Rural Alaska water treatment and distribution systems incur high energy costs: identifying energy drivers using panel data-analysis for 78 communities

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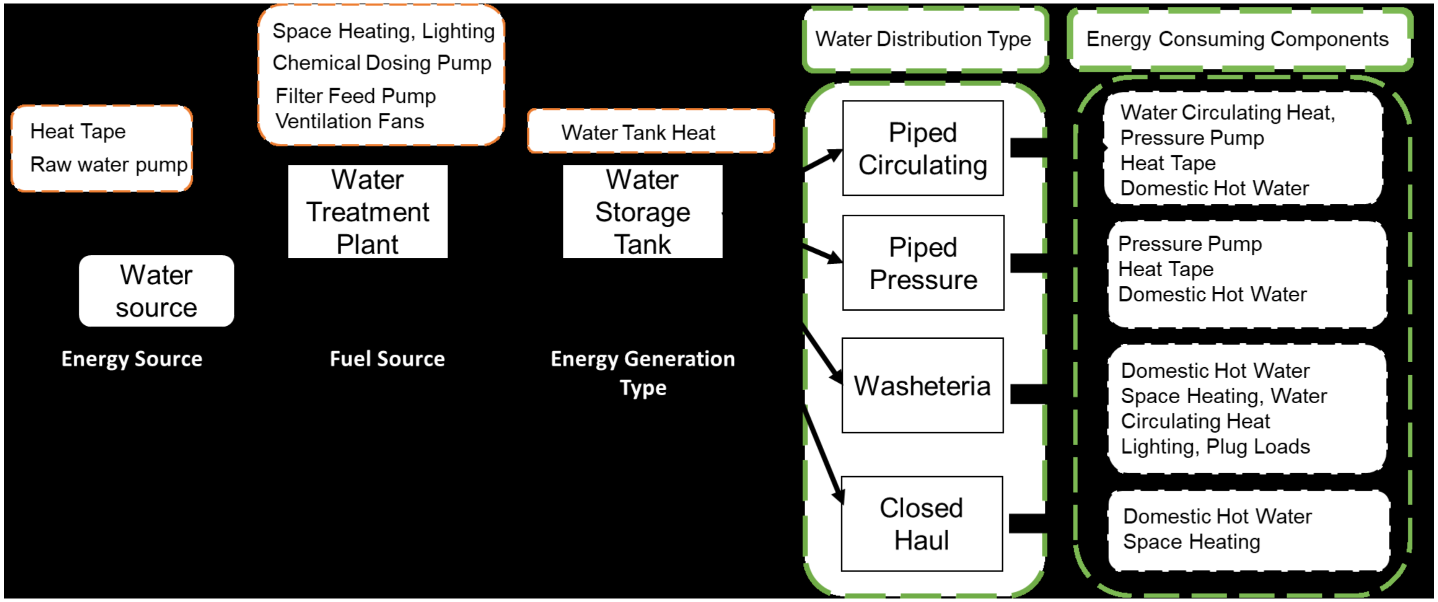
GRAPHICAL ABSTRACT



ABSTRACT

The energy consumption for water treatment and distribution in rural Alaska communities, that represent one of the coldest and most isolated regions in the U.S., has been unexplored. Using energy audits data from Alaska Native Tribal Health Consortium (ANTHC), we investigate the annual energy consumption patterns for water treatment and distribution in 78 rural Alaska communities (average population <500 people) along with seasonal, regional, and population variability, and water treatment/distribution system types. Regional trends of per capita annual energy consumption are as follows: Interior > Northern > Southwest > Gulf coast > Southeast regions of Alaska. Our results indicate that the per capita energy consumption is highest during the winter and lowest during the summer. Generally, the per capita energy consumption decreases with an increasing population. The variation of per capita energy consumption based on water distribution types shows that piped circulating systems consume the most energy, followed by washeteria, piped pressure, and closed haul. At the water treatment plant, space heating and electrical motors have the highest per capita energy consumption, followed by domestic hot water, tank heating, and lighting. Overall, the findings suggest that per capita energy consumption (kWh/p) for water treatment and distribution in rural Alaska is about 12-26 times higher than the national average and about two orders of magnitude higher economic costs for the same.

Keywords. *Rural Alaska; Water-Energy nexus; Water Distribution system; Water Treatment Plant; Oil; Energy consumption.*

Synopsis. Water treatment and distribution in rural Alaska is energy intensive with spatiotemporal variation depending on population, and distribution system types.

1. INTRODUCTION

While the availability of water resources is a basic life necessity essential for economic and social well-being – water supplies are being increasingly threatened due to climate change and increased demand.[1–4] The United States Geological Survey has reported that around 39,000 Mgal/day of water was withdrawn in 2015 for public water supply, which constituted almost 14% of total freshwater withdrawn that year.[5] Overall, water systems are responsible for consumption of nearly 4% of electricity produced in the United States.[6,7] Gradual decrease in non-renewable energy resources and deterioration of source waters poses a significant threat to continually meet high demand. In community water systems, energy is utilized for water source and conveyance, treatment, and distribution. Total energy consumption by water systems has been reported to be around 1500-3500 kWh/Mgal.[8] Overall, research in the area of 'energy-for-water' is currently underdeveloped across the U.S. and beyond, owing, in part, to a general lack of systematic process for energy data collection and archival at water utilities.[9] Alaska, the largest state in the U.S., is no exception to this larger trend. With harsh climate and being home to more than 200 remote and isolated communities, it is well documented that water and sanitation conditions in Alaska are one of the poorest in the nation.[10–12] The logistical challenges for the largest state in the country make data collection even more difficult. Community members and Tribal leaders all recognize that it is much more expensive to provide water services in remote Alaskan communities, than those in urban communities in Alaska or the contiguous U.S. There is, however, a woeful lack of specific data related to enhanced costs for these essential services in Alaskan communities – which motivates the analyses presented here.

Most of the rural communities in Alaska are inaccessible by road,[13] and 32 have no piped water distribution systems (unserved communities).[14] Also, most rural Alaskan communities are not connected to a large electrical grid, and instead operate individual diesel-powered microgrids.[15] These microgrids power the water and sewer utilities, that are built to withstand cold weather and permafrost ground conditions and thus consume more energy than those in the contiguous U.S. For example, pumping water and wastewater through the system accounts for 8-9% of the energy use of a piped system,[16] compared to the national average of 0.59%.[17] Water and sewer utilities typically use oil-based boilers for space and water-tank heating,[18] and the emergency back-up generators are diesel powered. To keep water from freezing in winter, electric heat tape is used in water distribution service lines.

Various types of water distribution systems are in place in rural Alaska including standard distribution, circulating distribution, individual wells, and closed haul.[19] Approximately 105 communities have standard distribution or circulating distribution systems, and 11 communities rely on covered haul systems[19] where water is delivered to homes using trucks and all-terrain vehicles (ATVs), and stored in cisterns.[20] Gasoline is used to power the trucks, ATVs, and snow machines for hauling water to homes. Electricity is used to pump water from the wells. Piped systems use electricity produced by diesel-fueled generators to pump water and wastewater through the pipes and in circulating systems (that continuously circulate water through the system to keep it from freezing in sub-zero temperatures). Wastewater is conveyed from a lift station to the sewage lagoon (typically) or wastewater treatment plant (rarely in rural Alaska). The distances of households from the pumping station and between each other impacts the energy usage for piped services for low-pressure or vacuum sewer systems. In winter, the water must be continuously heated to prevent freezing. Nonetheless, some piped water systems freeze every winter,[21,22] and operators try to prevent whole-system freeze-ups by applying heat tape and using blow torches on frozen pipes, both of which are energy intensive. Piped pressure systems are unidirectional water distribution lines that maintain pressurized water supply at the user end. On the other hand, piped circulating distributions systems maintain a circulating loop of water to keep it constantly moving which avoids water freezing (Figure S3). Most unserved communities have washeterias, which are centralized facilities with washers, dryers, showers and taps for treated water. These washeterias are unique to Alaska, are owned and operated by local governments and viewed as a cost-effective way to provide community access to treated water. These are like community laundromats in other rural regions but also have facilities for personal hygiene.

High energy costs for water along with hindered access to clean water negatively impact water-use practices in the rural Alaskan communities. An average of 64 Mgal of water is withdrawn and supplied every day in the entire state, with the average Alaskan using around 90 gal of water per day.[23] However, a survey of 21 rural northeastern Alaska communities reported that, in communities without piped water distribution facilities (unserved), each person uses only an average of 2.4 gal of water per day,[24] which is well below the World Health Organization's recommended >13.5 gal/day to ensure low levels of health concern.[25] In fact, rural Alaska has the lowest access rate to in-home water services within the United States. Residents in unserved communities self-haul water to their homes and haul their waste away.[10] Households rely on washbasins for handwashing and on "honey buckets" – buckets with a toilet seat on top – for toilets. In a recent study, 80% of participating households (in two remote, unserved communities) reported reusing washbasin water an average of 3 times before changing the water.[12] These result in a substantially lower standard of living, with unserved communities experiencing higher rates of skin, gastro-intestinal and respiratory diseases.[24]

It seems, thus, that there are several converging factors that contribute to this present scenario regarding water access and use patterns in rural Alaska – namely higher energy needs for water services, higher costs of energy itself, and lack of adequate water infrastructure in all communities or rural households. Consequently, it is critical to look at the provision of water treatment and distribution through an energy lens to help facilitate sustainable water infrastructure and public health for Arctic residents. Yet, to our knowledge, there are no studies on energy consumption for water treatment and distribution systems in rural Alaska. There is a gap between community needs and current understanding of energy use patterns, which hinders the adoption of cutting-edge solutions and identification of 'hot-spot' communities or regions to prioritize policy interventions. In this work we investigate spatiotemporal variation of the energy consumption for water treatment and distribution systems in rural Alaska. The overarching research goal inspiring this study is to understand the drivers of energy consumption for water treatment and distribution in rural Alaska. Specifically, we examine if and how the distribution system types, community population, and annual temperatures affect energy consumption for water treatment and distribution. We analyze one year of monthly panel data for more than seventy rural Alaska communities to develop models of energy consumption and compare the estimates to actual data. Overall, this work sheds light on energy-use for water treatment and distribution in rural Alaska and establishes a baseline which would be useful for the rural Alaska communities' adaptation to climate change efforts, specifically in planning for and designing new water systems or updated existing systems.

2. DATA AND METHODS

Data.

We used energy audit data for 78 rural communities obtained by the Alaska Native Tribal Health Consortium (ANTHC), which conducted surveys to determine total energy consumption for water treatment and distribution in rural Alaska communities.[16] The list of communities is provided in Table S1. The rural communities in Alaska are distributed throughout the Northern, Interior, Southwest, Gulf Coast and Southeast regions which have been classified based on the Alaska Department of Labor delineation (Fig. 1). Among the total communities considered in this study, 35 communities are spatially clustered in the Southwest region, 18 in the Northern region, 17 in the Interior region, and remaining 8 in the Gulf Coast and Southeast regions. The data from energy audit surveys consists of electricity data (kilowatt-hours; kWh), #1 heating fuel oil data (gallons), spruce and birch wood data (cords), and heat recovery system data (million BTUs). To calculate the total energy consumption by the water utilities, all data were converted to kWh using conversion factors listed in Table S4. Each community's boiler efficiency for energy generation was accounted while converting gallons of heating fuel oil to kilowatt-hours (Table S5). To estimate per capita consumption, population data was obtained from the US Census.[26] Heating degree days (HDD) which is a measure of temperature over a specific time-period and is often used to determine the energy needs for heating buildings,[27–29] was used as a proxy for ambient temperature. Information on the water system type was obtained from the Alaska Department of Environmental Conservation[30] and communities were clustered based on their respective water system types. Finally, the energy data for water treatment and distribution was queried for (i) temporal (January-December) trends, (ii) spatial variability by geographical regions (Southwest, Interior, Gulf Coast, Northern, and Southeast), (iii) effects of community population, (iv) water distribution system (WDS) types, and (v) water treatment plant (WTP) units.

Statistical Analysis.

To understand the differences in total energy consumption contributed by different factors, we performed one-way analysis of variance (ANOVA) using per capita total annual energy consumption as response variable, and community population number, temporal trends, geographic regions, and WDS types as input variables. We also conducted post-hoc analysis using Tukey's honest significant difference test to do the pairwise comparison between the geographical regions. All data were checked for normality using the Shapiro-Wilk test[31]. Statistical significance was set at $\alpha = 0.05$, and R programming language was used for all the analyses (R Core Team, 2013).

Panel Data Analysis.

Random effects (RE), and fixed effects (FE) modeling approaches were used to analyze the determinants of energy consumption. The models were developed in R using the plm package,[33] to investigate correlations of energy use (kWh) and per capita energy use (kWh/capita) with predictor variables that included the month of the year, HDD, community population, region, and water distribution system type. Of the 78 communities under consideration, data from 73 were used in this modeling exercise, as complete information for all the independent predictor variables was available only for those communities. The Driscoll-Kraay standard errors are reported to correct for heteroscedasticity and serial cross dependence.[34] Following RE models (equations 1 and 2) were used to explore how differences between communities' impact energy consumption.

$$kWh_{it} = \beta_0 + \beta_1 Month_t + \beta_2 HDD_{it} + \beta_3 Population_{it} + \beta_4 Region_{it} + \beta_5 System_{it} + \alpha_{it} + \varepsilon_{it} \qquad (1)$$

$$kWh/Capita_{it} = \beta_0 + \beta_1 Month_t + \beta_2 HDD_{it} + \beta_3 Population_{it} + \beta_4 Region_{it} + \beta_5 System_{it} + \alpha_{it} + \varepsilon_{it} \quad (2)$$

Where *'i'* represents a community and *'t'* is the time-period. *'kWh'* is the monthly energy used by the drinking water utility in kWh. *'kWh/Capita'* is the per capita monthly energy consumption in kWh. *'Month'* is a time dummy variable representing the month and '*HDD'* is the number of heating degree days. *'Population'* is a discrete variable while *'Region'* and *'System'* are dummy variables for the region of Alaska and the type of water system. The error term is represented by '*ε*', and the term *'α'* represents unobserved effects, which are assumed to be uncorrelated with the predictors.

FE models (equations 3 and 4) are used to reduce the risk of omitted variable bias. Each village has unique characteristics, such as location or tribe, that remain constant over time (time invariant). These characteristics may impact or bias the predictor variables.[35] In FE models the time invariant characteristics are removed through the fixed effects transformation, which also reduces the risk of omitted variable bias.[35] It is assumed that changes in energy consumption in a village can only be due to changes in time variant variables, which are represented by the estimated coefficients. The estimated FE models are as follows:

$$kWh_{it} = \beta_0 + \beta_1 Month_i + \beta_2 HDD_{it} + \varepsilon_{it} \quad (3)$$

$$kWh/Capita_{it} = \beta_0 + \beta_1 Month_i + \beta_2 HDD_{it} + \varepsilon_{it} \quad (4)$$

Correlating energy data*.*

The energy consumption by different units of WTP is a modelled data collected from AkWarm,[36] a publicly available software tool that uses historical energy use data and correlates with local weather to provide maximum accuracy in predicting energy use of various electrical units of water treatment and distribution systems. We correlated total annual energy consumption data from different communities collected from ANTHC audit data with AkWarm based modeled data to understand the closeness between the surveyed and AkWarm generated model data used in this study.

3. RESULTS AND DISCUSSION

Regions and communities included in this study are pictorially represented on the map in Fig. 1. The study area, communities, population, and descriptive statistics of variables of the panel data analysis are presented in Tables 1 and 2. Detailed information for each community is provided in Table S1. Study sample is diverse with the population size ranging from 30 to 3,270. The number of annual HDDs ranges from 6,290 to 12,452. The overall energy consumption and per-capita energy consumption vary between communities. The Interior communities in the study have the lowest population of the sample, with an average population of just 163 people. The Gulf Coast communities in the study are only slightly bigger, with an average population of 201. Southeast communities in the study have on average over 800 people and southwest have an average population of 1,048. The northern communities have an average size of 572 people.

Water Distribution System (WDS) Impacts.

The annual per capita energy consumption varied based on WDS types (Fig. 2A). We found that the annual per capita energy consumption was highest for piped circulating systems (1100 kWh), followed by washeterias (1000 kWh), closed haul (800 kWh), individual wells (550 kWh), and, lastly, piped distribution (300 kWh). The high energy consumption in piped circulating systems is likely due to continuously heating cold water and circulating it through the distribution loop during winter. Energy consumption for washeterias and closed haul systems was comparable, as water is not pumped for distribution in both cases, and many closed haul communities also operate washeterias. The energy requirements in washeterias include the use of washers, dryers, showers, bathrooms, and potable water supply. It is to be noted that electricity consumption of washer and dryers is included for communities served by washeterias but not for other categories. It is challenging to separate this from the overall washeteria energy consumption based on available data. As per some estimates,[37] however, an average American household may use as much as 950 kWh/year on washers and dryers (assuming 6 hours/week operation of each) – though the weekly usage of washer and dryer in the rural Alaska communities using washeteria facilities may be lower than the national average estimates. In a closed haul system, water is either transported from a single watering point to multiple households using fossil fuel powered vehicles or individual households are responsible for collecting water themselves – though transportation costs were not accounted for in the analyses. For individual wells, energy consumption solely depends on lifting pumps that withdraw and transport water from the source to the household. The data show that only two out of 78 communities used individual wells, and those two communities had a population of less than 200. Thus, more data on the energy consumption for individual wells is required to get a comprehensive understanding. Conventional buried piped pressure distribution systems consume the least amount of energy but are not possible in many Arctic and sub-Arctic communities due to permafrost soils.

Population and Regional variations.

Annual per capita energy consumption tends to correlate negatively with population (Fig. 2B). As the communities are completely off grid, power is typically generated in each community by individual diesel generators. It is likely that sparsely populated communities cannot scale to create generator efficiency and lack the benefit of economies of scale observable in communities with larger population size. Per capita energy consumption varies significantly by geographic location ($p = 2.65 \times 10^{-6}$; Fig. 2C). Interior Alaska communities had the highest annual per capita energy consumption, followed by Northern, Southwestern, Gulf Coast, and then Southeastern region. Regional weather and mean annual temperatures vary among communities which likely influences the observed energy use patterns here. Interior Alaska, away from the sea and bound by the Brooks Range and Alaska Range from the north and south respectively, experiences extreme temperature variations with cold winters and warm summers. Southwest Alaska has a maritime climate dominated by the Bering Sea and the Gulf of Alaska (Fig. 1), with moderate temperatures and less precipitation. The Gulf Coast region is in southcentral Alaska near Gulf of Alaska, bordered by Alaska mountain ranges on the north-west side and by the Chugach Mountains on the east.[38] Southeast Alaska has milder winters and more precipitation throughout the year, making it the warmest part of the state. Thus, energy consumption for heating remains the lowest compared to other regions. In general, regions at lower latitudes consumed less energy per capita. Apart from weather, another factor driving these trends (Fig. 2B) is population. Interior Alaska communities show higher per capita energy consumption than the northern communities even though belonging to similar latitude range due to lower mean population for the Interior communities (Table 2).

Seasonal Impacts.

Energy consumption for water treatment and distribution follow seasonal trends in rural Alaska (Fig. 2D). Seasonal temperature variation between summer and winter months has a significant correlation ($p < 0.05$) on energy consumption. This is, in part, owing to heating up the water in source waterlines and distribution network to prevent freezing in subzero temperatures; also, selfhauling requires fossil fuels to transport water from the washeteria or watering points to individual houses though transportation fuel was not considered in the energy audits. As heating is not required in summer months, the energy consumption is substantially lower. On average, in winter months, oil consumption is around 1.8-2.2 gallons/person, and in summer it is only 0.2-0.4 gallons/person (Fig. S1). The mean per capita energy consumption is around 120 kWh/person in winter and 30-40 kWh/person in summer.

WTP Energy Consumption Breakdown.

AkWarm based modeled total annual energy consumption data was linearly correlated with ANTHC based annual energy survey data (Fig. S2). Therefore, modeled energy consumption data was considered to evaluate the component-wise breakdown of annual per-capita energy consumption for different distribution system types. WTPs play a critical role in treatment and storage of source water, and the operation and maintenance of WTPs requires substantial energy. Depending on the WDS types, the energy consumptions by different components at WTP including space heating, raw water heat, tank heat, domestic hot water, water circulation heat, ventilation fans, lighting, and other electricals vary significantly (Fig. 3). Within all types of WDS except piped circulatory system, space heating is the dominant energy consumer followed by other electricals, domestic hot water, tank heating, and lighting. Most WTPs in Alaska are built indoors to prevent freeze-ups, and thus need space heating. Diesel powered boilers are used to heat glycol that radiates heat through space heaters. In some communities, heat recovery systems result in energy savings.[39,40] Other electricals, including pumps, air compressors and miscellaneous plug loads, are the second-highest energy consumers. Four types of pumps are common in WTPs: water pumps carry water from the source to storage tanks; chemical feeding pumps maintain the chemical ratios in the coagulation-flocculation process; and backwash pumps clean multigrade sand filters; and pumps continuously move water through distribution systems in circulating systems. These operations are common and vary with level of treatment based on the community water quality requirements and financial conditions. Lights used in WTPs are one of the highest sources in the other electrical loads category, likely due to low levels of daylight in winter. Usually, fluorescent lights are used in indoor locations such as mechanical rooms, boiler rooms, bathrooms, and pump houses. In outdoor or exterior locations, high-pressure sodium lights are generally used to withstand adverse weather conditions. Some miscellaneous use in WTPs includes laptops, radios, coffee pots and mini fridges. In piped circulating WDS which distributes water to maximum communities in Alaska, water circulation heat is the highest energy consumer followed by other electricals, space heating, tank heating, raw water heat, lighting, and ventilation fan.

Panel Data Analysis.

The statistically significant estimates of the panel data analysis are presented in Table 3. Seasonal variation is present in both the FE and RE models of overall energy consumption. Using April as the base month, we find that energy consumption is significantly lower during the months of May ($p<0.1$), June ($p<0.05$), July and August ($p<0.1$), and September ($p<0.05$). While the seasonal variation is not significant in the per capita models, the number of HDDs is significant ($p<0.01$) with a one unit increase in HDDs increasing per capita energy consumption by almost 200 BTU. Population has a significant impact on energy consumption: overall energy consumption increases by 148,070 BTU with every additional person ($p<0.05$), but per capita energy consumption decreases by 87 BTU ($p<0.1$). The type of water system does not have a statistically significant impact on energy consumption and the coefficients are omitted from Table 3.

Potential Study Limitations.

The sample size used in the study may be biased and unrepresentative, as we used readily available data from energy audits performed by ANTHC. The selection process to select communities to audit is unclear and may introduce bias in the population. The effects of a possible biased sample, however, are mitigated by the inclusion of ~40% of Alaska's rural communities from regions across the state. Another limitation stems from data availability. In remote areas, data collection is challenging due to missing records of fuel and electricity usage, a lack of staff dedicated to data tracking in the utilities, and the general inaccessibility of many of these off-grid communities. Better estimates would be generated by using the number of people served by utilities instead of the overall population of the community, which is often larger. However only a few utilities collect these data, and few make the data publicly available. The effects of the data gap are mitigated by the fact that unserved households still access community water services at the washeteria or by going to served households. Additional studies are needed to confirm the findings.

High Water Costs in Rural Alaska.

While it is common knowledge for rural Alaska residents and Tribal governments that basic services such as water are very expensive in rural Alaska, specific estimates for the magnitude of energy costs for water are lacking – owing to lack of data and/or dedicated analyses. U.S. average national energy consumption for water sourcing, treatment, and distribution ranges 1100 – 2300 kWh/million gallons,[17] which combined with a national average per capita water consumption of 85 gal/day/person[41] translates to 36 – 75 kWh/person for residential water supply. From this study we see that average per capita annual energy consumption for water withdrawal, treatment and distribution in rural Alaska is around 940 kWh/person (Figure 2, Table S1) -- about 12- 26 times higher (kWh/p) than the national average. Combined with five to ten-fold higher electricity generation costs in U.S. compared to the national average,[42,43] this translates to approximately 60 to 260 times higher costs for water sourcing, treatment, and distribution in rural Alaska as compared to the national average. While shocking, these high costs for water are not unexpected given the myriad challenges for rural Alaska communities discussed above including remoteness, extreme weather, and small community sizes.

Broader Implications

Access to safe and affordable drinking water is increasingly perceived as an environmental justice issue.[44,45] This work highlights the high costs of water access in rural Alaska communities as a prime factor driving equitable access to water. Such observations extend not only to rural regions outside of Alaska[46] but also to the urban fringe globally.[44] Across the United States, clusters of communities lack sustainable access to in-home water services including those at the Texas-Mexico border (the Colonias),[47] the Navajo Nation,[48] and the Appalachian region.[49,50] And beyond the U.S., there are several remote Arctic communities in Canada,[51,52] Greenland,[53] and Russia[54] that also face similar water access and water security challenges. Overall, this work presents a framework that can be used in other water insecure regions in the U.S. and beyond to assess drivers of residential water costs, to provide a comparative benchmark, and to help identify factors that can drive policy.

4. CONCLUSIONS

Water distribution systems can be expensive to operate and more so in rural Alaska, as we have shown here. Government agencies like the Alaska Department of Environmental Conservation lack sufficient data in these areas, and we hope this study may complement their existing database by incorporating various parameters that may help forecast energy requirements for future water needs of these communities. Rural Alaska communities often struggle to obtain adequate funding to maintain and operate existing water services. To help rural Alaskans balance out these differences, the Power cost equalization (PCE) program was introduced by the state government in 1984 to subsidize electricity. However, not all the communities are under the PCE program. Due to data unavailability, impacts of the PCE program were not included in this study.

The results of this study not only quantify the energy costs for water in rural Alaska, but also provide baseline information for policymakers as well as help Tribal governments and related organizations to make their case while applying for funding for water-related infrastructure improvements. Specifically, the results from this work can help guide water system selection for communities installing new systems as well as improvement of energy efficiency of the existing water systems, by prioritizing those that are more energy-intensive or focusing on the more energy inefficient components. For example, for pipe re-circulating systems, performing a cost-benefit analysis of adding extra insulation around the pipes may be recommended.

Supporting Information

Additional details of community specific energy consumption for water treatment and distribution in rural Alaska.

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Disclosure

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TABLES

Table 1. Descriptive statistics of the spatiotemporal variables included in the study

Variable	Mean	SD	Min	Max
Heating Degree Days (Monthly)	1,037	590	138	2,863
Population	407	417	30	3,270
Energy Use (BTU)	9.85×10^7	1.27×10^8	0	9.86×10^8
Energy Use per Capita (BTU)	320,608.90	342,498	0	1,809,914

Table 2. Number of communities included in the study, their population and total rural communities and total regional population

Region	Communities in Study	Population in Study	Total Rural Communities	Total Rural Population in Region
Northern	18	10404	37	27,484
Interior	17	2821	59	12,908
Gulf Coast	4	691	37	22,114
Southeast	4	2,419	41	40,798
Southwest	35	15895	92	42,295

Table 3: Statistically significant estimates of the panel data analysis.

	Fixed Effects		Random Effects	
	Per Capita kWh	**Total kWh**	**Per Capita kWh**	**Total kWh**
Population			-0.02**	41.87**
Month (Base = April)				
June	-13.31	-11,431.51***	-14.17	-11,502.99***
July	-11.88	-10,857.84**	-13.17	-11,111.93**
August	-12.43	-9,874.64**	-13.86	-10,229.37**
September	-12.68	-9,051.04***	-14.12	-9,522.45***
Heating Degree Days	0.06**	8.93**	0.06**	9.03**
Region (Base = Gulf Coast)				
Southeast			-4.57	-15,829.46*
R^2	0.41	0.30	0.42	0.32
p-value	$5.98e^{-80}$	$3.77e^{-52}$	$6.51e^{-110}$	$1.49e^{-67}$

All continuous predictors are mean-centered and scaled by 1 standard deviation.
Significant at the *10% level, **5% level and ***1% level

FIGURES

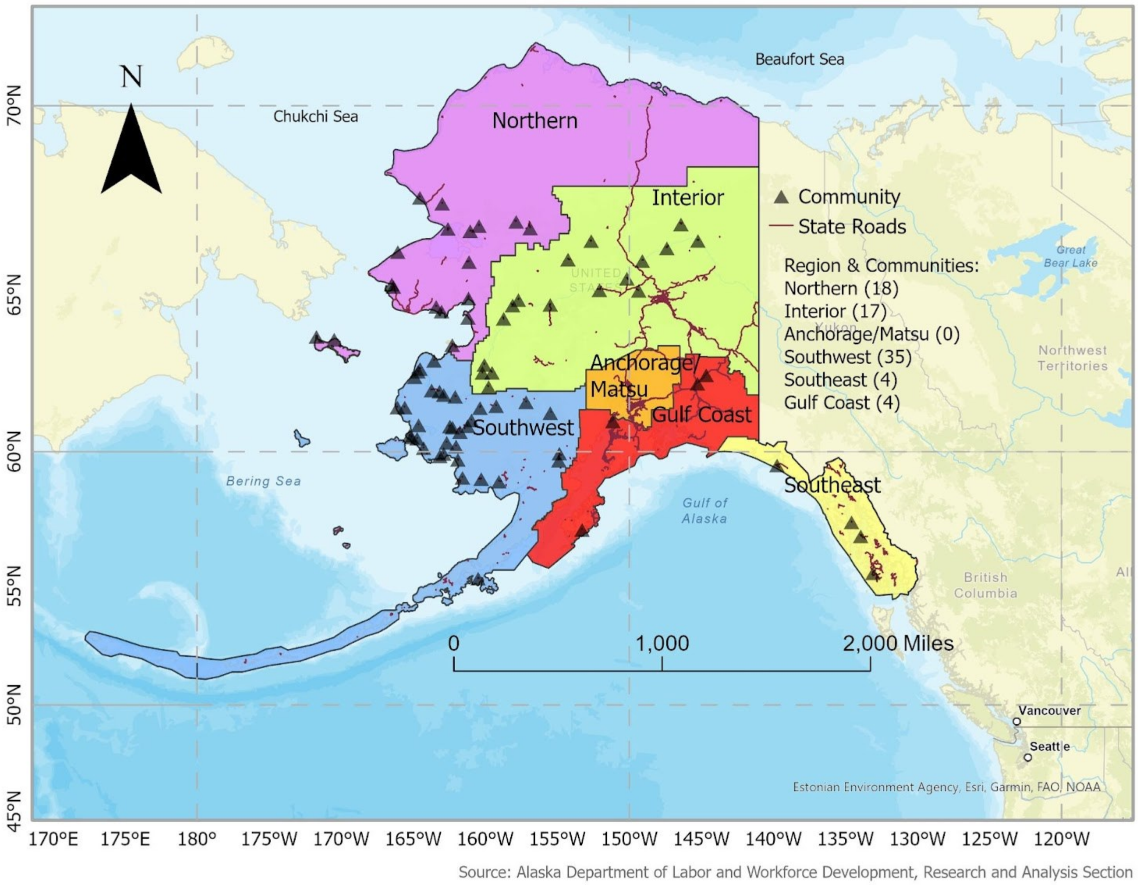

Figure 1. Map shows rural communities (n=78) in the state of Alaska selected for this study representing five geographical regions. Most of the communities are located in remote locations without road access. The map has been prepared using ArcGIS online platform by putting the coordinates for various remote communities selected in this study.

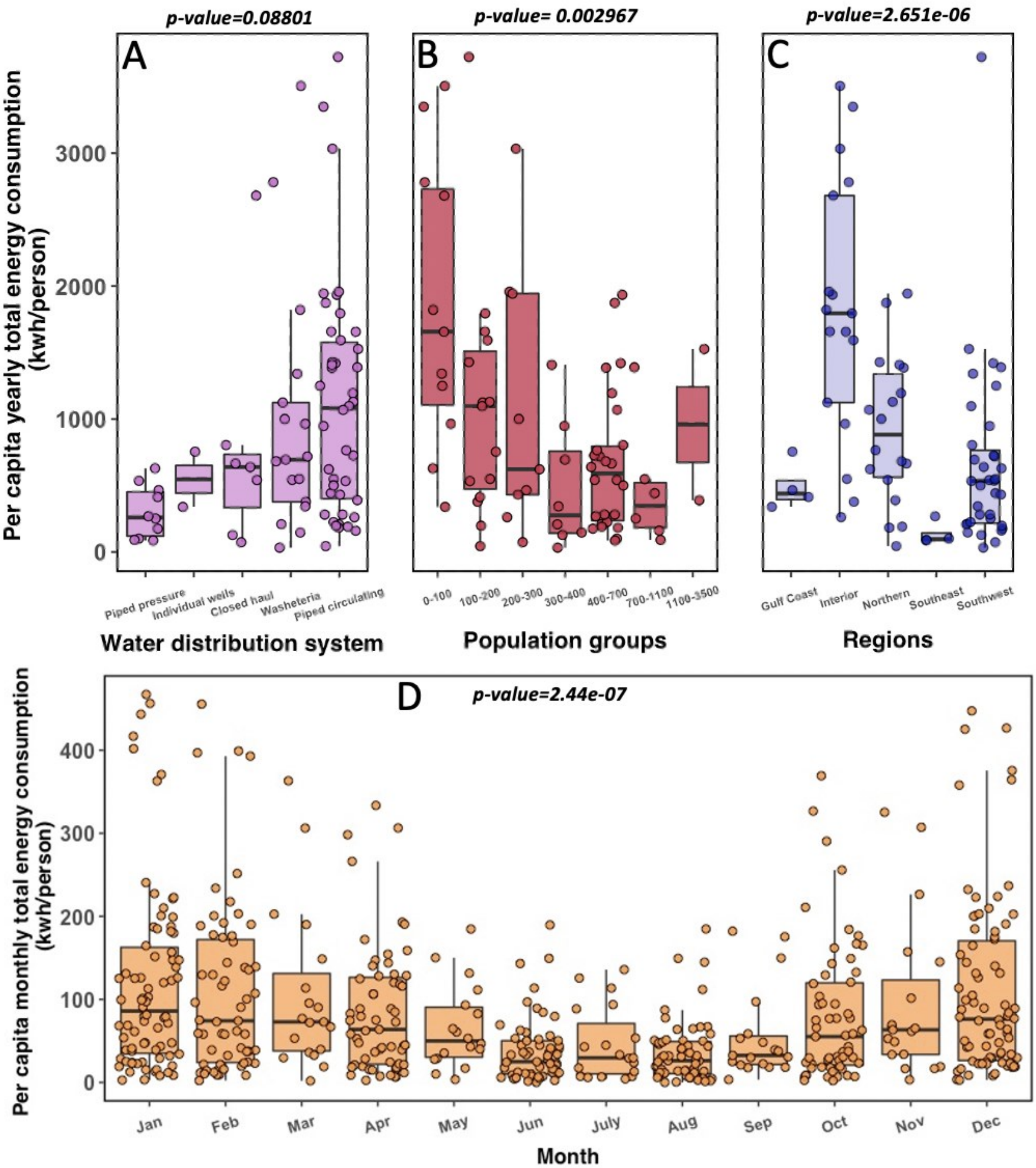

Figure 2. Per capita annual energy consumption in rural communities (n=78) based on water distribution system types (A), population range (B), geographical regions (C), and month of the year (D).

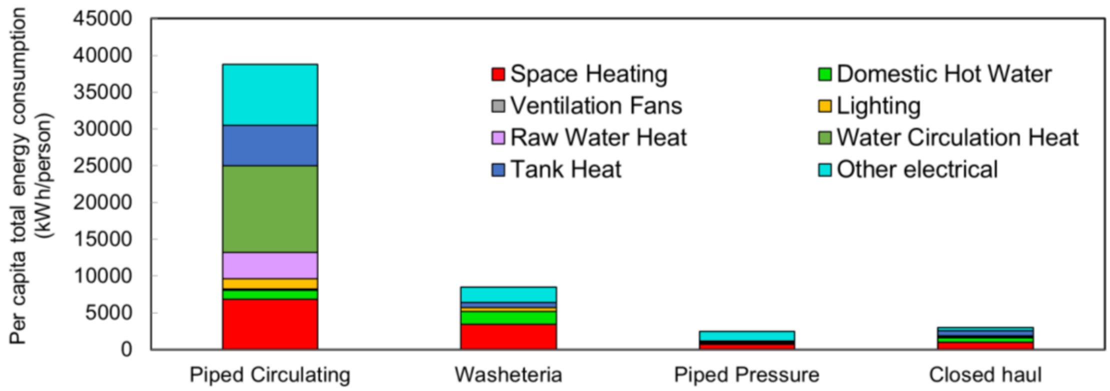

Figure 3. Component-wise breakdown of annual per capita energy consumption for water treatment and distribution in rural communities (n=78) based on the water distribution system type