Quantifying and Modeling Global Water Accessibility including Water Typology

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1-8-21

1 Introduction

In 2017, 29% of the global population (2.2 billion people) did not use a safely managed drinking - water service which is defined as water located on-premise, available, and free from contamination (Organization, 2020). If you meet about 100 people, you can imagine that 29 of the people you meet do not have access to improved drinking water. Another recognition is that many people spend a lot of time collecting water where their access to drinking water supplies located on-premises are not common, about 26.3 percent of the world's population (A. Cassivi et al., 2018). Where this raises concerns about inequality problems related to the task and time variation to collect water can be inferred in the urban and rural areas (A. Cassivi et al., 2018). Therefore, there needs to be a great motivation to bring improved drinking water sources to all people to improve their quality of life.

Globally, access to improved drinking water sources and sanitation is increasing. From 1990 to 2012, utilization of improved drinking water sources has increased globally from 76 percent to 89 percent, and utilization of improved sanitation has increased from 45 percent to 64 percent (Fuller et al., 2016). According to the MDG categorization, they consider improved drinking water sources as following: public tap, borehole, protected spring, rainwater collection, bottled water source, and piped water (Bartram et al., 2014). However, these variables do not truly explain if the households have speedy access to retrieve the water. Therefore, we will investigate further on what variables should be included to enhance the accessibility of improved drinking water.

In the next section we discuss relevant prior research on water accessibility quantification. We are interested in what type of modes of transportation are utilized to provide clean and drinking water to the community. Also, we desire to learn more about the time it takes to transport water to the community in a global modeling context. So that we can develop and quantify water accessibility in different countries to compare different trends. Also, we will be exploring the most efficient and effective modes of transportation of accessible water. Therefore, the new models will be able to influence and encourage policymakers in specific countries to improve water accessibility for all. Next we present the data and methods of approaching the quantification of the water accessibility.

2 Relevant work

Jagals (2006) highlights in his case study in rural area in South Africa discovered providing small communities, using untreated river water as their water source, with good quality water with a piped distribution system and increase of accessibility by installing communal taps did not fall within parameters of safe water. Their research gives a potential understanding even making the drinking water accessible might not improve the quality of the water itself.

Onda, LoBuglio, et al. (2012) discusses the global access to safe water by accounting for water quality and the resulting impact on MDG progress. They altered the current Joint monitoring programme (JMP) estimation by including for microbial water quality and sanitary risk utilizing national water quality data. Onda, LoBuglio, et al. (2012) used principal components analysis to analyze the national environment and development indicators and then created models. Overall, our analysis can highlight the potential fatigue illness caused by people transporting the water if it is done manually. How the modes of transportation can affect one's health.

Sima et al. (2013) highlights the relation of the topic where it discovered that over 76 percent of the city's water is utilized by less than ten percent of household piped water. The study is focused in Kisumu Kenya and Sima interviewed 260 informal water business operators. This article revealed a new insight where the majority of the population in Kisumu relied on purchased water from kiosks (1.5 million m^3 per day) and used hand-drawn water-carts (0.75 million m^3 per day)(Sima et al., 2013). Also, we discovered that the water trucking industry utilized the most energy consumption and was high cost: water delivery trucks have the highest per cubic meter energy demand (35 MJ/m^3)(Sima et al., 2013). The article utilized SPSS Version 19.0 to analyze the data.

Ho et al. (2014) highlights a head-to-head comparison of such indicators with other possible distance and time metrics among rural 1,103 households in Nampula province, Mozambique. The researchers found out that Euclidean line distance to be a good representative for route distance ($R^2 = 0.98$), while self-reported travel time is a poor representative ($R^2 = 0.12$). One of key insights was that, 15-minute decrease in one-way walk time to water source is related to a 41% reduction in diarrhea, improved children's nutrition, and an 11% reduction in under-five child mortality rate (Ho et al., 2014). This research can be a helpful tool to understand how long people are traveling in a rural area in Africa where many of our data focus. Also, understanding how people are traveling to receive the water can better understand the condition of the rural people and implement better policies that help them to thrive.

Bartram et al. (2014) highlights a background information about the Millennium Development Goals. How it has established global targets for drinking water and sanitation access (Bartram et al. 2014). The article indirectly gives much information about progress towards focused targets, directed by international monitoring, has reduced the global disease burden and improved the quality of life (Bartram et al., 2014). It utilizes a variety of sources such as JMP, DHS, MICS surveys to analyze the data of many different locations in the world, therefore, it is a broad scope of study of the progress of accessible and drinking water and sanitation globally. Our research can study further what modes of transportation of clean drinking water would affect the progress of improving drinking water and sanitation in one's community. Also, understanding how long it takes to attain the water can improve the quality of the services provided for the people.

Onda, Crocker, et al. (2014) discusses their new development of typology of country clusters pertain to water and sanitation sector based on congruence through multiple related indicators. Onda, Crocker, et al. (2014) used a hierarchical clustering method and a gap statistic analysis to cluster 156 countries which has 6.75 billion people into a relational clusters. Onda, Crocker, et al. (2014) suggests previous geography or income-based country clustering should be improved by using water and sanitation related indicators. Our research can improvise upon their finding and focus on identifying which water accessibility variables may improve water accessibility for people who are seeking clean drinking water.

Organization (2020) article gives an ambitious plan to reach universal drinking water by the year of 2030 that is affordable and safe followed by the Sustainable Development Goal six goals. The WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation (JMP) are monitoring progress on drinking water and sanitation since 1990 globally. The article outlines different plans with consistent traits to determine what is deemed to be safe and affordable drinking water and good sanitation. Our study can highlight which modes of transportation of safe and affordable drinking water can develop why one's community may excel in the improvement of safe and affordable drinking water and sanitation. Drinking, sanitation, and hand washing ladder explains the qualitative determination can indirectly help what is a good source of transporting safe and drinking water.

Fuller et al. (2016) highlights the global accessibility to safe drinking water and sanitation and concludes that it has been improving well during the Millennium Development Goal Period. This topic will benefit our research to understand what countries are doing for the mode of transportation of drinking water and sanitation which may have contributed to the improvements. Fuller et al. (2016) chose some countries and studied the overall countries progress which in his methodology revealed sigmoidal trends. Our study can reveal if certain methods of transportation of drinking water and sanitation may have influenced the effectiveness of the improved drinking water met by MDG standards.

Jia et al. (2016) highlights that there is inequality within safe sanitation. There is a great difference in wealth levels in many low-income countries. Therefore, this will hinder the improvement of MDG progress. Jia et al. (2016)discusses future interventions to be engaged with different wealth categories. Our study can assist in understanding improved sanitation increase by making inferences about how they receive water may give the community focusing on sanitation. Overall, income inequality affects who will have access to proper sanitation.

A. Cassivi et al. (2018) highlights about how there should be more information to the effect of including a 30-minute collection time to monitor access to drinking water. The lack of access to on-premises water sources can cause the use of greater distant alternative sources. Therefore causing the quantity of retrieved water to reduce as the water plateau phenomenon.A. Cassivi et al. (2018) hypothesizes that the households who must travel further are using unimproved sources. For our research, we can discover what modes of transportation people are traveling to retrieve the water and in what quantity depending on their means of transportation. Therefore, learning how to decrease the travel time of people to retrieve the water because according to the article, it can be a great burden and does not increase the quality of one's life to retrieve water daily and far away from their homes.

Tortajada and Biswas (2018) highlights that sharing the immense improvement at the 2015 convention negatively affected many people because they actually have not acquired clean drinking water. While 2.6 billion people gained access to drinking water, they did not have constructive feedback on the quality of the water. Also, our research can fill in the blank on how did these people actually retrieve the water? Our research can measure the performance of how people retrieve water which may not be in their premises.

Amit and Sasidharan (2019) highlights their data analysis similar to what we will be doing and found out that for non-piped households, collection costs are 22% of the coping costs, while collection costs for piped households are less than 2% of the coping costs. The researchers also realize that there is economic inequality because the majority of the piped households are in households that are considered wealthy households and vice versa. Our research can pinpoint how households are traveling to collect water to improve potential policy-making for water accessibility.

Price et al. (2019) highlights the temporal dynamics of drinking water access and quality in urban slums which is home to about 1 billion people globally. Price et al. (2019) discusses the temporal changes in drinking water access and quality in urban slums may influence on health risks. Price et al. (2019) believes that monitoring temporal dynamics should be considered over three interlinked time scales:

short-term   medium term   long-term

Price et al. (2019) recommends future research to explore the short-term water access and quality monitoring. Also we should learn to recognize the role of socio-cultural factors that may impact the temporal dynamics of safe water access. Our project can pinpoint additional water accessibility variables that can be used to focus to recognize the time variations as well.

Rawas et al. (2020) highlights the need for different approaches of intermittent water supplies (IWS) to monitor piped water supply perpetually in Peru. This relates and informs one mode of transportation of clean and accessible water. Our research can make inferences about if the customers receive clean water elsewhere, such as water tankers, kiosks, vendors, etc. Overall, the article found that the percent of households with (IWS) was a few percentage points greater than of the reported utilities.

Deshpande et al. (2020) discusses their findings of improved overall water availability and piped water accessibility for the globe (40% to 50.3%). Deshpande et al. (2020) also found that it was the lowest increase in sub-Saharan Africa, where the accessibility was mostly concentrated in urban regions. Deshpande et al. (2020) focuses mostly on understanding trends in diarrhea burden, where the needs are greatest for the improvement of access to safe drinking water and sanitation facilities. Our study can benefit this research by implementing the best and effective modes of transportation of clean water to improve safe drinking water and sanitation. Even with the water pipe access increasing, they can't conclude if the people had clean water as they needed right away. Overall, the access to safe drinking water and sanitation improved globally between 2000 and 2017, but dis-proportionality undermines reaching the Sustainable Development Goals.

Goal 6 (2020) explains specific targets that have goals and indicators to track global water accessibility. The article quantifies and provides Graphs: safe drinking water, safe sanitation, and hygiene, safe sanitation and hygiene, ambient water quality, water use efficiency, levels of freshwater stress, integrated water management, trans-boundary water cooperation, protect and restore water-related ecosystems, water and sanitation support, local participation in sanitation management. They have many ambitious plans to achieve by 2020 and 2030, and our research can find a correlation to why achieving this may be possible.

Alexandra Cassivi et al. (2021) focuses a case study in Southern Malawi, where data collected in March and April of 2019 at the conclusion of the rainy season. The sample was consisted of 375 households without access to water on their premises. The article highlighted using Euclidean Distance measurement is more reliable than the self-reported time. Also queuing time measurement can be hard to be measured because of their ambiguity. Her Research gives greater insight into how do we define water accessibility and how increase of water accessibility can impact people's lives beneficially.

Gaps and areas for improvement

We are interested in analyzing the impact of transportation modes (usage/ownership) on water accessibility. We also desire to see an implementation of this statistical research piloted in one of the countries to see if the water accessibility variables predictors can improve the water accessibility for its country.

Data

In this section, describe the data sources and the variables, along with data preparation procedures, variable selection criteria, etc. You should have a table summarizing the water accessibility variables and their definitions. Another table can summarize the explanatory variables (e.g. transportation-related, income-related, etc). Also discuss the number of countries, etc. I've started a table as an example. You can add other columns if needed.

Data Preparation

Data structure this study were collected from the Demographic Health Survey (DHS) program. We used the STATCompiler from the DHS Program to develop customized table based on focusing on water, transportation, and wealth indicators across 78 countries and from 1990 to 2019.

We prepossess the data by differentiating the different surveys collected by the DHS program between DHS and Malaria Indicators Survey (MIS) through excel. After, we used R to develop and simplify the table with the most recent surveys for the most up to date analysis for the 78 countries. There was two sets of data of population and households. Therefore, we decided to remove the population data from the table to simplify because population and households data were identical.

Next, there were many missing values from the data. Therefore, we had to do a simple missing value analysis. We determined to avoid using water, transportation, or wealth variables which had greater than 50% missing values. Ultimately, simplified data frame was 76 countries by 28 variables. After, two different tables are generated where one focused on the water accessibility variables and a explanatory variables. We selected 11 water accessibility variables based on the sources available such as location, time, and methodology (Price et al., 2019). The water accessibility variable was organized in the following table to allow for quick visualization for Table 1. The other variables were used as an explanatory variables for determining the water accessibility predictors in Table 2.

Summary of variables

Here, you show and discuss the data distributions (e.g. histograms, correlation plots, etc)

Across 78 countries in this study, the data provides 28 numerical variables and four descriptive variables. The majority of the data is from 2010 - 2020 as shown in Figure 1. Therefore, we can analyze the global condition of water accessibility by utilizing the most up to date surveys. Most of the variables are related to water accessibility by their locations, time, and water resources. This also allows us to find water accessibility predictor variables and new clustering graphs.

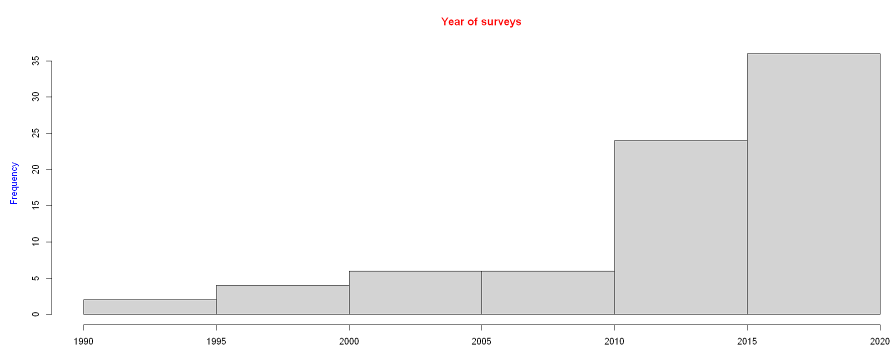

FIGURE 1 Distribution of years of water accessibility variables

Methods

Preamble

We analyzed data from the Demographic Health Survey (DHS) and the Malaria Indicator Survey (MIS) (1990-2020) to highlight water accessibility predictors in 78 countries throughout the world.

Variable	Description	Definition
ptap	Households using a public tap/standpipe	Percentage of households whose main source of drinking water is a public tap/standpipe.
bore	Households using a tube well/borehole	Percentage of households whose main source of drinking water is a tube-well/borehole.
pspr	Households using a protected spring	Percentage of households whose main source of drinking water is a protected spring.
uspr	Households using an unprotected spring	Percentage of households whose main source of drinking water is an unprotected spring.
pwel	Households using a protected well	Percentage of households whose main source of drinking water is a protected well.
uwel	Households using an unprotected well water	Percentage of households whose main source of drinking water is an unprotected well.
surw	Households using surface water	Percentage of households whose main source of drinking water is surface water.
tles	Households with water 30 minutes or less away round trip	Percentage of households with water 30 minutes or less away round trip.
tmor	Households with water more than 30 minutes away round trip	Percentage of households with water more than 30 minutes away round trip.
rain	Households using rainwater	Percentage of households whose main source of drinking water is rainwater.
phom	Households using water piped into dwelling	Percentage of households whose main source of drinking water is water piped into the dwelling.

TABLE 1 Summary of water accessibility variables (national averages at household level)

Cluster analysis

We elected 11 variables that describe water accessibility of 78 countries around the world (Price et al., 2019). Next, we decided to implement clustering which is an unsupervised machine learning method to identify and group water accessibility variables in large data set to understand and make inferences about particular water accessibility variables. All of the clustering analysis was assisted by using the R program. Clustering ultimately can continue to assist in discovering the water accessibility predictor variables.

First, we used a different clustering algorithm to determine the best clustering results. We tested and categorized differently by using single, average, complete, ward.D, and ward.D2 methods to develop clustering dendrogram. Then, we analyzed by determining the best hierarchical relationship of each of the methods by observing the tree diagram itself; if it has more of even distribution of each tree are the optimal clustering methods. We determined that ward.d2 had the best visual and even distribution, but to check this further, we used a function in R called 'NBClust' to determine the best algorithm as well as the best cut or groupings for the clustering methods as shown

Variable	Description	Definition
`imws`	Improved water source	Drinking water is an improved source.
`pipy`	Water piped into yard/plot	Drinking water is water piped into the yard or plot.
`truc`	Tanker truck	Drinking water is tanker truck.
`ctan`	Cart with tank	Drinking water is cart with tank.
`bott`	Bottled water	Drinking water is bottled water/demi john.
`uiws`	Unimproved water source	Drinking water is an unimproved source.
`othw`	Other water source	Drinking water is other.
`iwsp`	Improved water source on the premises	The de jure population living in households with an improved water source on the premises.
`basw`	Basic water service	Defined as an improved water source with either water on the premises or round-trip collection time is 30 minutes or less.
`liws`	Households with limited water service	Percentage of households with limited water service, defined as an improved water source with round-trip collection time greater than 30 minutes.
`prem`	Households with water on the premises	Percentage of households with water on the premises.
`bicy`	Households possessing a bicycle	Percentage of households possessing a bicycle.
`acar`	Households possessing an animal drawn cart	Percentage of households possessing an animal drawn cart.
`mcyc`	Households possessing a motorcycle	Percentage of households possessing a motorcycle.
`pcar`	Households possessing a private car	Percentage of households possessing a private car.
`boat`	Households possessing a boat with a motor	Percentage of households possessing a boat with a motor.
`wigc`	Wealth index Gini coefficient	The Gini coefficient indicates the level of concentration of wealth in the country.

TABLE 2 Summary of explanatory variables (National Household usage Averages measured as percentage for Main Source)

in Figure 7.

We compared Ward.D2, Ward.D, complete, and k-means algorithm methods to determine the best cuts, and also to confirm that Ward.D2 was the best clustering algorithm method to develop the deprogram tree. The 'NBClust' function was set to determine the best clustering methodology by choosing minimum clustering from 3 to max cuts of 7 and utilized all the indices. The majority rule was implemented by the 'NBClust' function for Ward.d2, Ward.D, and the complete algorithm determined that the best clustering cut was four. However, k-means determined to be 3, but we determined that Ward.D2 is the best methodology thus far.

Next, we compared the best indices values for different algorithm solving methodology to determine the best cuts to confirm that Ward.D2 is the best methodology. Once again, we determined that Ward.D2 was the best algorithm and learned that the best cut is four trees by analyzing within the different indices values of different algorithm theories. We compared the values by choosing KL, Ratkowsky, and Marriot values to compare what is the best cut for different clustering methods as shown in Figure 8.

Methods	**KL (clusters)**	**Value Index**		
`Ward.D2`	4	2.4982		
`Ward.D`	4	3.3397		
`Complete`	4	3.9093		
`K-Means`	12	8.6836		
Methods	**Ratkowsky (clusters)**	**Value Index**		
`Ward.D2`	4	0.2981		
`Ward.D`	4	0.2981		
`Complete`	3	0.3193		
`K-Means`	3	0.2948		
Methods	**Marriot(clusters)**	**Value Index**	**Gap**	**Majority Rule**
`Ward.D2`	4	1.54E+40	8	4
`Ward.D`	4	1.79E+40	8	4
`Complete`	4	1.77E+40	7	4
`K-Means`	4	1.54E+40	`N/A`	3

TABLE 3 Summary of optimal clustering index values (Different Clustering Methods)

Table 3 is a rough summary of why Ward.D2 is the best clustering methodology if we go by four cuts. For the KL cluster algorithm, we determined that the best Value index is 2.4982 which is the lowest for the index, and the KL algorithm determines that the lowest value index results from the best cut of four. Also, the Ratkowsky cluster theorem determined that Ward.D2 was the best method for four cuts because the value index was the lowest matching Ward.D at .2981. However, Ward.D is the incomplete version of Ward.D2 where they forgot to square one of the intermediate value in the theorem. Therefore, Ward.D2 is the best clustering method for Ward.D2. Similarly, for the Marriot clustering theorem, Ward.D2 is the best once again due to the Ward.D having the greatest value index which determines that it is the best clustering method. Similar to an explanation from Ratkowsky, Ward.D2 is chosen to be the best method for 4 cuts. Figure 8 shows the visual representation of the explanation by the Table 3.

Lastly, we developed a horizontal dendrogram using R focusing on Ward.D2 methodology for clustering. We also cut the dendrogram in 4 trees as an 'NBClust' analysis as shown in Figure 11. The clustering trees can be further be analyzed and the results and analysis will be discussed in the results and discussion section.

Classification model to explain water accessibility predictors

This is the second phase of the work, which you should hopefully start in January

Results and Discussion

Model results

First, we developed a correlation chart to quickly analyze if there is any great correlation between all the 28 numerical variables that may pertain to water accessibility. We recognized the strong and weak relationship by the size and color of the correlation plot is shown in Figure 2, which indicates households with limited water service (liws) has the strongest and positive relationship with Households possessing a bicycle (bicy). Meanwhile, households using an improved water source (imws) has the strongest and negative relationship with households using an unimproved water source (uiws). This initial finding results indicated that the initial variables are logical and can give us insight into further understanding and the relationship between these variables.

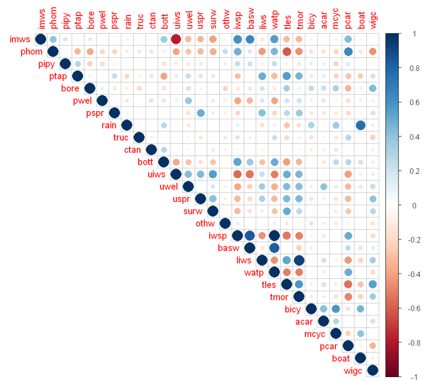

Figure 2 Correlation Graph of Numerical Variables

As we continued to study further upon the correlations of the variables, we used more advanced correlation graphs to determined their p-value, and to see a relationship between different categorical variables is shown in Figure 3, which again indicates a greater detailed comparison between the variables. Households with an improved water source on the premises (iwsp) have a strong relationship with households with basic water service (basw) of .84 and a p-value of less than 0.001. Also, we learned and discovered that Households using an unimproved water source (uiws) have a positive relationship with Households using unprotected well water (uwel), Households using an unprotected spring (uspr), and Households using surface water (surw) with a p-value of less than 0.001 as well. These relationships justify the necessity to research further if the particular water accessibility variables can increase the accessibility of particular water sources to reach universal access to water by 2030, as proposed in the SDGs.

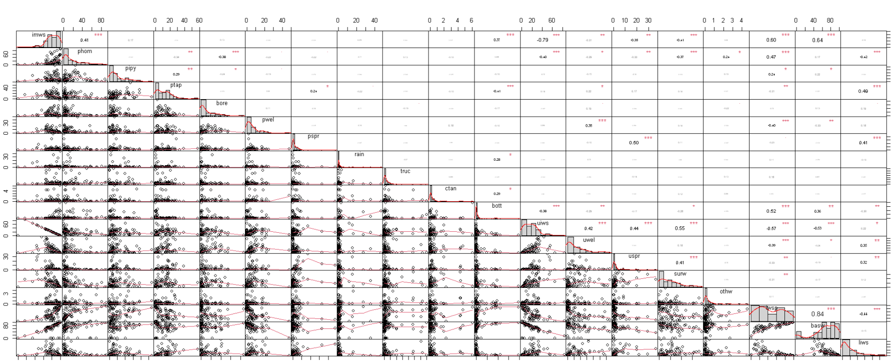

Figure 3 Advanced Correlation Graph of Numerical Variables

Additionally, we wanted to explore if the modes of transportation variables have any relationship with potential water variables. Therefore, we investigated by developing more correlation plots relating transportation variables with water accessibility variables which are shown in Figure 4, Figure 5, Figure 6. There is a significant positive relationship between households possessing a private car (pcar) and households with water on the premises (watp) as shown in Figure 4. There is also is a significant negative relationship between households possessing a private car (pcar) with households with water 30 minutes or less away round trip (tles) and households with water more than 30 minutes away round trip (tmor) with a p-value of less than 0.001. This information is essential to investigate further why this is the global trend.

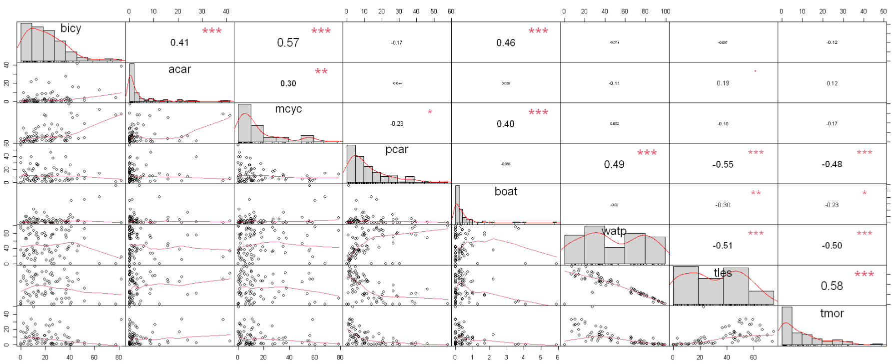

FIGURE 4 Advanced Correlation Graph of Modes of Transportation and Time

Figure 5 shows that Households possessing a motorcycle (mcyc) has a positive correlation with Households using a tube well/borehole (bore) and Households using rainwater (rain) with a p-value of less than 0.01. Similar to the previous analysis, there is a relationship between a mode of transportation to retrieve potential water sources. Figure 6 also shows that households possessing an animal-drawn cart (acar) have a positive and strong relationship with households using unprotected well water (uwel) with a p-value of less than 0.001. The results demonstrate that different modes of transportation factor into the accessibility of retrieving water sources on a global scale, therefore, there should be consideration of these variables to increase access to improved water sources.

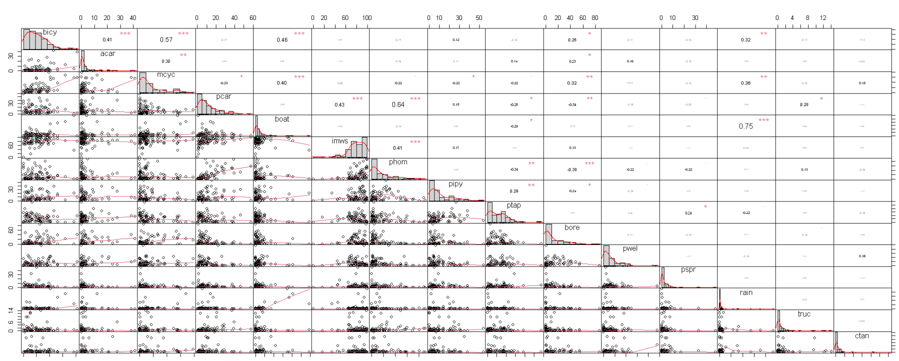

FIGURE 5 Advanced Correlation Graph of Modes of Transportation and Water Resources

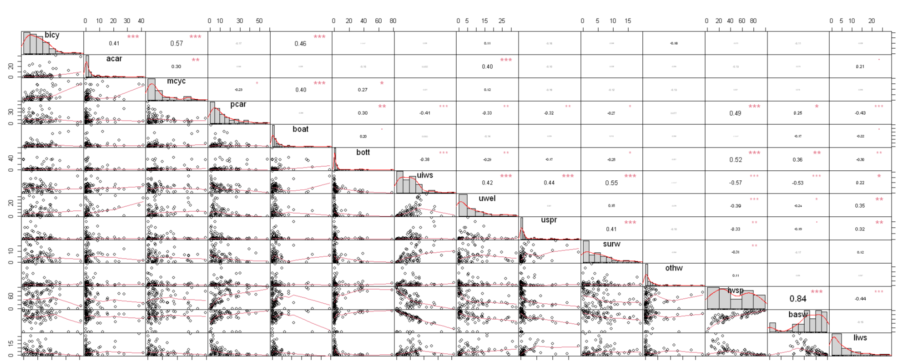

FIGURE 6 Advanced Correlation Graph of Modes of Transportation and Additional Water Resources

There is a problem of people not available to retrieve water quickly and there is a collection burden which is necessary to increase the water quality to improve many people's health and quality of life (A. Cassivi et al., 2018). These initial findings can allow us to research into what are the major factors of water accessibility for the 76 countries by developing clustering and determining the water accessibility variable predictors. A future study could use the water accessibility variable predictors to implement policies and experiment if it improved water accessibility for the community. This would be a necessary implementation to invest to improve their access to water to reach universal access by 2030.

Water accessibility typologies

Show the typology/cluster results and discuss. NBClust statistic analysis developed and determined four distinct groups. First cluster group composed of countries near the equator or in the Sub-Sahara Regions. The analysis of the second group represents countries considered developed or recently industrialized. Third cluster group represents most of the countries in the central Africa and may have similar factors as the first cluster group. The fourth cluster group represents most of countries in the middle east or predominately non-African countries. There is a great internally heterogeneous clusters for the 76 distinct countries. The cluster analysis' dendrogram is shown in Figure 11, and the corresponding NBClust curve yielding the optimal four clusters is shown in Figure 7, Figure 8. **??**

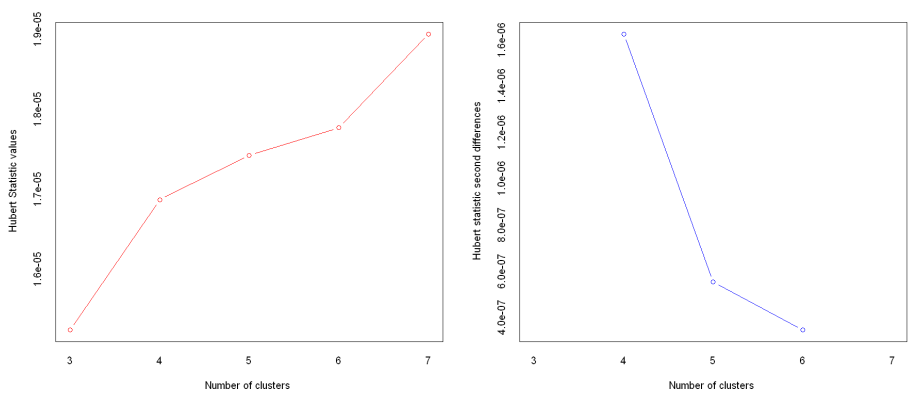

FIGURE 7 Optimal Number of Clusters for Ward.D2

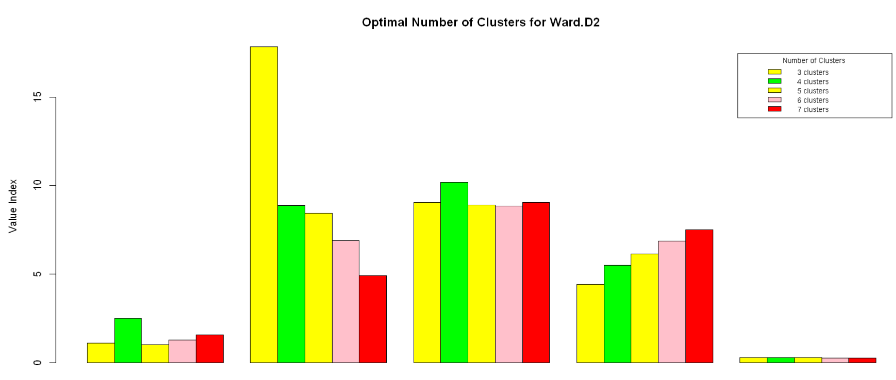

FIGURE 8 Optimal Number of Clusters for Ward.D2

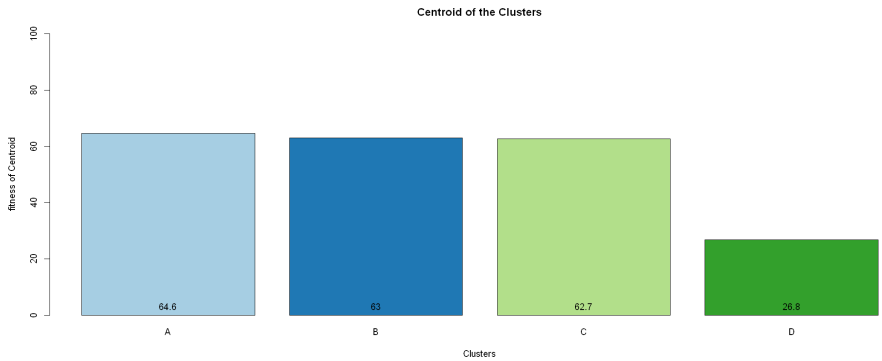

FIGURE 9 Centroid of the Four Cluster Groupings

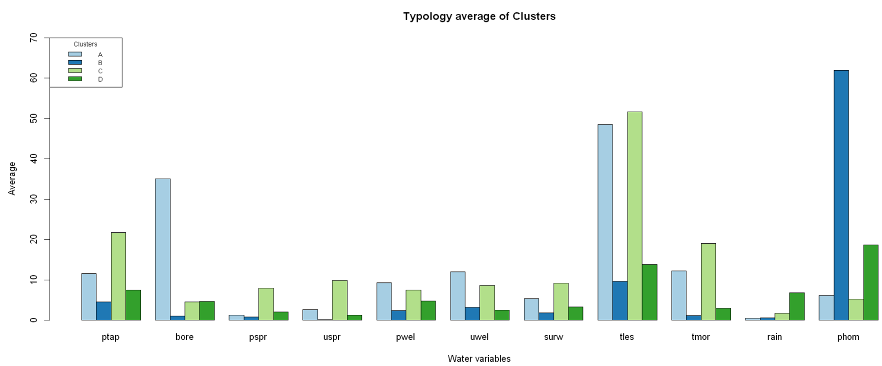

FIGURE 10 Cluster Typology Average of Water Accessibility Variables

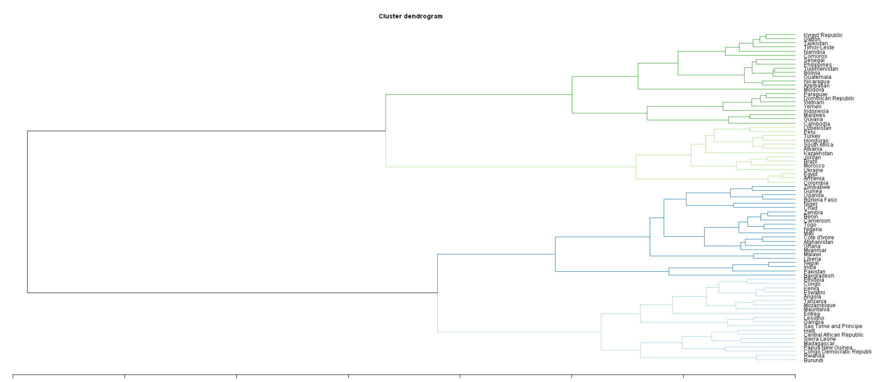

FIGURE 11 Cluster Dendrogram with Four Cuts

Model results

Conclusion

Limitation

References

Amit, R. K. and Subash Sasidharan (Feb. 1, 2019). “Measuring Affordability of Access to Clean Water: A Coping Cost Approach”. In: *Resources, Conservation and Recycling* 141, pp. 410–417.

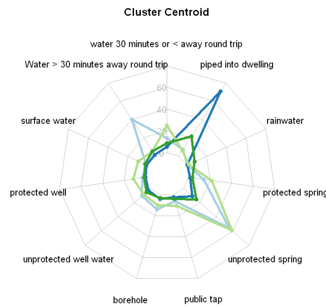

Figure 12 Spider Plot of Water Accessibility Variables by Typology

Bartram, Jamie et al. (Aug. 2014). "Global Monitoring of Water Supply and Sanitation: History, Methods and Future Challenges". In: *International Journal of Environmental Research and Public Health* 11.8, pp. 8137–8165.

Cassivi, A. et al. (Aug. 1, 2018). "Access to Drinking Water: Time Matters". In: *Journal of Water and Health* 16.4, pp. 661–666.

Cassivi, Alexandra et al. (Jan. 1, 2021). "Evaluating Self-Reported Measures and Alternatives to Monitor Access to Drinking Water: A Case Study in Malawi". In: *Science of The Total Environment* 750, p. 141516.

Deshpande, Aniruddha et al. (Sept. 1, 2020). "Mapping Geographical Inequalities in Access to Drinking Water and Sanitation Facilities in Low-Income and Middle-Income Countries, 2000–17". In: *The Lancet Global Health* 8.9, e1162–e1185.

Fuller, James A. et al. (Jan. 15, 2016). "Tracking Progress towards Global Drinking Water and Sanitation Targets: A within and among Country Analysis". In: *Science of The Total Environment* 541, pp. 857–864.

Goal 6 (2020). *Goal 6: Clean Water and Sanitation - SDG Tracker*. Our World in Data. URL: https://sdg-tracker.org/water-and-sanitation (visited on 09/03/2020).

Ho, Jeff C., Kory C. Russel, and Jennifer Davis (Mar. 1, 2014). "The Challenge of Global Water Access Monitoring: Evaluating Straight-Line Distance versus Self-Reported Travel Time among Rural Households in Mozambique". In: *Journal of Water and Health* 12.1, pp. 173–183.

Jagals, P. (Aug. 2006). "Does Improved Access to Water Supply by Rural Households Enhance the Concept of Safe Water at the Point of Use? A Case Study from Deep Rural South Africa". In: *Water Science and Technology* 54.3, pp. 9–16.

Jia, Peng et al. (July 12, 2016). "High-Resolution Spatial Distribution and Estimation of Access to Improved Sanitation in Kenya". In: *PLOS ONE* 11.7, e0158490.

Onda, Kyle, Jonny Crocker, et al. (Mar. 1, 2014). "Country Clustering Applied to the Water and Sanitation Sector: A New Tool with Potential Applications in Research and Policy". In: *International Journal of Hygiene and Environmental Health* 217.2, pp. 379–385.

Onda, Kyle, Joe LoBuglio, and Jamie Bartram (Mar. 2012). "Global Access to Safe Water: Accounting for Water Quality and the Resulting Impact on MDG Progress". In: *International Journal of Environmental Research and Public Health* 9.3 (3), pp. 880–894.

Organization, World Health (2020). *Drinking-Water*. URL: https://www.who.int/news-room/fact-sheets/detail/drinking-water (visited on 09/30/2020).

Price, Heather, Ellis Adams, and Richard S. Quilliam (June 25, 2019). "The Difference a Day Can Make: The Temporal Dynamics of Drinking Water Access and Quality in Urban Slums". In: *Science of The Total Environment* 671, pp. 818–826.

Rawas, Farah, Rob Bain, and Emily Kumpel (Mar. 12, 2020). "Comparing Utility-Reported Hours of Piped Water Supply to Households' Experiences". In: *npj Clean Water* 3.1 (1), pp. 1–9.

Sima, Laura C. et al. (Mar. 1, 2013). "Water Flows, Energy Demand, and Market Analysis of the Informal Water Sector in Kisumu, Kenya". In: *Ecological economics : the journal of the International Society for Ecological Economics* 87, pp. 137–144.

Tortajada, Cecilia and Asit K Biswas (Oct. 1, 2018). "Achieving Universal Access to Clean Water and Sanitation in an Era of Water Scarcity: Strengthening Contributions from Academia". In: *Current Opinion in Environmental Sustainability*. Sustainability Science 34, pp. 21–25.