Measuring Urban Water Conservation Policies:

Toward a Comprehensive Index

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ABSTRACT

This paper (1) discusses existing efforts to measure water conservation policies (WCPs) in the US; (2) suggests general methodological guidelines for creating robust water conservation indices (WCIs); (3) presents a comprehensive template for coding WCPs; (4) introduces a summary index, the Vanderbilt Water Conservation Index (VWCI), which is derived from 79 WCP observations for 197 cities for the year 2015; and (5) compares the VWCI to WCP data extracted from the 2010 American Water Works Association (AWWA) Water and Wastewater Rates survey. Existing approaches to measuring urban WCPs in U.S. cities are limited because they consider only a portion of WCPs or they are restricted geographically. The VWCI consists of a more comprehensive set of 79 observations classified as residential, commercial/industrial, billing structure, drought plan, or general. Our comparison of the VWCI and AWWA survey responses indicate reasonable agreement (ρ=0.76) between the two WCIs for 98 cities where the data overlap. The correlation suggests that the AWWA survey responses can provide fairly robust longitudinal WCP information, but we argue that the measurement of WCPs is still in its infancy, and our approach suggests strategies for improving existing methods.

KEY TERMS: Water conservation, water policy, water supply, cities, United States

INTRODUCTION

Cities face stress on their water supplies for a variety of reasons, including changing land use patterns, growth in population and demand, water quality problems, and climate change (Brown et al., 2013; Roy et al., 2012). In many cases, cities have responded to existing or predicted shortages of water supply and to water-quality problems by seeking new sources from the surrounding region. Strategies to increase water supply include building pipelines to distant water sources, constructing or expanding existing reservoirs, increasing the number of groundwater wells, and recharging aquifers. However, the strategy of expanding water sources can encounter political opposition from rural communities, environmentalists, and urban constituencies concerned with the costs of new investments (Hess et al., 2016). In this context, water conservation has become increasingly popular because it can avoid political opposition from rural communities, offer an environmentally sound solution to the water-shortage problem, and provide a source of water that is frequently less expensive than alternatives.

Nevertheless, water conservation can trigger its own types of opposition. For example, utilities are concerned with revenue loss from diminished demand, and urban growth coalitions sometimes prefer to pursue new water sources where available (Hess et al., 2016; Kenney, 2014).

Although there can be some opposition to a transition to higher levels of water conservation, water conservation policies (WCPs) have received growing attention among both researchers and water managers because they can provide an important contribution to solving the problem of water stress and shortages. To date we do not yet have comprehensive analyses of WCPs, and improvements in the methodology of tracking and analyzing WCPs can be beneficial to researchers and to policymakers. This study reviews existing strategies for measuring urban WCPs, outlines principles for a more comprehensive WCP data set, and describes our effort to build such a data set. We then develop one possible water conservation index (WCI) from our data set: a summary variable based on 79 observations. The rationale for our project is that researchers can use our summary index to determine the causes and effects of WCPs, and they will be able to construct other variables from the underlying data set to address specific questions. The research can also help policymakers to think about a relatively comprehensive set of options that they have for WCPs and to track their progress.

This study is methodological rather than empirical: we compare a summary WCI developed from our data set with a WCI that we developed from a survey of the American Water Works Association. We have completed empirical analyses elsewhere that use our data set to understand factors that predict a high score on a city's WCP index (Gilligan et al., 2017; Hess et al., 2016). In this study we provide details of the methodology used to develop our comprehensive WCP data set as part of a general contribution to the problem of developing better measures of WCPs. We review the existing approaches to tracking urban WCPs and develop a rationale for a more comprehensive strategy.

Review of Existing WCP Measures

Although many analyses of WCPs focus on pricing policies, the term "water conservation" generally also includes a broader range of programs and policies such as support for water efficiency and for changes in water use (Saurí, 2013). A comprehensive data set of WCPs has not been reported in the peer-reviewed literature, but there have been some efforts to survey a more limited range of WCPs such as outdoor water-use restrictions in Massachusetts (e.g., Milman and Polsky, 2016). In the U.S., the most spatially exhaustive source of general data on WCPs is the survey research published by the American Water Works Association (AWWA). This research is based on a nonrandom survey of water utilities that provide voluntary, self-reported responses. Although the survey includes several questions pertaining to WCPs, the primary focus is water and wastewater utility pricing.

Researchers who study WCPs have used the AWWA survey results to develop variables that measure WCPs. For example, Mullin (2007) found that mean daily maximum temperature, proportion of retail sales, population, and location in the Western and Midwestern regions of the U.S. are positively associated with the presence of an increasing block-rate pricing structure (a policy that increases the price per unit of water as the consumer uses more water). Teodoro (2010) found that the number of customer connections, aridity (climate-moisture index), and peak-to-average demand ratio are associated with the adoption of an increasing block-rate structure, but peak-to-average demand ratio was not significant for the prediction of landscape audit programs. Both researchers found that variations in governance structures can also affect the adoption of WCPs. Aubuchon and Roberson (2012) found that population growth, the 10-year annual temperature, the 10-year annual precipitation, and ratio of maximum-to-average daily water production were associated with a conservation rate structure (defined as increasing block rate and/or a seasonal rate). They also found that when the data set was partitioned into utilities with and without a conservation rate structure, demand-management programs were not significantly associated with water consumption. Hornberger et al. (2015) analyzed self-reported conservation in the 2010 AWWA survey and showed that cities tend to be conservation adopters if they have a high median household income, a high system development charge, and a high fee for residential customers who use over 3000 cubic feet of water per month.

These previous studies, using WCPs derived from the AWWA survey data, have accomplished a great deal within the limitations of AWWA's tracking of WCPs. They have also pointed to important differences among the type of WCP, such as landscape audits versus an increasing block rate structure (Teodoro 2010) and pricing versus demand-management policies (Aubuchon and Roberson 2012). These distinctions are limited by the small number of WCP categories (9) available to analyze in the AWWA data sets. We suggest that future research on WCPs could benefit from a more comprehensive tracking of WCPs so that researchers can make policy-relevant distinctions among the different types of WCPs implemented by water-supply systems. Furthermore, the AWWA data are voluntary, based only on utility self-reporting, and limited to WCPs from the perspective of utilities. Thus, there is a need to develop more comprehensive tracking of WCPs.

The scorecard literature on WCPs provides one point of departure for developing a more comprehensive approach for capturing information about the range of different WCPs. For example, in an analysis of WCPs in Texas cities, the National Wildlife Federation and Sierra Club Lone Star Chapter (2010) tracked the following types of programs: pricing structure, goal-setting, toilet replacement, funding, outdoor water ordinances, nontoilet retrofit programs, and educational outreach. The state-level Alliance for Water Efficiency (2012) survey contained 19 observations, including items for water-efficiency products, state policies, meters, billing structure, and drought and other conservation plans. The Sierra Club Los Angeles Chapter (2011) published a review of water conservation policies and programs for the period between August 2009 and November 2010 in 122 cities located in Los Angeles and Orange Counties. They used 19 observations grouped into four categories: six restricted use (e.g., outdoor water use and waste), four residential water efficiency (toilet, shower, faucet, and appliance efficiency ratings), six commercial water efficiency (also including offering water and linen laundry on request, no single-pass commercial water cooling towers), and three miscellaneous efficiency practices (e.g., efficient landscape irrigation). They assigned one point if the policy or program applied to the city, and their scores ranged from 0 to 19 points.

In summary, there are already various approaches to developing a WCI. Although the indices developed by the environmental and water efficiency organizations have the advantage of pointing to additional types of WCPs that are not included in the AWWA data set, they are limited geographically. Building on both the scorecards and the AWWA survey questions, we developed a more comprehensive data set of WCPs of large cities in the U.S.

METHODS

A More Comprehensive Data Set of WCPs

To develop our data set of urban WCPs, we began with the policies in the AWWA survey and the scorecards of environmental groups. We also reviewed categories of WCPs described in a state-government best practice guide (State of California Department of Water Resources Office of Water Use Efficiency and Transfers, 2008) and in federal water conservation programs (U.S. Environmental Protection Agency, 2002, 2014; U.S. Department of Energy, 2014). Using the information from these sources, we developed a more comprehensive list of urban WCPs. The list focuses on policies that affect urban consumers (either residential or commercial/industrial), but it also includes some relevant water-supply system programs or policies such as system-wide leak detection. At the initial stages of data gathering, we combined some observations that were related but appeared only rarely. We also created a "miscellaneous" category that captured WCPs that did not fit our categories. Although few WCPs were added in this residual category, we wanted to be comprehensive and give credit to a city that, for example, had WCPs for agricultural or government customers or that had rebates not otherwise included. Using this strategy, we were able to build on previous research to construct a more detailed inventory than previous scorecards or the AWWA survey. A record of the coding decisions was kept, and the final list was for 79 urban WCPs. (See Appendix 1.) We recognize that no list of urban WCPs will be perfect and that improvements can always be made, but we suggest that to date our approach is the most complete.

The final set of 79 WCP observations was divided into five main categories: (1) residential requirements, rebates, and other (N=24); (2) commercial/industrial requirements, rebates, and other (N=36); (3) drought plan (N=5); (4) billing structure (N=6); and, a (5) general category (N=8). We used the categories of residential and commercial/industrial because the distinction appears in the policy descriptions themselves in urban codes and ordinances and also in existing scorecards that employ the distinction. We separated requirements and rebates because our previous research with a subset of cities indicated that more conservative cities may have a preference for rebates (Hess et al. 2016). We retained a separate category for billing structure because of the attention to the topic in the literature and the fact that billing categories were frequently implemented across customer types. We recognize that there are many possible ways to group WCPs and that ours is only one strategy.

Based on this inventory of 79 WCPs, it is possible to produce a wide range of WCIs that describe the differences and similarities in WCPs between American cities. In this paper we describe a summary WCI developed at the Vanderbilt Institute for Energy and Environment, which we call the “Vanderbilt Water Conservation Index,” or VWCI. This summary variable is based on the overall unweighted sum of all observations made for each city, with a possible range from 0 to 79. (See Appendix 2). We used an unweighted, summary variable because it provides an overall picture of a city’s WCPs and because it makes comparison with the AWWA survey data transparent. It is possible to create additional variables based on different types of policies within the broad category of WCP, such as appliance efficiency, outdoor watering restrictions, types of pricing, and drought programs. Although there will likely be improvements on our strategy and categories in the future, we suggest that this overall approach—developing a detailed data set from which different summary variables can be constructed depending on the goal of the researcher or policymaker—is a good next step in the methodology for the study of WCPs and the construction of WCIs.

Populating the VWC Database for Cities

This study is about urban WCPs rather than suburban or rural WCPs. We developed a sample of large U.S. cities by beginning with a list of all U.S. MSAs (N=382; U.S. Census Bureau, 2010). After estimating time and cost constraints, we decided to focus on the largest city in the largest 200 MSAs. We found that WCPs were very limited in the smaller cities outside arid regions, and hence variation was low for this group of cities. We could have sampled the 200 largest U.S. cities by population, but doing so would have concentrated the sample geographically by including more than one city in some MSAs and by eliminating some medium-sized MSAs. Thus, our sampling strategy increased geographical diversity, which was a factor that interested us for multivariate analyses. It is important to emphasize that our unit of analysis is the city, not the MSA. We cannot draw conclusions about the representativeness of the city for the entire MSA because we do not analyze all cities in an MSA.

Our goal was to capture a comprehensive range of policies and programs for each city. Unlike the AWWA survey, which is by water utility, we included multiple water utilities that serve the city where the city has more than one water provider. We also collected data by reviewing publicly available information obtained on the websites of city water departments, state and regional agencies, and commercial water providers as well as by reviewing city municipal codes. Thus, we examine all WCPs that were possible to identify regardless of institutional source. We believe that this approach is valuable in comparison with the AWWA approach because we avoid biases introduced by self-reporting and by non-reporting, and we include WCPs that are implemented by city governments or other governmental units.

Thus, our goal was to develop a comprehensive inventory of all of the WCPs in effect in a city rather than policies restricted to a specific organization. A policy or program may be based on the implementation of rules from higher levels of government, from programs developed by a utility or a city water department, or from an ordinance approved by a city council. Tracking the source of a WCP would require extensive and prohibitively costly interviewing, and even with interviewing it might not be possible to track all sources because people may not know the full history of the source of a policy or program. Future research may be able to divide WCPs by institutional source (state governments, city governments, water utilities, special water districts), but this task is beyond the scope of our project.

To gather the data, teams of three or more students reviewed the available information for each city (approximately 2500 hours total). Students were advanced undergraduates who generally had a related research interest and were selected from a competitive pool after a vetting process. The student team was supervised by Wold in consultation with Hess and the entire research group. The team met weekly in person to discuss the information identified by each student for each city and then decided on a final version of the water conservation coding for each city. We coded for 200 cities but eliminated three cities (Birmingham, Alabama; Flint, Michigan; and, Huntington, West Virginia) because of inadequate information.

The resulting data set is a binary matrix where a code of 1 was given if a city had a specified policy or program and a 0 if it did not. We did not give double credit at the state and local level; for example, we gave one point for “limits on washing vehicles” if the requirement existed at both the city level and at the state level. Again, our focus was on the policy or program in effect regardless of source. We also captured the web pages and available documents where we collected data in order to document the decisions for assigning a value for each observation.

Building the AWWA Data Set

We selected relevant survey responses from the 2010 AWWA Water and Wastewater Rates survey to build a data set of WCPs (American Water Works Association, 2010). There are nine items pertaining to water-demand management:

- Restricted use: survey participants are asked if the utility had imposed (1) voluntary and/or (2) mandatory water use restrictions in the past year.
- Special rates: respondents are asked if they have (3) implemented a special rate or surcharge during times of restricted use.
- Other water-related services: respondents were asked if they had implemented (4) a demand management program, (5) a xeriscaping program, (6) interior plumbing retrofits, (7) landscape water audits, (8) an education program, or (9) customer discounts.

We gave one point to each of the 9 items if the utility answered the questions above in the affirmative. We then summed all of the points to give each city a score ranging from zero to nine, which we refer to here as the AWWA-WCI. We identified 98 cities that were in the 2010 AWWA survey that were also in our database. We only compared cities in the contiguous 48 states, resulting in a comparative analysis of 96 cities. (See Appendix 2.)

Comparing the VWC Data Set to the AWWA Data Set

We then explored the correlation between the course-grained AWWA-WCI and the finer-grained VWCI. The two indices were scaled using max-min scaling (Han et al., 2011), which is defined as:

$$x_i' = \frac{x_i - x_{min}}{x_{max} - x_{min}} \quad (1)$$

where i refers to the i[th] city, x_i' is the scaled conservation score, x_i is the raw conservation score, and x_{min} and x_{max} are the minimum and maximum raw conservation scores respectively. Max-min scaling was performed for both the VWCI and the AWWA-WCI. One desirable feature of max-min scaling is that the scaled data are on the interval [0, 1], where the lowest raw score is equal to zero and the largest raw score is equal to one. In addition to the intuitive appeal of equal ranges for both indices, max-min scaling allows the direct calculation of percent differences between the VWCI and AWWA-WCI for a given location. The scaled indices are only used for the comparative analysis between the two indices.

We calculated correlation coefficients for the scaled VWCI scores and the scaled AWWA-WCI scores to explore degree of agreement between the VWCI and the AWWA-WCI. With both indices scaled and covering the same range of values, we were able to calculate the percent difference between the two scores for each city to highlight cities with significantly different conservation scores. The percent difference is:

$$d_i = \frac{100 * (VWCI_i - AWWAC_i)}{VWCI_i} \quad (2)$$

where i refers to the i[th] city for both indices, and d_i is the percent difference for each city.

RESULTS

VWC Database and VWCI

The VWCI scores range from a minimum of 3 (Anchorage, AK, and Baton Rouge, LA) to a maximum of 53 (Los Angeles, CA) with a median of 15 and a mean of 18.6 (Figure 1; see also Appendix 2). Cities with the highest VWCI scores were in the Southwest, particularly in California and Texas, followed by cities located in Florida and some scattered along the East Coast.

Figure 1. Map of VWCI scores for 195 cities in the contiguous United States. (Alaska and Hawaii are not included.)

Comparative Analysis

The VWCI and the AWWA-WCI are correlated with a Pearson's correlation coefficient (ρ) of 0.76 and Spearman-rank correlation of .64 (Figure 2, left panel). There are not any apparent systematic-spatial differences between the two data sets based on the percent differences (Figure 2, right panel). The frequency counts are crudely similar in shape (Figure 3).

Figure 2. Left Panel: Correlation of the scaled VWCI and AWWA-WCI. Right Panel: City-level percent differences between the two indices.

Figure 3. Frequency counts of VWCI and AWWA-WCI.

Small percent positive differences (VWCI > AWWA-WCI) are evident in several areas (e.g., southern California and Iowa-Nebraska-South Dakota). Small percent negative differences (VWCI < AWWA-WCI) are also represented (e.g., parts of Texas). Large percent positive differences (VWCI >> AWWA-WCI) indicate cities for which the AWWA-WCI is much lower than the VWCI, and large negative percent differences (VWCI << AWWA-WCI) indicate the opposite. In summary, although the indices are correlated, the VWCI captures the variability among cities at a higher resolution than is possible using the 9 self-reported items in the AWWA data set.

CONCLUSION

Existing methods to document WCPs lack coverage of the full range of policies and programs, nationwide spatial representation at the city scale, or both attributes. The results of this study contribute to the development of a more comprehensive and spatially extensive approach to the measurement of WCPs. The database has been populated for 197 cities and includes 79 observations. In order to demonstrate the types of variables that can be created from the VWC database, we calculated a summary index, the VWCI, which is the unweighted sum of all observations for each city and is made available for other researchers (Appendix 2). The highest VWCI scores are for cities in the Southwest, particularly in California and Texas, followed by cities located in Florida and scattered along the East Coast. The variability in the VWCI confirms uneven adoption of WCPs for cities. The variability in VWCI scores can be explained by a combination of socio-economic-environmental factors, most notably the aridity and political leanings of a region (Gilligan et al., 2017; Hess et al., 2016). The VWCI captures detailed WCP information for each city and is the most comprehensive U.S. WCI available to date.

Our summary index—an unweighted sum of all 79 WCPs—is one way to utilize the data for a general WCI variable. When the full data set is made available, researchers will be able to construct variables beyond the index presented here by combining, weighting, eliminating, or adding to the 79 observations. We note that the data set will have value for researchers who wish to study the causes and effects of WCPs, but it can also assist policymakers and policy advocates who wish to improve the range of WCPs in their city or to track their city's progress.

Although we think that our approach to the methodology of measuring WCPs represents a significant improvement over the more limited data sets currently available, the VWCI represents only a snapshot of WCPs during the time when the data were collected (August, 2014, though December, 2015). This limitation restricts the use of the VWCI to cross-sectional analyses unless the database is updated in future years. In contrast, WCIs created from the AWWA survey data include limited but valuable longitudinal information and therefore provide an advantage to researchers who wish to examine temporal trends in water conservation policy. Our comparative analysis suggests that the correlation between the VWCI and a simple index created from the AWWA database, the AWWA-WCI, lends some support for the use of the AWWA data set for longitudinal analysis, although the results for individual cities would not reflect the resolution possible with the VWCI.

We do not propose that the AWWA-WCI be used as a proxy for the VWCI, as there are marked differences between the two variables for specific cities (Appendix 2). The coarse nature of the AWWA-WCI can make the interpretation of differences more difficult than would otherwise be even in the face of high variability in potential explanatory variables. For example, 87 of the cities in our comparison data set overlap with the cities for which a water availability index has been determined (Padowski and Jawitz, 2012). The water availability index considers available water from both local runoff and water imported from surrounding basins. Both the VWCI and the AWWA-WCI are negatively correlated with the water availability index, a relationship that makes sense because lower water availability would likely contribute to use of WCPs, but the negative correlation is stronger for the VWCI (Figure 4).

Figure 4. The negative correlation of the water availability index (Padowski and Jawitz, 2012) is stronger for the VWCI than for the AWWA-WCI.

Notwithstanding the improvements represented by the approach discussed here, the relative agreement between the two WCIs provides some confidence in the WCP variables and scores calculated from the AWWA database. Thus, we suggest that there is continued value in using the AWWA survey data, especially for longitudinal research. However, the AWWA survey data are limited by the small number of WCP-related questions and dependence on self-reported answers. The shortcoming could produce null responses for utilities that may actually have the WCP policy, and it could exclude policies in effect for a city that are not implemented by utilities. If our data set were to be recoded every five years, it could begin to provide the basis for more comprehensive longitudinal analysis.

The improvement of methodologies for measuring WCPs is not merely a scholarly exercise of value to researchers. Because many cities face water stress, there is a need for research based on comprehensive summaries of WCPs. Utilities, advocates, and policymakers also need access to a comprehensive list of WCPs that could help them to evaluate where their city could make improvements. Because of the importance of the policy implications, we suggest that the AWWA could also consider including a larger set of WCPs and questions in future versions of its Water and Wastewater Rates surveys.

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APPENDICES

APPENDIX 1: Description of Variables in the Vanderbilt Water Conservation Database

APPENDIX 2: List of Cities and Conservation Scores

APPENDIX 3: Interactive Map of VWCI Scores for U.S. Cities

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APPENDIX 1: DESCRIPTION OF VARIABLES IN THE VANDERBILT WATER CONSERVATION DATABASE

Residential			
Requirements	1	Limits on Watering Hours/Duration/Days	Homeowners/tenants are required to water their lawns and/or gardens only during certain times of the day and/or certain days of the week
	2	Limits on Washing Down Hard or Paved Surfaces	Homeowners/tenants are prohibited from washing down driveways or sidewalks or may be limited to certain times of the day and/or certain days of the week and/or for sanitation purposes only
	3	Limits on Washing Vehicles/Equipment	Homeowners/tenants are prohibited from washing vehicles/equipment or may be limited to certain times of the day and/or certain days of the week; they may also be required to only wash their vehicles at a commercial carwash facility; they may also be required to only wash their vehicles with a sponge and bucket; or they may also be required to wash their vehicles with a shut-off nozzle
	4	Obligation to Fix Leaks, Breaks, or Malfunctions	Homeowners/tenants/landlords are required to fix any leaks, breaks, or malfunctions in the home
	5	Prohibit Excess Water Flow or Runoff	Homeowners/tenants/landlords are prohibited from allowing excess water flow or runoff; for example, leaving the hose on unattended or requiring use of a shut-off nozzle
	6	Require Water Recirculation for Fountains	Homeowners/tenants/landlords are prohibited from having a water fountain or other decorative water feature that does not recirculate the water; alternatively, they may be prohibited from having a water fountain or other decorative water feature or they may be required to use non-potable water
	7	Require Efficient Plumbing	Require that new or retrofitted construction have water-efficient toilets, faucets, showerheads, etc.
	8	Require High-Efficiency Appliances	Require that new or retrofitted construction have water efficient dishwashers, washing machines, etc.
	9	Require Efficient Irrigation Systems	Require that new or retrofitted construction have water efficient irrigation; for example a rain sensing sprinkler system
	10	Require Landscaping with Low-Irrigation Needs	Require that new or retrofitted construction is landscaped with plants and trees that reduces or eliminates the need for supplemental water from irrigation (also called xeriscaping)
	11	Require Efficient Pools	Require products and actions that improve the water efficiency of pools; for example, pool cover, pool maintenance, or prohibiting the draining of pools
	12	Miscellaneous Requirements	Listed in the notes

Rebates	13	Rebate Efficient Plumbing	Financial incentive for purchasing a water-efficient toilet, faucet, showerhead, etc.
	14	Rebate High-Efficiency Appliances	Financial incentive for purchasing a water-efficient dishwasher, washing machine, etc.
	15	Rebate Pools	Financial incentive for purchasing products that improve the water efficiency of pools; for example, pool cover or pool maintenance
	16	Rebate Efficient Irrigation Systems	Financial incentive for purchasing/installing water-efficient irrigation; for example, a rain sensing sprinkler system
	17	Rebate Landscaping with Low-Irrigation Needs	Financial incentive for landscaping with plants and trees that reduces or eliminates the need for supplemental water from irrigation (also called xeriscaping)
	18	Rebate for Rainwater Harvesting System	Financial incentive for setting up a rainwater harvesting system, including discounted barrels. Rainwater harvesting is the accumulation and deposition of rainwater for reuse on-site, including water for gardening, livestock, irrigation, etc.
	19	Rebate for Graywater Recycling System	Financial incentive for setting up a graywater recycling system; graywater is wastewater generated from wash-hand basins, showers, and baths, and it can be recycled for on-site usage
	20	Miscellaneous Rebates	Listed in coding notes.
Other	21	Graywater Recycling is Permitted	Homeowners/tenants/landlords are allowed to use graywater for toilets and/or landscaping (state or municipal provision)
	22	Water Audit	Homeowners/tenants/landlords have access to a water audit; indicate if the audit is for outdoor use, indoor use, or both; indicate if the audit is for high water users only; water audits are an analysis of a home's water use in order to identify ways to make it more efficient
	23	Partnership Programs	Partnerships with residents/homebuilders to promote the implementation of water-efficient equipment and strategies; for example, a labeling program; described in the notes
	24	Miscellaneous	Listed in the notes; including PACE (property-assessed clean energy) funding and loans
Commercial/Industrial			
Requirements	25	Limits on Watering Hours/Duration/Days	Owners/landlords/building managers are required to water their lawns and/or gardens only during certain times of the day and/or certain days of the week
	26	Limits on Washing Down Hard or Paved Surfaces	Owners/landlords/building managers are prohibited from washing down driveways or sidewalks or may be limited to certain times of the day and/or certain days of the week and/or for sanitation purposes only
	27	Limits on Washing	Owners/landlords/building managers are prohibited from

		Vehicles/Equipment	washing vehicles/equipment or may be limited to certain times of the day and/or certain days of the week; they may also be required to wash their vehicles only at a commercial carwash facility; they may also be required to wash their vehicles with a sponge and bucket; or they may also be required to wash their vehicle with a shut-off nozzle
	28	Obligation to Fix Leaks, Breaks, or Malfunctions	Owners/landlords/building managers are required to fix any leaks, breaks, or malfunctions in the apartment/building
	29	Prohibit Excess Water Flow or Runoff	Owners/landlords/building managers are prohibited from allowing excess water flow or runoff; for example, they cannot leave the hose on unattended or must use a shut-off nozzle
	30	Require Water Recirculation for Fountains	Owners/landlords/building managers are prohibited from having a water fountain or other decorative water feature that does not recirculate the water; alternatively, they may be prohibited from having a water fountain or other decorative water feature or they may be required to use non-potable water
	31	Require a Water Management Plan	Owners/landlords/building managers must develop and implement a plan for improving building water efficiency
	32	Require Efficient Plumbing	Require that new or retrofitted construction have water-efficient toilets, urinals, faucets, showerheads, etc.
	33	Require High-Efficiency Appliances	Require that new or retrofitted construction have water-efficient dishwashers (i.e. commercial pre-rinse spray valves), washing machines, ice machines etc.
	34	Require Efficient Irrigation Systems	Require that new or retrofitted construction have water-efficient irrigation; for example, a rain-sensing sprinkler system; indicate what the efficient irrigation applies to; for example, general purpose, golf courses, athletic field, public park, cemetery, agricultural, large property/land use (over 1 acre), etc.
	35	Require Landscaping with Low-Irrigation Needs	Require that new or retrofitted construction is landscaped with plants and trees that reduces or eliminates the need for supplemental water from irrigation (also called xeriscaping)
	36	Require "Non-Single-Pass Cooling Equipment"	Require that equipment with water-cooling needs use a water-efficient system; require cooling systems to maintain the proper temperature of the equipment. The types of equipment that require a cooling system include CAT scanners, degreasers, hydraulic equipment, condensers, air compressors, welding machines, vacuum pumps, x-ray equipment, air conditioners, etc.
	37	Require Efficient Carwashes Equipment	Require that new or retrofitted carwash facilities use water recirculation systems
	38	Require Efficient Cooling Towers	Require that new or retrofitted cooling towers are water efficient. Several steps can be taken to improve efficiency, including reducing the amount of blow down, control blow down using automatic controls, etc.
	39	Require Efficient	Require laundromats to have water recirculation systems

		Laundromats	
	40	Require Efficient Hotel Practices	Require commercial lodging establishments to provide guests with the option to decline linen services
	41	Require Efficient Restaurant Practices	Require restaurants to serve drinking water upon request
	42	Require Efficient Pools	Require products and actions that improve the water efficiency of pools; for example, pool cover, pool maintenance, or prohibiting the draining of pools
	43	Miscellaneous Requirements	Listed in the notes
Rebates	44	Rebate Efficient Plumbing	Financial incentive for water-efficient toilets, urinals, faucets, showerheads, pre-rinse spray valves, etc.
	45	Rebate High-Efficiency Appliances	Financial incentive for water-efficient dishwashers (i.e. commercial pre-rinse spray valves), washing machines, ice machines, coin-operated laundry machines etc.
	46	Rebate Pools	Financial incentive for purchasing products that improve the water efficiency of pools; for example, pool cover or pool maintenance
	47	Rebate Efficient Irrigation Systems	Financial incentive for water-efficient irrigation; for example, a rain sensing sprinkler system; indicate what the efficient irrigation applies to; for example, general purpose, golf courses, athletic field, public park, cemetery, agricultural, large property/land use (over 1 acre), etc.
	48	Rebate Landscaping with Low-Irrigation Needs	Financial incentive for landscaping with plants and trees that reduces or eliminates the need for supplemental water from irrigation (also called xeriscaping)
	49	Rebate "Non-Single-Pass Cooling Equipment"	Financial incentive for equipment with water-cooling to use a water-efficient system and for cooling systems to maintain the proper temperature of the equipment. The types of equipment that require a cooling system include CAT scanners, degreasers, hydraulic equipment, condensers, air compressors, welding machines, vacuum pumps, x-ray equipment, air conditioners, etc.
	50	Rebate Efficient Carwash Equipment	Financial incentive for water recirculation systems in commercial carwash facilities
	51	Rebate Efficient Cooling Tower	Financial incentive for new or retrofitted cooling towers that are water efficient; several steps can be taken to improve efficiency, including reducing the amount of blow down, control blow down using automatic controls, etc.
	52	Rebate Efficient Laundromats	Financial incentive for laundromats to install water recirculation systems
	53	Rebate for Rainwater Harvesting System	Financial incentive for setting up a rainwater harvesting system, including discounted barrels. Rainwater harvesting is the accumulation and deposition of rainwater for reuse on-site; including water for gardening, livestock, irrigation, etc.
	54	Rebate for Graywater Recycling System	Financial incentive for setting up a graywater recycling system; graywater is wastewater generated from wash hand basins,

			showers and baths, which can be recycled for on-site usage
	55	Incentive Program for Water Conservation Projects	Financial incentive or funding for large-scale commercial/industrial retrofits/construction projects to improve water conservation; for example, rebate for 50% of the cost of the project or $25 per 1,000 gallons of water saved annually
	56	Miscellaneous Rebates	Listed in the notes
Other	57	Graywater Recycling is Permitted	Owners/landlords/building managers are allowed to use graywater for toilets and/or landscaping (state or municipal provision)
	58	Water Audit	Owners/landlords/building managers have access to a water audit; indicate if the audit is for outdoor use, indoor use, or both; indicate if the audit is for high water users only; water audits are an analysis of a building's water use in order to identify ways to make it more efficient
	59	Partnership Programs	Partnerships with businesses/builders to promote the implementation of water-efficient equipment and strategies; for example, a labeling program; describe in the notes
	60	Miscellaneous	Listed in the notes, including PACE funding and loans
Drought Plan			
	61	Drought Plan Exists	Drought plan can be found at the city, regional, or state level; if drought restrictions have been in place for longer than 5 years, we will consider the restrictions as mandatory requirements
	62	Tiered Approach to Water Savings	Drought plan includes a tiered approach in which water saving programs are ratcheted up based on the level of drought severity
	63	Enforcement Mechanisms	Drought plan includes enforcement mechanisms; for example fines, water flow restricting, and discontinuation of service; listed in the notes
	64	Rate Increases	Increased water rates when drought conditions are present
	65	Public Information Mechanism	Public awareness campaign is implemented when drought conditions are present; for example, a website with drought related updates, outreach to news and media, etc.; describe in the notes
Billing Structure			
Residential	66	Increasing Block Rate	An increasing block rate is a rate structure in which the unit price of each succeeding block of usage is charged at a higher unit rate than the previous block(s). Increasing block rates are designed to promote conservation.
	67	Water Budget-Based Rates	A water budget-based rate is a rate structure in which households are given a "water budget" based on the anticipated needs of that household either by the number of people living in the house and/or property size. Users are charged a certain rate for use within their budget and a higher rate for use that exceeds their budget.

	68	Seasonal Rates	Seasonal rates cover a specific time period. They are established to encourage conservation during peak use periods. Examples of seasonal rates may be increases for the summer season due to increased demand associated with lawn watering and outside activities.
Commercial/Industrial	69	Increasing Block Rate	An increasing block rate is a rate structure in which the unit price of each succeeding block of usage is charged at a higher unit rate than the previous block(s). Increasing block rates are designed to promote conservation and are most often found in urban areas and areas with limited water supplies.
	70	Water Budget-Based Rates	A water budget-based rate is a rate structure where a business is given a "water budget" based on anticipated needs. Customers are charged a certain rate for use within their budget and a higher rate for use that exceeds their budget.
	71	Seasonal Rates	Seasonal rates cover a specific time period. They are established to encourage conservation during peak use periods. Examples of seasonal rates may be increases for the summer season due to increased demand associated with lawn watering and outside activities.
General Category			
	72	Public Information Programs	Public awareness campaign aimed at promoting water conservation. Examples include a website with water conservation tips, outreach to local schools, etc.; the program must be administered by the city/county/state government or water provider/utility; describe in the notes
	73	Permanent and Full Time Staff Conservation Staff	There are permanent and full-time staff members in charge of developing and implementing water conservation programs; for example, a water conservation manager. We include city sustainability departments if they also focus on water conservation.
	74	Enforcement Mechanisms for Requirements	Mechanisms exists for the enforcement of requirements; for example fines, water flow restricting, and discontinuation of service; listed in the notes
	75	Metering	A city where the majority of homes and businesses (over 50%) are metered; we give credit if the city billing structure is based on the amount of water used
	76	System Wide Water Audit, Leak Detection, and Repair	City/utility conducted a system wide water audit. We give credit if the city follows Advanced Metering Infrastructure or Functionality guidelines and/or if leak sensors are placed throughout. We only give credit if the city has conducted a water audit in the past 5 years; a water audit determines the amount of water loss from a distribution system due to leakage and the cost of this loss to the utility; water audits balance the amount produced with the amount billed and account for the remaining water (loss); comprehensive audits can give the utility a detailed profile of the distribution system and water users, allowing easier management of resources and improved

			reliability
	77	Desalination (Salt Water)	City/utility uses desalination for saltwater (e.g., seawater); desalination removes salt and other minerals from sea water to produce potable water for drinking and irrigation
	78	Desalination (Brackish Groundwater)	City/utility uses desalination for brackish groundwater
	79	Non-Potable Water for Construction Purposes	City/utility requires the use of non-potable water to wash down surfaces in order to reduce dust and other particulates

APPENDIX 2: List of Cities and Conservation Scores

VWCI score for 197 cities and AWWA-WCI score where applicable.

City	VWCI	AWWA-WCI	City	VWCI	AWWA-WCI
Akron, OH	12	0	Cleveland, OH	17	2
Albany, NY	13		College Station, TX	30	5
Albuquerque, NM	45	5	Colorado Springs, CO	20	
Allentown, PA	10	0	Columbia, SC	13	
Amarillo, TX	17	0	Columbus, GA	19	2
Anchorage, AK	3	0	Columbus, OH	15	1
Ann Arbor, MI	8		Corpus Christi, TX	25	2
Appleton, WI	6		Crestview, FL	10	
Asheville, NC	14	3	Dallas, TX	28	2
Atlanta, GA	23	1	Davenport, IA	4	
Atlantic City, NJ	15		Dayton, OH	15	
Augusta, GA	21	2	Deltona, FL	20	
Austin, TX	47	8	Denver, CO	43	6
Bakersfield, CA	23		Des Moines, IA	11	1
Baltimore, MD	12	0	Detroit, MI	5	
Baton Rouge, LA	3		Duluth, MN	12	
Beaumont, TX	12		Durham, NC	27	6
Binghamton, NY	13		El Paso, TX	38	
Boise, ID	13		Erie, PA	12	0
Boston, MA	20	0	Eugene, OR	22	3
Boulder, CO	24	5	Evansville, IN	12	
Bremerton, WA	12		Fargo, ND	14	
Bridgeport, CT	12	2	Fayetteville, AR	13	
Brownsville, TX	13	2	Fayetteville, NC	20	2
Buffalo, NY	12		Fort Collins, CO	37	5
Canton, OH	15	0	Fort Smith, AR	16	
Cape Coral, FL	21		Fort Wayne, IN	10	
Cedar Rapids, IA	17		Fresno, CA	44	
Champaign, IL	11		Gainesville, FL	24	4
Charleston, SC	12	0	Grand Rapids, MI	8	
Charleston, WV	8		Greeley, CO	23	
Charlotte, NC	16	1	Green Bay, WI	8	
Charlottesville, VA	20	6	Greensboro, NC	16	2
Chattanooga, TN	11		Greenville, SC	19	
Chicago, IL	14	1	Gulfport, MS	4	
Chico, CA	19		Hagerstown, MD	12	
Cincinnati, OH	13	1	Harrisburg, PA	11	
Clarksville, TN	7		Hartford, CT	15	

City	VWCI	AWWA-WCI
Hickory, NC	14	
Honolulu, HI	18	4
Houston, TX	18	1
Huntsville, AL	12	
Indianapolis, IN	16	
Jackson, MS	8	
Jacksonville, FL	27	2
Kalamazoo, MI	13	1
Kansas City, MO	13	
Kennewick, WA	14	2
Killeen, TX	13	
Kingsport, TN	4	
Knoxville, TN	12	1
Lafayette, LA	8	3
Lakeland, FL	30	0
Lancaster, PA	15	0
Lansing, MI	5	1
Laredo, TX	30	
Las Vegas, NV	40	7
Lexington, KY	17	
Lincoln, NE	18	2
Little Rock, AR	10	3
Los Angeles, CA	53	8
Louisville, KY	13	1
Lubbock, TX	16	
Lynchburg, VA	13	
Macon, GA	16	
Madison, WI	15	
Manchester, NH	13	
McAllen, TX	15	
Memphis, TN	8	
Merced, CA	26	
Miami, FL	38	5
Milwaukee, WI	6	1
Minneapolis, MN	8	1
Mobile, AL	7	
Modesto, CA	27	0
Montgomery, AL	10	
Myrtle Beach, SC	15	
Naples, FL	27	
Nashville, TN	15	1
New Haven, CT	14	

City	VWCI	AWWA-WCI
New Orleans, LA	5	1
New York, NY	35	1
North Port, FL	29	
Norwich, CT	7	
Ocala, FL	23	4
Ogden, UT	21	
Oklahoma City, OK	18	0
Olympia, WA	26	
Omaha, NE	15	
Orlando, FL	34	1
Oxnard, CA	49	
Palm Bay, FL	26	
Pensacola, FL	10	1
Peoria, IL	13	
Philadelphia, PA	10	2
Phoenix, AZ	21	5
Pittsburgh, PA	14	0
Portland, ME	8	
Portland, OR	12	4
Port St Lucie, FL	25	
Prescott, AZ	32	
Providence, RI	17	2
Provo, UT	21	4
Raleigh, NC	31	3
Reading, PA	9	
Reno, NV	26	4
Richmond, VA	8	0
Riverside, CA	45	6
Roanoke, VA	14	
Rochester, NY	11	
Rockford, IL	10	1
Sacramento, CA	34	7
Salem, OR	18	
Salinas, CA	40	
Salisbury, MD	13	
Salt Lake City, UT	35	3
San Antonio, TX	46	9
San Diego, CA	52	6
San Francisco, CA	42	
San Jose, CA	48	8
San Luis Obispo, CA	32	
Santa Cruz, CA	48	7

City	VWCI	AWWA-WCI
Santa Maria, CA	23	
Santa Rosa, CA	50	
Savannah, GA	22	2
Scranton, PA	8	
Seattle, WA	23	3
Shreveport, LA	5	
Sioux Falls, SD	28	3
South Bend, IN	8	
Spartanburg, SC	6	
Spokane, WA	14	
Springfield, MA	15	1
Springfield, MO	15	
St Louis, MO	10	0
Stockton, CA	37	
Syracuse, NY	11	
Tallahassee, FL	15	
Tampa, FL	35	
Toledo, OH	11	0
Topeka, KS	14	
Trenton, NJ	14	
Tucson, AZ	26	6
Tulsa, OK	11	2
Tuscaloosa, AL	8	
Tyler, TX	9	
Utica, NY	11	
Vallejo, CA	35	
Virginia Beach, VA	18	2
Visalia, CA	26	
Waco, TX	11	
Washington, DC	18	1
Wichita, KS	20	1
Wilmington, NC	12	
Winston, NC	14	2
Worcester, MA	17	
Yakima, WA	10	1
York, PA	17	
Youngstown, OH	12	

APPENDIX 3: Interactive Map of VWCI Scores for U.S. Cities

An interactive map of the VWCI scores for U.S. cities can be found at: http://scworland-usgs.github.io/vwci/ .

List of Figures

Figure 3. Map of VWCI scores for 195 cities in the contiguous United States. (Alaska and Hawaii are not included.)

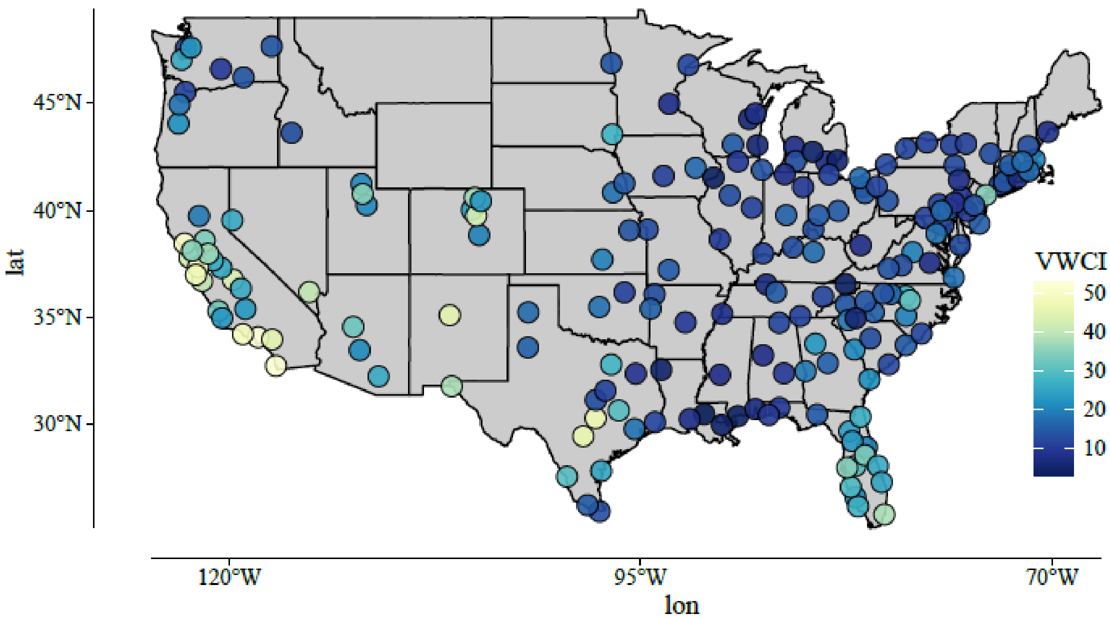
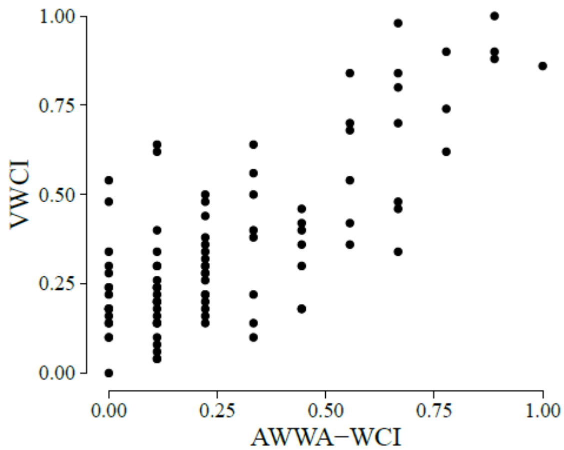


Figure 4. Left Panel: Correlation of the scaled VWCI and AWWA-WCI. Right Panel: City-level percent differences between the two indices.



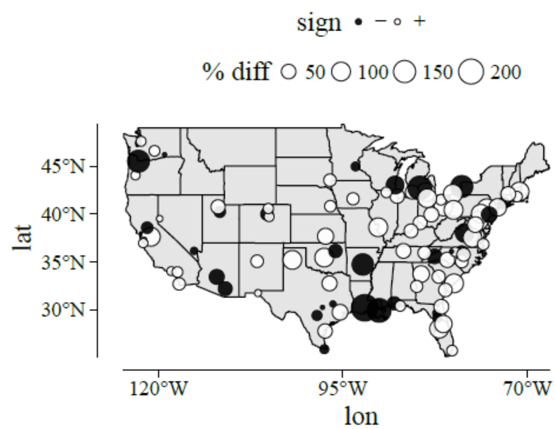


Figure 3. Frequency counts of VWCI and AWWA-WCI.

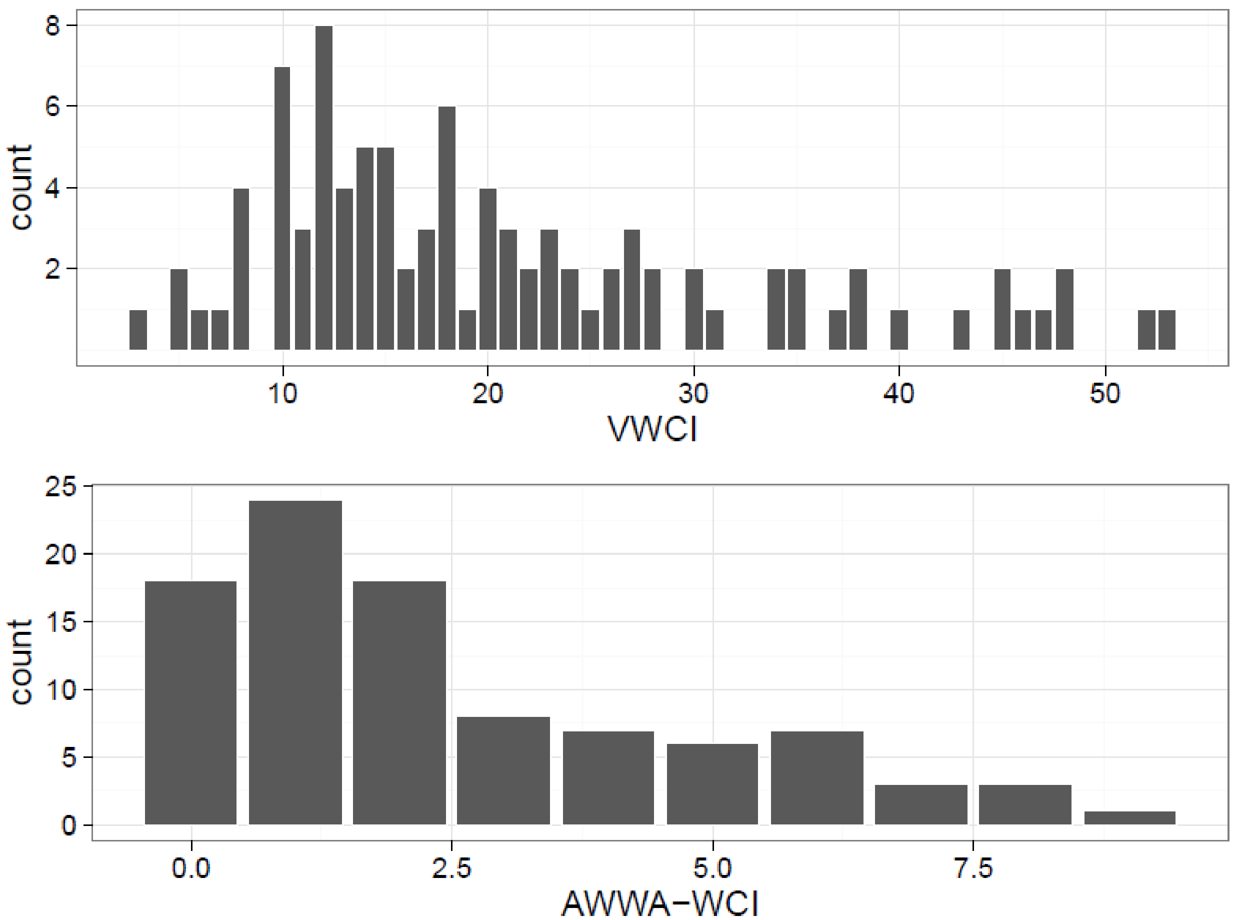


Figure 4. The negative correlation of the water availability index (Padowski and Jawitz, 2012) is stronger for the VWCI than for the AWWA-WCI.