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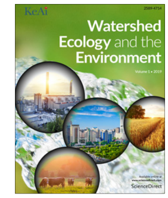

Welfare impacts of water security in Kenya: Evidence from the Upper Ewaso Ngiro North Catchment Area

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ABSTRACT

Water insecurity is a major concern both in the global and local contexts. The study estimated the sub-catchment water poverty index and the household water security index, on cross-sectional farm household data collected from 652 households randomly selected from eight sub-catchments of the Upper Ewaso Ng'iro North Catchment Area (ENNCA). The impact of water security on household income per adult equivalent and prevalence of waterborne diseases was assessed using ordinary least squares regression and Poisson regression models respectively. Water Poverty Index (WPI) results revealed that Sirimon and Ewaso Narok sub-catchments are faced with acute water stress, while the rest of the sub-catchments are faced with moderate water stress despite being in the sub-catchment area. The results showed that improved water security can offer welfare benefits to households through increments in household income and reduced water-borne disease prevalence. From the findings, therefore, improved water security can offer both economic and health solutions to some of the country's problems including poverty alleviation and reduce the government's budget spending on communicable and non-communicable water-related diseases.

1. Introduction

Small-holder irrigation has been proven to be a pathway out of poverty and inequality, with the returns on irrigation investments in Sub-Saharan Africa (SSA) ranging from 17 per cent for large-scale farmers to 43 per cent for small-scale farmers, with the ability to triple per capita farm incomes, resulting in significant impacts on poverty reduction (World Bank Group, 2019). Despite, the huge potential of irrigation cropping, water scarcity is becoming a challenge across the globe (Kummu et al., 2016; Falkenmark, 2013; Falkenmark et al., 1998), and more so in SSA. Agriculture is a key contributor to rural incomes in Kenya, with a majority of rural households depending on farming for their livelihoods (GOK, 2019; World Bank Group, 2019; Nyoro, 2002).

Kenya is faced with several water-related challenges which include; climate variability, growing population, catchment degradation, pollution and invasive species (UN-Water/WWAP, 2006). Water demand has also risen sharply due to increased water uses and users across sectors such as energy, construction and domestic use (Misra, 2014; Strzepek and Boehlert, 2010). According to Davies and Gustaffson (2015), despite the country having some of the greatest water towers in the region, 90 per cent of the country is either arid or semi-arid (ASAL). Further, local water stress is a challenge, not only in the ASAL areas but also in more water-rich regions where water-intensive economic activities have grown rapidly, the Upper ENNCA included (Davies and Gustaffson, 2015; Mungai et al., 2004; Gichuki, 2002).

The benefits of improved water security cannot be overstated. Previous studies have shown evidence of a positive and significant relationship between water security and improved household food security, nutrition, livelihoods and welfare (Rosegrant, 2020; Brewis et al., 2020; Hadush, 2018; WFP, 2017; Pérez-Escamilla, 2017; Sinyolo et al., 2014; FAO, CFS, 2015; Cosgrove and Loucks, 2015; Fanadzo, 2012; Ludi, 2009; Khan et al., 2009; Penning de Vries et al., 2003; Rosegrant and Cai, 2001; Webb and Iskandarani, 1998). Further water security plays a major role in women empowerment as a result of time savings and health benefits due to reduced drudgery as a result of improvement in water access and water quality (Rosegrant, 2020; Bisung and Elliot, 2018;

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Otufale and Coster, 2012; Crow and McPike, 2009; James et al., 2002). Other benefits arise due to income and time savings (Bisung and Elliot, 2018). Further, improved water security results in reduced exposure to faecal contamination and the risk of infectious diseases due to effective management of multiple water uses, and wastewater (Rosegrant, 2020; Bain et al., 2014; Collins et al., 2007). Finally, according to Cooper (2020), strengthening water security is essential for preventing and combating future pandemics, including the current COVID-19 pandemic, since handwashing is one of the key measures to suppress the spread of COVID-19.

While water security is a concern, the main challenge in research circles is the measurement of household water insecurity and establishing its effects on household welfare. Since, researchers and practitioners have few tools to quantitatively measure, assess and compare the scope and scale of household and individual water insecurity across cultural and climatic variations (Jepson et al., 2017). Further, Jepson et al., (2017), notes that water insecurity metrics can be categorized into four conceptual domains; human development; sustainability; geopolitics; and vulnerability. While our scale of interest is the sub-catchment level and the unit of study is the household, we, therefore, use the Water Poverty Index (WPI), to measure water security for three reasons; first is that it follows the human development concept in its approach (Jepson et al., 2017; Sullivan, 2002) and secondly, it uses a holistic approach since it considers; available water resources; the access to the water resources; the capacity to manage the water resources; the current uses of the available water resources in including shortfalls and any environmental factors that may affect water resource availability. Finally, it can be used to measure household water security through the use of principal component analysis (PCA) and factor analysis (Garriga and Foguet, 2010). Previous studies have used the WPI in economic analysis (Senna et al., 2019; Sinyolo et al., 2014; Matshe et al., 2013; Garriga and Foguet, 2010; Sullivan, 2002). The novelty of this study is that it will generate new discourse about water security or insecurity thereof, in water catchment areas, which are mostly perceived to be water-secure, on the basic classification as "water catchment areas". This study, therefore, sought to add more knowledge to the existing knowledge on the measurement of household water security and extend the same to assess the impacts of water security on household welfare through a quantitative analysis approach. In consideration that welfare is quite broad and multidimensional, we use household income per adult equivalent and prevalence of water-borne diseases as proxies for welfare. The study has the following objectives; to determine sub-catchment water security in the Upper ENNCA; to assess the impact of household water security on household income per adult equivalent and; to assess the impact of household water security on the prevalence of water-borne diseases in the Upper ENNCA. The study has the following hypothesis;

- There is a relationship between household-level water security and household income per adult equivalent in the Upper ENNCA.
- There is a relationship between household-level water security and the prevalence of water-borne diseases in the Upper ENNCA.

2. Materials and methods

2.1. The study area

The study was undertaken in the Upper Ewaso Ng'iro North Catchment Area (ENNCA), which is the catchment area for the Ewaso Ng'iro River basin. The Ewaso Ng'iro River basin is the largest in Kenya (ENNDA, 2019). It covers an area of about 210,226 km^2, which is about 36% of the total area of Kenya's 576,000 km^2. It is the largest of all the six basin areas but with the least population, this is because it falls in Arid and Semi-Arid (ASAL) parts of Kenya. Altitude ranges from 150 m at the Lorian swamp to 5,199 m at the peak of Mount Kenya. The map of the Ewaso Ng'iro North Basin is shown in Fig. 1. The map shows the upper, middle and lower basin areas. From the map, the importance of the upper catchment area cannot be overemphasized, since it serves a large portion of the country which is mostly arid and semi-arid areas (ASAL).

According to Mungai et al. (2004), the Upper Ewaso Ng'iro North Basin is located to the north and west of Mount Kenya, extending to the Aberdare Ranges between longitudes $36^{0}30'$E and $37^{0}45'$E and latitudes $0^{0}15'$N and $1^{0}00'$N. The map of the Upper Ewaso Ng'iro North Catchment area is shown in Fig. 2. The catchment area is divided into 21 sub-catchment areas as shown. The upper catchment area is highly utilized for agricultural production due to favourable weather conditions, fertile soils and irrigation water availability through river abstractions. The main economic activity in Upper Ewaso Ng'iro North Catchment, is small-scale farming (rain-fed and irrigation), small-scale fishery and pastoralism. The area ranges from high potential high altitude to low potential arid and semi-arid zones. Due to the arid nature of most parts of the basin, the atmospheric demand for water is very high (Ericksen et al., 2012; Mutiga et al., 2010).

2.2. Sampling strategy and sample frame

Data was collected in the period between September 2019 and February 2020 from a sample of 652 households. A multistage sampling technique was employed in the study. In the first stage, eight sub-catchments were sampled randomly out of the twenty-one sub-catchments of the Upper ENNCA; as a result, the following sub-catchments were sampled; Ewaso Narok, Pesi, Rongai, Naromoru, Likii, Timau, Sirimon and Ngare Ndare. In the second stage, stratified sampling was done disproportionately to the population size of the sampled sub-catchments, since the number of households in each sub-catchment was unknown. Finally, simple random sampling was undertaken using a list from the WRUAs.

2.3. Types of data and data sources

This study utilized both primary and secondary data sources. Primary data was collected from households, WRUAs and key informants. Secondary data was collected from sources such as books, journals and reports. Data collected for the study included household data, group data, farm produce data and income data. A semi-structured questionnaire was administered to the small-scale farmers by trained enumerators, using the World Bank's Computer Aided Personal Interview (CAPI) Program, through face to face interviews. Data for the study were analyzed using STATA version 15.0 statistical software.

3. Analytical framework

3.1. Determination of Sub-catchment water security

To determine sub-catchment water security in the Upper ENNCA Kenya, the Water Poverty Index (WPI) was calculated for each of the sampled sub-catchments following Korc and Ford (2013). The Water Poverty Index (WPI) is a composite index principally designed to assist decision-makers at different levels in developing and targeting interventions that aim to increase water security for the poor (Matshe et al., 2013; Sullivan et al., 2003. The

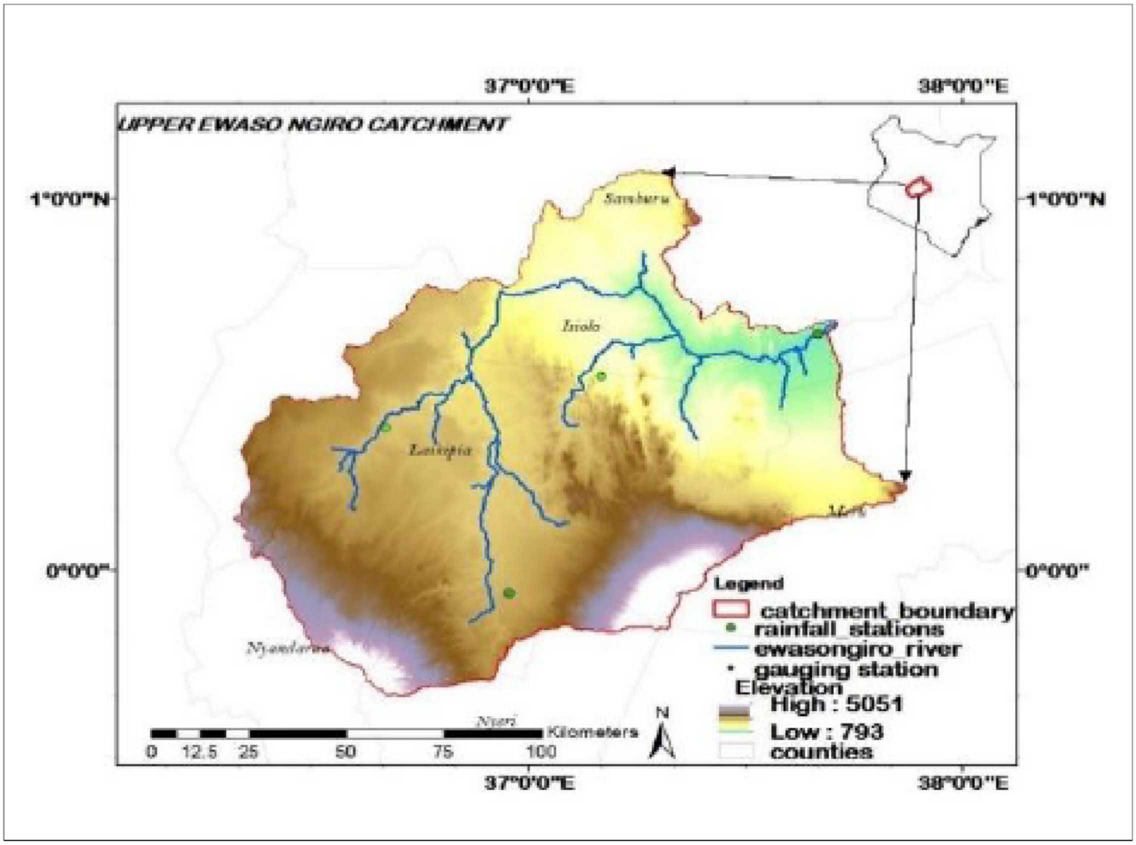

Fig. 1. Map of the Upper Ewaso Ng'iro North Catchment Source: Omwoyo et al. (2017).

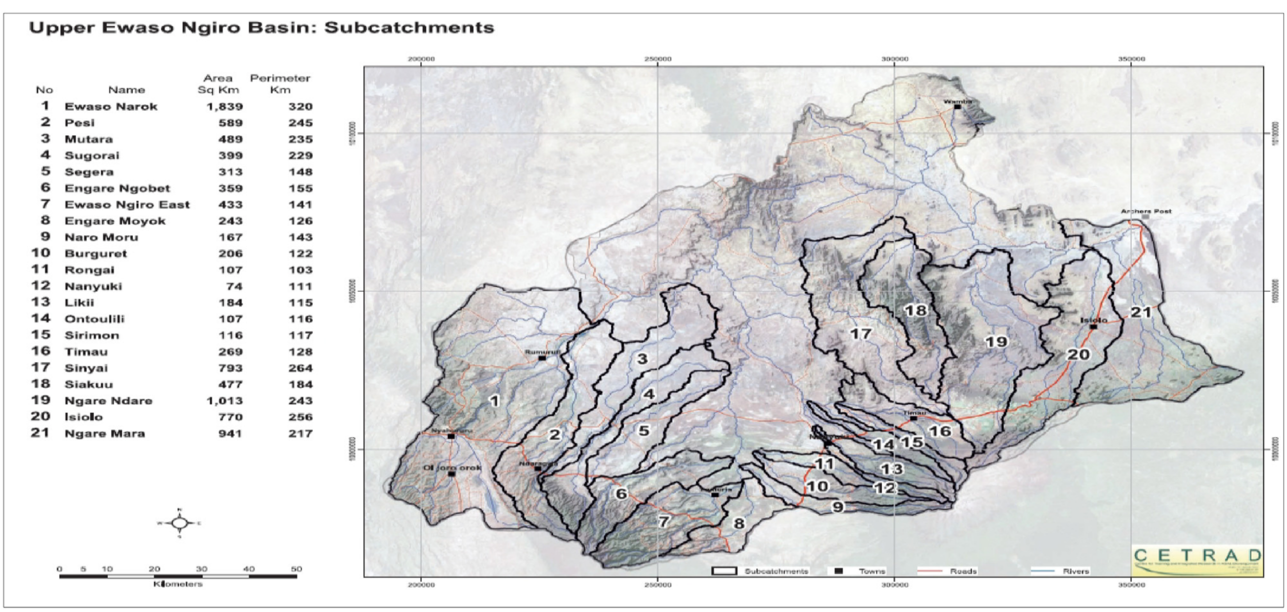

Fig. 2. Map of Upper Ewaso Ng'iro Basin Sub-catchments Source: (CETRAD, 2014).

WPI stems from a realization that assessing households' access to water requires a holistic approach that takes into consideration not only whether or not a household has access to water, but also issues relating to water quality and variability, multiple uses of water, households' capacity to manage water, as well as environmental and spatial scale aspects related to water. According to Korc and Ford (2013), WPI as a water management tool has found great relevance in policy formulation, primarily in resource allocation and prioritization processes particularly in water-poor countries like Kenya. In proposing a WPI that considers these aspects, Sullivan et al., (2003) identify, via a community participatory approach, the following five components as key to a holistic WPI: Resources(R): this component captures the physical availability of both surface and groundwater: Access (A), this component

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Table 1
Sub-catchment Water Poverty Index.

Sub-catchment	R1	R2	z R3	R4	R5	R6	R7	**R**	A1	A2	A3	A4	**A**	C1	C2	C3	C4	C5	**C**	U1	U2	U3	U4	**U**	E1	E2	E3	E4	**E**	**WPI**
Ewaso Narok	79.45	86.30	21.92	24.66	79.97	83.56	93.15	**93.80**	35.62	90.41	8.22	4.11	**27.67**	89.04	76.92	89.04	50.68	19.18	**64.97**	43.84	31.67	65.75	16.44	**31.54**	53.42	39.73	19.18	12.33	**24.93**	**48.58**
Pesi	81.08	56.76	24.32	25.68	74.32	85.14	85.14	**86.40**	37.84	95.95	55.41	35.14	**44.87**	97.30	76.39	85.14	33.78	20.27	**62.58**	54.05	51.88	74.32	32.43	**42.54**	72.97	37.84	36.49	17.57	**32.97**	**53.87**
Naro Moru	79.77	35.72	38.10	52.38	76.19	80.95	90.48	**90.72**	55.95	98.81	50.00	26.19	**46.19**	95.24	78.75	94.05	61.54	29.76	**71.87**	53.57	38.91	75	28.57	**39.21**	84.52	53.57	44.05	29.76	**42.38**	**58.07**
Rongai	67.95	35.89	25.64	41.03	66.67	69.23	75.65	**76.41**	30.77	100	75.64	24.36	**46.15**	89.74	77.14	92.31	53.85	29.49	**68.51**	55.13	45.11	66.67	38.46	**41.07**	91.03	71.79	46.15	47.44	**51.28**	**56.68**
Likii	62.82	37.18	52.56	65.38	71.79	79.49	80.77	**89.87**	78.21	97.44	46.15	17.95	**47.95**	92.31	58.33	91.03	65.38	23.08	**66.03**	66.67	48.13	80.77	20.51	**43.22**	65.38	44.87	29.49	26.64	**33.28**	**56.07**
Timau	74.44	51.13	31.11	45.56	84.44	82.22	86.67	**91.11**	72.22	97.78	59.09	33.33	**52.48**	94.44	76.47	85.56	46.67	31.11	**66.85**	46.67	47.73	71.11	42.22	**41.55**	77.78	37.78	32.22	26.67	**34.89**	**57.38**
Ngare Ndare	81.71	57.31	53.66	64.63	69.51	73.17	85.36	**97.07**	58.54	97.56	56.10	39.02	**50.24**	93.90	53.25	76.83	52.44	19.51	**59.19**	46.34	43.34	70.73	23.17	**36.72**	74.39	59.76	35.37	50.00	**43.90**	**57.42**
Sirimon	65.89	42.35	23.53	34.12	62.35	68.23	72.94	**73.87**	52.94	95.29	32.94	14.12	**39.01**	94.44	67.47	87.06	52.94	14.12	**63.21**	43.53	33.00	58.82	23.53	**31.61**	76.47	30.59	36.47	15.29	**31.73**	**47.89**
Average	**74.14**	**50.33**	**33.86**	**44.18**	**73.16**	**77.75**	**83.77**	**87.41**	**52.76**	**96.66**	**47.94**	**24.28**	**44.32**	**93.30**	**70.59**	**87.63**	**52.16**	**23.32**	**65.40**	**51.23**	**42.47**	**70.40**	28.17	**38.43**	**74.50**	**46.99**	**34.93**	**28.21**	**36.92**	**54.50**

Where:
Resources -R1- Surface water assessment.
R2- Groundwater assessment.
R3- Is water available throughout.
R4-Is source reliable.
R5-Is quality good.
R6-Taste.
R7-Smell.
Access -A1: Access to piped water.
A2: Access to a sanitation facility.
A3: Access to irrigation water.
A4: Is irrigation water available throughout.
Capacity – C1: Owning land Capacity – C2: Title.
C3: Level of Education.
C4: Primary occupation not farming.
C5: Access to credit.
Uses – U1: Is water sufficient for your uses?
U2: Proportion of land under irrigation.
U3: Is water sufficient for livestock needs throughout the year?
U4: Water conflicts in the community in the past year.
Environment – E1: Crop loss to drought in the last five years.
E2: Crop loss to floods in the last five years.
E3: Livestock loss to drought in the last five years.
E4: Soil erosion in the last five years.

considers access to water for human use (drinking and nondrinking): Capacity (C), this component relates to the ability of people to manage water: Use (U), this component considers the multiple uses of water, and: Environment (E), this component seeks to factor in environmental integrity related to water resources.

These five components are used to construct a WPI. Sullivan et al. (2003) argue that the construction of the WPI should follow a structure similar to that of the Human Development Index (HDI). Specifically, each component is constructed via the following general formula:

$$WPI = \varpi_i = \frac{\sum_{i=1}^{N} w_i C_i}{\sum_{i=1}^{N} w_i} \tag{1}$$

where for each household, *WPI* and ϖ_I refers to the Water Poverty index; C_i refers to component *I* of the household's WPI, with *I = Resources (R)*, *Access (A)*, *Capacity (C)*, *Use (U)*, and *Environment (E)*, while w_i is the weight applied to that particular component. The scores of each component are calculated using the average of all the sub-components in each. For instance, the resources component has seven subcomponents for each sub-catchment, that is, R1 to R7 as shown in Table 1. One of the key challenges in the calculation of the WPI is the assignment of the respective weights to the components. According to Sullivan, 2002; Sullivan et al. (2003) and Sullivan and Meigh (2007) assignment of equal weights is preferred to avoid problems of subjectivity since weights are applied to indicate the relative importance of a particular component in the WPI. For the current study, we used equal weights for two reasons; the first is because of the recommendations by Sullivan and Meigh (2007). Secondly, during the piloting phase, we conducted three focus group discussions with different stakeholders, to determine the relative importance of the different components and subcomponents and the results showed that the stakeholders felt indifferent since they considered all the components equally important. The final WPI questionnaire can be found in Table A1 of the appendix.

3.2. Determination of household-level WPI

Principle Components Analysis (PCA) and Factor Analysis have been used to create a multi-criteria water security index for households (Senna et al., 2019; Nadeem et al., 2018; Sinyolo et al. 2014; Matshe et al., 2013). Therefore, for this study, all the five components of the conventional WPI were reduced using PCA to obtain the household level water security index. According to Achia et al. (2010), PCA is a multivariate statistical technique used to reduce the number of variables without losing too much information in the process. However, the use of the conventional PCA would have been erroneous since our data were not continuous but were dummy. Therefore the PCA results would not be reliable, to remedy this problem we used polychoric PCA.

The first principal component with the largest variation was then used as the independent variable (Water security index) in an Ordinary Least Squares (OLS) to determine the determinants of household income per adult equivalent and in a Poisson model to analyse the determinants of water-borne disease prevalence in the study area.

3.3. Determination of the impact of household water security on household welfare

To measure welfare we used the household income per adult equivalent, where the income per adult equivalent is the total annual household income factored in per adult equivalent terms. Equivalent scales are the deflators that are used to convert household real incomes into money metric utility measures of individual welfare. There are three methods of calculating the adult equivalents; behavioural approach, subjective approach and arbitrary approach. However, the first two are considered unreliable due to subjectivity. To calculate the household adult equivalents for this study we used the arbitrary approach following the recommendations by Deaton and Zaidi, (1999).

The OLS regression of the determinants of household income per adult equivalent was specified as follows;

$$Y_i = \alpha + \beta x_i + \boldsymbol{\delta W}_i + \varepsilon_i \tag{2}$$

where Y_i is the log household income per adult equivalent for household *i*, x_i is a vector of household characteristics, $\alpha$is the intercept and β is the vector of coefficients to be estimated, δ is the impact parameter, W_i is the water security index for household *i* and ε_i is the error term. The impact parameter, δ, shows the change in household income Y_i as a result of a change in household water security W_i.

To assess the prevalence of water-borne diseases, the respondents were asked to respond on whether any household member suffered from any of the following illnesses related to water and hygiene: malaria, diarrhoea, stomach ache, vomiting, cholera, typhoid fever, and skin and eye infections. From the data a count variable for water-borne diseases was generated, ranging between 0 and 7 depending on the number of the listed illnesses or symptoms and zero if none of the household members experienced any of the said illnesses or symptoms within the reference period. As such the assessment of the determinants of the extent of prevalence should be conducted using the Poisson regression model (Greene, 2003). Therefore, the following reduced form Poisson regression econometric model was applied to the household data and was specified in equation (3) as follows;

$$\begin{aligned} A = {} & \beta_0 + \beta_1 Age + \beta_2 Gender + \beta_3 Formal\_Educ + \beta_4 HH\_Size \\ & + \beta_5 Credit\_access + \beta_6 Water\_Security\_Index \\ & + \beta_7 Sub\_catchment + \varepsilon \end{aligned} \tag{3}$$

where ***A*** is the number of water-borne diseases affecting a particular household, in this case (0–7), β_0 is the constant term (y-intercept), β_1-β_7 are the coefficients of the different independent variables and $\boldsymbol{\varepsilon}$ is the error term.

4. Results and discussions

4.1. WPI results of the Sub-catchment water security

4.1.1. Resources component

From the findings in Table 1, most of the sub-catchments are endowed with water resources. The results show that the least score achieved for the component of the overall resources was in Sirimon sub-catchment which had an average of 73.87%; while Ngare Ndare sub-catchment had the highest score at 97.07%. The overall average score for the resources component was 87.41%. However, such a high average could be misinterpreted to mean that the Upper Ewaso Ng'iro Catchment Area has no water challenges, as such a deeper dive into the sub-components reveals interesting findings. First, the average scores for surface water assessment (R1), water quality (R5), taste (R6) and smell (R7) are quite high at 74.14%, 73.16%, 77.75%, and 83.77% respectively. These findings imply that the surface water sources are of good quality, fit for consumption and agricultural production. Secondly, there is potential for groundwater exploration to supplement the surface water sources, since, the average assessment of groundwater (R2) is 50.33%. Third, the results show that the average scores for water availability (R3) (33.86%) and reliability (R4) (44.18%) are below the 50% threshold. This implies that, whereas water resources in the catchment area are of good quality and there is potential for further development, most households lack a continuous and reliable water supply and have to bear with rationing and interruptions in the water supply. For households to make proper irrigation investment decisions, water supply availability and reliability is a prerequisite, whereby if water is available and reliable they decide to invest, if not they decide to reduce the proportion of land under irrigation or decide not to invest at all, due to the inherent risk of crop failure.

4.1.2. Access component

The water access component is a crucial component in the WPI since it helps measure household access to water sanitation and hygiene facilities. From the results in Table 1, the water access component is generally low, since, the overall component average is 44.32% less than the 50% threshold. The overall access to piped water (A1) average was 52.76%, however, three sub-catchments which included; Rongai (30.77%), Ewaso Narok (35.62%) and Pesi (37.84%) were below the threshold. Regarding access to a sanitation facility (A2), all the sub-catchments had an overall 96.66% average. However, access to irrigation water (A3) remained relatively low across all the sub-catchments with an overall average of 47.94%. And, finally, where irrigation water was available, only 24.28% of the households, across the sub-catchments had access to irrigation water throughout (A4). These findings imply, that, despite the importance of the access component, water access remains low in the Upper ENNCA. These low access scores may explain the continued over-exploitation and degradation of water resources in the very important catchment areas because water is not enough for household domestic and irrigation needs.

4.1.3. Capacity component

The capacity component seeks to know the household endowment of important assets, knowledge and skills that can have a bearing on how the households use and manage the water resources at their disposal. All sub-catchments are well endowed in terms of capacity whereby; the overall capacity score is 65.40%, however, access to credit (C5) is still an impediment with an average of 23.32%.

4.1.4. Uses component

The overall score for the uses component is well below the threshold as shown in the results, whereby, it stands at 38.43%, this implies that there is insufficient water for all uses in the catchment area and as such water resources need to be planned, allocated and used prudently for posterity. From the findings all the sub-catchments are quite constrained in the following order; Ewaso Narok (31.54%), Sirimon (31.61%), Ngare Ndare (36.72%), Naro Moru (39.21%), Rongai (41.07%), Timau (41.55%), Pesi (42.54%), and Likii (43.22%). Households are mostly constrained with regard to U2 (proportion or land under irrigation) (42.47%), whereby due to increased water un-reliability, they are forced to allocate less land to irrigation cropping to minimize losses and risks. The other constraint stems from U4 (Water conflicts in the community in the past one year) (28.17%), whereby water conflict incidences affected households. The worst affected sub-catchments are Timau (42.22%) Pesi (32.43%) and Rongai (38.46%).

4.1.5. Environment component

The environment component has an overall mean of 36.92 showing that the Upper ENNCA is quite vulnerable to environmental degradation. In the last five years, 74.50% of the households were affected by crop loss due to drought, 46.99% lost their crop to floods, 34.93% lost livestock to drought and 28.21% were affected by soil erosion.

The different component scores for the different components can be illustrated in a pentagram as shown in Fig. 3.

4.1.6. Overall water poverty index

While, in the previous subsections we have looked at the component scores for each sub-catchment, here, we discuss the overall WPI for the Upper ENNCA as a unit. From the computed component indices, the water poverty index for the different sub-catchments was calculated as shown in the last column of Table 1. The overall results show that the overall WPI for the Upper ENNCA is 54.50, this WPI is just on the margin and is not as good, since a higher WPI signifies a better status of water resources use and management. The distribution of the WPI across sub-catchments in descending order is as follows Naro Moru, Ngare Ndare, Timau, Rongai, Likii, Pesi, Ewaso Narok and Sirimon. Households in Sirimon and Ewaso Narok are faced with acute Water poverty, while households in the rest of the sub-catchments are faced with moderate water poverty.

Finally, the WPI index is depicted using a pentagram as shown in Fig. 4 to make a visual distribution of water poverty across the sub-catchment areas.

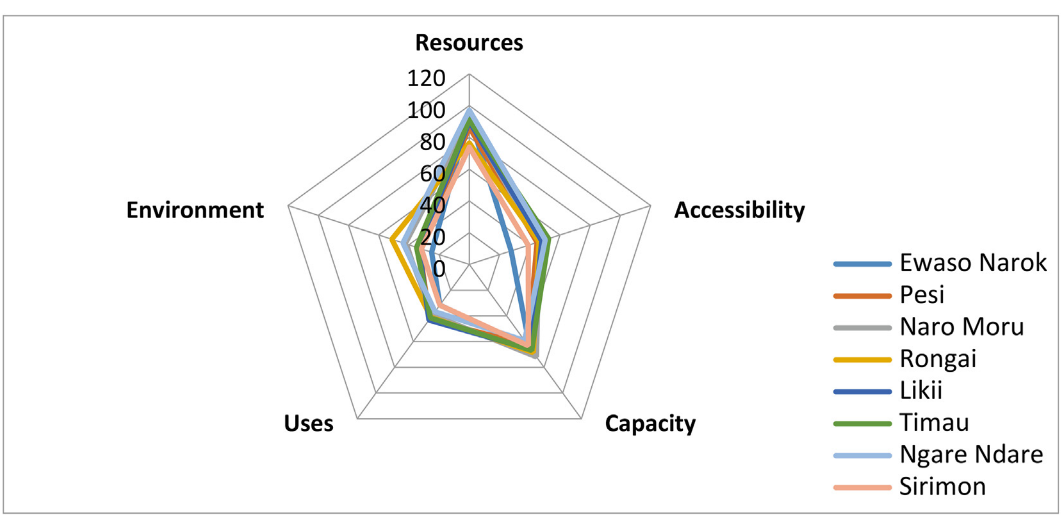

Fig. 3. WPI components by sub-catchment.

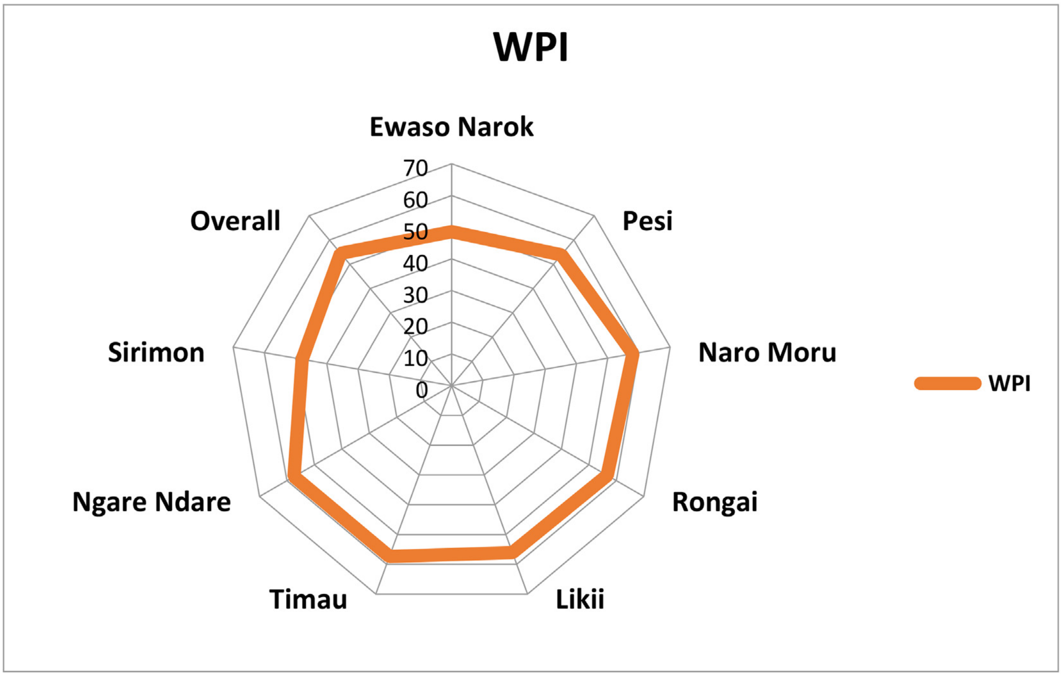

Fig. 4. Overall WPI.

Table 2
Water security principle components.

Component	Eigenvalues	Proportion explained	Cum. explained
PC1	4.72355	0.3765	0.3765
PC2	2.38180	0.1898	0.5663
PC3	1.69781	0.1353	0.7016
PC4	1.30389	0.1039	0.8055

4.2. Determinants of household water security

4.2.1. Principal component analysis (PCA)

Twenty-one principal components (PCs) were extracted using polychoric correlations, while only 4 components that had Eigenvalues greater than one were retained using the Kaiser criterion, as shown in Table 2. Cumulatively the four retained principal components explain 80% of the variance in the data.

The first PC (PC1) explained 38% of the variation with an Eigenvalue of 4.724, while PC2 explained 19% of the variation. The third component PC3 had an Eigenvalue of 1.698 and explained about 14% of the variation, and finally, PC4 had an Eigenvalue of 1.304 and explained 10% of the variation. The results of the factor loadings of the four PCs are illustrated in Table 3.

The results of the factor1 loadings indicated that a majority of the variables are dominant and are positive except for crop loss to drought, livestock loss to drought and holding a title deed for land owned. From the loadings, since PC1 explains much of the variation, it is clear that those households which are water secure

Table 3
Factor loadings of the four Principal Components.

Variable	PC1	PC2	PC3	PC4
Surface water assessment	0.463	−0.505	0.242	0.157
Groundwater assessment	0.134	−0.321	−0.034	0.116
Water availability	0.502	0.264	−0.545	0.559
Reliability of water source	0.684	0.294	−0.386	0.415
Water quality	0.691	−0.366	0.150	0.102
Water taste	0.693	−0.508	0.331	0.144
Water smell	0.654	−0.491	0.278	0.177
Piped water	0.588	0.121	0.081	−0.438
Sanitation facility	0.449	0.093	0.294	−0.173
Access to irrigation water	0.704	0.431	0.201	−0.385
Irrigation water availability	0.719	0.483	−0.078	−0.092
Water sufficiency	0.543	0.103	−0.288	−0.197
Access to livestock water throughout	0.625	0.072	−0.233	−0.197
Crop loss to drought over the last 5 years	−0.229	0.454	0.403	0.199
Crop loss to floods over the last 5 years	0.118	0.467	0.304	0.192
Livestock loss to drought over the last 5 years	−0.131	0.312	0.500	0.218
Soil erosion over the last 5 years	0.179	0.493	0.393	0.247
Title	−0.019	−0.075	0.052	0.210
Access to credit	0.104	0.081	0.176	−0.016
Education	0.125	−0.029	−0.113	−0.184

Table 4
Ordinary least squares results estimating the determinants of water security.

Variables	Coef.	Robust Std. Err.
WRUA membership	0.782***	0.116
Age	−0.002	0.006
Experience farming	−0.001	0.005
Gender	0.160	0.143
Marital status	−0.069	0.166
Formal education	0.232	0.179
Number of male adults	−0.044	0.059
Number of female adults	0.132**	0.070
Number of children	−0.037	0.044
Primary occupation	0.392**	0.202
Land size	0.065**	0.031
Income	9.24e-07***	3.48e-07
Livestock ownership	−0.238	0.170
TLU	−0.003	0.005
Extension	0.078	0.114
Credit	0.161	0.133
Water-related conflicts	−0.365***	0.122
Irrigation cropping	0.774***	0.127
Rain-fed cropping	−0.427***	0.169
Smartphone	0.213**	0.108
Radio	−0.135	0.150
Constant	−1.078**	0.505
F(19, 591)	13.59***	
R-squared	0.303	
Root MSE	1.2732	
Mean VIF	1.30	
Highest VIF	1.93	
Ramsey RESET Test F(3, 586)	0.26	
Prob > F	0.8568	

Note: * Significant at 10% ** significant at 5% *** significant at 1%.

perceive surface water and groundwater to be very good, water should be available throughout, should be reliable, be of good quality, be of very good taste and smell, have access to piped water, have access to a sanitation facility, have access to irrigation water available throughout, have sufficient water at all times for household domestic, irrigation needs and livestock needs.

PC_1 was used to generate the water security index because it explained the highest variation (37.65%) and it captured most of the water security components.

4.3.2. OLS results of the determinants of household water security

The OLS results of the determinants of household water security are presented in Table 4. The results show that the model is well fit as indicated by a highly significant F value and an R-squared (R^2) value of 0.303. Robust standard errors were estimated to take care of heteroscedasticity. Multicollinearity did not pose a challenge, since the model had a low average variance inflation factor (VIF) of 1.30 with the highest VIF of 1.93. To test for omitted variable bias, Ramsey's RESET test was carried out, the results show that the model has no missing variables since the F value was not significant ($F = 0.26$, $p = 0.857$). From the diagnostic tests, it was concluded that the OLS model estimated coefficients were unbiased, consistent and efficient.

The results showed that WRUA membership, female adults, primary occupation, land size, income, water conflicts, irrigation cropping, rain-fed cropping, owning a smartphone, and the constant were the positive and significant determinants of household water security. WRUA membership is positive and significant, implying that WRUA membership, has a positive and significant influence on household water security. Therefore, WRUA members had more water security as compared to non-members. These findings are similar to the findings of Speranza et al. (2016) who found that community water projects in the Upper Ewaso Ng'iro North Catchment area, largely met the goals of water provision to member households. This could be attributed to the fact that WRUAs and community water projects are the main institutions that are tasked with water allocation and distribution and therefore membership almost guarantees water availability. The number of female adults in a household had a positive and significant influence on household water security. This implies that households with more female members were less likely to be water insecure, this finding is consistent with literature that the water responsibility in the household is mostly women's work and responsibility. This result is consistent with previous studies (see, Graham et al., 2016; Tsukada and Hailu, 2016), who found, that the task of collecting water falls mainly to women and children.

The primary occupation of the household head had a positive and significant influence on household water security. This finding reveals that household heads whose primary occupation was farming were more water secure, than households whose primary occupation was not farming. This can be explained by the fact that farming households are always at home working and can get enough time to get water as compared to employed households or households engaged in trade away from home.

Land size had a positive and significant influence on household water security. Households with more land were more water-secure than those with less land. While Sinyolo et al. (2014) found the land size to have a positive influence, it was not a significant determinant of water security. The total household income (unscaled) had a positive and significant influence on household water security, implying that households with more income were more water-secure than households with less income. This finding is consistent with the findings of Sinyolo et al. (2014) who found that having more off-farm income increased perceived water security since more income implies the ability to pay for water without failure thus improving water security.

Water conflicts according to the results, have a highly negative and significant influence on household water security. Households whose communities had encountered water conflicts had less water security. Water conflicts have been documented in the study area especially during the dry season when demand for water rises

Table 5
OLS Regression results of the determinants of household income per adult equivalent illustrating the impact of water security on household income per adult equivalent.

Variables	Coef.	Robust Std. Err.
Age	−0.093***	0.021
Age squared	0.001***	0.000
Gender	0.156	0.120
Formal education	0.171	0.200
Land size	0.044	0.035
Title	0.145	0.119
Livestock	0.042	0.150
Extension access	0.336***	0.114
Credit access	0.227*	0.125
Primary occupation	−0.916***	0.128
Owning a smartphone	0.501***	0.115
Firewood as the primary source of cooking fuel	−0.426***	0.141
Improved crops	0.325**	0.150
Distance to market	−0.008	0.007
Household water security index	0.102***	0.035
Constant	13.275**	0.568
F(15, 549)	13.57***	
R-squared	0.228	
Root MSE	1.256	
Mean VIF	1.13	
Highest VIF	1.34	
Ramsey RESET Test F(3, 546)	0.08	
Pro > F(25, 539)	0.97	

Note: the dependent variable is the log of household income per adult equivalent. * Significant at 10% ** significant at 5% *** significant at 1%.

sharply and allocation and distribution fails. This finding is also consistent with the findings by Sinyolo et al.(2014), who found that the occurrence of conflicts had a negative and significant influence on perceived water security.

Irrigation cropping had a positive and significant influence on household water security. This finding implies that irrigators were more water secure. This can be explained by the commercial nature of irrigation cropping, and its ability to generate high returns at minimal risk as compared to rain-fed cropping. The income generated can be used to pay for water (maintenance and development charges); install water storage infrastructure on the farm, such as water pans, water tanks and water-saving irrigation infrastructures such as sprinklers and pipes; or pumping equipment such as water pumps in. On the contrary households dependent on rain-fed cropping were water insecure. This is due to the negative and significant influence of rain-fed cropping on household water security at a significance level of 1%. As compared to irrigation cropping, rain-fed cropping is highly risky and prone to failure due to the challenges posed by climate change and unpredictable weather patterns.

Finally, owning a smartphone had a positive and significant influence on household water security. This finding shows the importance of mobile connectivity to development. Smartphones are devices with several capabilities such as telephone, mobile money, radio, internet and customized applications (Apps) for different uses. Owing to the many capabilities the households can get information on water availability; water conservation; access mobile loans to pay for water or even pay water charges using mobile money, ending up with more water security. Baumüller (2012) argued that information regarding the existence of (new) agricultural technologies is of course a prerequisite for technology adoption. Such information can be obtained from various external sources, such as extension agents, fellow farmers or different media such as mobile phones, TV or radio. In the case of our study, the mobile phone seems to have a major role in providing connectivity for water security.

4.3. Impact of water security on household income per adult equivalent

The results of the impact of water security on household income per adult equivalent are presented in Table 5. The results show that the model is well fit as indicated by a highly significant F value and an R-squared (R^2) value of 0.228. Robust standard errors were estimated to take care of heteroscedasticity. Multicollinearity did not pose a challenge, since the model had a low average variance inflation factor (VIF) of 1.13 with the highest VIF of 1.34. To test for omitted variable bias, Ramsey's RESET test was carried out, the results show that the model has no missing variables since the F value was not significant (F = 0.08, p = 0.97). From the diagnostic tests, it was concluded that the OLS model estimated coefficients were unbiased, consistent and efficient.

The regression results on the impact of water security on household income per adult equivalent show a positive and significant relationship. This finding implies that water-secure households are likely to have higher incomes as compared to water insecure households all factors held constant. We, therefore, accept the hypothesis, that there is a relationship between water security and household income per adult equivalent in the Upper ENNCA. Previous studies have shown that water security is strongly related to household welfare (Katuva et al., 2020; Brewis et al., 2020; Tsukada and Hailu, 2016). The other positive and significant factors that influence household income per adult equivalent include; age squared; access to extension services; access to credit; smartphone ownership; and growing improved crop varieties. The negative and significant factors that influence the household income per adult equivalent include; age; primary occupation; and the main source of cooking fuel being firewood.

Table 6
Poisson regression results of the impacts household water security on the prevalence of water-borne diseases.

Variables	Coef.	Robust Std. Err.
Age	−0.011**	0.005
Gender	−0.290**	0.143
Formal education	−0.073	0.216
Household size	0.114***	0.030
Credit access	−0.076	0.164
Water security index	−0.071**	0.044
Sub-catchment		
Pesi	−0.021	0.360
Naro Moru	0.316	0.322
Rongai	0.609**	0.318
Likii	0.667**	0.315
Timau	0.552*	0.312
Ngare Ndare	0.855***	0.311
Sirimon	0.209	0.312
_cons	−0.802	0.515
Log-likelihood	−596.061	
Wald chi2(13)	41.84***	
Pseudo R2	0.050	

Note: * Significant at 10% ** significant at 5% *** significant at 1%.

The results reveal that farmers with access to extension services had more incomes than farmers without access. This finding demonstrates the important role that extension plays on household welfare and rural household livelihoods. This finding concurs with the findings by Gebrehiwot (2015), who found that access to extension services had an incremental impact on household incomes. Access to credit had a positive influence on household income, this implies that households with access to credit could obtain output improving inputs such as improved seeds, fertilizer, artificial insemination (AI) among other capital intensive inputs in advance, either in cash or in-kind and pay later. Therefore, access to credit ensures that the production cycle is smooth and is uninterrupted. Previous studies have demonstrated the impacts of access to credit as an enabler for household welfare and poverty alleviation (Teka and Lee, 2020), other studies have demonstrated the links between credit access and adoption of new technologies and improved crop varieties (Darkwah et al., 2019; Danso-Abbeam et al., 2017; Matuschke et al., 2007).

Households owning a smartphone were more likely to have higher income per adult equivalent than households without, implying that households with smartphones have more information at their disposal due to the multiple application capabilities of smartphones i.e., call, message, internet, social media, farming applications, mobile money, mobile banking among other uses. Previous studies have documented a positive influence of smartphones on household income (Mwaura et al., 2020; Teka and Lee, 2020). Further, households growing improved crops were more likely to have higher income per adult equivalent than households that do not grow improved crop varieties. This finding was expected since, improved crop varieties are fast maturing, offer resistance to pests, diseases and drought, while at the same time producing higher yields. Previous studies have documented household welfare effects attributable to the adoption of improved crops (Wossen et al., 2019; Shiferaw et al., 2014)

While old household heads had a lower income per adult equivalent than households with younger heads, the age squared was significant and positive, this finding implies that age has a diminishing impact on household income per adult equivalent. This finding is consistent with the findings by Tuyen (2015), who found that the age of the household head has a diminishing impact on household income per capita. The results further show that households' whose primary occupation is farming were likely to have a lower household income per adult equivalent as compared to non-farming households. This finding is consistent with economic theory since primary production is of low value as compared to secondary and tertiary production. This finding is consistent with the findings by Tuyen (2015), who found that there is a negative relationship between household income per capita and farming as the primary occupation. Finally, households whose main source of cooking fuel was firewood were likely to have lower income per adult equivalent as compared to households using improved sources. This finding is consistent with the findings by Morrissey (2017) that it is the poor who are highly dependent on unimproved energy sources in Sub-Saharan Africa.

4.4. Impact of water security on water-borne disease prevalence

The results of the Poisson regression model are shown in Table 6. The coefficient for the water security index is negative and significant. The results show that improvements in the water security index have a reducing effect on the household prevalence of water-borne diseases. These results imply that water-secure households are likely to have a lower extent of water-borne disease burden. We, therefore, accept the hypothesis, that there is a relationship between water security and the prevalence of water-related diseases in the Upper ENNCA. This finding is consistent with the findings by Rosengrant (2020), Bain et al. (2014) and Collins et al. (2007), on the effects of water security and management on the prevalence of waterborne diseases.

Households headed by older household heads were less likely to have a heavy water-borne disease burden. This result implies two things; first old age comes with more experience and secondly, older household heads are aware and understand the risks posed by low-quality water and stagnant water, and therefore put in place safety measures to safeguard their households. Further, male-headed households (MHHs) were less likely to have a heavy water-borne disease burden, as compared to female-headed households (FHHs). This un-even vulnerability to the exposure of water-borne diseases is attributable to the differential resource endowments between MHHs and FHHs as documented by previous studies (Pouramin et al., 2020; Caruso et al., 2015). According to Caruso et al. (2015), women's vulnerability in water matters arises due to the inequitable division of power, work, access and control of resources between men and women. Women's exposure to water-borne diseases is further reinforced by the risk of physical assault when fetching water such as rape and sexual assault, and as a result, due to women's physical vulnerability to such assaults, FHHs may end up using un-safe water sources, which they perceive as 'safe' for personal safety and security. Households with more members were likely to have a higher water-borne disease burden as compared to smaller-sized households. Larger, households share household resources including; water and sanitation facilities, food, beddings and utensils. Therefore, where hygiene standards are low, diseases spread quite fast especially communicable water-borne diseases like diarrhoea and vomiting. Finally, sub-catchments with a positive and significant probability of having a higher prevalence of water-borne diseases include Rongai, Likii, Timau and Ngare Ndare.

5. Conclusions

The WPI results revealed that Sirimon and Ewaso Narok sub-catchments were faced with acute water poverty, while the rest of the sub-catchments were faced with moderate water poverty despite being in the sub-catchment area. Further, the study assessed the drivers of household water security. The results revealed that WRUA membership, female adults, primary occupation, land size, income, water conflicts, irrigation cropping, rain-fed cropping, owning a smartphone were the significant factors that determined household water security.

The factors that influenced household income per adult equivalent positively included, water security, age squared; access to extension services; access to credit; smartphone ownership; and growing improved crop varieties. The negative and significant factors that influenced the household income per adult equivalent included; age; primary occupation; and the main source of cooking fuel being firewood. Finally, the factors that influenced the prevalence of water-related diseases negatively included; age of the household head, gender of the household head, and the household water security index. The positive factors that influenced the prevalence of water-borne diseases were the household size and the following sub-catchments which were found to have a significantly higher probability of having a higher prevalence of water-borne diseases including; Rongai, Likii, Timau and Ngare Ndare.

5.1. Policy recommendations

The WPI results provide evidence that there are existential threats to water security in the Upper Ewaso Ng'iro North Catchment Area, which need urgent action due to the relative importance of the Upper ENNCA to the whole Ewaso Ng'iro North River Basin, most of which is ASAL. The welfare assessment results have shown that improvements in water security can offer welfare benefits to households, since, evidence has shown that, improved water security can offer both economic and health benefits to households. As a result, improvements in water security could offer solutions to some of the country's problems including poverty alleviation and reduced budget spending on communicable and non-communicable water-related diseases. However, it is important to note that, water security improvement would come at a social cost to both the households and the government which should be quantified before rolling out any programmes aimed at water security improvement. The study makes the following policy recommendations;

The government should prioritize sensitization campaigns for the conservation of the Upper ENNCA, since, water insecurity at the catchment area spells doom for the middle and lower basin all of which are ASAL areas. These campaigns should focus on the restriction of land-use changes, controlling of soil erosion, tree planting, forest conservation, on-farm water conservation and collaborative water resources management for ecologically sound downstream flows. Secondly, since, water is a devolved function to the county governments, county governments should continue making water investments, since these investments are worthwhile from both economic and health perspectives. This calls for increased budgetary allocation, to provide irrigation and domestic water to all households. Thirdly, counties should also invest in water treatment and sewerage treatment plants. Fourth, Social-safety-net programmes should focus more on the vulnerable. From the results, households headed by the old and female-headed households should be given special attention among other vulnerable groups. Access to affordable and accessible credit remains one of the key ways to increase household incomes. The government should provide a proper legislative framework and rethink interest rate caps. Finally, the results have shown that WRUA membership is a key determinant of water security. Therefore, the government through concerned agencies should consider the agency role played by WRUAs in the water governance framework and increase WRUA capacity through training and budgetary facilitation.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

Table A1

Table A1
WPI Questionnaire.

S/N	Component/Subcomponents	Index
	Resources	
	How do you assess surface water in your locality?	(Good = 1, Bad = 0)
	How do you assess surface water in your locality?	(Good = 1, Bad = 0)
	Is water available throughout?	(Yes = 1, No = 0)
	Is the source reliable?	(Yes = 1, No = 0)
	Is it of good quality?	(Yes = 1, No = 0)
	How can you rate the taste of the water?	(Good = 1, Bad = 0)
	How can you rate the Smell of the water?	(Good = 1, Bad = 0)
	Accessibility	
	Does the household have access to piped water?	(Yes = 1, No = 0)
	Does the household have access to sanitation (access to toilet facility)?	(Yes = 1, No = 0)
	Do you have access to irrigation water?	(Yes = 1, No = 0)
	Is irrigation water available throughout the cropping calendar?	(Yes = 1, No = 0)
	Capacity	
	Do you own land?	(Yes = 1, No = 0)
	Does the household head have any formal education qualifications?	(Yes = 1, No = 0)
	What is the primary occupation of the head?	(Off-farm job = 1, Farming = 0)
	Did the household head have access to credit in the last cropping calendar?	(Yes = 1, No = 0)
	Water Uses	
	Is the amount of water for use sufficient for your uses?	(Yes = 1, No = 0)
	What is the proportion of farmland under irrigation?	(% of land proportion)
	Do you have available water for livestock water needs throughout?	(Yes = 1, No = 0)
	Was your community affected by water conflicts in the past year?	(Yes = 1, No = 0)
	Environment	
	Have you experienced Crop loss over the last 5 years due to drought?	(Yes = 1, No = 0)
	Has your household been affected by floods in the past 5 years?	(Yes = 1, No = 0)
	Has your household been affected by soil erosion in the past 5 years?	(Yes = 1, No = 0)

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