

Prevalence and Predictors of Chronic Kidney Disease of Undetermined Cause (CKDu) among Small-Scale Fishers in Northwest Tanzania: Application of DEGREE Protocol

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Prevalence and Predictors of Chronic Kidney Disease of Undetermined Cause (CKDu) among Small-Scale Fishers in Northwest Tanzania: Application of DEGREE Protocol

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Abstract

Background: Chronic kidney disease of unknown etiology (CKDu) has emerged as a significant public health problem among disadvantaged populations engaged in physically demanding occupations in tropical regions. Evidence on CKDu among small-scale fishing communities in sub-Saharan Africa remains limited. This study estimated the prevalence of reduced kidney function suggestive of CKDu and identified associated factors among small-scale fishers in Northwest Tanzania using the Disadvantaged Populations eGFR Epidemiology (DEGREE) protocol.

Methods: A community-based cross-sectional study was conducted among 422 small-scale fishers in Northwest Tanzania. After applying the DEGREE protocol age criterion, 379 participants aged 18–59 years were eligible for further analysis. Kidney function was estimated using the 2021 CKD-EPI creatinine equation. Participants with hypertension, diabetes mellitus, or heavy proteinuria were excluded to identify reduced kidney function not explained by common causes of chronic kidney disease; a modified DEGREE analysis additionally excluded participants living with HIV. Multivariable linear regression was used to assess factors associated with continuous eGFR, while multivariable logistic regression examined factors associated with reduced kidney function (eGFR <60 mL/min/1.73 m²). Sensitivity analyses assessed the potential influence of dehydration, urinary tract infection, haematuria, and urogenital schistosomiasis.

Results: The prevalence of reduced kidney function was 16.6% in the overall population, 13.8% in the DEGREE subset, and 13.6% after additionally excluding participants living with HIV. In multivariable analyses, increasing age was consistently associated with lower continuous eGFR and higher odds of reduced kidney function, whereas male sex was independently associated with higher eGFR and lower odds of reduced kidney function. Occupational heat exposure, dehydration, daily working hours, body mass index, *Schistosoma haematobium* infection, sugary drink consumption, and energy-drink consumption were not independently associated with kidney function. Sensitivity analyses showed stable prevalence estimates after excluding participants with urinary abnormalities suggestive of acute kidney insults.

Conclusions: Reduced kidney function suggestive of a CKDu-compatible phenotype was relatively common among small-scale fishers in Northwest Tanzania. The persistence of elevated prevalence after excluding conventional causes suggests that other locally relevant occupational, environmental, infectious, biological, or socioeconomic factors may contribute. Because kidney function was measured once, CKDu could not be confirmed. Longitudinal studies with repeated kidney-function measurements and objective exposure assessment are needed.

Key words: Chronic Kidney Disease of unknown etiology (CKDu), Small-scale fishers, DEGREE protocol, Estimated glomerular filtration rate (eGFR), Occupational exposures, Heat stress, Lake Victoria, Tanzania

Introduction

Chronic kidney disease (CKD) is a major global public health challenge, affecting approximately 10% of the world's population and contributing substantially to premature mortality, disability, and escalating healthcare costs. (1,2)The

burden of CKD continues to increase disproportionately in low- and middle-income countries (LMICs), where delayed diagnosis, limited access to renal replacement therapy, and constrained healthcare resources contribute to poor clinical outcomes. (3,4) Although diabetes mellitus and hypertension remain the leading causes of CKD worldwide, an increasing proportion of patients develop chronic kidney disease in the absence of these traditional risk factors. (5,6) This condition, commonly referred to as chronic kidney disease of unknown etiology (CKDu), is characterized by persistent reduction in kidney function that cannot be explained by diabetes, long-standing hypertension, primary glomerular diseases, congenital abnormalities, obstructive uropathy, or other recognized causes of CKD. (7–10) Consequently, CKDu has emerged as an important occupational and environmental health problem, particularly among economically disadvantaged populations living and working in tropical and subtropical regions. (2,11)

In the last three decades, CKDu has been reported in various regions of the world, including Central America, Sri Lanka, India, Egypt, and some parts of sub-Saharan Africa. (11,12) Notwithstanding the geographical and cultural differences, these outbreaks have shown very much similar epidemiological traits, where CKDu mainly affects young adults involved in labor-intensive activities outdoors in hot environments. (13,14) Unlike conventional CKD, CKDu frequently presents with little or no proteinuria during the early stages, relatively normal blood pressure, progressive decline in estimated glomerular filtration rate (eGFR), and chronic tubulointerstitial injury on kidney biopsy. (15,16) While the exact cause of the disease is not known, many studies have shown that CKDu may be a multi-factorial illness that arises due to the interaction of repetitive occupational heat stress, dehydration, exposure to environmental nephrotoxins, heavy metals, contaminated drinking water, pesticides, infections, and genetically vulnerable population. (14,17–21)

Climate change has intensified concerns regarding CKDu by increasing ambient temperatures, prolonging heat exposure, and increasing the frequency of extreme weather events across tropical regions. (2,11,14,18,19,22) Outdoor workers are increasingly exposed to prolonged periods of environmental heat while performing strenuous physical labour, often without adequate access to drinking water, rest breaks, or shade. Repeated episodes of heat stress and dehydration may induce recurrent subclinical acute kidney injury through renal hypoperfusion, tubular ischemia, oxidative stress, inflammation, and activation of profibrotic pathways. Cumulative renal injury may subsequently progress to irreversible tubulointerstitial fibrosis and chronic loss of kidney function, providing a plausible biological mechanism linking climate-related occupational exposures with CKDu. (2,14,23,24) This heat stress–dehydration paradigm is now widely recognized as one of the leading hypotheses explaining the emergence of CKDu among vulnerable occupational populations, although environmental contaminants, infections, and other coexisting risk factors may act synergistically to accelerate disease progression. (2,25)

However, the majority of studies about the occurrence of CKDu have concentrated on farm workers, especially sugarcane harvesters and rice growers, while the health risks faced by artisanal fishers have been largely ignored despite having similar occupational risks. Occupational heat stress and CKDu susceptibility experienced by fishers in Sri Lanka is believed to be equivalent to those of farmers; therefore, it would be necessary to examine kidney health of fishers in sub-Saharan Africa. (2,11,17,26) Fishing activities in tropical regions require prolonged exposure to direct sunlight, high ambient temperatures, intense physical exertion, extended working hours, and irregular hydration practices, all of which increase susceptibility to heat-related kidney injury. (27–30) In addition to heat exposure in occupations, fishing populations are also subjected to a variety of stressors such as malnutrition, poor sanitation, constant contact with water, and parasitic infections like schistosomiasis. Another possible factor in the cause of nephropathy is exposure to environmental pollutants such as mercury and other heavy metals in mining and industrial activities. However, a recent study conducted in Lake Victoria showed that levels of heavy metals in common fish species were within acceptable international levels, (31–33) meaning that the consumption of fish was not likely to be the main route of heavy metal exposure. Nevertheless, there is limited information on other routes of environmental exposure in fishing populations. These interacting occupational, environmental, and infectious exposures may collectively increase the risk of chronic kidney injury, suggesting that CKDu among fishing communities is likely multifactorial rather than attributable to a single environmental or behavioural exposure. Nevertheless, despite the importance of fisheries for livelihoods and food security across sub-Saharan Africa, epidemiological evidence regarding CKDu among small-scale fishers remains extremely limited, highlighting an important gap in occupational and environmental kidney health research. (11,34)

Therefore, this study aimed to determine the prevalence of chronic kidney disease of unknown etiology and identify its predictors among small-scale fishers in Northwest Tanzania after excluding individuals with established causes of CKD, including diabetes mellitus, hypertension, and heavy proteinuria, using the standardized DEGREE (Disadvantaged Populations eGFR Epidemiology) approach. The findings are expected to provide important evidence

on the burden of CKDu in an understudied high-risk occupational population and inform preventive strategies addressing climate-related occupational kidney disease in sub-Saharan Africa.

Methodology

Design and study population

This community-based cross-sectional study was conducted between October 2025 and April 2026 among small-scale fishers in Bunda District, Mara Region, north-western Tanzania, along the south-eastern shores of Lake Victoria. Bunda District was purposively selected because fishing appears to be the predominant livelihood; fishers may experience chronic exposure to climate-related occupational hazards, including prolonged heat stress, dehydration, adverse weather conditions, and frequent contact with lake water. According to the 2022 Tanzania Population and Housing Census, the district has a population of 426,701 and comprises 36 recognised fishing villages (with BMU administration). We used a three-stage cluster sampling design to recruit a representative sample of small-scale fishers. First, Bunda District was stratified into Bunda Town and Bunda Rural. Second, 10 fishing villages were randomly selected from the 36 registered villages (BMU leadership). We determined the sample allocated to each selected village using probability proportional to size (PPS). The sample allocated to each selected village was determined using probability proportional to size. With support from the Beach Management Units, a sampling list of eligible small-scale fishers was compiled for each village. Participants were randomly selected from their respective village lists, contacted by telephone, and asked to provide verbal consent to participate. Those who agreed were mobilised and screened for eligibility. Individuals who declined or were ineligible were replaced by other fishers randomly selected from the same village list using the same procedure. Recruitment continued until the allocated sample size for each village was reached. Eligible participants were adults aged ≥ 18 years who had resided in Bunda District for at least one year and were actively engaged in small-scale fishing for subsistence or trade, either near-shore or offshore, including fishers who also performed related shoreline activities such as fish landing, sorting, processing, trading, net preparation and repair, boat maintenance, or fish collection. To minimize transient influences on kidney function, temporary fishers, pregnant or menstruating (minimize contamination and false negative hematuria) women, and individuals with fever or other acute infections were excluded. The sample size was calculated using the Kish and Leslie formula based on an expected CKD prevalence of 13.6%, (35) a 95% confidence level, and a 5% margin of error. After applying a design effect of 2 and a 10% allowance for non-response, the target sample size was 400 participants. Overall, 445 fishers were screened, 23 were excluded, and 422 were enrolled, of whom 398 provided blood samples for eGFR estimation. The study independently applied the freely available DEGREE methodological framework, with a study-specific modification that additionally excluded participants living with HIV as a locally relevant potential cause of kidney disease; this modification was not part of the original DEGREE core protocol. Residual serum samples were stored under appropriate conditions. (69) This study formed part of a broader investigation of climate-related occupational exposures, nutrition, and kidney dysfunction among small-scale fishing communities in northwestern Tanzania.

Outcomes

We defined kidney dysfunction (KD) as an estimated glomerular filtration rate (eGFR) < 60 mL/min/1.73 m². We classified participants according to the KDIGO 2024 eGFR (G1–G5) these classifications represent estimates of kidney dysfunction and kidney risk rather than a definitive diagnosis of chronic kidney disease (CKD). (47)

Table A. Summary of Outcome and Predictors of Kidney Disease

Domain	Data source or instrument	Measures	Classification or analytical role
Occupational Exposures			
Occupational history	Structured electronic questionnaire (KoboToolbox)	Work hours/day, part of day worked, years in fishing, fishing activity. (11,34)	Analysed continuously or categorically and included as potential confounders
Covariates (Susceptible, Initiative & Progressive Risk Factors of Chronic Kidney Disease Pathway)			
Sociodemographic, lifestyle and medical factors	Structured electronic questionnaire (Kobo Toolbox)	Age, sex, residence, education, lifestyle behaviors, medical history and medication use.	Analysed continuously or categorically and included as potential confounders

Domain	Data source or instrument	Measures	Classification or analytical role
Lifestyle and dietary factors	Structured electronic questionnaire adapted from previous studies. (66,67)	Self-reported frequency of sugar-sweetened beverage and energy-drink consumption: daily, once a week, occasionally, rarely, or never	Categorical predictor variables; “never” used as the reference category
Anthropometry	Standardized physical measurements	Height, weight, and BMI. (36)	Analysed continuously or using predefined thresholds as indicators of general and central adiposity. (36)
Blood pressure and hypertension	Calibrated Omron HEM-7120/7121 automated sphygmomanometer was used.	Standardized blood-pressure measurements and current antihypertensive medication use. (37)	Hypertension defined from measured blood pressure or current antihypertensive treatment and included as a clinical covariate. (37)
Glycaemic status	On Call® Plus glucometer	Capillary blood glucose and history of glucose-lowering medication use. (39)	Diabetes and prediabetes classified according to the Tanzania Standard Treatment Guidelines.
HIV status	SD Bioline HIV-1/2 3.0 and Uni-Gold™ rapid tests	HIV testing performed according to the Tanzania National HIV Testing Services algorithm.	Classified as positive or negative and included as a potential clinical covariate.
Proteinuria	Fresh midstream urine; URiT® 10G reagent strips	Dipstick protein recorded as negative, trace, 1+, 2+ or 3+ by trained personnel following the manufacturer’s instructions.	Heavy Proteinuria defined as ≥2+. Because ACR was not feasible, dipstick protein was used as a pragmatic proxy for kidney damage and interpreted cautiously. (40)
Sensitivity analysis and interpretation	Urine dipstick and urine microscopy	Markers of dehydration (USG >1.020), urinary infection/inflammation (positive leukocyte esterase, nitrites and/or elevated urinary WBC >20HPF), and urogenital schistosomiasis (haematuria and/or <i>Schistosoma haematobium</i> ova). (44,45,46)	Participants with markers of potential acute or transient renal insults were excluded in sensitivity analyses to assess the robustness of the kidney-dysfunction prevalence estimates and associated findings. (44,45,46)
OUTCOMES			
Serum creatinine and eGFR	IDMS-traceable enzymatic assay on the ARCHITECT c4000 analyser	Venous blood analysed at an ISO 15189-accredited (SADCAS) laboratory under GCLP, with internal quality control and external proficiency testing. (41)	Primary eGFR estimated using CKD-EPI 2021. CKD-EPI 2012 and MDRD equations were used in sensitivity analyses. (41)
Reduced kidney function	Calculated eGFR	eGFR assessed continuously and at thresholds <90, <60, <45, <30 and <15 mL/min/1.73 m ² .	Primary reduced-eGFR outcome defined as <60 mL/min/1.73 m ² ; additional cut-offs assessed the sensitivity of prevalence estimates.

Abbreviations: ACR, albumin-to-creatinine ratio; BMI, body mass index; CI, Conicity Index; CKD, chronic kidney disease; CKD-EPI, Chronic Kidney Disease Epidemiology Collaboration; COEI, Cumulative Occupational Exposure Index; eGFR, estimated glomerular filtration rate; GCLP, Good Clinical Laboratory Practice; HETA, Heat Exposure and Treatment Assessment; HFIAS, Household Food Insecurity Access Scale; HPF, high-power field; IDMS, isotope-dilution mass spectrometry; MDRD, Modification of Diet in Renal Disease; OHS, occupational health and safety; PPE, personal protective equipment; RAM, Risk Assessment Matrix; RBC, red blood cell; USG, urine specific gravity; WBC, white blood cell; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio. *Note:* The dipstick-protein categories were pragmatic proxies used in a resource-limited field setting and should not be interpreted as equivalent to quantitative ACR.

DEGREE definition

The Disadvantaged Populations eGFR Epidemiology Study (DEGREE) framework was applied to estimate the prevalence of reduced eGFR compatible with a CKD of uncertain aetiology phenotype. The standard DEGREE analysis was restricted to participants aged 18–59 years and excluded those with hypertension, diabetes mellitus or heavy proteinuria. A modified DEGREE-Tanzania definition additionally excluded participants living with HIV because HIV is a locally relevant recognized cause of kidney disease. These definitions were used for epidemiological classification and did not constitute a clinical diagnosis of CKDu, which requires confirmation of chronicity and more comprehensive exclusion of recognized causes.

Data analysis

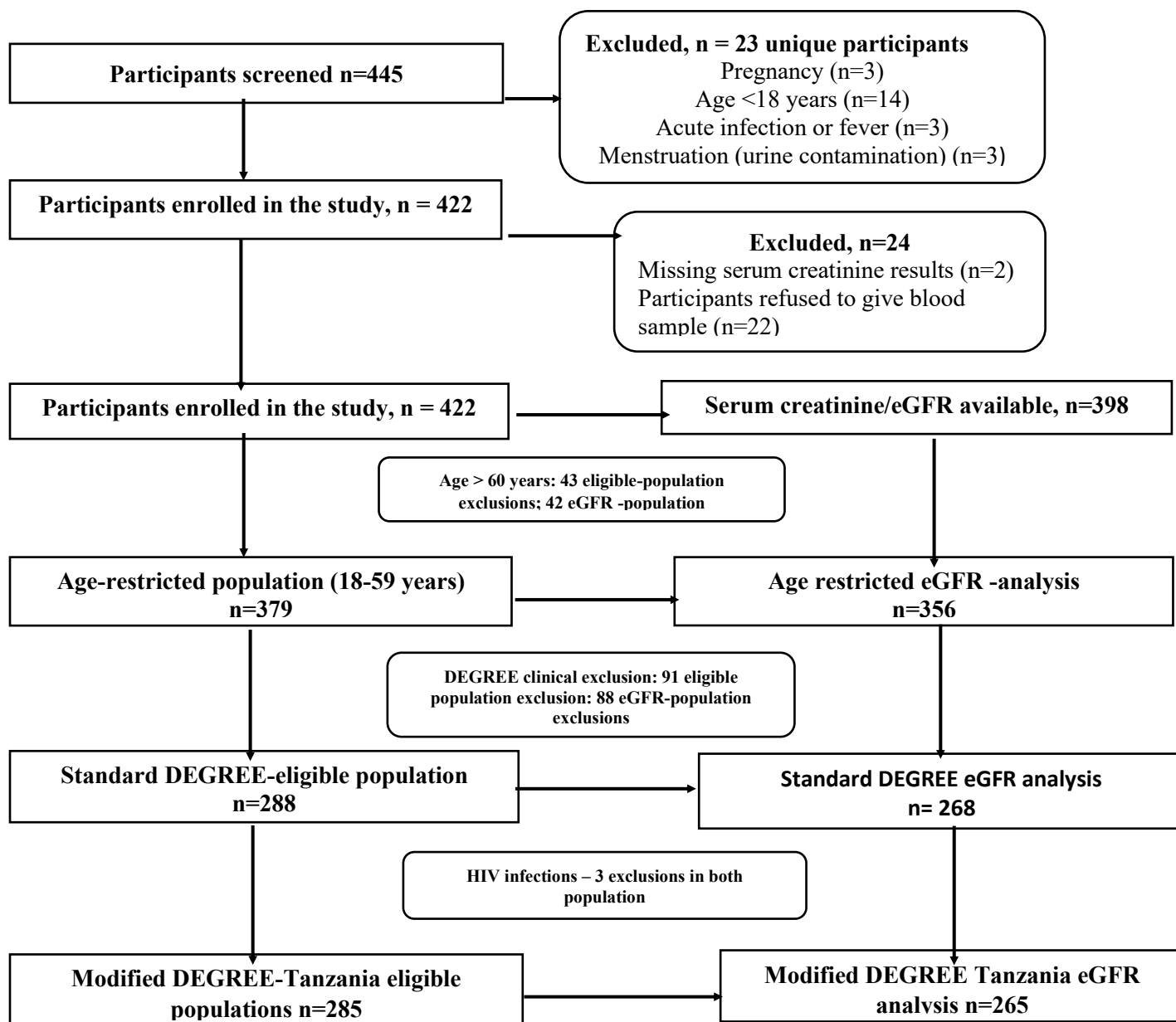
Data cleaning and statistical analysis was done in R (version 4.5.1), using RStudio. Data cleaning operations were all executed through an R script, which included all processes involved in data cleaning, including data validation,

recoding of variables, handling of missing values and outliers, and generation of analytical variables. We summarized descriptive statistics as frequencies and percentages for categorical variables and as means (SD) or medians (IQR) for continuous variables. We performed univariable and multivariable logistic regression analyses to identify factors associated with albuminuria, reduced kidney function (eGFR <60 mL/min/1.73 m²), and composite kidney dysfunction (albuminuria and/or eGFR <60 mL/min/1.73 m²), with results reported as crude and adjusted odds ratios (COR and AOR) with 95% confidence intervals (CI). We used linear regression to identify factors associated with eGFR as a continuous outcome, presenting results as unstandardized regression coefficients (β) with 95% CIs. We defined statistical significance as a two-sided $p < 0.05$.

Results

Of the 445 participants screened, 23 were excluded and 422 were enrolled, of whom 398 had serum creatinine measurements and available eGFR results. After excluding participants aged ≥ 60 years, 379 participants remained eligible, including 356 with available eGFR data. Further exclusion of participants with hypertension, diabetes mellitus, or heavy proteinuria resulted in 288 participants meeting the standard DEGREE criteria, of whom 268 had eGFR data. Finally, excluding three participants with HIV infection left 285 participants in the modified DEGREE-Tanzania subset, including 265 with available eGFR data (Figure 1).

Figure 1: Participants Flow and DEGREE analytical subsets



Participant characteristics

Table 1 summarizes the sociodemographic characteristics, health habits, anthropometric status, and clinical characteristics of the 379 study participants included in the analysis after excluding individuals aged >60 years. Most participants were male (77.0%) and resided in rural areas (89.0%). The largest age groups were 30–39 years (28.0%) and 18–29 years (27.0%), followed by 40–49 years (23.0%) and 50–59 years (21.0%). The majority of participants had a normal body mass index (68.0%), while 19.0% were overweight, 8.7% were underweight, and 4.0% were classified as obese. More than half of the participants (57.0%) reported neither smoking nor alcohol consumption, whereas 43.0% reported smoking and/or alcohol use. Self-reported HIV infection was uncommon, affecting only four participants (1.1%). Most participants (90.0%) had normal blood pressure, while 10.0% had hypertension or were taking antihypertensive medication. Physician-diagnosed diabetes or current use of antidiabetic medication was reported by 2.1% of participants. Heavy proteinuria (2+ or 3+ on urine dipstick) was present in 15.0% of participants, whereas 85.0% had negative, trace, or 1+ proteinuria.

Table 1. Study participant characteristics (n = 379, after excluding participants aged >60 years)

Variable	n (%)
Sex	
Female	88 (23%)
Male	291 (77%)
Residence	
Rural	338 (89%)
Urban	41 (11%)
Age	
18–29 years	104 (27%)
30–39 years	106 (28%)
40–49 years	88 (23%)
50–59 years	81 (21%)
Body mass index (kg/m²)	
Underweight (≤ 18.5)	33 (8.7%)
Normal (>18.5 to ≤ 25)	258 (68%)
Overweight (>25 to ≤ 30)	73 (19%)
Obese (>30)	15 (4.0%)
Health habits	
Non-smoker and non-alcohol drinker	215 (57%)
Smoker and/or alcohol drinker	164 (43%)
Self-reported HIV	4 (1.1%)
Blood pressure and antihypertensive medication use	
$<140/90$ mmHg and not taking antihypertensive medication	340 (90%)
$\geq 140/90$ mmHg or taking antihypertensive medication	39 (10%)
Physician-diagnosed diabetes or use of diabetes medication	8 (2.1%)
Proteinuria	
2+ or 3+	57 (15%)
Negative, trace, or 1+	322 (85%)

Data are presented as n (%). BMI, body mass index; HIV, human immunodeficiency virus.

Estimated glomerular filtration rate (eGFR) classification by DEGREE protocol subsets

Table 2 presents the distribution of eGFR categories among all participants and across the DEGREE protocol subsets. Among the 356 participants with available serum creatinine measurements, 192 (53.9%; 95% CI: 48.6–59.2) had normal kidney function (eGFR ≥ 90 mL/min/1.73 m²), 105 (29.5%; 95% CI: 24.8–34.5) had mildly reduced kidney function (eGFR 60–89 mL/min/1.73 m²), and 59 (16.6%; 95% CI: 12.9–20.9) had an eGFR <60 mL/min/1.73 m². After excluding participants with hypertension, diabetes mellitus, and heavy proteinuria according to the DEGREE protocol (n = 268), 153 (57.1%; 95% CI: 50.9–63.1) had an eGFR ≥ 90 mL/min/1.73 m², 78 (29.1%; 95% CI: 23.7–34.9) had an eGFR of 60–89 mL/min/1.73 m², and 37 (13.8%; 95% CI: 9.9–18.5) had an eGFR <60 mL/min/1.73 m².

In the modified Tanzania DEGREE subset, which additionally excluded participants with self-reported HIV infection (n = 265), 153 (57.7%; 95% CI: 51.5–63.8) had an eGFR ≥ 90 mL/min/1.73 m², 76 (28.7%; 95% CI: 23.3–34.5) had

an eGFR of 60–89 mL/min/1.73 m², and 36 (13.6%; 95% CI: 9.7–18.3) had an eGFR <60 mL/min/1.73 m². The prevalence of reduced kidney function (eGFR <60 mL/min/1.73 m²), used as a proxy measure for CKD/CKDu, was 16.6% in the overall study population, 13.8% in the DEGREE subset, and 13.6% in the modified Tanzania DEGREE subset.

Table 2. eGFR classification by DEGREE protocol subsets

eGFR category	All participants (n = 356) N (%)	95% CI	DEGREE subset (n = 268) N (%)	95% CI	Modified DEGREE TZ (n = 265) N (%)	95% CI
≥90 mL/min/1.73 m ² (normal eGFR)	192 (53.9%)	48.6–59.2	153 (57.1%)	50.9–63.1	153 (57.7%)	51.5–63.8
60–89 mL/min/1.73 m ² (mildly reduced eGFR)	105 (29.5%)	24.8–34.5	78 (29.1%)	23.7–34.9	76 (28.7%)	23.3–34.5
<60 mL/min/1.73 m ² (proxy for CKD/CKDu)	59 (16.6%)	12.9–20.9	37 (13.8%)	9.9–18.5	36 (13.6%)	9.7–18.3

eGFR, estimated glomerular filtration rate; CKD, chronic kidney disease; CKDu, chronic kidney disease of undetermined cause; DEGREE, Disadvantaged Populations eGFR Epidemiology Study. The DEGREE subset excluded participants with hypertension, diabetes mellitus, and heavy proteinuria; the modified DEGREE Tanzania subset additionally excluded participants with HIV.

Sensitivity analysis

Table 3 presents sensitivity analyses evaluating whether the prevalence of reduced eGFR (<60 mL/min/1.73 m²) changed after excluding participants with urinary biomarkers suggestive of dehydration, urinary tract infection, hematuria, or urogenital schistosomiasis. Across all restricted analyses, the prevalence of reduced eGFR remained remarkably stable, ranging from 16.1% to 17.3%, with none of the differences reaching statistical significance ($P > 0.05$). Excluding participants with dehydration (urine specific gravity >1.020), positive leukocyte esterase, nitrite positivity, hematuria, pyuria, or *Schistosoma haematobium* ova resulted in minimal changes in the prevalence of reduced eGFR compared with the overall estimate of 16.6%. Likewise, exclusion of all abnormal urinary biomarkers simultaneously, with or without dehydration, yielded nearly identical prevalence estimates (16.5% and 17.1%, respectively). These findings indicate that the observed prevalence of reduced eGFR was robust and was not materially influenced by concurrent urinary abnormalities suggestive of acute dehydration, urinary tract infection, hematuria, or schistosomiasis, supporting the validity of the estimated burden of impaired kidney function in this population.

Table 3. Sensitivity analysis of reduced eGFR prevalence excluding abnormal urinary biomarkers

Overall sample			Sensitivity analysis			
Analysis	n	Reduced eGFR n (%)	(Excluding abnormal biomarker) n	Reduced eGFR n (%)	Difference (%)	P-value
Overall	356	59 (16.6)	356	59 (16.6)	ref	—
Excluding dehydration (USG > 1.020)	356	59 (16.6)	162	28 (17.3)	0.7	0.776
Excluding leukocyte esterase positive (≥2+)	356	59 (16.6)	329	53 (16.1)	-0.5	0.42
Excluding nitrite positive	356	59 (16.6)	355	59 (16.6)	0	1
Excluding hematuria	356	59 (16.6)	354	58 (16.4)	-0.2	0.304
Excluding pyuria (>20 WBC/HPF)	356	59 (16.6)	311	53 (17.0)	0.5	0.67
Excluding Schistosoma ova positive	356	59 (16.6)	327	55 (16.8)	0.2	0.8
Excluding all abnormal urinary biomarkers	356	59 (16.6)	278	46 (16.5)	0	1
Excluding all abnormal	356	59 (16.6)	123	21 (17.1)	0.5	0.881

Overall sample	Sensitivity analysis
biomarkers + dehydration	

Base sample: participants aged ≤ 60 ($n = 356$). Outcome: reduced eGFR (< 60 mL/min/1.73 m²). Each row shows prevalence after excluding participants positive for the specified urinary biomarker. Difference = restricted prevalence minus overall prevalence (16.6%). P-values from Fisher's exact test comparing reduced-eGFR prevalence between excluded and retained participants. Dehydration defined as USG > 1.020 ; leukocyte esterase, nitrite, and hematuria as dipstick grade $\geq 2+$; pyuria as > 20 WBC/HPF on microscopy. The first composite excludes the five infection/pathology markers (leukocytes, nitrite, hematuria, pyuria, *Schistosoma* ova); the final row additionally excludes dehydration.

Predictors of eGFR as Continuous Outcome in the DEGREE Subset

Table 4 presents the results of three nested linear regression models examining predictors of continuous eGFR among participants included in the DEGREE subset ($n = 268$). In Model 1, which included demographic characteristics only, increasing age was independently associated with lower eGFR ($B = -1.07$ mL/min/1.73 m² per year; 95% CI: -1.36 to -0.77 ; $p < 0.001$), while male participants had significantly higher eGFR than female participants ($B = 13.19$ mL/min/1.73 m²; 95% CI: 5.24 – 21.15 ; $p = 0.001$). This model explained 19.5% of the variation in eGFR ($R^2 = 0.195$). Model 2 additionally adjusted for occupational factors, including heat exposure risk, dehydration status, and daily working hours. Age and male sex remained significantly associated with eGFR, whereas heat exposure risk (low and moderate risk categories), dehydration, and work duration were not significantly associated with eGFR. The inclusion of occupational variables resulted in a modest increase in the proportion of explained variance ($R^2 = 0.202$). In the fully adjusted model (Model 3), infection-related variables (any infection and *Schistosoma haematobium* ova) and body mass index were added. Increasing age remained independently associated with lower eGFR ($B = -1.07$; 95% CI: -1.37 to -0.77 ; $p < 0.001$), while male sex remained positively associated with eGFR ($B = 13.87$; 95% CI: 5.15 – 22.60 ; $p = 0.002$). None of the occupational variables, infection markers, schistosomal ova, or body mass index were significantly associated with eGFR. Although participants with *S. haematobium* ova tended to have lower eGFR ($B = -10.45$ mL/min/1.73 m²; 95% CI: -25.37 to 4.47), this association did not reach statistical significance ($p = 0.169$). The fully adjusted model explained 21.6% of the variability in eGFR ($R^2 = 0.216$; adjusted $R^2 = 0.188$).

Table 4. Linear regression predictors of continuous eGFR in the DEGREE subset ($n = 268$)

Model	Term	β (95% CI)	p-value
Model 1: Demographics	Intercept	123.81 (110.22, 137.40)	<0.001
	Age (per year)	$-1.07 (-1.36, -0.77)$	<0.001
	Male sex	$13.19 (5.24, 21.15)$	0.0012
Model 2: + Occupational	Intercept	123.85 (103.89, 143.81)	<0.001
	Age (per year)	$-1.07 (-1.37, -0.77)$	<0.001
	Male sex	$14.06 (5.46, 22.65)$	0.0014
	Low heat-risk score	$2.22 (-6.98, 11.41)$	0.6353
	Moderate heat-risk score	$4.73 (-4.91, 14.37)$	0.3351
	Dehydration	$2.13 (-4.29, 8.54)$	0.5142
	Work duration (hours/day)	$-0.43 (-1.49, 0.64)$	0.4310
Model 3: Full	Intercept	140.60 (110.87, 170.32)	<0.001
	Age (per year)	$-1.07 (-1.37, -0.77)$	<0.001
	Male sex	$13.87 (5.15, 22.60)$	0.0019
	Low heat-risk score	$2.79 (-6.42, 11.99)$	0.5515
	Moderate heat-risk score	$5.05 (-4.57, 14.67)$	0.3022
	Dehydration	$1.03 (-5.54, 7.61)$	0.7570
	Work duration (hours/day)	$-0.44 (-1.50, 0.62)$	0.4120
	Any infection marker	$1.32 (-8.20, 10.84)$	0.7849
	Schistosoma ova positive	$-10.45 (-25.37, 4.47)$	0.1691
	BMI (kg/m ²)	$-0.68 (-1.60, 0.25)$	0.1496

Model R^2 : Model 1 = 0.195; Model 2 = 0.202; Model 3 = 0.216 (adjusted $R^2 = 0.188$). β , unstandardised regression coefficient; CI, confidence interval; BMI, body mass index; DEGREE, Disadvantaged Populations eGFR Epidemiology Study; eGFR, estimated glomerular filtration rate.

Multivariable predictors of reduced eGFR

In bivariate logistic regression, male participants had significantly lower odds of reduced eGFR than female participants in the overall population (OR 0.40, 95% CI 0.22–0.72), DEGREE subset (OR 0.38, 95% CI 0.18–0.82),

and DEGREE-Tanzania subset (OR 0.36, 95% CI 0.17–0.79). Increasing age was consistently associated with higher odds of reduced eGFR across all three populations, with the odds increasing by 8–10% for each additional year of age (all $p < 0.001$). Hypertension was associated with higher odds of reduced eGFR in the overall population (OR 2.20, 95% CI 0.99–4.62; $p = 0.042$), but it was not assessed in the DEGREE subsets because hypertension was an exclusion criterion. Residence, diabetes, HIV infection, NSAID use, traditional medicine use, consumption of sugary or energy drinks, and years of work experience were not significantly associated with reduced eGFR (Table 5).

Table 6 presents the multivariable logistic regression models examining factors associated with reduced eGFR (<60 mL/min/1.73 m²) in the overall study population, the DEGREE subset, and the modified Tanzania (TZ) subset. Variables with $P < 0.20$ in the bivariate analyses were entered into multivariable logistic regression models. Three outcome definitions were evaluated: reduced eGFR in all participants, reduced eGFR among participants meeting the DEGREE criteria (excluding hypertension, diabetes mellitus, and heavy proteinuria), and the modified TZ definition, which additionally excluded participants living with HIV.

Across all three models, increasing age remained the strongest independent predictor of reduced eGFR. Each additional year of age increased the odds of reduced kidney function by 8% in the overall population (OR = 1.08, 95% CI: 1.04–1.12; $P < 0.001$), 9% in the DEGREE subset (OR = 1.09, 95% CI: 1.05–1.15; $P < 0.001$), and 11% in the modified TZ subset (OR = 1.11, 95% CI: 1.06–1.17; $P < 0.001$). Sex was also consistently associated with reduced eGFR across all models, with male participants having significantly lower odds of reduced kidney function than females (overall OR = 0.31, 95% CI: 0.14–0.66; $P = 0.002$; DEGREE OR = 0.33, 95% CI: 0.13–0.87; $P = 0.025$; TZ OR = 0.33, 95% CI: 0.12–0.88; $P = 0.026$).

In contrast, hypertension, HIV infection, work experience, sugary drink consumption, and energy drink consumption were not independently associated with reduced eGFR after adjustment. Although occasional sugary drink consumption showed a borderline association with reduced eGFR in the overall (OR = 2.59, $P = 0.070$) and DEGREE (OR = 2.81, $P = 0.099$) models, these associations did not reach statistical significance. Similarly, no category of energy drink consumption demonstrated an independent association with reduced eGFR. Overall, these findings indicate that age and sex were the only consistent independent predictors of reduced kidney function, and the magnitude and direction of these associations remained stable across the progressively restricted DEGREE and modified TZ analytical subsets.

Table 5. Bivariate logistic regression of characteristics associated with reduced eGFR

		Reduced eGFR			Reduced eGFR DEGREE			Reduced eGFR TZ		
		(n = 356)			(n = 268)			(n = 265)		
Variable	Level	All n	All OR (95% CI)	All p-value	DEGREE n	DEGREE OR (95% CI)	DEGREE p-value	TZ n	TZ OR (95% CI)	TZ p-value
Sex	Male (ref: Female)	356	0.40 (0.22–0.72)	0.002	268	0.38 (0.18–0.82)	0.011	265	0.36 (0.17–0.79)	0.009
Residence	Urban (ref: Rural)	356	0.65 (0.19–1.72)	0.431	268	0.47 (0.07–1.68)	0.32	265	0.48 (0.08–1.72)	0.333
Age (per year)	Per year increase	356	1.08 (1.05–1.11)	0	268	1.09 (1.05–1.13)	0	265	1.10 (1.06–1.15)	0
Hypertension (HTN)	Yes (ref: No)	356	2.20 (0.99–4.62)	0.042		NA	NA		NA	NA
Diabetes mellitus (DM)	Yes (ref: No)	356	1.70 (0.25–7.60)	0.521		NA	NA		NA	NA
HIV	Yes (ref: No)	356	5.18 (0.61–43.86)	0.104	268	3.18 (0.15–34.03)	0.35		NA	NA
NSAIDs use	Yes (ref: No)	356	1.26 (0.06–8.73)	0.836	268	2.11 (0.10–17.00)	0.523	265	2.15 (0.10–17.35)	0.512
Traditional medicine use	Yes (ref: No)	356	1.28 (0.42–5.56)	0.703	268	1.22 (0.32–7.92)	0.801	265	1.19 (0.32–7.77)	0.821
Consumption of sugary drinks	Daily	356	0.77 (0.11–3.19)	0.745	268	0.48 (0.03–2.94)	0.508	265	0.48 (0.02–2.89)	0.498
	Never	356	1.15 (0.17–5.02)	0.865	268	1.04 (0.05–7.01)	0.975	265	1.02 (0.05–6.89)	0.988
	Occasionally	356	1.58 (0.63–3.98)	0.323	268	1.41 (0.48–4.14)	0.521	265	1.39 (0.47–4.08)	0.542
	Once a week	356	1.66 (0.79–3.70)	0.192	268	1.36 (0.56–3.56)	0.504	265	1.27 (0.52–3.34)	0.609
	Rarely	356	1.38 (0.47–3.82)	0.538	268	0.87 (0.18–3.29)	0.846	265	0.86 (0.18–3.24)	0.827

		Reduced eGFR			Reduced eGFR DEGREE			Reduced eGFR TZ		
		(n = 356)			(n = 268)			(n = 265)		
Energy drinks	Daily	356	0.95 (0.13–4.23)	0.951	268	0.59 (0.03–3.86)	0.635	265	0.59 (0.03–3.86)	0.635
	Never	356	1.63 (0.50–4.96)	0.397	268	1.26 (0.25–5.22)	0.764	265	1.26 (0.25–5.22)	0.764
	Occasionally	356	0.97 (0.34–2.65)	0.953	268	1.08 (0.34–3.43)	0.896	265	1.11 (0.35–3.53)	0.86
	Once a week	356	1.58 (0.74–3.62)	0.251	268	1.32 (0.53–3.62)	0.559	265	1.27 (0.51–3.49)	0.622
	Rarely	356	0.34 (0.07–1.19)	0.118	268	0.00 (0.00–26919476276161.66)	0.987	265	0.00 (0.00–44129565930301.60)	0.987
Work experience (years)	Per year increase	356	1.02 (0.99–1.05)	0.182	268	1.01 (0.97–1.05)	0.606	265	1.01 (0.97–1.05)	0.561

Bivariate logistic regression. Outcome: eGFR < 60 mL/min/1.73m². All: participants aged ≤60; DEGREE: excluding HTN, DM, heavy proteinuria (≥2+); TZ: DEGREE + excluding HIV. NA = variable excluded by subset definition. Reference categories for sugary drinks and energy drinks: 2-4 times per week.

Table 6. Multivariable logistic regression of characteristics associated with reduced eGFR

		Reduced eGFR			Reduced eGFR DEGREE			Reduced eGFR TZ		
		(n = 352)			(n = 264)			(n = 261)		
Variable	Level	n	OR (95% CI)	p-value	n	OR (95% CI)	p-value	n	OR (95% CI)	p-value
Sex	Male (ref: Female)	352	0.31 (0.14–0.66)	0.002	264	0.33 (0.13–0.87)	0.025	261	0.33 (0.12–0.88)	0.026
Age (per year)	Per year increase	352	1.08 (1.04–1.12)	<0.001	264	1.09 (1.05–1.15)	<0.001	261	1.11 (1.06–1.17)	<0.001
Hypertension (HTN)	Yes (ref: No)	352	0.93 (0.38–2.16)	0.865						
HIV	Yes (ref: No)	352	3.93 (0.39–41.43)	0.228	264	2.09 (0.08–32.21)	0.6			
Work experience (years)	Per year increase	352	1.01 (0.97–1.05)	0.726	264	0.99 (0.93–1.04)	0.611	261	0.98 (0.93–1.04)	0.562
Consumption of sugary drinks	2–4 times per week (ref)	352	1		264	1		261	1	
	Daily	352	0.73 (0.09–3.93)	0.735	264	0.74 (0.03–5.84)	0.803	261	0.75 (0.04–6.06)	0.814
	Never	352	1.71 (0.21–9.13)	0.56	264	3.10 (0.14–28.92)	0.369	261	3.27 (0.14–31.91)	0.353
	Occasionally	352	2.59 (0.93–7.38)	0.07	264	2.81 (0.82–9.81)	0.099	261	2.74 (0.78–9.84)	0.115
	Once a week	352	1.88 (0.83–4.51)	0.14	264	1.90 (0.71–5.51)	0.215	261	1.82 (0.66–5.39)	0.258
	Rarely	352	1.39 (0.42–4.33)	0.576	264	0.97 (0.17–4.43)	0.973	261	0.90 (0.16–4.19)	0.898
Energy drinks	2–4 times per week (ref)	352	1		264	1		261	1	
	Daily	352	0.97 (0.12–5.92)	0.978	264	0.40 (0.02–3.72)	0.471	261	0.35 (0.01–3.40)	0.415
	Never	352	1.73 (0.47–5.98)	0.393	264	1.80 (0.31–8.84)	0.483	261	1.90 (0.32–9.68)	0.449
	Occasionally	352	0.81 (0.26–2.42)	0.7	264	0.98 (0.27–3.56)	0.975	261	1.06 (0.29–3.93)	0.928
	Once a week	352	1.24 (0.53–3.03)	0.631	264	0.98 (0.35–2.91)	0.966	261	0.92 (0.33–2.78)	0.881
	Rarely	352	0.30 (0.06–1.14)	0.098	264	0.00 (0.00–2325356008418.24)	0.986	261	0.00 (0.00–420768741033.07)	0.986

Multivariable logistic regression. Outcome: eGFR < 60 mL/min/1.73 m². Variables included based on $p < 0.20$ in bivariate analysis (Table 2). All: participants aged ≤60; DEGREE: excluding HTN, DM, heavy proteinuria (≥2+); TZ: DEGREE + excluding HIV. NA = variable excluded by subset definition. Reference categories for sugary drinks and energy drinks: 2–4 times per week.

Discussion

Summary of findings

Among the 356 participants in the age-restricted (18 to 59 years) sample, 59 (16.6%; 95% CI 12.9–20.9) had reduced eGFR (<60 mL/min/1.73 m²). The prevalence decreased to 13.8% (95% CI 9.9–18.5) after applying the standard DEGREE exclusions and remained similar at 13.6% (95% CI 9.7–18.3) after additionally excluding participants with self-reported HIV infection in the modified DEGREE-TZ analysis. Sensitivity analyses excluding participants with urinary biomarkers suggestive of dehydration, infection or inflammation, haematuria, or urogenital schistosomiasis produced only minor changes in prevalence, with estimates ranging from 16.1% to 17.3%. This stability indicates that the estimated prevalence of reduced eGFR was not substantially influenced by the measured urinary abnormalities. In the multivariable logistic regression models, increasing age and female sex were consistently associated with greater odds of reduced eGFR across the age-restricted, DEGREE, and modified DEGREE-TZ populations. Each additional year of age was associated with an 8–11% increase in the adjusted odds of reduced eGFR, whereas male participants had approximately 67–69% lower adjusted odds than female participants. Hypertension, HIV status, fishing work experience, and sugary- or energy-drink consumption were not independently associated with reduced eGFR. The continuous-eGFR analysis supported these findings. In the fully adjusted DEGREE model, each additional year of age was associated with a mean eGFR reduction of 1.07 mL/min/1.73 m², while male participants had a mean eGFR 13.87 mL/min/1.73 m² higher than female participants. Occupational heat-risk score, dehydration, daily work duration, urinary infection markers, *Schistosoma* ova and BMI were not significantly associated with continuous eGFR. Overall, the findings were consistent across the different analytical definitions and sensitivity analyses, with age and sex emerging as the principal factors associated with reduced kidney function.

Comparison with other studies

The present study found that 16.6% of participants had an eGFR below 60 mL/min/1.73 m², a prevalence higher than the 7.0% CKD prevalence previously reported in a community-based study in northern Tanzania (51). In that earlier study, approximately half of the identified CKD cases occurred in participants without hypertension, diabetes, or HIV, suggesting that kidney dysfunction not readily explained by these conventional risk factors may also occur in Tanzanian populations (51). However, a direct comparison between the studies should be made cautiously due to differences in age distribution, occupational characteristics, geographic setting, kidney function equations, and case definitions (1,34,51). Previous studies of CKDu and reduced kidney function have frequently examined occupational heat exposure, recurrent dehydration, strenuous physical work, and other environmental or contextual factors (17,52–54). In the present study, however, heat exposure, dehydration, and working hours were not independently associated with reduced eGFR. Increasing age and female sex were the main factors associated with reduced kidney function. These findings suggest that the factors contributing to kidney dysfunction among small-scale fishers may differ from those reported in other CKDu-affected populations and may reflect variation in occupational activities, environmental exposures, population characteristics, exposure assessment, and definitions of kidney dysfunction. Because kidney function was assessed at a single time point, the observed cases should be interpreted as reduced kidney function compatible with a CKDu phenotype rather than confirmed CKDu.

Earlier Tanzanian studies assessed kidney dysfunction in the general population (35,51), whereas the present study focused specifically on small-scale fishers, an occupational group potentially exposed to a distinct combination of environmental, occupational, and infectious risks. Studies from other CKDu-affected settings have suggested that the occurrence of kidney dysfunction may also differ across occupational groups. In Sri Lanka, De Silva et al. (55) compared fisherfolk with farming and plantation-worker populations and found that, despite greater exposure to heat and dehydration among fisherfolk, CKDu susceptibility was lower among fisherfolk than among farmers (5.36% vs 13.33%). This suggests that heat and dehydration alone may not fully explain differences in kidney dysfunction between occupational groups. Similarly, we found no independent association between heat exposure and reduced eGFR among small-scale fishers in the present study. These findings suggest that other locally relevant occupational, environmental, biological, or infectious factors may contribute to kidney dysfunction in fishing communities. Further studies incorporating more detailed assessment of these exposures are

warranted to clarify the factors underlying the observed burden of reduced kidney function among Tanzanian fishers.

The prevalence of reduced eGFR remained relatively high after applying the DEGREE exclusions. Among participants without hypertension, diabetes, or heavy proteinuria, 13.8% had an eGFR <60 mL/min/1.73 m², and the prevalence changed only slightly to 13.6% after participants living with HIV were additionally excluded. The small difference between these estimates suggests that these conventional causes explained only a limited proportion of reduced eGFR in this study population. Compared with population-based DEGREE studies in Kenya and Malawi, the prevalence observed in the present study was higher [56–58]. However, these comparisons should be interpreted cautiously because the Kenyan and Malawian studies were conducted in general populations, whereas the present study focused on small-scale fishers, an occupational group potentially exposed to a different combination of environmental, occupational, and infectious risks. Higher estimates of reduced kidney function have also been reported in selected populations in Sri Lanka, India, and Central America (56–60). Differences across these settings suggest that locally specific factors may contribute to the observed variation in kidney dysfunction. The factors underlying the relatively high prevalence observed among Tanzanian fishers are not clear. Previous studies in CKDu-affected regions have reported associations with strenuous physical work, occupational heat exposure, recurrent dehydration, and agrochemical exposures (59,60,63–65). In the present study, however, heat exposure, dehydration, and working hours were not independently associated with reduced eGFR. Increasing age and sex were the main factors associated with reduced kidney function. The higher prevalence among women also differs from the predominantly male pattern reported in several classical CKDu hotspots, although similar sex differences have been observed in some DEGREE populations (56). These findings may indicate that the epidemiological pattern of reduced kidney function among Tanzanian fishing communities differs from that observed in agricultural CKDu settings. Possible explanations include differences in occupational activities, environmental exposures, infectious diseases, nutritional factors, and other locally relevant characteristics that were not fully assessed in the present study. Further focused studies are needed to investigate these possibilities.

The DEGREE framework provides a standardized approach for comparing reduced eGFR after excluding selected conventional causes of kidney disease (1). However, it does not establish the diagnosis of CKDu in individual participants. In the present study, kidney function was assessed at a single time point; therefore, the findings represent reduced kidney function compatible with a CKDu phenotype rather than confirmed CKDu. Confirmation of chronic kidney disease requires evidence that reduced kidney function or another marker of kidney damage persists for at least three months. Longitudinal studies with repeat kidney-function measurements and more detailed evaluation of occupational, environmental, infectious, and other potential exposures are needed to determine the persistence and possible causes of the reduced eGFR observed in this population.

A major strength of this study is the community-based application of the DEGREE framework among small-scale fishers around Lake Victoria, an occupational population rarely included in African kidney epidemiological research. The study identified a relatively high prevalence of reduced eGFR that persisted after excluding participants with hypertension, diabetes mellitus and heavy proteinuria, and remained similar after additionally excluding HIV infection. The use of the standardized DEGREE framework facilitated comparison with studies from other settings, while analysis of both continuous eGFR and reduced eGFR, together with multivariable and sensitivity analyses, allowed the robustness of the findings to be examined. Nevertheless, several limitations should be considered. First, the cross-sectional design meant that exposures and kidney outcomes were measured at approximately the same time, limiting the ability to establish temporal or causal relationships. Second, a single serum creatinine measurement could not establish chronicity. Third, creatinine-based eGFR may be influenced by factors such as muscle mass, diet, and hydration, and the equation has not been fully validated in all African populations. Age and sex are incorporated into the CKD-EPI 2021 equation; consequently, their associations with calculated eGFR are partly structurally determined and should be interpreted cautiously. Self-reported occupational exposures and single-time assessments of dehydration may also have resulted in exposure misclassification or recall bias. In addition, unmeasured occupational,

environmental, infectious, genetic, and socioeconomic factors may have contributed to residual confounding. Some subgroup analyses had limited sample sizes, and recruitment of currently active fishers may have introduced a healthy-worker effect. The use of BMU leader-provided lists and replacement of non-participants may have introduced selection bias by underrepresenting unregistered, less-connected or unavailable fishers. Future studies should incorporate repeated creatinine measurements, cystatin C or measured GFR where feasible, and objective assessment of occupational and environmental exposures to better characterize the persistence and determinants of kidney dysfunction among small-scale fishers.

Conclusion

We found a relatively high prevalence of reduced kidney function among small-scale fishers in Northwest Tanzania. The prevalence remained 13.8% after applying the DEGREE exclusions for hypertension, diabetes, and heavy proteinuria and changed only slightly to 13.6% after additionally excluding participants living with HIV. These findings suggest that conventional causes accounted for only a limited proportion of reduced eGFR in this population. Although small-scale fishers frequently work under hot and physically demanding conditions, heat exposure, dehydration, and working hours were not independently associated with reduced eGFR. Instead, increasing age and sex were the main factors associated with reduced kidney function. If occupational heat and dehydration were the sole drivers of kidney dysfunction, stronger associations with these exposures might have been expected. The findings therefore suggest that kidney dysfunction among Tanzanian fishing communities may reflect an interaction of occupational, environmental, biological, infectious, and other locally relevant factors. Because kidney function was measured at a single time point, these findings represent reduced kidney function suggestive of a CKDu phenotype rather than a confirmed case of CKDu. Longitudinal studies incorporating repeated kidney-function measurements and objective assessment of occupational and environmental exposures are needed to confirm chronicity and identify the factors contributing to the observed burden among small-scale fishers.

List of Abbreviations

CKD Chronic kidney disease

CKDu Chronic kidney disease of undetermined causes

eGFR Estimated glomerular filtration rate

DEGREE The Disadvantaged Populations

eGFR Epidemiology Study

DM Diabetes mellitus

HTN Hypertension

HP Heavy proteinuria

HIV Human immunodeficiency virus

BMI Body Mass Index

EPI Epidemiology

NSAID Nonsteroidal anti-inflammatory drug

AKI Acute kidney injury

ART Antiretroviral therapy

OR Odds ratio

Supporting Information

S1 Appendix. Standard Operating Protocol (SOP) for Fishing Village Selection

Ethics approval and consent to participate

We obtained ethical approval from the National Institute for Medical Research (NIMR), Tanzania (Ref. No. NIMR/HQ/R.8a/Vol.IX/5204), and the Kilimanjaro Christian Medical University College (KCMUCo) Research Ethics Committee (Ref. No. 2756); we also secured administrative permission from relevant local authorities. We obtained written informed consent from all participants. For participants unable to write, thumbprint consent was recorded in the presence of an impartial witness. Participation was voluntary, and confidentiality was maintained through unique participant identifiers and secure data management. Participants with abnormal clinical or laboratory

findings were counselled and referred for appropriate medical care. All study procedures were conducted in accordance with the ethical principles of the Belmont Report.

Consent for publication

Approved

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare no competing interests.

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Authors' contributions

K.K. conceived and designed the study, served as principal investigator, coordinated field activities, supervised data collection, contributed to data management and quality assurance, performed data analysis and interpretation, and drafted and revised the manuscript. K.G.K., V.M., and M.S.B. contributed equally to study conceptualization, supervision, interpretation of findings, and critical revision of the manuscript. PK verifying, compiling, digitizing laboratory results, data processing and interpretation, and JO assistance with statistical analysis and interpretation of the findings.

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