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Research Paper

How are we actually doing? Comparing water and sanitation in Kenya with MDG and SDG criteria

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ABSTRACT

This cross-sectional study assesses the extent to which water and sanitation access differs among respondents in three counties in Western and Rift Valley Kenya. By using both Millennium Development Goal (MDG) and Sustainable Development Goal (SDG) criteria, we utilize important geographical nuances of SDG water and sanitation provisioning across rural and urban settings to highlight the strengths and weaknesses of the MDGs and SDGs in each context. Purposive heterogenous sampling using local knowledge was employed to select households who represent varying rural and urban contexts with differing land use practices. Differences in water and sanitation access based on varying MDG/SDG water criteria showcase how the shift from technology-based criteria to service provisioning criteria affects understanding of progress and remaining challenges toward water and sanitation provisioning. Results indicate that although 72% of respondents have Improved Water per MDG criteria, only 34% have Safely Managed Water and 36% have Basic Water as per the SDGs. Component analyses show SDG criteria with the lowest percentages of achievement were: microbial and fluoride water quality and that sanitation facilities were not shared with other households. These results pinpoint areas where there is a need for increased research and investment surrounding how to achieve specific SDG criteria and increase access to safe water and sanitation.

Key words: Kenya, monitoring and evaluation, sanitation, Sustainable Development Goals (SDGs), water, water quality

HIGHLIGHTS

- SDG water service provisioning is lower than MDG Improved Water access.
- Safely Managed Water and Sanitation criteria with lowest percentages of achievement are fluoride and microbial water quality and sanitation facilities, which are not shared.
- Component analyses show which SDG criteria may limit realization of water and sanitation provisioning.
- SDG criteria have stronger linkages between WASH provisioning and rural and urban settings.

INTRODUCTION

Access to clean drinking water and safe sanitation are top global health priorities and have been strategically pursued over the past 30 years through the Millennium Development Goals (MDGs) and now the Sustainable Development Goals (SDGs). MDG and SDG targets for water and sanitation have motivated billions of dollars of investment, and throughout the course of implementing the MDGs, over 2.6 billion people gained access to improved drinking water and over 2.1 billion people gained access to improved sanitation (UN 2015). While important progress has been made, researchers, development practitioners, and policymakers alike continue to seek to improve target criteria, address matters of geographical unevenness, and meet contextual challenges that constrain more full realization of safe drinking water and sanitation (Bain *et al.* 2012; Grady *et al.* 2015).

The modification of MDGs and implementation of SDGs represent the continual drive to improve global monitoring of human development. Throughout the era of the MDGs, many scholars and practitioners cautioned the use of drinking water, and sanitation targets, based primarily on an improved water source or sanitation type, could obfuscate important aspects of service provision and underestimate the proportion of the global population still without access to adequate water and sanitation (Godfrey *et al.* 2011; Zawahri *et al.* 2011; Bain *et al.* 2012, 2014; Onda *et al.* 2012; Baum *et al.* 2013, 2014; Bartram *et al.* 2014; Dos Santos *et al.* 2017; Martínez-Santos 2017). Drinking water and sanitation ladders were implemented in 2008 to draw more clear distinctions between the importance of water and sanitation use types (UNICEF & WHO 2008). Since 2015, the SDGs, now focused on sustainable water and sanitation service provisioning, represent a departure from the improved technology type proxies of the MDGs. Given this paradigm shift from technology focus to service focus, there is a need to better understand how these two sets of criteria differ in how they report on water and sanitation services. Grounding an analysis between MDG and SDG achievement across varying rural/urban contexts, which is yet to be done, can illuminate how the shift from MDG to SDG criteria can affect our views of water and sanitation provisioning.

This need for a greater understanding is particularly salient in sub-Saharan Africa, which bears a disproportionate share of the global population without access to water and sanitation (Bain *et al.* 2014; Dos Santos *et al.* 2017; UNICEF & WHO 2019). Continued population growth in parallel with changing lifestyles, increasing pollution, and accelerating urbanization threaten to only increase pressure on water and sanitation services (Dos Santos *et al.* 2017; Mara & Evans 2018). Kenya has made significant progress, yet there is still marked heterogeneity in water and sanitation access in various regions and between rural and urban communities (UNICEF & WHO JMP 2020). This study seeks to increase knowledge of how the use of MDG and SDG water and sanitation criteria affects the understanding of WASH provisioning among three counties of Western and Rift Valley Kenya. In partnership with Aqua Clara Kenya (ACK), a Kenyan-led social enterprise, we characterized access to water and sanitation among clients who purchased ACK hollow fiber membrane technology filters in two counties from Western Kenya, Kisii County and Nyamira County, and one county along the Rift Valley, Narok County. In this cross-sectional case study, we directly compare water and sanitation access as per MDG and SDG water and sanitation ladders and compare how progress is understood between the use of these two sets of criteria. As the availability of water quality data for SDG 6.1's criteria is rare, this case study provides a unique analysis on water quality challenges within the SDGs.

METHODS

Study site

Across Kenya, a country covering an area of 591,971 km^2 with a population of 49,413,000, agriculture is the largest employer, and pastoralism is practiced in the south and northwest (Ingham & Ntarangwi 2020). In the Lake Victoria basin and highlands, in which Kisii and Nyamira counties are situated, the average annual precipitation varies from 1,000 to 1,800 mm of rain with daily maximum temperatures of 27°C in July and 32°C in October and February (Ingham & Ntarangwi 2020). The floor of the Rift Valley, where Narok is located, is generally dry and known for high levels of fluoride in groundwater (Ndambiri & Rotich 2018; Ingham & Ntarangwi 2020). In this study, respondents in Kisii, Nyamira, and Narok are from a range of rural and urban settings (Figure 1). In Kenya, urban areas generally have greater access to water and sanitation services than rural areas (UNICEF & WHO JMP 2020). In addition, the Kenyan Ministry of Health (2021) reports that in Kisii County, 32% of village communities are Open Defecation Free (ODF), while in Nyamira County, 7% are ODF, and in Narok County, 3% are ODF. Most respondents in Kisii were from Kisii Town, the largest urban center in Kisii County (Kisii County Government 2019). Nyamira respondents live in more rural conditions, where agriculture production mainly consists of maize and tea (County Government of Nyamira 2020). Narok respondents come from semi-nomadic pastoralist Maasai communities in the southern part of the county.

Survey instrument design and testing

Structured surveys were programmed into the mWater Surveyor App for cross-sectional data collection using smart phones. Water and sanitation in the rainy and dry season were estimated through questions asking about expected water and sanitation experiences in typical rainy and dry seasons. The survey design and questions were created according to WHO & UNICEF definitions to assess levels of water and sanitation provisioning according to MDG/SDG criteria (Table 1, Supplementary Material, Tables S1 and S2; UNICEF & WHO 2006, 2017b, 2020; WHO 2012, 2017). Questionnaires for this study were developed within ACK's monitoring and learning department and pretested among their staff before it was field implemented. As ACK regularly follows up with clients using survey instruments and trained staff enumerators, this was part of their standard protocols.

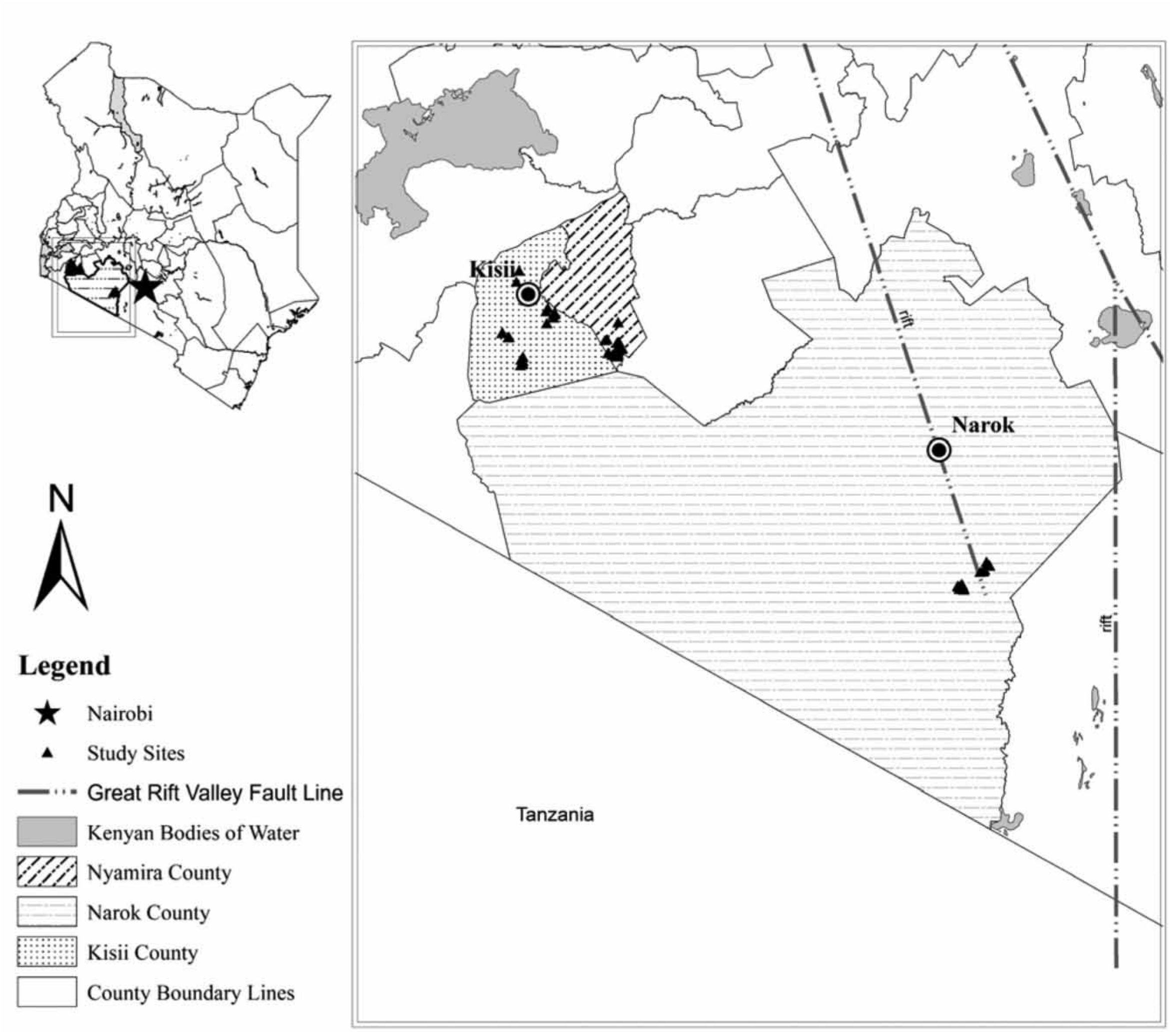

Figure 1 | Sampling Frame in Nyamira, Narok, and Kisii Counties.

Instruments for measuring water quality

During sampling in June 2019, water samples were collected at four different points in the household and tested for SDG 6.1 Safely Managed Water quality criteria (Supplementary Material, Table S2 for WHO water quality guidelines; WHO 2017). Safely Managed Water quality criteria require that water samples contain no *Escherichia coli* per 100 mL sample, and fluoride concentrations are below 1.5 mg/L, and there is no detectable amount of arsenic (UNICEF & WHO 2017a). We used Aquagenx Compartment Bag Tests standard protocols to assess most probable number (MPN) of *E. coli* (Aquagenx 2020). Testing for fluoride content was conducted using an ExTECH FL700: Waterproof Exstik Fluoride Meter, and arsenic was evaluated using an EconoII Quick Rapid Arsenic Test Kit #481304 (Extech 2019; Industrial Test Systems 2020). The four points sampled include water entering the hollow fiber household filter purchased from ACK, filter effluent, filtered water collected in a cup found in the home, and water stored elsewhere in the home. In total, 344 samples were evaluated for microbial quality and fluoride and arsenic contents.

Sampling

The cross-sectional sample frame consisted of ACK clients in Kisii, Nyamira, and Narok Counties who had purchased hollow fiber membrane technology water filters (Figure 1). Although ACK equally sells institutional, school, community, and household filters, only household filters were sampled for this evaluation. This sample frame was chosen due to availability and willingness of clients to participate in the study as well as proximity and cost constraints for water quality testing. During

Table 1 | JMP water and sanitation ladders

MDG drinking water and sanitation ladders[a]	
Improved Sanitation	Ensure hygienic separation of human excreta from human contact: They are use of the following facilities: flush/pour flush to: piped sewer system, septic tank, pit latrine; ventilated pit latrine; pit latrine with slab, composting toilet
Shared	Sanitation facilities of an otherwise acceptable type shared between two or more households. Only facilities that are not shared or not public are considered improved
Unimproved	Do not ensure hygienic separation of human excreta from human contact. Unimproved facilities include pit latrines without a slab or platform, hanging latrines, and bucket latrines
Open Defecation	When human feces are disposed of in fields, forests, bushes, open bodies of water, beaches, or other open spaces or disposed of with solid waste
Other Improved Drinking	Public taps or standpipes, tubewells or boreholes, protected dug wells, protected springs or rainwater collection. Improved water is a source that, by nature of its construction, adequately protects the water from outside contamination, from fecal matter
Water piped into a dwelling, plot or yard	Piped household water connection located inside the user's dwelling, plot or yard
Unimproved drinking water sources	Unprotected dug well, unprotected spring, cart with small tank/drum, surface water (river, dam, lake, pond, stream, canal, irrigation channels), and bottled water
SDG drinking water and sanitation ladders[b]	
Safely Managed Sanitation	Use of improved facilities,* which are not shared with other households and where excreta are safely disposed *in situ* or transported and treated off-site
Basic Sanitation	Use of improved facilities,* which are not shared with other households
Limited Sanitation	Use of improved facilities* shared between two or more households
Unimproved Sanitation	Use of pit latrines without a slab or platform, hanging latrines, or bucket latrines
Open Defecation	Disposal of human feces in fields, forests, bushes, open bodies of water, beaches, and other open spaces or with solid waste
Safely Managed Drinking Water	Drinking water from an improved water source, which is located on premises, available when needed and free from fecal and priority chemical contamination. Water quality should meet local or national water quality standards or WHO Guidelines for Drinking Water Quality, where local or national standards are unavailable
Basic Drinking Water	Drinking water from an improved source for which collection time is not more than 30 min for a roundtrip including queuing
Limited Drinking Water	Drinking water from an improved source for which collection time exceeds 30 min for a roundtrip including queuing
Unimproved Drinking Water	Drinking water from an unprotected dug well or unprotected spring
Surface Water	Drinking water directly from a river, dam, lake, pond, stream canal, or irrigation canal

[a]UNICEF & WHO (2008).
[b]UNICEF & WHO (2018).
*The definition for improved sanitation facilities regarding pit latrine slabs changed in 2018 to specify that pit latrine slabs that completely cover the pit, with a small drop hole, and are constructed from materials that are durable and easy to clean (e.g. concrete, bricks, stone, fiberglass, ceramic, metal, wooden planks, or durable plastic) should be counted as improved. Slabs made of material not easy to clean (e.g. sticks, logs, or bamboo) should be classified as 'pit latrine without slab' and counted as 'unimproved', even if they are covered with a smooth layer of mortar, clay, or mud.

June 2019, we used the knowledge of our local partners and purposive heterogeneous sampling to select 30 ACK clients within each of the three counties that represented varying water and sanitation access levels within differing rural, urban, and land use contexts. Due to distance between sites, difficulty of travel, and some household filter owners absent at the time of sampling, we were only able to collect samples from 86 sites. In total, 33.7% of the sample frame was from Kisii ($N = 29$); 37.2% was from Nyamira ($N = 32$); and 29.1% was from Narok ($N = 25$). Because this sampling method provided results regarding water and sanitation access among clients from different counties and a range of urban and rural experiences, this method proved to be mutually beneficial to our partner organization ACK. It also provided mutual benefit to their community partners, the Public Health Office of Nyamira County and Africa Hope, who facilitated our research among the communities in Nyamira County and Narok County. Results from this research were utilized to improve community outreach. While this sampling technique was nonrandomized, it gave the opportunity to elucidate rich details from this case and organize findings in a way that provides context otherwise missed through randomization (Tongco 2007).

Data collection

The household surveys were conducted by trained ACK staff enumerators, and water quality sampling was conducted by the ACK staff and the Penn State research team. Questions related to demographic information were not included in the survey, but demographic information was obtained from ACK's sales database. When households were surveyed, the first choice of respondent was an adult woman caretaker who lived in the house. If such a respondent was not available, then a girl older than 18 years who lived in the home was prioritized. If neither were available, then an adult male who lived in the home was surveyed. The respondents were prioritized in this order because in Kenya, females are considered as the ones who have the most knowledge of WASH in the home.

This cross-sectional data collection was conducted during the rainy season in June 2019. Questions pertaining to water and sanitation in the rainy and dry season were asked regarding typical rainy and dry season experiences. Ethical clearance was obtained from Penn State University under IRB Study 00012661 and from Research Ethics Committee of the University of Eastern Africa Baraton under application approval number UEAB/REC/10/48/2019. Local consent to survey and to collect water quality samples in Nyamira County was facilitated by the Public Health Office of Nyamira County. In Narok County, community consent was obtained through coordination with Africa Hope. For Kisii County, ACK called clients before the visit to seek consent to participate in the research. For all clients, after explaining to the households the objective of the visit, ACK asked the interviewee for signed consent before any data collection was done.

Data analysis

We calculated descriptive statistics of the initial results from the surveys deployed by ACK. Observations were separated based on county. The main drinking water source and sanitation type were categorized as either improved or unimproved based on JMP standard classification, and water quality results were evaluated based on WHO Water Quality Guidelines (Supplementary Material, Table S2). Using results from the rainy season only, water and sanitation service levels of the WHO/UNICEF JMP service ladders were calculated for MDG water and sanitation service ladders and SDG water and sanitation service ladders. Because this study included water quality measurements for all three of the key WHO/UNICEF JMP criteria, we were able to calculate the highest level of drinking water service, Safely Managed Water. To understand the water service level at point of consumption, only samples from filter effluent were used in calculations for Safely Managed Water. Results for all four points are provided in Supplementary Material, Table S3. We conducted component analyses of the top SDG water and sanitation service levels to understand the percentage of households, which achieved the varying criteria for Safely Managed Water and Sanitation.

Overall, 33 fluoride samples and 38 microbial water quality samples are missing from our dataset due to inconclusive testing. For these inconclusive water quality tests, each sample was evaluated to determine whether it should be included in the final sample. In total, we maintained 225 fluoride samples and 306 microbial samples in our data. Analysis of missing data was conducted in a way to maximize the information that could be utilized from the sample frame. Missing fluoride values in Kisii were filled with the overall average fluoride value of filter effluent among all Kisii respondents (Schafer & Graham 2002). This was decided because all Kisii clients lived near each other, and the fluoride levels were all well below the WHO limit (1.5 mg/L). It was assumed that all Kisii household water sources would have similar levels of fluoride also below this threshold. In the case of missing microbial water quality values, however, it was determined there was too much variance to impute values for these missing cases (Schafer & Graham 2002). In these cases, it was decided that respondents would be evaluated up to the level of Basic Water, which does not require water quality measurements. Many respondents selected a response of 'other' for sanitation type and indicated an improved latrine with a slab made of wood. This type of sanitation response was analyzed as Unimproved Sanitation, because in choosing the choice of 'other', the client was not prompted to fill in the number of households that shared the sanitation type, which was necessary to assess higher levels of sanitation.

RESULTS

Sample characteristics

Demographic information about this study's respondents was obtained from ACK's sales database and indicates that the respondents come from a wide range of backgrounds (Table 2). While all Narok respondents are pastoralists

Table 2 | Respondent demographic information

	Overall (N = 86)		Kisii (N = 29)		Nyamira (N = 32)		Narok (N = 25)	
	n	%	*n*	%	*n*	%	*n*	%
Gender of respondent								
Male	9	10	6	21	3	9	0	0
Female	77	90	23	79	29	81	25	100
Highest education level								
Degree	7	8	7	24	0	0	0	0
Vocation	15	17	9	31	6	19	0	0
Secondary	36	42	11	38	23	72	2	8
Primary	8	9	2	7	2	6	4	16
Preprimary	12	14	0	0	1	3	11	44
None	8	9	0	0	0	0	8	32
Occupation								
Farming	35	41	11	38	24	75	0	0
Teaching	9	10	5	17	4	13	0	0
Nursing	6	7	6	21	0	0	0	0
Business	7	8	4	14	1	3	0	0
Pastoralism	25	29	0	0	0	0	25	100
Accountant	1	1	1	3	0	0	0	0
Lecturer	1	1	1	3	0	0	0	0
Engineer	1	1	1	3	0	0	0	0
Plumbing	1	1	0	0	1	3	0	0

(*Continued*)

Table 2 | Continued

	Overall ($N = 86$)		Kisii ($N = 29$)		Nyamira ($N = 32$)		Narok ($N = 25$)	
	n	%	*n*	%	*n*	%	*n*	%

Average household income per month (KES)

Overall ($N = 86$)				Kisii ($N = 29$)				Nyamira ($N = 32$)				Narok ($N = 29$)			
Min	Max	Mean	Med	Min	Max	Mean	Med	Min	Max	Mean	Med	Min	Max	Mean	Med
200	80,000	10,927	4,000	1,500	80,000	24,138	20,000	300	33,000	6,984	4,000	200	2,000	648	550

Respondent age

Overall ($N = 86$)				Kisii ($N = 29$)				Nyamira ($N = 32$)				Narok ($N = 29$)			
Min	Max	Mean	Med	Min	Max	Mean	Med	Min	Max	Mean	Med	Min	Max	Mean	Med
19	83	42	39	26	73	43	41	27	83	46	45	19	57	34	32

Household size

Overall ($N = 86$)				Kisii ($N = 29$)				Nyamira ($N = 32$)				Narok ($N = 29$)			
Min	Max	Mean	Med	Min	Max	Mean	Med	Min	Max	Mean	Med	Min	Max	Mean	Med
2	10	6	6	2	10	5	5	4	10	6	6	3	10	6	6

(100%), most Nyamira respondents are farmers (75%), and Kisii respondents have a range of vocations, which include farming (38%), teaching (17%), nursing (21%), and business (14%). Education levels and average monthly income among respondents also vary. Most Narok respondents have an education that is primary level or less (92%), while most Nyamira respondents have a secondary education (72%), and most Kisii respondents' education ranges from secondary (38%), vocational (31%), and university degree (24%). Average household monthly income of Narok respondents is 648 KES, while Nyamira respondents had an average of 6984 KES per month, and Kisii respondents had an average of 24,138 KES per month. Most respondents in this study were female (90%), while there were some male respondents (10%).

Drinking water characteristics

In assessing typical experiences for rainy and dry seasons, it was found that respondents in Nyamira and Kisii generally had access to higher tier water sources during both rainy and dry seasons compared to respondents from Narok (Table 3). Narok respondents most often used water pans or other surface water sources. Water pans are shallow water reservoirs ranging from 1 to 3 m deep intended to collect and store runoff water from hillsides, roads, and open rangeland (Mati 2015). These were located off premises and required an average of 88.5 min to secure water in the dry season (median = 120 min) and 21.8 min (median = 10 min) to secure water in the rainy season. Nyamira respondents all relied on rainwater in the rainy season (100%) and a mix of surface water sources and protected and unprotected springs in the dry seasons. Rainwater was most often located on premises, while other sources were located off premises, requiring respondents on average to spend 28 min for collection (median = 30 min). For Kisii respondents, most relied on protected springs in the dry seasons (76%) and rainwater in the rainy season (79%). Rainwater was most often located on premises, while dry season sources were not, requiring respondents on average 47.2 min for collection (median = 30 min).

Sanitation characteristics

While all Narok respondents practiced Open Defecation, respondents in Nyamira and Kisii often used a type of improved pit latrine that was commonly shared between two or more households (Table 3). For Kisii respondents, the most frequent sanitation type was ventilated improved pit latrine (59%), while Nyamira respondents most frequently used pit latrines made of wood (47%) and ventilated pit latrines (28%). All respondents in Kisii reported that excreta were safely disposed *in situ* or transported and treated off-site, while this was true for almost all Nyamira respondents (94%). Among Kisii respondents, 20 had Safely Managed Sanitation, 7 Limited Sanitation, and 2 Unimproved Sanitation (Table 4). Of the seven respondents with Limited Sanitation, where the sanitation facility was shared with another household, on average 3.7 households shared one toilet or pit latrine (max = 7, min = 2; Table 3). Among Nyamira respondents, 8 had Safely Managed Sanitation, 9 Limited Sanitation, and 15 Unimproved Sanitation (Table 4). Of the nine respondents with Limited Sanitation, where the sanitation facility was shared with another household, on average five households shared one toilet or pit latrine (max = 10, min = 2).

Water quality results

Less than half of samples for filter effluent complied with WHO microbial water quality guidelines, where there was 0 MPN *E. coli* per 100 mL (49%; Supplementary Material, Table S3). The majority of water quality samples among Kisii respondents (58%) and Nyamira respondents (63%) had 0 MPN *E. coli* per 100 mL. In contrast, water quality samples among Narok respondents almost equally had estimated levels of 48.3 (19%) and 100 (24%) MPN *E. coli* per 100 mL as they did 0 MPN *E. coli* per 100 mL (19%). There were no detectable amounts of arsenic in any of the water quality samples, and among Narok respondents, the fluoride levels were on average much higher than for Kisii and Nyamira respondents (Supplementary Material, Table S3).

Figure 2 shows the microbial water quality results for all four points of sampling in the household: prefiltration and postfiltration, water collected from the filter with a household cup, and water sampled from another household storage container. Figure 2(a) and (b) demonstrates that there are more 'low-risk' water samples postfiltration for Nyamira (63%) and Kisii (52%) respondents than for Narok respondents (16%). For Narok respondents, postfiltration water samples are somewhat equally distributed among low risk (16%), intermediate risk (24%), high risk (20%), and unsafe (20%). Similar results can be seen in

Table 3 | Drinking water and sanitation characteristics among Kisii, Nyamira, and Narok clients

Drinking water characteristics		Overall ($N = 86$)		Kisii ($N = 29$)		Nyamira ($N = 32$)		Narok ($N = 25$)	
		n	%	*n*	%	*n*	%	*n*	%
What is the main source of drinking water for members of this household during the dry season?	Protected spring	35	41	22	76	13	41	0	0
	Surface water (river, pond, lake)	31	36	0	0	8	25	23	92
	Unprotected spring	8	9	0	0	8	25	0	0
	Water pan	2	2	0	0	0	0	2	8
	Protected dug well	5	6	4	14	1	3	0	0
	Unprotected dug well	0	0	0	0	0	0	0	0
	Rain water collection	4	5	2	7	2	6	0	0
	Piped water into dwelling	1	1	1	3	0	0	0	0
Is the water source located on premises?	Yes	12	14	7	24	4	13	1	4
	No	74	86	22	76	28	88	24	96
What is the main source of drinking water for members of this household during the rainy season?	Protected spring	4	5	4	14	0	0	0	0
	Surface water (river, pond, lake)	8	9	0	0	0	0	8	32
	Unprotected spring	0	0	0	0	0	0	0	0
	Water pan	10	12	0	0	0	0	10	40
	Protected dug Well	0	0	0	0	0	0	0	0
	Rainwater collection	62	72	23	79	32	100	7	28

		Overall (N = 86)		Kisii (N = 29)		Nyamira (N = 32)		Narok (N = 25)	
		n	%	n	%	n	%	n	%
	Unprotected dug well	1	1	1	3	0	0	0	0
	Piped water into dwelling	1	1	1	3	0	0	0	0
Is the water source located on premises?	Yes	62	72	26	90	29	91	7	28
	No	24	28	3	10	3	9	18	72
Did you have sufficient water last week?	Yes	69	80	29	100	31	97	16	64
	No	17	20	0	0	1	3	9	36
Is water available for at least 12 hours per day?	Yes	72	84	29	100	32	100	14	56
	No	14	16	0	0	0	0	11	44

		Overall (N = 86)		Kisii (N = 29)		Nyamira (N = 32)		Narok (N = 25)	
Sanitation characteristics		n	%	n	%	n	%	n	%
Where do you relieve yourself? (urinate and dispose fecal matter)	Ventilated improved pit latrine	26	30	17	59	9	28	0	0
	No facility, bush, plastic bag	25	29	0	0	0	0	25	100
	Simple pit latrine with cement slab	11	13	5	17	6	19	0	0
	Flush/our-flush toilet to piped sewer system, septic tank, or pit latrine	7	8	5	17	2	6	0	0
	Other[a]	17	20	2	7	15	47	0	0

(*Continued*)

Table 3 | Continued

The following questions were asked only of individuals who indicated sanitation type as ventilated improved pit latrine, simple pit latrine with cement slab or flush/or flush toilet to piped sewer system, septic tank, or pit latrine.

		Overall ($N = 44$)		Kisii ($N = 27$)		Nyamira ($N = 17$)		Narok (N/A)	
		n	%	*n*	%	*n*	%	*n*	%
Where is the toilet? (Circle one answer only)	In the compound	37	84	22	81	15	88	N/A	N/A
	Inside or attached to dwelling	7	16	5	19	2	12	N/A	N/A
Is excreta safely disposed *in situ* or transported and treated off-site?	Yes	43	98	27	100	16	94	N/A	N/A
	No	1	2	0	0	1	6	N/A	N/A

For households that share toilets, number of households that share one sanitation facility

	Overall ($N = 16$)			Kisii ($N = 7$)			Nyamira ($N = 9$)			Narok (N/A)		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Median	Max
Number of households	4.4	2	10	3.7	2	7	5	2	10	N/A	N/A	N/A

[a]Other responses indicated latrines with the floor made of timber/wood, with mud or iron sheet walls.

Table 4 | WHO/UNICEF JMP service ladders for MDG and SDG water and sanitation

	Overall (*N* = 86)		Kisii (*N* = 29)		Nyamira (N = 32)		Narok (N = 25)	
Water service levels	*n*	%	*n*	%	*n*	%	*n*	%
MDG water ladder								
Water piped into dwelling, plot or yard	1	1	1	3	0	0	0	0
Other improved drinking water source	61	71	27	94	28	88	6	24
Unimproved drinking water sources	24	28	1	3	4	13	19	76
SDG water ladder								
Safely Managed Water	29	34	12	41	17	53	0	0
Basic Water	31	36	14	48	11	34	6	24
Limited Water	2	2	2	7	0	0	0	0
Unimproved Water	5	6	1	3	4	13	0	0
Surface Water	19	22	0	0	0	0	19	76
	Overall (*N* = 86)		**Kisii (*N* = 29)**		**Nyamira (*N* = 32)**		**Narok (*N* = 25)**	
Sanitation service levels	*n*	%	*n*	%	*n*	%	*n*	%
MDG sanitation ladder								
Improved	28	32	20	69	8	25	0	0
Shared	16	19	7	24	9	28	0	0
Unimproved	17	20	2	7	15	47	0	0
Open Defecation	25	29	0	0	0	0	25	100
SDG sanitation ladder								
Safely Managed Sanitation	28	32	20	69	8	25	0	0
Basic Sanitation	0	0	0	0	0	0	0	0
Limited Sanitation	16	19	7	24	9	28	0	0
Unimproved Sanitation	17	20	2	7	15	47	0	0
Open Defecation	25	29	0	0	0	0	25	100

Figure 2(c), where there are more 'low-risk' water samples collected from the filter with a household cup for Nyamira (72%) and Kisii (45%) respondents than for Narok respondents (8%).

MDG and SDG water and sanitation service levels

The MDG water ladder shows that the respondents from all counties had a mix of improved and unimproved water with one respondent from Kisii enjoying access to piped water in their dwelling, plot or yard (Table 4). Application of the MDG sanitation ladder shows most respondents in Kisii had access to an improved sanitation facility that was not shared with other households (69%), while 24% of respondents from Kisii shared an otherwise improved sanitation facility with one or more households, and 7% only had access to unimproved sanitation. Some respondents in Nyamira had an improved sanitation facility that was not shared with another household (25%), some had an improved sanitation facility that was shared (28%), while more only had access to an unimproved sanitation facility (47%). All Narok respondents practiced Open Defecation (100%).

Within SDG water and sanitation service criteria, the most frequent levels of water service were Safely Managed Water, Basic Water, and Surface Water, and the most frequent levels of sanitation service were Safely Managed Sanitation, Limited Sanitation, or practicing Open Defecation (Table 4). The percentages of respondents who had Safely Managed Water (34%) or at least Basic Water (36%) were approximately equal, although the majority of these were situated in Kisii and Nyamira. The third most prevalent access to water was surface water (22%), and all these respondents are situated in Narok. Most

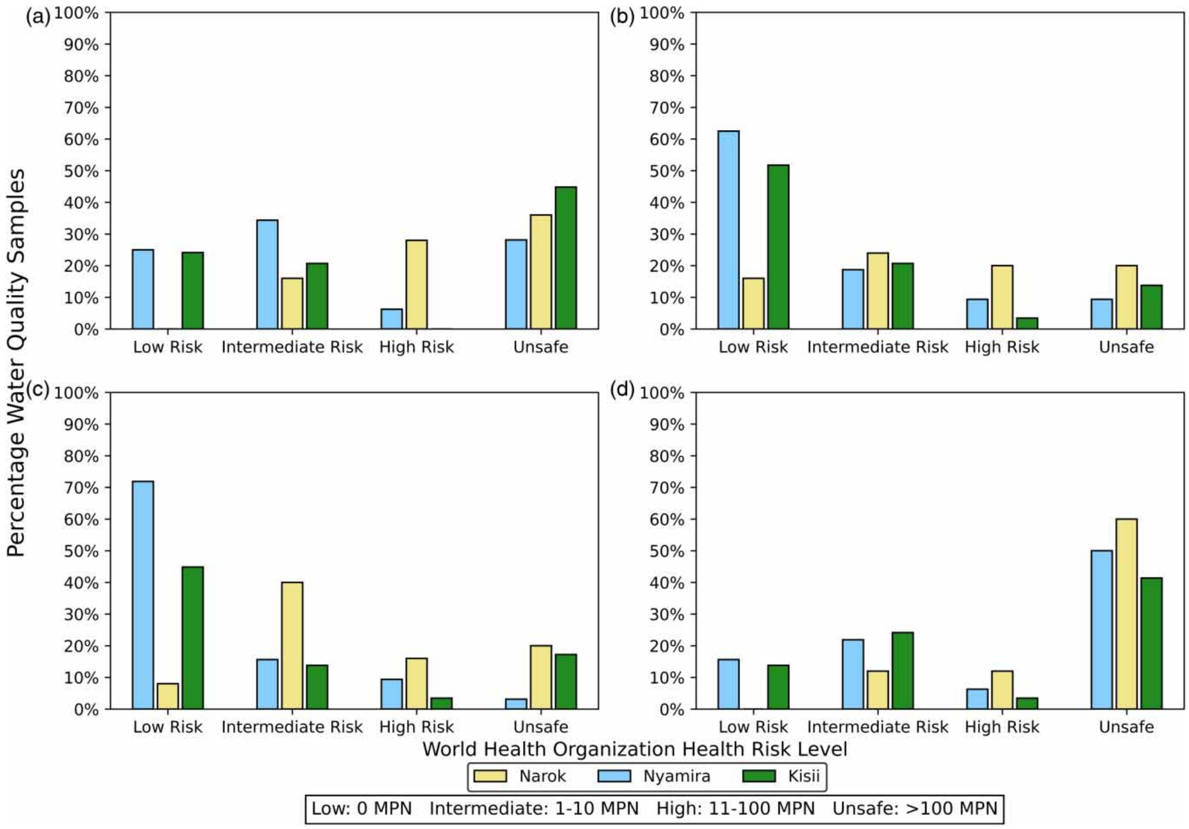

Figure 2 | Biological Water Quality Results. WHO health risk associated with the number of water samples: (a) prefiltration and (b) postfiltration, respectively, based on the levels of *E. coli*. (c) The WHO estimated health risk of water collected from the filter with a cup used by the household members. (d) The WHO health risk of water sampled from another storage container in the home based on levels of *E. coli*.

respondents in Kisii used Safely Managed Sanitation (69%), while the rest used Limited Sanitation (24%) or Unimproved Sanitation (7%). Among Nyamira respondents, similar numbers had access to Safely Managed Sanitation (25%) and Limited Sanitation (28%), while the rest only had access to Unimproved Sanitation (47%). All Narok respondents practiced Open Defecation (100%).

Component analysis of Safely Managed Water and Sanitation

Analyzing the percentage of respondents that achieved each of the criteria for Safely Managed Water, we find that a higher percentage of respondents in Kisii and Nyamira counties achieved Safely Managed Water criteria compared to respondents in Narok County (Figure 3). Less than a third of Narok respondents (24%) achieve Improved Water source criteria, while the majority of Nyamira (88%) and Kisii (97%) respondents did so. Similarly, most respondents in Nyamira and Kisii met 'on premises' (Nyamira: 91%; Kisii: 90%) and 'available when needed' (Nyamira: 100%; Kisii: 100%) criteria, while only 28 and 48% of Narok respondents achieved these. Microbial water quality showed the lowest percentage of achievement within the respondents of all three counties. All respondents in Nyamira and Kisii counties met WHO standards for fluoride, while only 48% of Narok respondents did. No respondents had any detectable amount of arsenic in the water supplies.

Similarly, we analyze the percentage of respondents who achieved each criteria for Safely Managed Sanitation, and we find a higher percentage of respondents in Kisii achieved each of the criteria of Safely Managed Sanitation than in Nyamira and Narok (Figure 3). In Narok County, no respondents achieved any component of Safely Managed Sanitation. In Nyamira and Kisii counties, the component of Safely Managed Sanitation with the lowest achievement was that the sanitation type was 'Not shared with other household'. Fewer respondents from Kisii shared sanitation facilities with other households than Nyamira respondents.

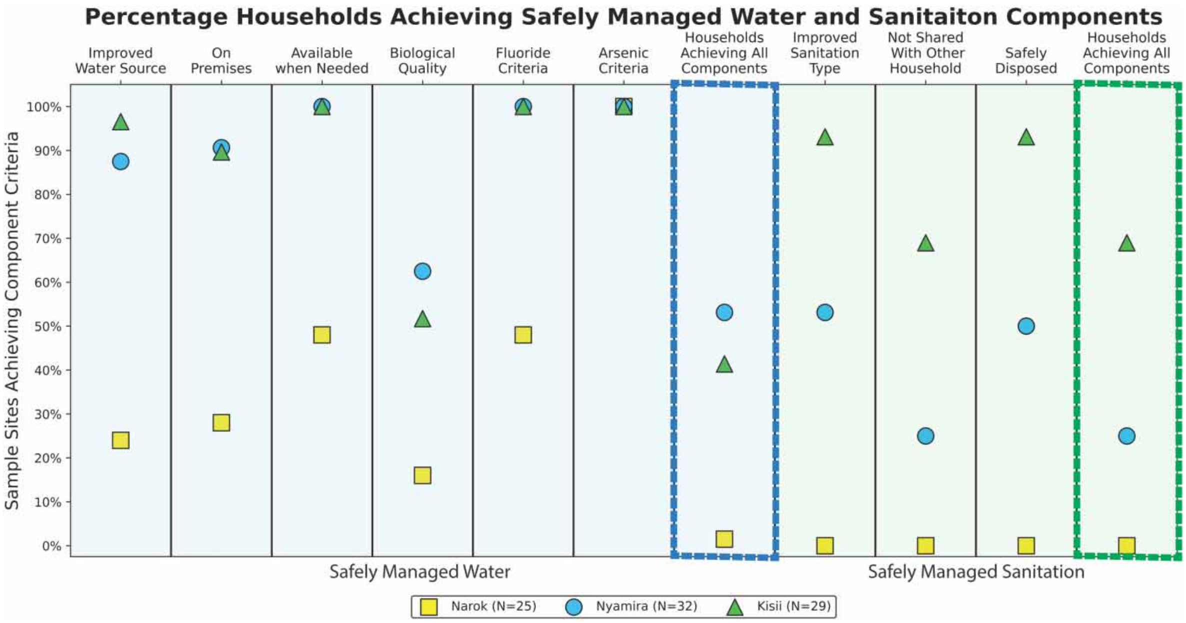

Figure 3 | Safely Managed Water and Sanitation component analyses.

Analysis between MDG and SDG water and sanitation provisioning

Within this case study, applying MDG and SDG water and sanitation criteria brings to light linkages between WASH provisioning in rural and urban settings with differing land use practices. There are linkages between various levels of the MDG water and sanitation service ladders and whether the context is more urban, rural, or pastoralist. Among the more urban Kisii respondents, application of the MDG water service ladder shows one respondent has access to piped water, while most others have improved drinking water. For more rural respondents in Nyamira, no respondent has access to piped water, but most rely on other improved drinking water sources. There are also more Nyamira respondents relying on unimproved drinking water sources than Kisii respondents. For Narok pastoralist respondents, some have improved drinking water sources, while most rely on unimproved drinking water sources. Among more urban Kisii residents, most respondents have Improved Sanitation (69%) or Improved Sanitation that is otherwise shared (31%), while more rural respondents in Nyamira range in their sanitation access with some having Improved Sanitation (25%), some having Shared Sanitation (28%), and more having Unimproved Sanitation (47%). Pastoralist respondents in Narok all practice Open Defecation (100%).

Application of the SDG water ladder clarifies water service provisioning with linkages between the service levels and rural, urban, or pastoralist contexts. While the MDG water service ladder shows that Kisii and Nyamira respondents have similar prevalence of improved drinking water (Kisii: 97%, Nyamira: 88%), the SDG water service ladder shows with finer detail that Nyamira respondents have higher prevalence of Safely Managed Water (53%) than Kisii respondents (41%). Kisii respondents, however, have higher prevalence of Basic Water (48%) and Limited Water (7%) than Nyamira and Narok respondents for Basic Water (Nyamira: 34%, Narok: 24%) and Limited Water (Nyamira: 0%, Narok: 0%). The SDG water service ladder also clarifies that the prevalence of Improved Water among Narok respondents (24%) is entirely composed of Basic Water (24%) but neither Safely Managed Water (0%) nor Limited Water (0%).

In contrast, the SDG sanitation service ladder results for respondents from the three counties are almost identical to the service levels from the MDG sanitation ladder. The exception is that no respondent had access to Basic Sanitation. All respondents who used Improved or Shared Sanitation with the MDG sanitation ladder correspondingly used Safely Managed Sanitation or Limited Sanitation with the SDG sanitation ladder. Unimproved and Open Defecation results from the MDG sanitation ladder were identical to the same service levels for SDG sanitation ladder.

Our results confirm many hypotheses that prevalence of water provisioning would be lower if water quality were included in water access criteria (Bain *et al.* 2012; Grady *et al.* 2015). Our component analysis reveals in finer detail why there are lower prevalence of Safely Managed Water than Improved Water through the demonstration of the percentage of respondents which achieve each of the six criteria for Safely Managed Water (Figure 3). The component analysis also shows which criteria need greater attention to increase access to such water provisioning. Finer distinctions of water and sanitation servicing, which can be seen through the application of the SDGs and our use of component analyses, bring to light specific challenges these communities may face in water and sanitation provisioning which are largely obscured when only MDG criteria are used. Understanding these distinctions, which are more clearly seen with SDG component analyses, is important when pursuing investment for increased global water and sanitation provisioning (Marshall & Kaminsky 2016; Mara & Evans 2018).

DISCUSSION

Water quality results in our study indicate that there may be multiple contextual and geographical factors limiting fuller realization of Safely Managed Water. Considering microbial water quality, the number of 'intermediate risk', 'high risk', and 'unsafe' samples postfiltration among Narok respondents is unexpected, because in laboratory settings, the hollow fiber membrane filter has been shown to remove up to log 7 *E. coli* (Murray *et al.* 2017). Our results are more in line with studies that have demonstrated mixed results of household filter effectiveness in the field and emphasize that such mixed results may depend on a variety of conditions that are particular to the study site (Fewtrell *et al.* 2005; Clasen *et al.* 2014; Murray *et al.* 2017). Our results demonstrate that in assessing how hollow fiber membrane filtration contributes to achievement of Safely Managed Water, there is a need for further detailed analysis as to what environmental conditions influence household water filter effectiveness.

The result of high levels of fluoride found among respondents in Narok, which is situated in the Rift Valley, is similar to previous research, which found groundwater in the Rift Valley to have levels of fluoride that exceed 10 mg/L (Ndambiri & Rotich 2018). This may indicate that respondents in Narok County may face challenges related to high levels of fluoride, while those in Nyamira and Kisii may not. For Narok respondents and others who do face challenges related to high levels of fluoride, there will be a need for fluoride remediation to achieve Safely Managed Water.

With our case study, we find that MDG and SDG water and sanitation service provisioning have linkages with varying rural and urban contexts. This is an important finding because continuing to strive for improved water and sanitation across rural and urban contexts will require the consideration of contextual challenges. These contextual factors may be hidden by MDG and SDG water and sanitation service levels, however. For example, pursuing increased sanitation access will need to take into consideration situations where household access to one or more toilets may be dynamic and unreliable (Foggitt *et al.* 2019).

Given our comparison of the MDGs and SDGs across different rural and urban contexts, the component analyses provide useful information to investigate whether the MDG improved water indicator was a sufficient proxy for broader water service provisioning (Figure 3). Considering only Nyamira and Kisii respondents, the 'improved water source' type could be seen to be a useful proxy for all other criteria than microbial water quality: 'on premises', 'available when needed', 'fluoride criteria', and 'arsenic criteria'. This should be carefully considered, however, because the areas of Nyamira and Kisii do not have issues with fluoride and arsenic, while an area such as Narok does have high levels of fluoride. The case of Narok also shows that 25% of respondents had an 'improved water source' type, while 50% respondents indicated that water was 'available when needed'. The case of Narok demonstrates that the 'improved water source' type may not be a good proxy for all contexts. Our case study suggests that there could be important underlying geographical and contextual factors affecting different dimensions of water provisioning to varying degrees.

Limitations

Due to distance between sites, cost of sampling materials, difficulty of travel, limitation of resources, and some household filter owners absent at the time of sampling, it was only feasible to collect samples from 86 respondents. While our sample sets were small and nonrandomized, our purposive heterogeneous sampling techniques provided the opportunity to elucidate rich details from our cases to provide context and interconnections that have helped us interpret our results (Tongco 2007).

In purposively sampling households that were representative of Aqua Clara Kenya's clients in Narok, Nyamira, and Kisii counties, our findings may be limited in their generalizability to their broader county and country context. This limitation can be seen when comparing the education levels of our sample to that of the surrounding county and subcounty. While most Narok respondents have an education that is primary level or less (primary: 16%, preprimary: 44%, none: 32%), most residents of the broader Narok South subcounty and Narok County have reached a higher level of education (preprimary: 16.5%, 15.6%, primary: 61.5%, 58.4%, secondary: 16.3%, 19.4%; Supplementary Material, Table S6; KNBS 2019). This indicates that the Narok respondents in this study are biased toward those with less education. In a similar manner, Nyamira respondents in this study are biased toward residents with a secondary education (72%) compared to the broader Nyamira Borabu subcounty and Nyamira County context (Supplementary Material, Table S6; KNBS 2019). Kisii respondents in this study are biased toward residents with secondary, vocational, and university education compared to residents in the broader Kisii Central subcounty and Kisii County context (Supplementary Material, Table S6; KNBS 2019).

Even though data analysis methods that dealt with missing values were carefully selected, they may have introduced elements of bias into our analysis. This bias can be seen in how we conservatively estimated water access levels up to Basic Water when all water quality results were not available, and how we conservatively estimated sanitation levels to Unimproved Sanitation, when there was not enough information about whether sanitation facilities were shared. There also may be additional bias in the results of Safely Managed Sanitation, as questions related to safe disposal of fecal matter are based on a question of self-reported practice. Future studies should include multiple questions related to safe disposal of fecal matter and sanitary inspections to better assess Safely Managed Sanitation. Even with such limitations, however, our results provide enough evidence to raise important questions for additional research efforts that can be broader in scope, which will only continue to improve understanding of water and sanitation access around the globe.

CONCLUSION

This study sought to address gaps in the previous literature by directly comparing water and sanitation access using both MDG and SDG criteria among communities with varying rural and urban contexts and land uses. The MDG water ladder elucidates that 3% of Kisii respondents have piped water, while the sanitation ladder usefully highlights the range of sanitation service levels across Kisii, Nyamira, and Narok respondents. Only approximately one-third of respondents had access to Safely Managed Water (34%) and more than one-third had Basic Water access (36%). Respondents from Kisii and Nyamira counties have prevalence of Safely Managed Sanitation that ranges from 25 to 69%, prevalence of Limited Sanitation that ranges from 24 to 28%, and Unimproved Sanitation that ranges from 7 to 47%. All respondents from Narok practice Open Defecation. Investigating water and sanitation service levels across varying rural, urban, and land use contexts shows the strengths and weaknesses of the SDGs and MDGs in these different settings and highlight limitations that persist in our understanding of water and sanitation access in ways that are unique to each setting.

The Safely Managed Water and Sanitation component analyses also show which of the Safely Managed Water and Sanitation criteria may be limiting fuller realization of WASH service provisioning. Within Safely Managed Water, microbial water quality was the lowest-achieved criterion among respondents from all counties, and fewer respondents from Narok met the fluoride water quality criterion. Within Safely Managed Sanitation, toilet facilities that were not shared with other households was the lowest-achieved criterion for Nyamira and Kisii respondents. While there are many factors that limit fuller water and sanitation access, the component analyses we introduce in our research detail progress while simultaneously identify that to increase water and sanitation access, there may be need for increased research and investment surrounding fluoride remediation, treatment for microbial contamination, and shared sanitation facilities. Additional research will be necessary to understand what factors limit the effectiveness of household water treatment. In addition to confirming that MDG projections of water and sanitation provisioning may be largely overestimated, comparison of water and sanitation servicing using MDG and SDG criteria provides strengthened understanding surrounding areas needing increased research and investment to accomplish greater strides for WASH servicing worldwide.

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CONFLICT OF INTEREST

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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