics. The EQI-adjusted health domain scores could be used to highlight areas that are at higher potential risk for poorer overall health in the longer term based on chronic exposures to adverse environmental conditions, even when current HWBI health domain scores alone suggest better health characteristics. Conversely, improved HWBI health domain scores resulting from EQI-modifications could help identify geographical areas where factors other than adverse environmental exposures (e.g., culture, behaviors, availability of healthcare, age distribution) may be more influential in overall health conditions.

The approach provides empirical results that can be visualized to identify hotspots of current or potential future adverse environmental-health relationships. Having a sense of where problems may exist could help inform environmental improvement decisions that may have the greatest community impact. Equally important, the EQI-modified HWBI health scores could be used to communicate the important linkages between a healthy lifestyle and a healthy environment to support that lifestyle and overall well-being. While the demonstration focused on a county-level application, the approach can be used at any spatial-scale, provided the appropriate data are available. The resulting suite of indicators and indices could provide decision-makers and stakeholders alike with measures to assess and track human health and well-being progress over time in the context of socio-ecological interactions. The EQI-modified HWBI demonstration may serve as the first step towards building robust information frameworks to support indicator and index development that promote more integrated decision-support tools.

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Appendix A. Applications and Adaptations of the HWBI Framework

A1. Research Highlight: Transferability of the HWBI Framework to Native American Populations

The applicability and integrity of the HWBI framework was demonstrated using metrics scaled to assess well-being for American Indian Alaska Native (AIAN) and large tribal populations. The HWBI approach can be used to estimate well-being for Native Americans collectively with a reasonable level of confidence. The degree to which the HWBI structure can be utilized is dependent upon the availability and quantity of quality data. Greater than 80% of the data available for a national AIAN assessment were specific to the target population, while the remaining data were derived from the general U.S. population. The remaining data were derived from AIAN population weighted U.S. HWBI values. Despite using roughly 20% non-specific population data, the AIAN well-being signature could still be differentiated from the U.S. HWBI.

To overcome limitations, data substitution using the described approach, is the most robust method for scaling the index, but the limited availability of comparable metrics at smaller spatial scales and for specific demographics may also be problematic. The metrics utilized in the U.S. HWBI range in nature from individuals' perceptions (survey questions) to rates of occurrences of certain behaviors and outcomes in a population. In order to maintain index integrity and capture the most holistic and comprehensive picture of a population, it is sometimes necessary to identify alternative metrics. When choosing alternative metrics, it is imperative that both the qualitative nature of the information as well as the type of information is as closely matched as possible. Alternative metrics for AIAN populations were suggested for the HWBI metric Performing Arts Attendance. This substitution caused a dramatic increase in the metric and the domain score (Figure A-1)

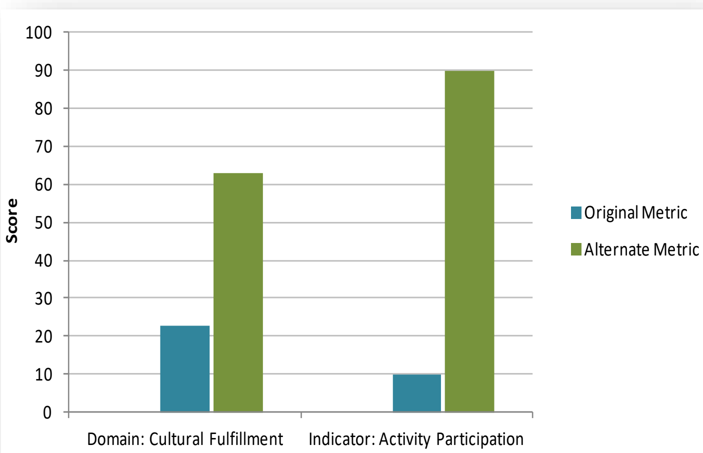


Figure A- 1 Comparison of the results of using an alternative metric for the Activity Participation indicator in the Cultural Fulfillment domain

Only data that could be readily identified as AIAN-related were collected from sources. Data records were encoded to differentiate between single ethnic and multi-ethnic identified information, AIAN and AIAN-mixed, respectively. For each record, the collection method was identified as either random (e.g., exit polls) or complete (e.g., vital statistics). Metric categorization was based upon reported ethnicity, sample size and temporal scale data availability. All 80 metrics were categorized into one of six categories. Raw data were organized hierarchically by population group and temporal resolution (e.g., AIAN and Tribal grouping by year and decade). National AIAN and Tribal Group datasets were created by populating metric values from the most robust data available according to the metric categorization process and from existing U.S. HWBI metric data (Figure A-2).

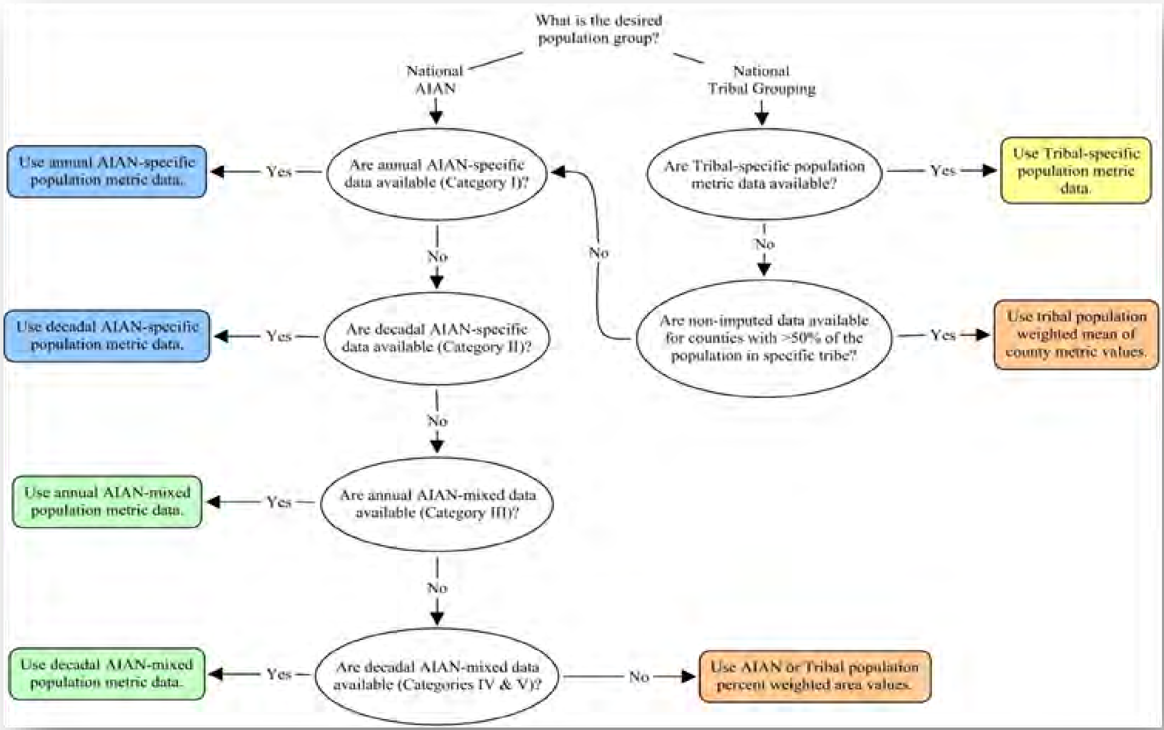


Figure A- 2. Process for selecting the most robust AIAN and Tribal Group data available for HWBI assessments

Where, tribal specific data were available, a Tribal Group identifier was included with the data appropriate. Tribal specific metric values were aggregated into one of 38 Tribal Groups as represented in the tribal assignments for the U.S. Census (2000). 7 of the 38 Tribal Groups with the greatest percentage of tribal specific data were selected for HWBI and domain score comparison. The 7 tribal groups with sufficient data include the Menominee, Navajo, Chippewa, Blackfeet, Alaskan Athabascan, Eskimo, and Sioux. Each of the seven Tribal groups was compared to the county HWBI scores for which the counties had greater than 50% of the population identified as tribal-specific.

For the 2000-2010 period, the lowest ranked indicator scores for the Tribal groups were in the domains of Health, Living Standards, Safety and Security and Social Cohesion (Fig. 3). Differentiation between tribal domain scores is dependent upon the specificity of the data included in the assessment. Where AIAN, AIAN-mixed and U.S. data comprised the majority of the metrics used to calculate tribal indicators, rarely were differences in domain values observed. Differences among tribal scores were attributed to tribal specific and county population weighted metric data which better characterize individual Tribal groups.

The tribal application of the HWBI provides a unique opportunity to examine the performance of the EQI modified HWBI relationship-equation functions with a population group often underrepresented in national assessments.

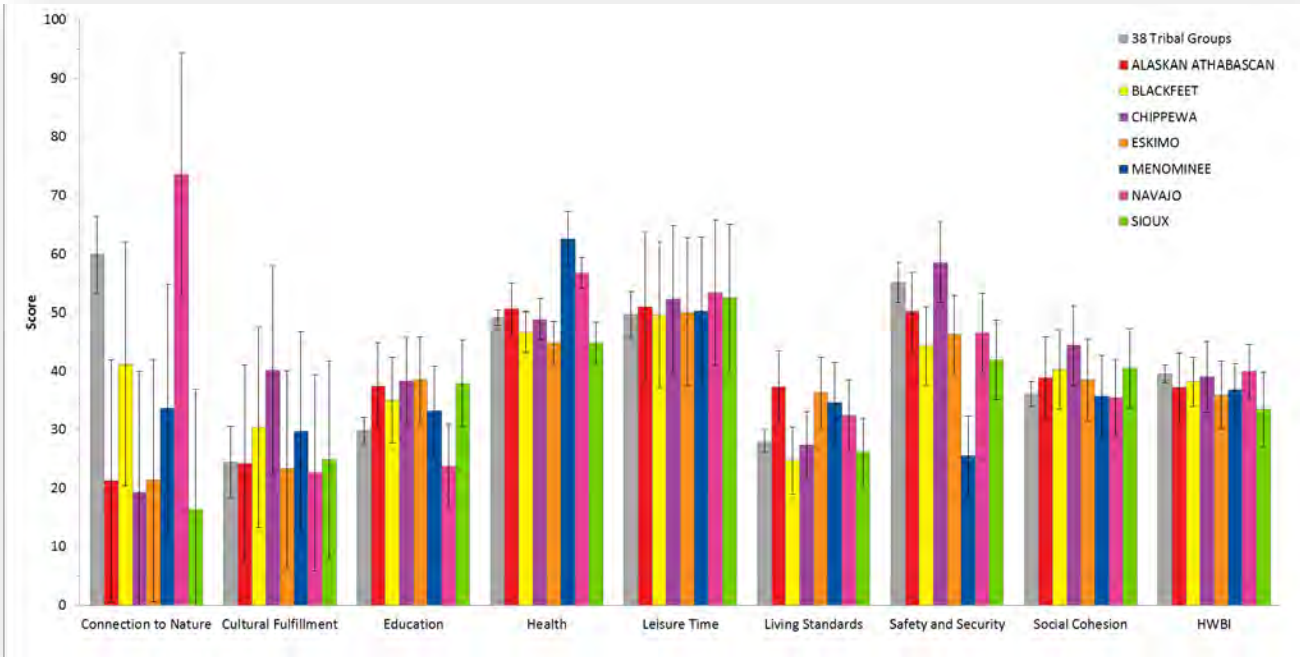
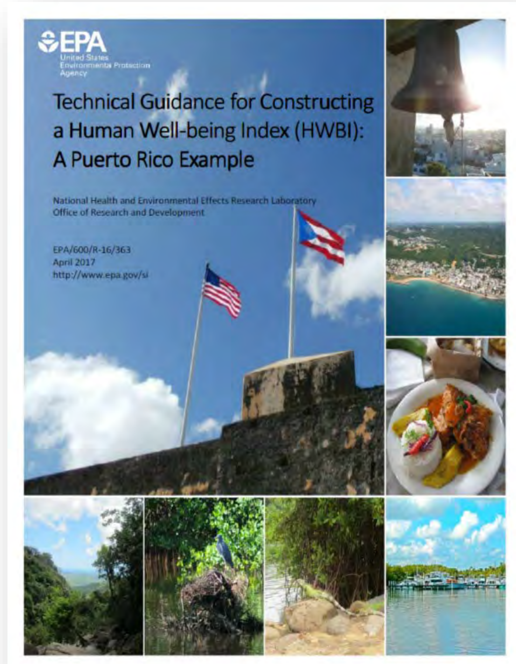


Figure A-3. Large Tribal Group domain and HWBI scores for the 2000-2010 time-period.

A2. Technical Guidance for Constructing a Human Well-Being Index (HWBI): A Puerto Rico Example



The U.S. Environmental Protection Agency (EPA) Office of Research and Development's Sustainable and Healthy Communities Research Program (USEPA 2015) developed the Human Well-being Index (HWBI) as an integrative measure of economic, social, and environmental contributions to well-being. The HWBI is composed of indicators and metrics representing eight domains of well-being: connection to nature, cultural fulfillment, education, health, leisure time, living standards, safety and security, and social cohesion. The domains and indicators in the HWBI were selected to provide a well-being framework that is broadly applicable to many different populations and communities, and can be customized using community-specific metrics (Orlando et al. 2017).

A primary purpose of this report was to adapt the U.S. Human Well-Being Index (HWBI) to quantify human well-being for Puerto Rico. This application provided an example of how the HWBI could be adapted to different communities, especially locations outside the mainland U.S. Additionally, technical guidance on processing data and calculating index using R is offered.

The domains and indicators in the HWBI were selected to provide a well-being framework, which can be transferred across different populations and communities and customized using more community specific metrics. The San Juan Puerto Rico case study was a demonstration of how this can be done utilizing data substitutions more closely link to local environments.

The HWBI adaptations were calculated to compare human well-being both within Puerto Rico and to the U.S. population. Puerto Rico's population is linked to the U.S. government, economy, and institutions, yet culturally distinct and geographically isolated from the mainland. Therefore, Puerto Rico presented an opportunity to explore the transferability of the HWBI to this unique group of islands. The adaptation of the HWBI to Puerto Rico built upon the existing framework, but considered data selection options that better informed indicator development within the context of Puerto Rico communities. Two suites of HWBI indicators and indices were generated, a HWBI using Puerto Rico specific-data only—dropping metrics where data did not exist--and another using U.S. metrics to fill information gaps. An HWBI and suite of related domain and indicator values were scaled to the 78 municipios.

Similar to the approach used to examine the transferability of HWBI for American Indian and Alaska Native (AIAN) populations (Smith, et al. 2015), the Puerto Rico metrics used to calculate the HWBI were based data availability and the appropriate data substituted for characterizing HWBI indicators for Puerto Rico populations. HWBI scores for Puerto Rico municipios were calculated based on the range of values within PR and the range of values for the U.S. (Figure A-4). Additional HWBI comparisons are also presented for Puerto Rico in context of all U.S. states (Figure A-5)

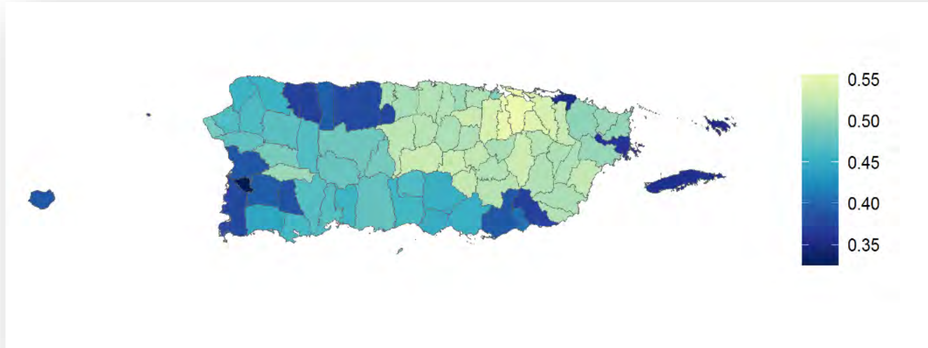


Figure A-5. Map of mean decadal (2000-2010) HWBI for Puerto Rico municipios. Higher HWBI scores are indicated with lighter colors; darker blues indicate lower HWBI scores

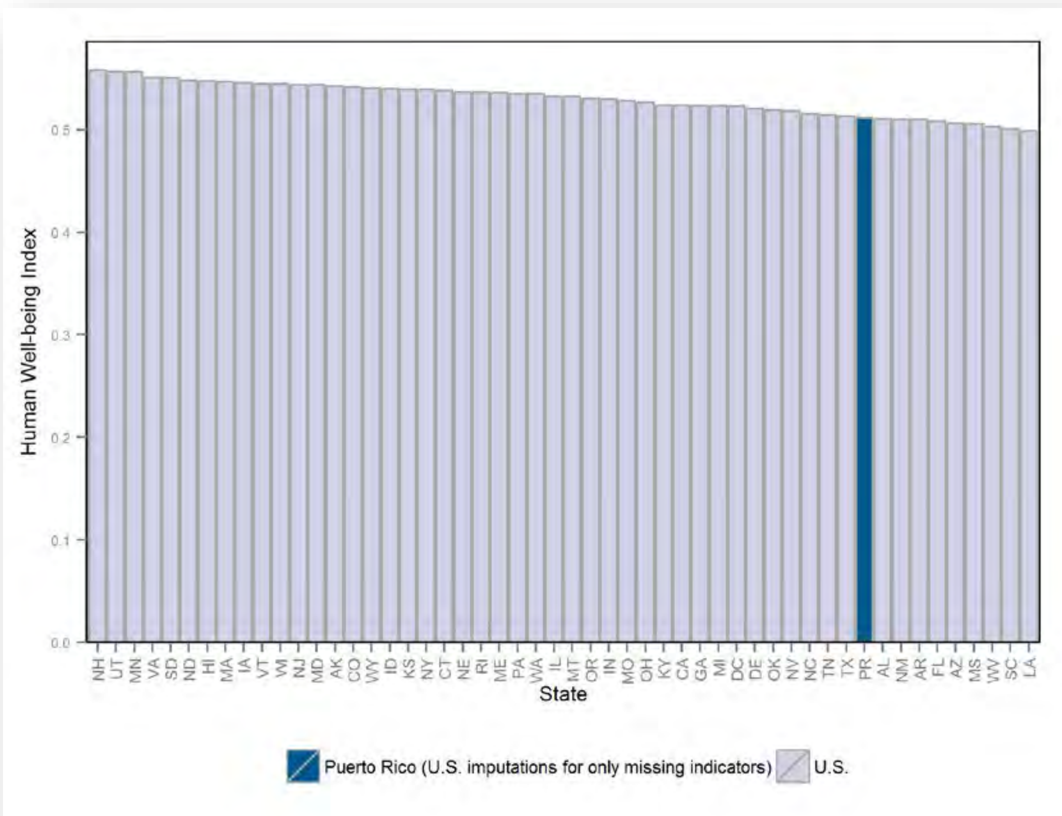


Figure A-4. Comparison of mean decadal (2000 – 2010) HWBI for U.S states and Puerto Rico.

A comparison at the indicator level for Puerto Rico and the U.S. states with highest and lowest HWBI scores is depicted in Figure A-6. The Puerto Rico application of the HWBI provides a basis for future consideration of an EQI-modified HWBI demonstration in a geographic area with unique environmental considerations.

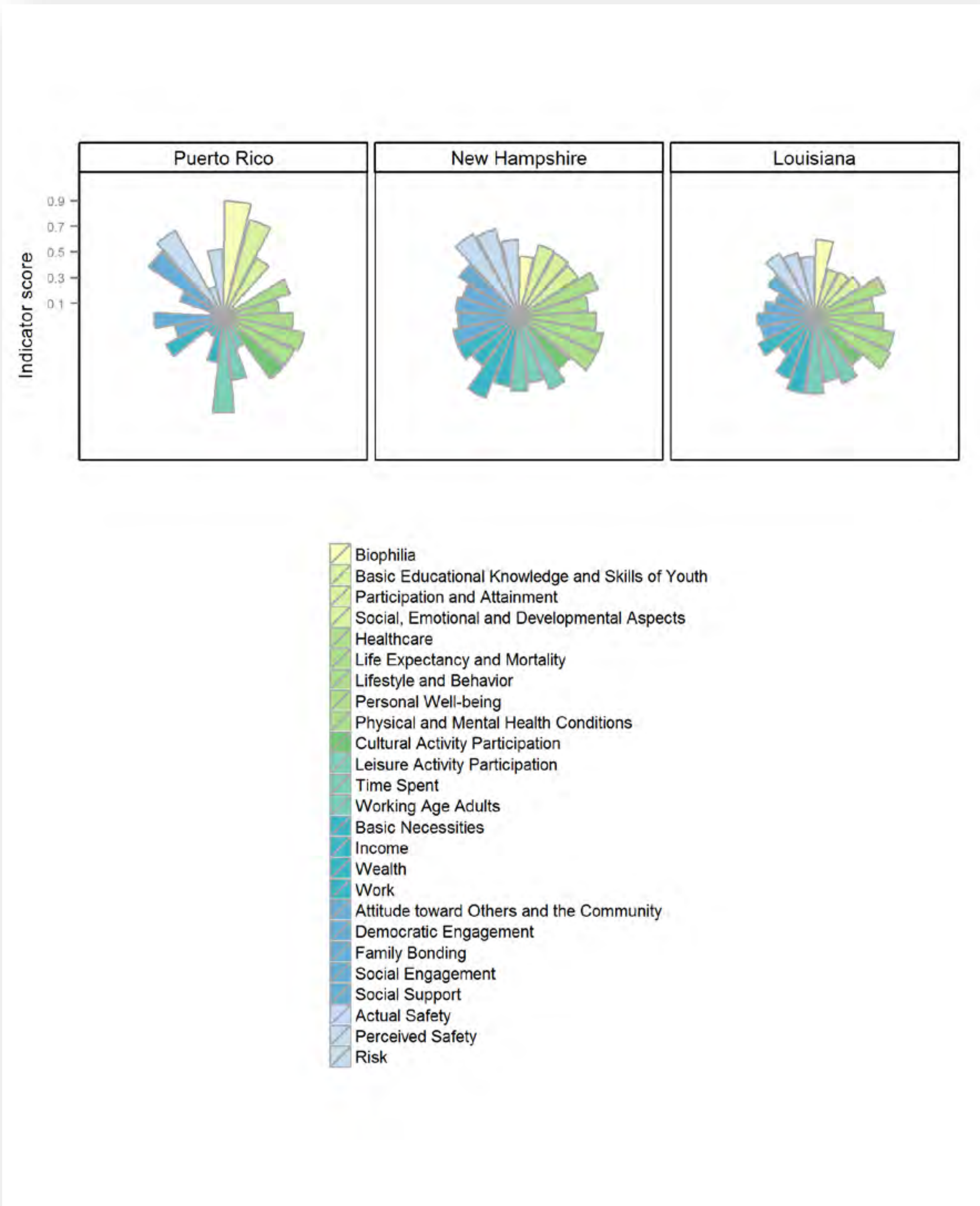


Figure A-6. Comparison of mean decadal (2000-2010) indicator scores for Puerto Rico and the U.S. states with the highest (New Hampshire) and lowest (Louisiana) HWBI scores.

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A3. Application of the Human Well-Being Index to Sensitive Population Divisions: A Children's Well-Being Index Development

Since its development, the Human Well-Being Index (HWBI) has undergone two adaptations in order to both assess its applicability and highlight specific populations – U.S. adults (Summers et al. 2014; Smith et al. 2015). In Puerto Rico, the application of HWBI focused on data and adapting existing metrics and index structure (county to municipio) to a US territory, whereas the Native American application focused on distinct populations living within the US boundaries. Results from these studies demonstrate the adaptability of the HWBI, which allows selected population groups to be highlighted and compared to the larger US population. However, characteristics such as age and ethnicity also play large roles in how groups are either benefited or harmed by the access to resources on a larger scale (Crimmins et al., 2004). While the average citizen may benefit from a community characteristic, individuals existing outside of the socio-demographic norms may be adversely impacted.

To test this socio-demographic theory, another adaptation of HWBI is undertaken in order to both conceptually and empirically test a version of the index specifically adapted to children. Children, defined in the U.S. as those under the age of 18, are considered dependents and under their parent's care and guidance. The primary objective of this research is to determine whether the HWBI can be effectively calculated for an age-specified sub-population in the United States (i.e., children). This requires identification of clear theoretical connections between the original HWBI metrics and the CWBI in addition to data isolated by age (Figure 1). Success in this age-specific application is defined by: 1) a clear model for adaptation of the index, 2) availability of data at appropriate scale and capturing the proper concepts, and 3) a resulting index that is statistically robust and consistent with other indices of children's health and well-being.

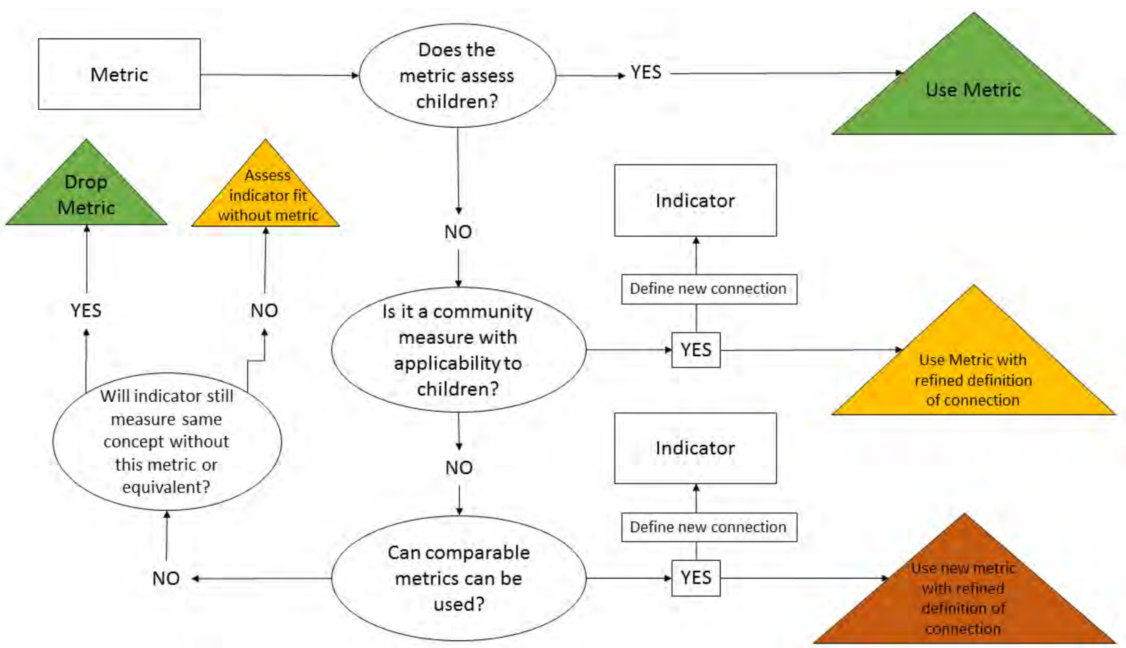

Figure A- 7. Decision flow chart for metric adaptation in children's well-being index creation for the original HWBI. Start with metric in order to minimize changes at indicator or domain level. Move to right indicates metric retention, while move to left indicates metric drop.

Benefits of child-specific research are two-fold. First, children are very susceptible to environmental conditions, whether natural, built or social (Del Carmin Ruis et al., 2016). From pregnancy up to adulthood, children are developing physically and emotionally and are more vulnerable to poor environmental conditions than adults (Goldman, 1995; Punch, 2002). Another reason for interest in child-specific well-being is to serve as a point of reference for children within the larger societal constructs. Developing a conceptually identical index that examines a specific sub-population (statistically speaking) allows for direct comparisons between groups. In the case of children, they are future adults; hence, their development and current well-being can provide a window into adult well-being ten to twenty years in the future. If the well-being of children is higher compared to the general population, there is a possibility that the general population's well-being will improve over the next few generations. Conversely, if children are doing poorly in comparison to the general population, the future may not look quite as bright. There also exists the possibility that both the present and future well-being of adults will be positively influenced by investments in family and community centered issues. While, most communities recognize the importance of investing in children to improve their well-being, not all investments pay off in predictable ways. A forecasting assessment tool for adult well-being based on leading indicators of children's well-being in the present would be preferable to waiting 20 years for the resultant well-being to materialize.

The end result of the adaptation is a set of 8 domains matching those of the original HWBI, 3 changes of indicator terminology, and the adjustment of 42 metrics to accommodate data availability and theoretical differences between an index meant to represent an entire population and one specific to children (Table A-1). While many of the metrics are altered, they are all able to maintain a structure and premise closely resembling the original HWBI (Summers et al., 2014).

Table A - 1. Indicator and metric count per domain. Data representation (HWBI count/CWBI count).

Domain	Indicator Count	Metric Count
Social Cohesion	5/5	17/17
Living Standard	4/4	9/12
Education	3/3	11/12
Connection to Nature	1/1	2/1
Cultural Fulfillment	1/1	2/3
Health	5/5	26/19
Safety and Security	3/3	6/8
Leisure Time	3/3	6/7

Much of what makes the original HWBI, and by extension the CWBI unique is the ability to assess individual counties across all of the indicators and domains. This allows for the identification of not only regional trends, but also approaches community level assessment where scores can be compared given time, monetary and policy investments to determine effectiveness. Every effort is made in the development of this index to strike the balance of change from the original HWBI and to find metrics directly representative of children in the community. Such an approach was intended to help to draw distinct conclusions about their well-being while also remaining rooted in the general well-being of the community. Looking at the overall CWBI scores, there are definite regional clusters apparent (Figure 2). The highest well-being values exist in the much of the upper Midwest and in the Southeast. The lowest scores are in parts of the deep South, the Southwest, and along areas of the East Coast.

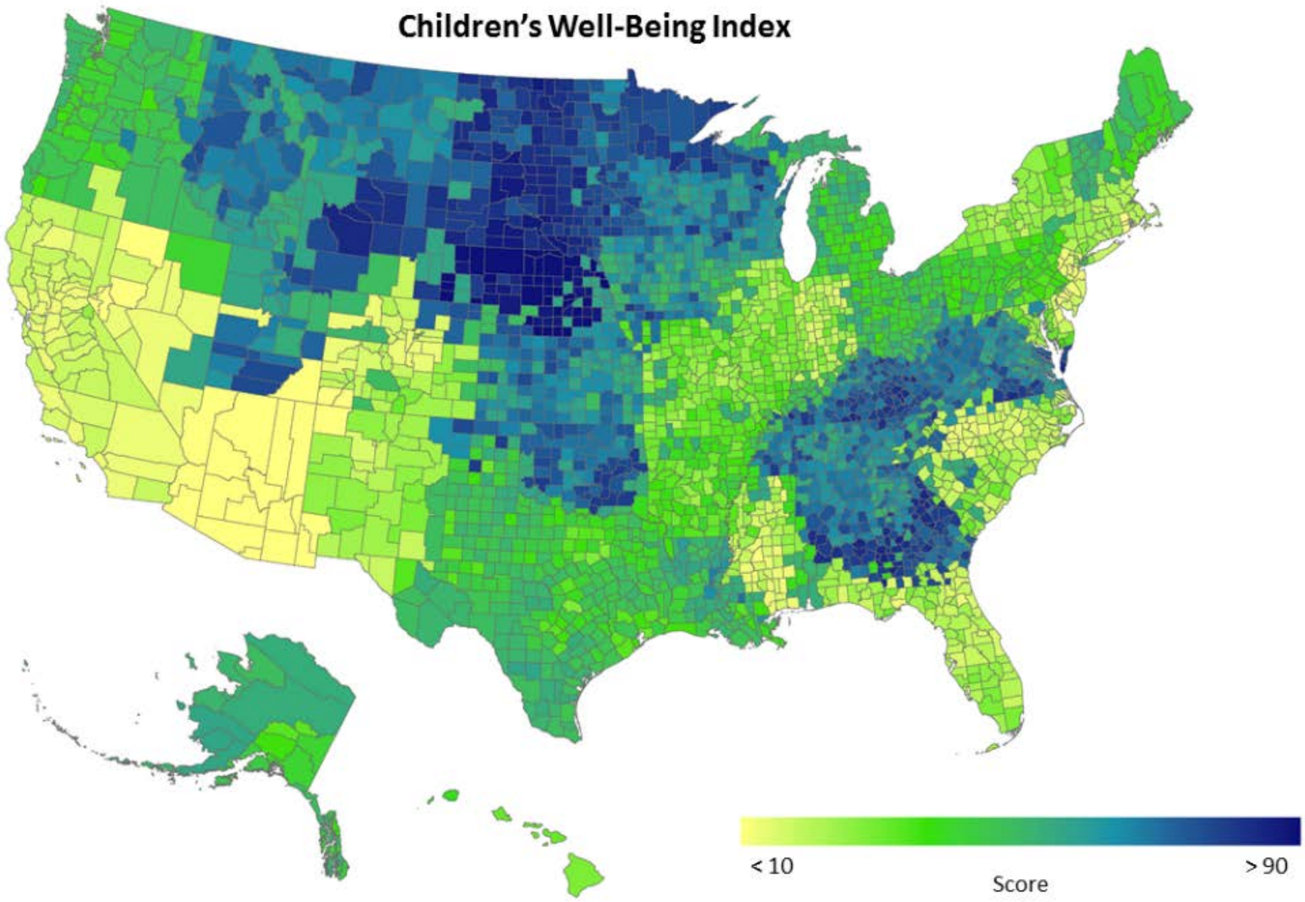

Figure A- 8. Children's Well-Being Index scores for all US Counties in 2010.

A final comparison of CWBI to the original HWBI, both at index and domain levels, reveals a key finding that involves drivers of well-being between the general population and children. Much of the influence in a more adult-centric index comes from economic drivers, whereas health and education tend to drive more of the CWBI. This corresponds to comparisons, where only a few of the domains, principally Living Standards and Health, have a moderate correlation, while Social Cohesion has a very weak correlation across the indices. In the case of Living Standards, many of the metrics used to assess this domain are community level and traits of parents should be very similar to those of the children. Along the same lines, healthy parents will be more likely to have healthy kids.   The remaining domains: Leisure Time, Safety and Security, Education, and Social Cohesion are more subjective and it is possible that parent's views do not align with those of their children, or the domain simply measures a very different conceptual piece when comparing children to the greater community.

The CWBI presents a unique case for identifying the strengths and weakness of the EQI-modified HWBI relationship function equations.

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Appendix B. HWBI Relationship-Function Equation Coefficients

Table B1. Relationship-function equation coefficients used for the HWBI domain models to predict well-being from service categories. The health domain model, which is primarily used in this report, is highlighted in gray. The remaining domain models are used to calculate the HWBI with EQI-modified health domain values. More information about this table is available in Summers et al. (2016).

Domain	**Service**	**Coefficient**	**Partial R^2**
Connection to Nature (R^2=0.78)	Intercept	+2.4312	
	Community and Faith-Based Initiatives	+0.5772	0.29
	Consumption	+0.4655	0.14
	Re-Distribution	-0.3704	0.08
	Activism	-1.7559	0.07
	Healthcare	-0.1117	0.05
	Greenspace	-0.524	0.04
	Emergency Preparedness	-2.3885	0.03
	Water Quality	+0.0505	0.02
	Labor	-1.9341	0.01
	Education	+0.2116	0.01
	Community and Faith-Based Initiatives*Emergency Preparedness	-1.999	0.01
	Activism*Emergency Preparedness	+2.1033	0.01
	Emergency Preparedness*Labor	+3.2228	0.01
Cultural Fulfillment (R^2=0.43)	Intercept	-0.2239	
	Community and Faith-Based Initiatives	+2.4296	0.21
	Air Quality	-0.1007	0.08
	Water Quantity	-0.1314	0.03
	Emergency Preparedness	+0.0847	0.02
	Education	+0.1918	0.02
	Innovation	+0.0999	0.02
	Communication*Community and Faith-Based Initiatives	-4.4056	0.02
	Communication	+1.2805	0.01
	Production	-0.0972	0.01
	Air Quality*Community and Faith-Based Initiatives	+0.2347	< 0.01
Education (R^2=0.81)	Intercept	+0.3928	
	Family Services	+0.3508	0.47
	Community and Faith-Based Initiatives	+0.4638	0.14
	Consumption	-0.3737	0.06
	Production	-0.4887	0.04
	Public Works	+0.0782	0.04
	Justice	-0.4415	0.03
	Activism	+0.5748	0.02
	Re-Distribution*Greenspace	+0.3906	0.02
Health (R^2=0.54)	Intercept	+0.2311	
	Family Services	+0.0727	0.25

Domain	Service	Coefficient	Partial R^2
	Communication	+0.1949	0.08
	Labor	+0.0977	0.07
	Water Quantity	+0.0204	0.04
	Innovation	+0.096	0.02
	Emergency Preparedness	+0.0491	0.01
	Community and Faith-Based Initiatives	+0.525	0.02
	Justice	+0.1491	0.03
	Community and Faith-Based Initiatives*Justice	-0.8663	0.01
	Activism*Education	+0.0503	< 0.01
Leisure Time (R^2=0.74)	Intercept	+0.5062	
	Employment	-0.341	0.22
	Water Quantity	-0.7197	0.10
	Food, Fiber and Fuel Provisioning	+0.6821	0.18
	Water Quality	-0.0537	0.07
	Water Quantity*Education	+1.6	0.04
	Activism	+0.9347	0.03
	Greenspace	+0.1382	0.03
	Education	-0.5449	0.03
	Public Works	+0.5773	0.02
	Community and Faith-Based Initiatives	-0.2174	0.01
	Finance*Communication	+0.2062	0.01
	Activism*Public Works	-1.2947	0.01
	Consumption	-0.3924	<0.01
	Innovation*Education	-0.1715	<0.01
Living Standards (R^2=0.79)	Intercept	+0.2750	
	Employment	+0.0923	0.38
	Public Works	-0.1462	0.12
	Labor	+0.1347	0.10
	Activism	+0.3676	0.06
	Finance	-0.2594	0.05
	Justice	-0.1786	0.03
	Water Quantity	+0.0784	0.02
	Capital Investment	-0.0249	0.01
	Finance*Public Works	+0.7086	0.01
	Capital Investment*Water Quality	-0.0383	0.01
	Food, Fiber and Fuel Provisioning*Communication	+0.1772	0.01
Safety and Security (R^2=0.48)	Intercept	+0.6039	
	Community and Faith-Based Initiatives	+0.2941	0.18
	Water Quality	-0.3806	0.17
	Public Works	-0.3853	0.04
	Water Quantity	+0.0854	0.01
	Activism*Labor	+1.3532	0.02
	Finance*Public Works	+0.574	0.02

Domain	Service	Coefficient	Partial R^2
	Emergency Preparedness*Justice	+0.8986	0.01
	Water Quality*Public Works	+0.6556	0.01
	Production*Food	+0.2951	0.01
	Production*Healthcare	-0.3043	< 0.01
	Justice*Labor	-1.1474	< 0.01
	Greenspace*Emergency Preparedness	-0.7423	< 0.01
	Finance*Activism	-0.6023	< 0.01
Social Cohesion (R^2=0.77)	Intercept	-0.8102	
	Justice	+1.0728	0.41
	Air Quality	+0.0425	0.11
	Production	-0.3830	0.06
	Community and Faith-Based Initiatives	+1.9806	0.04
	Capital Investment	+0.1004	0.03
	Public Works	+0.0473	0.02
	Re-Distribution	+1.2823	0.02
	Labor	+0.1207	0.02
	Family Services	+0.1529	0.01
	Consumption	-0.1481	0.01
	Re-Distribution*Community and Faith-Based Initiatives	-3.5943	0.01
	Greenspace*Justice	-2.0480	0.01
	Employment*Water Quality	-0.0365	< 0.01
	Greenspace	+1.2913	< 0.01

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