The Invisibility of Health Effects Associated with Water Pollution within Disease Burden Estimates: Analysis from a Colombian Andean Watershed

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ABSTRACT

Modernization goes along with a significant increase in pollution-related health risks linked to the ever growing economic and technological development. In addition to water-related communicable diseases, there are emerging concerns regarding the burden of disease attributable to the complexity of chemical pollution loads released into the environment. Studies demonstrating an association between chemical exposure and the occurrence of disease are abundant, particularly in occupational settings, although fewer assessments are available for the open environment. Agrochemicals, pharmaceutical compounds, disinfection byproducts, heavy metals, and many other emerging chemicals in very small concentrations, plus the mixture (cocktail effect) of several pollutants have shown ecotoxicological and genotoxic effects among various species in the trophic web of both terrestrial and aquatic ecosystems, at the apex of which are humans. Despite this evidence, water quality standards focus mostly on communicable diseases risks, and the widely promoted burden of disease approach mainly integrates the effects of gastrointestinal and respiratory infections. Based on previous research and information collected in a tropical Andean watershed at southwestern Colombia, we characterized drivers and hazards of disease and estimated water-related environmental burden of communicable diseases and an approximation to the likely burden of noncommunicable diseases. Estimates of disease burden are analyzed to find out disparities driven by ethnic, gender and socioeconomic status. Results show that profound inequalities persist affecting the most vulnerable populations for preventable communicable diseases. In addition, lack of information and more research continues to make the impacts of noncommunicable diseases, related to chemical pollution from individual substances and their cocktail effect alike, largely

invisible. The DALY addition effect and its econometric approach ought to be enriched with historical and critical perspectives to make visible the profound social and health inequalities immersed in the socioecological systems of the global South.

1. INTRODUCTION

Economic and technological development goes along with a significant increase in risks posed by contamination and its possible health effects. There is growing concern about the burden of disease arising from the complexity of pollution loads related to chemicals released into the environment. However, current water quality standards mostly focus on the risk of communicable diseases (CDs), and the burden of disease approach, widely promoted by multilateral agencies, mainly integrates the effect of gastrointestinal and respiratory infections. Several studies. particularly in occupational settings, show relationships between chemicals and disease, but less evidence is available for the open environment. It has been reported, for example, that endocrine disruptors, heavy metals, many other emerging chemicals in very small concentrations (micropollutants), and the mixture of several of these have ecotoxicological and genotoxic effects among organisms in the food web of aquatic ecosystems, ultimately reaching human populations.

Micropollutants are compounds of diverse origin and chemical nature, with consequences on ecosystems, which affect living beings by chronic ecotoxicity and endocrine disruption. i.e., alteration of hormonal and homeostatic systems (1). Although these contaminants have gained the attention of the scientific community, they continue to go unnoticed in the regulations of most countries. Agrochemicals, heavy metals, pharmaceutical compounds, disinfection byproducts-DBPs, personal care products, plasticizers, polyaromatic hydrocarbons, hormones and illicit drugs are part of this range of pollutants (2),(3).

As heavy metals are non-biodegradable and persistent in ecosystems. they remain bioavailable and bio-accumulative within and across various organisms and species. Most of these compounds are of priority for environmental and health authorities because they lead to carcinogenic effects in organs and tissues such as: bladder, lung, kidney, prostate, skin, and blood (leukemia) among others; there are also proved neurological disorders as well as cognitive and motor dysfunctions (4).

On the other hand, Trihalomethanes (THMs) and Haloacetic Acids (HAAs) are the most studied and quantified disinfection byproducts (DBPs) worldwide, whose evidence has led to their carcinogenic potential for human exposure. Although they do not represent the greatest health risk among the more than 700 DBPs found in drinking water, the THMs are the most regulated (i.e., European Union and Canada 100 $\mu g\ L^{-1}$; EPA 80 $\mu g\ L^{-1}$ and Colombia 200 $\mu g\ L^{-1}$) because preventing their formation may reduce the occurrence of other DBPs that have shown more toxicity and harm to human health -i.e., Haloacetonitriles (5), (6),(7),(8),(9),(10). Current scientific evidence shows that some of the above mentioned micropollutants have harmful effects on both human and animal health (especially for those organisms related to aquatic ecosystems). These compounds affect key life processes such as homeostasis, reproduction, development, and behavior of organisms -mesoscale population dynamics (3). Table 1 displays some documented effects of different micropollutants on human health.

Table 1. Micropollutants and their links to chronic diseases

Micropollutants Category	Name	Hazard Category	Health Effects	References
Agrochemicals	Paraquat	Type II Moderately hazardous[1]	Melanoma. severe lung lesions. DNA compound insertion. also includes immune system damages. and multiorgan dysfunction syndrome.	Chen. et al., 2021; Shen et al., 2017; Hichor. et al., 2017
	Chlorpyrifos	Type II Moderately hazardous[1]	Cancer of breast. lung. brain. straight. leukemia. Chromosomal aberrations and micronucleus formation.	(Badii. et al., 2015)

Heavy Metals	Arsenic	1 (IARC)[2] A (EPA)[3]	Associated with diabetes and increased risk of cancers of bladder. lungs. liver. and other organs. Contact with arsenic can also contribute to cardiovascular and respiratory disease. reduced IQ in children. and skin problems. such as lesions. discoloration. and the development of corns.	(Sankhla et al., 2016; WHO. 2019)
	Chromium	1 (IARC)[2] A (EPA)[3]	Skin disorders and allergies, kidney and liver failure, gastrointestinal effects, oxidative stress.	(WHO. 2020)
	Lead	2A (IARC)[4]	Damage to the central and peripheral nervous system, learning disabilities, slow growth rate, hearing problems, anemia, reproductive problems, cardiovascular disease.	(Collin et al., 2022; WHO. 2022)
	Mercury (Methyl-Mercury)	2B (IARC)[5]	Causes damage to the central nervous system, particularly in fetuses.	(Hong et al., 2012; Diez. 2009)
Pharmaceutical compounds	Ethinylestradiol*	EC List	Exists a correlation between exposure to EE2 in the environment with affectations in some aquatic biota un their endocrine system.	Laurenson et al., 2014
	Ibuprofen*	EC List	Disruption of the synthesis of enzymes involved in reproductive processes in species of vertebrates and aquatic invertebrates. Exposures < than 100 ng L^{-1} in freshwater sources have effects such as the reduction in the number of fish offspring and delay in the hatching of fish eggs.	(Flippin et al., 2007; Han et al., 2010).
DBPs[4]	Total Trihalomethanes (TTHMs)	2B (IARC)[5]	Bladder and colon cancer. low weight and size to birth. miscarriages. damage to the heart. lungs. kidney. liver and central nervous system. genotoxicity and cytotoxicity effect. micronuclei formation.	(Egwari et al., 2020)
	Halo acetic acids HAA (i.e., DCAA and TCAA).	B (EPA)[6] for DCAA C (EPA)[7] for TCAA	Undesirable reproductive effects, negative effects on growth, mutagenic, carcinogenic.	(Egwari et al., 2020; Sinha et al., 2021)

[1] WHO classification
[2] Carcinogenic
[3] Carcinogenic for humans
[4] 2A: Probably carcinogen in humans
[5] Possibly carcinogenic for humans
[6] Possibly carcinogenic for humans
[7] Probably carcinogen in humans
* There is evidence of effects on aquatic ecosystems but there is still no evidence of effects on human health due to environmental exposure.

Disability-adjusted life years (DALYs) are widely used as a tool for prioritization of health interventions by estimating the distribution of the Global Burden of Disease. DALYs combine mortality and morbidity data, with various valuation options such as disability weighting, age weighting and discounting, and has been proposed by the World Health Organization (WHO) as a model for ranking priorities. In this paper we argue that estimates of water-related environmental disease burden largely render invisible the entire system of multiple connections between water and health. This is partly because it lacks relevant information to systematically integrate health effects associated with infectious diseases and noncommunicable diseases (NCDs) due to chemical water pollution. Therefore, firstly, this paper aims at presenting the estimation of the burden of CDs related to the lack of water treatment or its incomplete disinfection in the Upper Cauca River Basin (UCRB) in southwestern Colombia. As a supplement to the above, we also present an analysis of these estimates in conjunction with the potential effects from chemical pollutants prevalent in the region. The final purpose is to contribute to the understanding of watersheds as socioecological units whose analysis requires indicators that comprehensively portrait the multiple and complex connections between water and health and the inequities so forth generated.

2. METHODS

2.1. Study area

The UCRB has got a length of 520 Km and an area of 2,180,940 ha. distributed in 5 regions: Valle del Cauca (49%), Cauca (34%), Risaralda (5.6%), Quindío (8.8%), and Caldas (2.3%) (see Figure 1a and 1b). The UCRB comprises 25 hydrographic sub-zones and 83 municipalities; the river has an average annual flow of 404 $m^3 s^{-1}$. The current population of the UCRB is 5.9 million people, 65% of which is concentrated in Valle del Cauca, followed by Cauca with 15.5%. The share of urban population in the basin is 75%. In terms of ethnicity, 80% are mixed and whites, whilst 10% are indigenous, and the remaining 10% are Afrodescendants.

Figure 1. a) Municipal GDP; and b) BOD_5 loads in the UCRB.

The UCRB has 41 types of life zones related to ecosystems (11), where agroecosystems predominate (1,727,771 ha); these are mostly composed of livestock (373.860 ha), and permanent crops such as sugarcane with 230,668 ha; followed by forests and shrublands with 217,993 ha. Finally, the third most important ecosystem in the UCRB is the paramo with 153,675 ha.

This distribution of ecosystem types is already portraying a high environmental pressure, as 82% (79% of agroecosystems and 3% of urban areas) of the UCRB area has been heavily transformed by anthropogenic activities into agro-industrial monocrop ecosystems, livestock, and urban areas. These activities generate continuously both point and diffuse pollution loads that increase the degradation processes of the socioecological systems at the UCRB.

In addition, the total coverage of municipal wastewater treatment at secondary stage is less than 25%. Therefore, the river receives an average daily Biological Oxygen Demand (BOD_5) loading of 215 Ton d^{-1} (12), and this increases the threats related to various infectious diseases, microbiological in origin (i.e., *Campylobacter, Salmonella, Giardia, Cryptosporidium, Entamoeba and Norovirus*) which have been found and reported in the Cauca River (13). There seems to be a direct relationship between the increase of the regional GDP and the discharge of polluting loads into the river, where the largest city in the UCRB, Cali with 2.8 million people out of 4.7 million in the whole catchment, contributes with 97 Ton d^{-1} alone.

The increase in GDP is related to the growing development of mostly industrial activities in the basin, thus, the main industries in urban settings are: i) metal-mechanics. ii) stain and coating. iii) plastics and synthetics and iv) photographic, cosmetics, tannery, pharmaceutical and food. These industries discharge chemicals with deleterious effects on the socioecological systems health; among them are Cr, Ba, Ar, Al, Pb, Sb, Hg, Cd, Zn, Cu, Phenols, Benzene, Toluene, Ethylbenzene, 1.2-Dichloroethane, Sulphur, Cyanide, and several others.

On the other hand, mining activities in rural areas such as dredging material, sand and clay extraction represent 61.3% of the total mining activity in the area; meanwhile, gold mining accounts for 17.5%; coal. 10.9%; and others, 10.3%. The latter economic activities generate health threats mainly related to the following chemicals: Hg, Pb, As, Mn, Ni and Zn, Cyanides, Sulphides, Sulphates and Carbonates (13).

Finally, another source of diffuse pollution is industrial monocrop agriculture(12). The UCRB has approximately 594,000 hectares between perennial and transitory crops, where sugar cane, coffee and banana crops stand out. These three crops account for over 78% of the total cultivated area in the basin, followed by corn, cassava, citrus trees, avocado, banana, potato, sisal, rice, cocoa, and beans(14).

The combined sugarcane monocrop industry together with the rest of the agricultural activity use around 2,500 Tons per year of agrochemicals into agricultural soils (Data taken from regional Agricultural Secretariats not accounting for fertilizer application). This intensive use of agrochemicals combined with the hydrological cycle in the tropical zone and the low protection of forest or riparian strips along the Cauca River increase the discharge probability of high loads of diffuse pollution into the water resources network (14).

All the above factors in the basin affect the quality of surface and groundwater used for human consumption as demonstrated by the 2019 Water Quality Risk Index (WQRI) report (which considers basic physicochemical and microbiological parameters) from 555 organizations supplying water for human consumption in the UCRB.

Large city water utilities with high GDP (including regional water utilities for cities and small towns) show WQRI values with low to null risk, whilst community-based organizations in charge of rural village water supply, which are in areas with low GDP, show a higher number of unacceptable to high and medium risks in terms of WQRI values (Figures 2a and 2b). These figures show unequal access to drinking water quality in different subregions of the basin; consequently, many people are exposed to different water-related health risks.

Figure 2. a. Percentage of WQRI associated with water utilities (large and small cities and towns with high GDP)

Figure 2.b. Percentage of WQRI for community-based rural water supply organizations (located in villages with low GDP)

2.2 Micropollutants in the UCRB

Studies conducted at UCRB have shown the presence of the following four groups of these contaminants.

2.2.1. Agrochemicals: Agrochemicals of the organochlorine (OC) family have been found in the Cauca riverbed, with the following ones standing out: α-HCH, β-HCH Lindane, Heptachlor, Endrin, 4.4'-DDE, 4.4'-DDDD, DDT, Methoxychlor (14).These compounds were banned by the Stockholm Convention, of which Colombia is a member since 2008; however, these agrochemicals are present in the aquatic environment of the UCRB (15).On the other hand, OP-organophosphates such as Chlorpyrifos and Dimethoate. are pesticides widely used in agricultural crops at the UCRB, and were detected to a lesser extent (16).

Therefore, several ecological populations, species, and individuals of aquatic and terrestrial ecosystems at the UCRB are chronically exposed to these contaminants, which represents a multi-scale ecological threat going from specific habitats to life zones and whole ecosystems (17). In this sense, as pointed out by several authors (18), there is a continuous process of bioaccumulation and bioaugmentation of these contaminants in the trophic chain with all the implications this may have for the socioecological systems that use water in the UCRB.

Alkylphenols are used in chemical formulations with pesticides and are frequently found in agricultural runoff (19). These compounds exhibit high estrogenic activity with different effects on living organisms that are passed on later generations (3), (15). Among these, BPA and 4-iso-nonylphenol stand out, and represent a high threat due to their implications on population dynamics of various aquatic organisms in the river ecosystem. The latter are two of the most relevant compounds in the Cauca River.

2.2.2. Heavy metals: Some authors found Hg concentrations ranging from $2.5x10^{-3}$ to 1.00 μL^{-1} due to artisanal gold mining, quantified in different tributaries of the Cauca River. In 2016 sediment sampling carried out by RICCLISA project at seven points, along a 440 Km stretch of the Cauca River plus some tributaries, evidenced high concentrations of Cr (between 1.46 - 181 mg kg^{-1}); Pb at all sampling points with a record mean concentration of 25.03 mg kg^{-1}; and Hg with a mean value reaching 369.85 mg kg^{-1}. Thus, the UCRB data show the presence of heavy metals in at least two abiotic compartments, the water column, and the riverbed sediments (4).

2.2.3. Pharmaceutical compounds: several pharmaceutical compounds were found in the urban water cycle of Cali city, with sampling points along the river, treated water for human consumption and primary treated sewage discharge. The main compounds and range of concentrations were Gemfibrozil ($6.5\text{-}2.6x10^{-2}\mu L^{-1}$), Ibuprofen ($3.5\text{-}2.3x10^{-2}\mu L^{-1}$), 17β

Estradiol ($6.5x10^{-3}$-$2x10^{-4}\mu L^{-1}$), and 4-Iso-Nonylphenol (1.7-$5.6x10^{-2}\mu L^{-1}$). These compounds represent a high hazard to the aquatic biota of the Cauca River, and the most critical point is the discharge from the city's wastewater treatment plant (20).

A toxicity assessment for each compound was carried out in drinking water network samples and showed no potential threat to human health, this according to the reference doses reported in the literature. However, for a real mixture (cocktail) of all types of micropollutants, the presence of potential estrogenic activity at concentrations between 5.9 - 8.5 ngL^{-1} of Estradiol Equivalent values was reported. Although these values mean a low hazard, this is in fact a more adequate estimation of the potential cumulative risk due to the cocktail effect of such pollutants (16).

2.2.4. Disinfection byproducts (DBPs): To our knowledge, only two studies related to this type of micropollutants were conducted in the UCRB characterized the presence of precursors and THMs in the Puerto Mallarino drinking water treatment plant-DWTP in the city of Cali. They found a mean concentration of 69±18 μgL^{-1} for THMs that was related to many organic precursors of anthropogenic origin (i.e., raw sewage discharges and runoff flows). Meanwhile, in the distribution network the mean THMs concentration ranged between 66 and 101 μgL^{-1}. Thus, Chloroform, one of the four key THMs, was found in concentrations above the EPA regulatory requirements (30 ug L^{-1}) in all sampling points such as the effluent of the DWTP and at nine sampling points of the distribution network (21). The second study was also conducted in Puerto Mallarino DWTP analyzing the presence of some DBPs such as THMs in the biofilm of distribution network pipes, and bulk water samples from the same pipes (22). The high costs of sampling and characterization of DBPs. as well as the laboratory analytical requirements make this type of investigations quite unusual in the country, and much more so when it comes to correlating the presence and exposure to DBPs with real health risks.

2.3. Estimation of the environmental disease burden

To estimate the environmental disease burden associated with water in the upper Cauca River in the period 2015-2020, reported cases of incidence and mortality were included for three epidemiologically relevant CDs and two NCDs related to water: Acute Diarrheal Disease (ADD), Acute Respiratory Infection (ARI), and typhoid fever; and leukemia and spontaneous abortion, respectively. These conditions were chosen based on available and reliable data provided by national and state Health Service Institutions. Additionally, in the case of the two NCDs there is a plausible causation attributed to water pollutants as reported in the literature. Based on the incidences of morbidity and mortality, the synthetic indicator of disability-adjusted life years and mortality-adjusted life years (DALYs) were calculated for each of the events to be studied. The analysis of inequalities was carried out considering the variables of sex, age, urban or rural area, and health regime. The estimation was developed in two phases:

<u>1. Calculation of the burden of disease:</u> the burden of disease was calculated considering the standardized methodology by the World Health Organization (WHO) and the Institute for Health Measurement and Evaluation (23). Thus, it was necessary to estimate the Healthy Life Years Lost "DALYs". The DALYs combine the disease impact of the number of years lost due to premature mortality (YLL) and those years of healthy life lost due to disability (YLD). Years of Life Lost due to Disability (YLD), were obtained by applying methods and data sources established by WHO for the global burden of disease estimates 2000-2019 (24). Estimated disability duration weighting factors were used for ADD, ARI, typhoid fever, leukemia, and spontaneous abortion. The calculation of YLD was developed according to the parameters used by the Global Burden of Disease Study 2019 (25) using the following equation (25) using the following equation (26).

$$YLD\lfloor r.\mathrm{K}.\beta\rfloor = D\ X\ [\frac{KCe^{r\alpha}}{(r+\beta)^2}\{e^{-(r+\beta)(\text{ļ}+\alpha)}[-(r+\beta)(\text{ļ}+\alpha)-1]-e^{-(r+\beta)\alpha-1}[-(r+\beta)\alpha-1]\}+\frac{1-\mathrm{K}}{r}(1-e^{-r\text{ļ}})$$

Where:

r the discount rate taken as 3%

K is the modulation of social weighting by age (value between 0 and 1). We set k=1

β is the parameter of the weighting function according to age (0. 04)

C the constant value = 0.1658

α is the age of disease onset

L is the duration of illness expressed in years (27)

As for YLL the equation used was the following (26):

$YLL = N * \mathrm{L}$

Where:

N is number of deaths from specific causes

L is the standard life expectancy at the age of death

Life expectancy was taken from global estimations of fertility, mortality, and healthy life expectancy (24) with a 3% discounting rate and unequal weighting factor by age (28); these were considered for the calculation of years of life lost due to premature death and the estimation of the DALYs. The standard expected YLL method was run with data on disease duration and onset age as provided by the Colombian disease burden study 2005 (26)(27). Then, the YLD estimation was run with a discount rate of 3% and differential weighting by age, which are the values of the parameters included in Equation 2. Finally, the total DALYs were estimated by adding the years lived with disability DALYs and the years of life lost due to disability DALYs.

<u>2. Burden attributable to water pollution (microbiological and chemical):</u> The calculation of the disease burden attributable to unsafe water sources and household sanitation was performed using the population attributable fraction -PAF- from prevalence data. relative risk and the

theoretical minimum risk of exposure based on the Global Burden of Disease study (29), (23) and other supplementary reviews (25), (30), (31).

The attributable burden rate for each of the infectious diseases was calculated using the categories of exposure to poor household sanitation, with data from the National Quality of Life Survey, taken from the National Statistics Department-DANE (32). Additionally, for the two NCDs, water sources for food preparation were used as subcategories. The latter allowed for the primary estimation of exposure factors and the proportion of population.

In relation to micropollutants and its likely relation to NCDs, it is important to bear in mind that they have physical and chemical characteristics (i.e., structure and molecular weight. partition coefficients. sorption properties and solubility in water) that hamper their removal in water treatment plants with conventional processes (i.e., coagulation, flocculation, sedimentation, filtration and disinfection) (33),(34),(35). Moreover, the final process of chlorination increases the probability of harmful DBPs generation such as chloroform and THMs in the presence of organic matter (2).

The typical technologies for drinking water treatment mostly used in the UCRB are of the conventional type as mentioned earlier. However, differential exposure to micropollutants is also related to raw water quality depending on its source (i.e., rainwater, boreholes, water wells, and temporary storage reservoirs). In this sense, there are inequalities in access to safe water depending first on the water source and second on the presence or absence of water treatment plants (36). Therefore, for the analysis of the burden of NCDs, the categories suggested were grouped into the following: treated water and raw water that includes rainwater, boreholes, water wells, and temporary storage reservoirs (32).

3. RESULTS

3.1 Estimation of water-related disease burden: The burden of CDs (ADD, ARI and typhoid fever) in the UCRB was estimated at 5,458.6 DALYs for the 2015-2020 period. The age group 0-4 years contributed to the highest number of YLL with a rate (581.2 DALYs per 100,000) 5 times higher than to the other age groups (See supplementary information). The total distribution of the burden between both sexes was similar, with 52% of the burden being contributed by men (2,834.0 DALYs). Figure 3 displays incidence rates of DALYs by age and sex and disease.

Figure 3. DALYs of infectious diseases per 100.000 individuals by age group and gender. UCRB. 2015-2020

The burden of CDs in urban areas accounts for 70% of all DALYs (3,733.1 DALYs), but the rate per 100,000 individuals is 55% higher than in rural areas. As for the health care regime, 65% (3,317.5 DALYs) corresponds to the subsidized and lower-income population, which has more than twice the DALYs per 100,000 individuals of the non-subsidized population (See table 2). In addition to the latter, the DALYs is even higher among the group under 15 years of age (data not shown) in rural areas, which is twice or higher than that in urban settings.

Table 2. DALYs for infectious diseases according to area of residence and health regime. UCRB, 2015-2020

		DALYs	DALYs per-100,000	Ratio
Area	Urban	3,733.1	96.5	1
	Rural	1,607.1	149.7	1.55
Health regime	Non-subsidized	1,800.0	69.1	1
	Subsidized	3,317.5	161.5	2.34

On the other hand, the burden of NCDs (spontaneous abortion and leukemia) in the UCRB was estimated at 44,011.4 DALYs for the 2015-2020 period. The burden of NCDs increases with age, especially among men, who are more affected by leukemia (See supplementary information). As expected, spontaneous abortion affects women especially between 15 and 29 years of age. Figure 4 shows DALY incidence rates by age, sex and NCD.

Figure 4. DALYs of chronic diseases per 100,000 individuals by age group and gender. UCRB. 2015-2020

The burden of disease due to NCDs for the urban area was estimated at 35,532.7 DALYs, or 82% of the total DALYs. For every 100,000 inhabitants, the rural area presented 22% less burden of disease compared to the urban area (rate ratio: 0.78). Regarding the health regime, it was found that 56% (23,621.9 DALYs) corresponded to the non-subsidized regime, with no differences with the subsidized regime in the number of DALYs per inhabitant (see table 3).

Table 3. DALYs for chronic diseases according to area of residence and health regime UCRB, 2015-2020

		DALYs	**DALYs per-100,000**	**Ratio**
Area	Urban	35,532.7	918.8	1
	Rural	7,686.0	721.6	0.78
Health regime	Non-subsidized	23,621.9	907.3	1
	Subsidized	18,487.7	897.8	0.99

3.2 Attributable disease burden: Estimates of disease burden for typhoid fever and ADD attributable to the risk factors analyzed are presented in table 4. Specifically, compared to the baseline exposure (i.e., occurrence of toilet connected to sewer), the attributable burden was estimated for exposure to: toilet connected to septic tank, toilet without connection (i.e., absorption well), latrine, toilet flushing to water source, or no sanitary service (open defecation).

The burden attributable to all these exposures is a total of 917.2 years of healthy life lost. On the other hand, the burden of acute respiratory infection attributable to not washing hands with soap and water was 58.8 years of healthy life lost (see table 4).

Table 4. Water-related attributable burden for infectious diseases according to risk factors. UCRB. period 2015-2020

	Attributable DALYs Total	Frequency households exposed	Attributable DALYs Index per-100.000 households
Typhoid fever and ADD:			
Toilet connected to septic tank	506.8	230.145	220.2
Toilet without connection	43.1	14.247	302.6
Latrine	84.3	22.761	370.7
Toilet with direct discharge to water sources	108.8	26.498	470.7
No sanitary service	174.0	36.623	415.2
Acute respiratory infection:			
Failure to wash hands with soap and water	58.8	179.643	32.7

On the other hand, the attributable burden of NCDs was estimated based on the risk of exposure to contaminants in food washing. Specifically, water supply from raw freshwater, water well (water drawn less than 3 m depth), borehole (water drawn more than 70mts depth) and rainwater in the UCRB for the period 2015-2020 accounts for 3,030.8 years of healthy life lost for all age groups (see table 5).

Table 5. Burden attributable to risk factors for NCDs UCRB, 2015-2020

	Attributable DALYs Total	Frequency households exposed	Attributable DALYs Index per-100.000 households
Spontaneous abortion and leukemia:			
Water supply system with raw fresh water	1,681.5	151,142	1,112.5
Water well (extracted less than 3mts depth)	1,072.6	91,828	1,168.1
Borehole (water extracted more than 70mts depth)	90.7	9,908	916.0
Rainwater	185.7	21,516	863.4

In addition, since many micropollutants are not safely removed by conventional water treatment plants with chlorination included, we recalculated the attributable disease burden for NCDs including full conventional water treatment to account for the likely risk this may still pose. Therefore, a total of 24.412.6 years of healthy life lost was estimated for all age groups (See table 6). It may be argued that the latter risk estimation might be somehow prevented by bringing the exposed population to the ideal situation, that is, to have treated water for human consumption complying with national water quality standards. However, national water quality standards in the global South do not yet consider the presence of many specific water pollutants related to the industrializing transition of their economies over the past 30 years and their concomitant chronic health risks.

Table 6. Adapted Burden attributable to risk factors for NCDs. UCRB, 2015-2020

	Attributable DALYs Total	Frequency households exposed	Attributable DALYs Index per-100.000 households
Spontaneous abortion and leukemia:			
water supply with conventional water treatment	19,907.4	2,047,914	972.08
Water supply system with raw fresh water	1,681.5	151,142	1,112.5
Water well (extracted less than 3mts depth)	1,072.6	91,828	1,168.1
Borehole (water extracted more than 70mts depth)	90.7	9,908	916.0
Rainwater	185.7	21,516	863.4

4. DISCUSSION

Burden of disease estimates are useful in determining the number of years of healthy life lost due to disability and death. These estimates have been used as prioritization tools based on the assumption that the conditions that compromise the most years of life are the most relevant. Our analysis, within CDs and using stratification and per capita estimates, allowed us to identify how impoverished populations and those living in rural areas are more likely to lose years of life to CDs than those in urban areas and with more economic resources. Moreover, as for NCDs, per capita DALYs stratified by area of residence suggest a higher risk among urban population, and no difference by socioeconomic status. Both findings are consistent with global trends and epidemiological transition theories in the sense that poor sanitation primarily affects poor populations through CDs, while chemical contamination affects urban areas with NCDs to a greater extent (37).

Despite the usefulness of the above findings, if (as it is usually done to estimate the total environmental burden associated with water), we add up the CD and NCDs in a single estimate, the sum of years of life lost does not make visible the inequalities that are reflected in the unfair persistence of preventable infectious diseases. This is due to the econometric nature of DALYs indicator that sums years of life lost without regard to the type of cause and preventability. Our estimates show 8 times more DALYs for 2 NCDs than for 3 CDs. Most DALYs from CDs could be avoided by providing access to safe water and sanitation measures, which are widely proven and cost-effective technological alternatives available for more than a century. Therefore, the lack of availability and/or access to sanitation technologies for vulnerable populations reflects deep historical and social conditions of injustice that disproportionately affect children under five, women, ethnic minorities, rural populations, and low-income communities; thus, these social disparities cannot be measured based solely on the total quantification of years of life lost.

Consequently, analyses of DALYs should differentiate the impacts of preventable CDs with recognized etiology and available sanitation measures in contrast to NCDs of multi-causal etiology resulting from complex networks of social and ecological processes. The most rational recommendation would be to perform analyses within specific categories and not to aggregate a lump sum for prioritization.

In addition, we propose that the connections between water and health could be expanded and complemented by an integration of other dimensions that reflect the complexity of the socioecological relations that occur in watersheds at different scales (comprising whole ecosystems, life zones and specific habitats), seen as both territories and socioecological systems. In particular, the conceptual framework of water security could help in this purpose. According to UN-Water, water security is *“The capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability.”* (38). Therefore, a systemic approach from water security impels a better understanding of three additional impacts on health: from ecosystem degradation due to lack of freshwater supply of an adequate quality, from economic activities related to food insecurity, and from the effects of water-related hazards (i.e., pollution, landslides, floods, and droughts) exacerbated by climate change. Furthermore, the DALYs do not consider other dimensions of human life that try to counter-balance mainstream notions of development indicators (mostly based on wealth), such as, well-being, "Good Living" (i.e., “Buen Vivir”). Sumak Kawsay or happiness, as well as other aspects of life related to the sovereignty of communities in their relationship with water and nature in general (39)(40).

On the other hand, the fact that disease burden estimates focus on infectious diseases does not allow a comprehensive view of the global and structural dimensions of persistent inequalities. Consequently, by overlooking the nature and intensity of pollution in the global South, the impacts on NCDs occurring because of slowly industrializing or primary economies, are kept invisible. In so doing more critical analyses will help to challenge how the worldwide imposed globalization order that has embodied low-income countries (i.e., through mining and all sorts of extractivist activities that use and generate pollutants, but also increased ecosystemic degradation) in the international trade scenario, at the same time generate environmental and health liabilities, for mostly but not exclusively, disadvantaged human populations in the global South.

Thus, much more effort is required to have more robust estimates of the health impacts attributable to exposure to micropollutants and other chemical agents. These chemicals reach watersheds, and some persist or are transformed, enter food chains, and finally reach humans through different pathways. There are many gaps in knowledge about the environmental doses they reach and their medium- and long-term effects, particularly in relation to chronic conditions secondary to hormonal alterations, cytotoxicity, or genotoxicity.

5. CONCLUSIONS

DALYs indicator remains one of the main prioritization tools, despite the multiple limitations implied by its uncritical use, particularly because of its totalizing and econometric approach. In addition, the limited capacity to measure many micropollutants in the Global South, due to technological and financial limitations, leads to a limited knowledge of their spatial-temporal dynamics and possible effects on socioecological systems, which in turn reifies the geopolitics of reprimarization of global South economies within the framework of globalization. Consequently, a shift towards a systemic view and cross analyses from critical geography and the history of social inequalities is required to compound a better and more complex interpretation of health indicators such as DALYs.

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REFERENCES

1.Roig B. Pharmaceuticals in the Environment. IWA Publishing; 2010. 221 p.

2.Benítez JS. Rodríguez CM. Casas AF. Disinfection byproducts (DBPs) in drinking water supply systems: A systematic review. Phys Chem Earth Parts ABC. 1 de octubre de 2021; 123:102987.

3.Jung C. Son A. Her N. Zoh KD. Cho J. Yoon Y. Removal of endocrine disrupting compounds. pharmaceuticals. and personal care products in water using carbon nanotubes: A review. J Ind Eng Chem. 25 de julio de 2015; 27:1-11.

4.Gallo JA. Pérez EH. Figueroa R. Figueroa A. Water quality of streams associated with artisanal gold mining; Suárez. Department of Cauca. Colombia. Heliyon. 1 de junio de 2021;7(6): e07047.

5.United States: National Archives and Records Administration: Office of the Federal Register. United States: Environmental Protection Agency. National Primary Drinking Water Regulations: Disinfectants and Disinfection Byproducts. Part IV: Rules and Regulations. Fed Regist Vol 63 No 241. 16 de diciembre de 1998;69177-537.

6.Hrudey SE. Chlorination disinfection by-products. public health risk tradeoffs and me. Water Res. 1 de mayo de 2009;43(8):2057-92.

7.Resolución Número 2115. Colombia: Ministerio de Protección Social. Ministerio de Ambiente. Vivienda y Desarrollo Territorial; 2017.

8.Comisión Europea. "Directiva COM (2017) 0753 relativa a la calidad de las aguas destinadas al consumo humano." vol. Versión re. Bruselas. 2017.

9.Peng F. Peng J. Li H. Li Y. Wang B. Yang Z. Health risks and predictive modeling of disinfection byproducts in swimming pools. Environ Int. 1 de junio de 2020; 139:105726.

10.Health Canada.Guidelines for Canadian Drinking Water Quality: Guideline Technical Document — Haloacetic Acids. Water. Air and Climate Change Bureau. Healthy Environments and Consumer Safety Branch. Health Canada. Ottawa. Ontario.2018.

11.IDEAM. Reporte de avance del Estudio Nacional del Agua ENA. 2018.Instituto de Hidrología. Meteorología y Estudios Ambientales – IDEAM.2018. pág.

12.Hub-WS&SD. Diagnóstico socioeconómico de la Cuenca Alta del Río Cauca. Water Security and Sustainable Development Hub. Funded by the UK Research and Innovation's Global Challenges Research Fund (GCRF). 2020.pág

13.Pérez Vidal A. Torres Lozada P. Escobar J. Hazard identification in watersheds based on water safety plan approach: case study of Cali-Colombia. Environ Eng Manag J. 1 de abril de 2016; 15:861-72.

14.RICCLISA. “Red interinstitucional de Cambio Climático y Seguridad Alimentaría”. Informe Técnico WP3 Calidad de Agua. Universidad del Valle. Cali. Colombia. 2016.pág

15.Liu L. Tang J. Zhong G. Zhen X. Pan X. Tian C. Spatial distribution and seasonal variation of four current-use pesticides (CUPs) in air and surface water of the Bohai Sea. China. Sci Total Environ. 15 de abril de 2018; 621:516-23.

16.Toro. A.F. Evaluación integral de la presencia de micro-contaminantes en la cuenca alta del río cauca. Doctoral Thesis. Universidad del Cauca. Colombia.2021; pág.

17.Snow DD. Chakraborty P. Uralbekov B. Satybaldiev B. Sallach JB. Thornton Hampton LM. et al. Legacy and current pesticide residues in Syr Darya. Kazakhstan: Contamination status. seasonal variation and preliminary ecological risk assessment. Water Res. 1 de octubre de 2020; 184:116141.

18.Gosset A. Polomé P. Perrodin Y. Ecotoxicological risk assessment of micropollutants from treated urban wastewater effluents for watercourses at a territorial scale: Application and comparison of two approaches. Int J Hyg Environ Health. 1 de marzo de 2020; 224:113437.

19.EPA. UEPA. "Nonylphenol (NP) and nonylphenol ethoxylates (NPEs) action plan." RIN (2010).

20.Madera CA. Jiménez EM. Toro AF. Lara JA. Bedoya DF. Duque V. Estudio Exploratorio De La Presencia De Microcontaminantes En El Ciclo Urbano Del Agua En Colombia: Caso De Estudio Santiago De Cali. Rev. Int Contam Ambient. 2018;34(3):475-87.

21.Rosero M. Latorre J. Torres W. Delgado L. Presencia de Materia Orgánica y Subproductos de la Desinfección con Cloro. Caso Sistema de Tratamiento de Agua para Consumo Humano. Puerto Mallarino. Cali-Colombia. 2005.

22.Montoya C. Douterelo I. Noakes C. Camargo-Valero MA. Sleigh A. Escobar-Rivera JC. et al. Field assessment of bacterial communities and total trihalomethanes: Implications for drinking water networks. Sci Total Environ. 1 de marzo de 2018;616-617:345-54.

23.Wang H. Abbas KM. Abbasifard M. Abbasi-Kangevari M. Abbastabar H. Abd-Allah F. et al. Global age-sex-specific fertility. mortality. healthy life expectancy (HALE). and population estimates in 204 countries and territories. 1950–2019: a comprehensive demographic analysis for the Global Burden of Disease Study 2019. The Lancet. 17 de octubre de 2020;396(10258):1160-203.

24.WHO. A. "WHO Methods and Data Sources for Life Tables 1990–2019." (2020).

25.Murray CJ. Lopez AD. Jamison DT. The global burden of disease in 1990: summary results. sensitivity analysis and future directions. Bull World Health Organ. 1994;72(3):495-509.

26. Velásquez. "Guía metodológica para las estimaciones epidemiológicas del estudio de carga de enfermedad.” Promoviendo alianzas y estrategias. Abt AssociatesInc.2006.

27.Acosta N. R. Enrique N. P. R. J. G. Carga de la Enfermedad en Colombia 2005. En Cendex. (2008);73-81

28.WHO. A. " WHO methods and data sources for country-level causes of death 2000-2019" (2020).

29.GBD 2015 Risk Factors Collaborators. Global. regional. and national comparative risk assessment of 79 behavioural. environmental and occupational. and metabolic risks or clusters of risks. 1990-2015: a systematic analysis for the Global Burden of Disease Study 2015. Lancet Lond Engl. 8 de octubre de 2016;388(10053):1659-724.

30.Wolf J. Prüss-Ustün A. Cumming O. Bartram J. Bonjour S. Cairncross S. et al. Assessing the impact of drinking water and sanitation on diarrhoeal disease in low- and middle-income settings: systematic review and meta-regression. Trop Med Int Health TM IH. agosto de 2014;19(8):928-42.

31.García J. Peruga A. "Riesgo atribuible: sus formas. usos e interpretación." Gaceta Sanitaria 4.18 (1990): 112-117.

32.Dirección Nacional de Estadística - DANE. Encuesta Nacional de Calidad de Vida. 2018

33.Abel. Chol Deng Thon. Soil aquifer treatment: assessment and applicability of primary effluent reuse in developing countries. CRC Press Inc.. 2014.

34.Arcos. Marta Carballa. Fate of pharmaceutical and personal care products (PPCPs) in sewage treatment plants focusing on the anaerobic digestion of sludge. Diss. Universidade de Santiago de Compostela. 2005.

35.Schwarzenbach RP. Gschwend PM. Imboden DM. Environmental Organic Chemistry. John Wiley & Sons; 2016. 1026 p.

36.Sánchez LD. and Quiroga E. "Sostenibilidad de las tecnologías de tratamiento de agua para la zona rural." Revista de Ingeniería 49 (2020): 52-61.

37.McKeown RE. The Epidemiologic Transition: Changing Patterns of Mortality and Population Dynamics. Am J Lifestyle Med. 2009 Jul 1;3(1 Suppl):19S-26S. doi: 10.1177/1559827609335350. PMID: 20161566; PMCID: PMC2805833.

38. UN-Water. What is water security? Infographic [Internet]. UN-Water. 2013. Disponible en: https://www.unwater.org/publications/what-water-security-infographic

39. Waldmüller JM. Buen Vivir. Sumak Kawsay. ’Good Living’: An Introduction and Overview Alternautas. 1(1); 2014.

40. Domínguez R. Caria S. León M. Buen Vivir: Praise. instrumentalization. and reproductive pathways of good living in Ecuador. Lat Am Caribb Ethn Stud;2017;12(2):133–54.

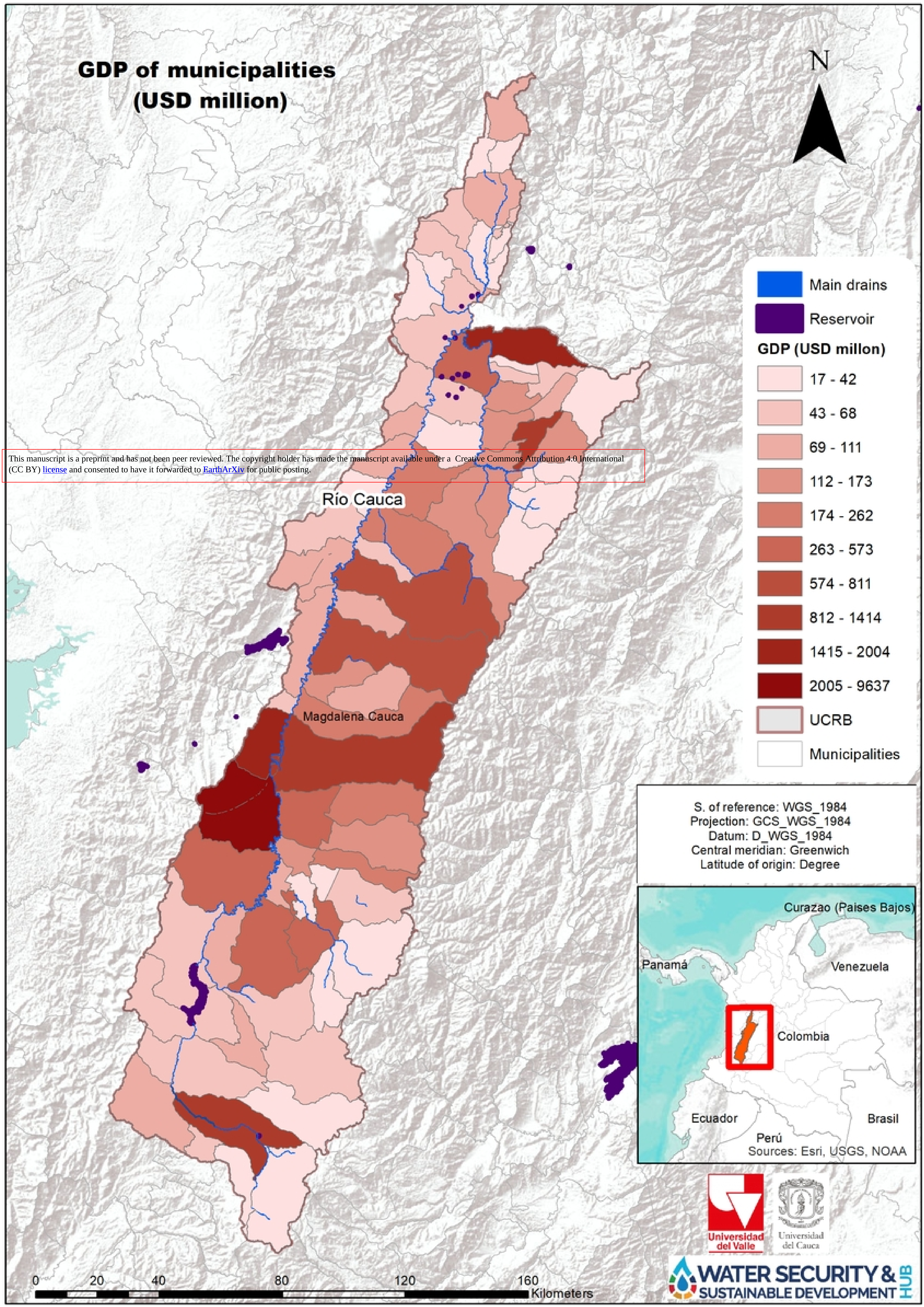
GDP of municipalities
(USD million)
N
Main drains
Reservoir
GDP (USD millon)
17 - 42
43 - 68
69 - 111
112 - 173
174 - 262
263 - 573
574 - 811
812 - 1414
1415 - 2004
2005 - 9637
UCRB
Municipalities
Río Cauca
Magdalena Cauca
S. of reference: WGS_1984
Projection: GCS_WGS_1984
Datum: D_WGS_1984
Central meridian: Greenwich
Latitude of origin: Degree
Curazao (Paises Bajos)
Panamá
Venezuela
Colombia
Ecuador
Brasil
Perú
Sources: Esri, USGS, NOAA
Universidad del Valle
Universidad del Cauca
WATER SECURITY & SUSTAINABLE DEVELOPMENT HUB
0
20
40
80
120
160
Kilometers

Figure1a

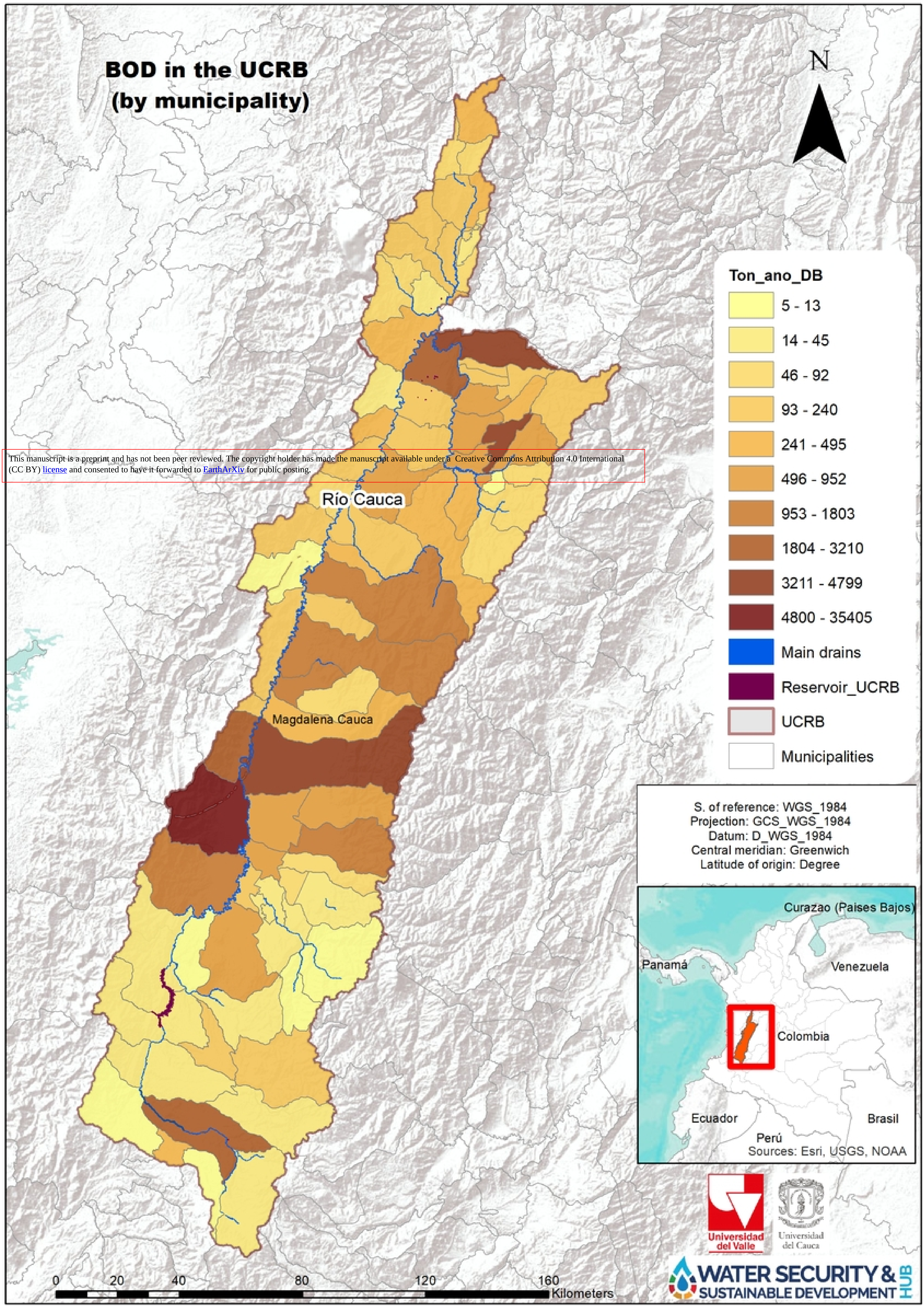
BOD in the UCRB
(by municipality)
N
Río Cauca
Magdalena Cauca
Ton_ano_DB
5 - 13
14 - 45
46 - 92
93 - 240
241 - 495
496 - 952
953 - 1803
1804 - 3210
3211 - 4799
4800 - 35405
Main drains
Reservoir_UCRB
UCRB
Municipalities
S. of reference: WGS_1984
Projection: GCS_WGS_1984
Datum: D_WGS_1984
Central meridian: Greenwich
Latitude of origin: Degree
Curazao (Paises Bajos)
Panamá
Venezuela
Colombia
Ecuador
Brasil
Perú
Sources: Esri, USGS, NOAA
Universidad del Valle
Universidad del Cauca
WATER SECURITY & SUSTAINABLE DEVELOPMENT HUB
0
20
40
80
120
160
Kilometers

Figure1b

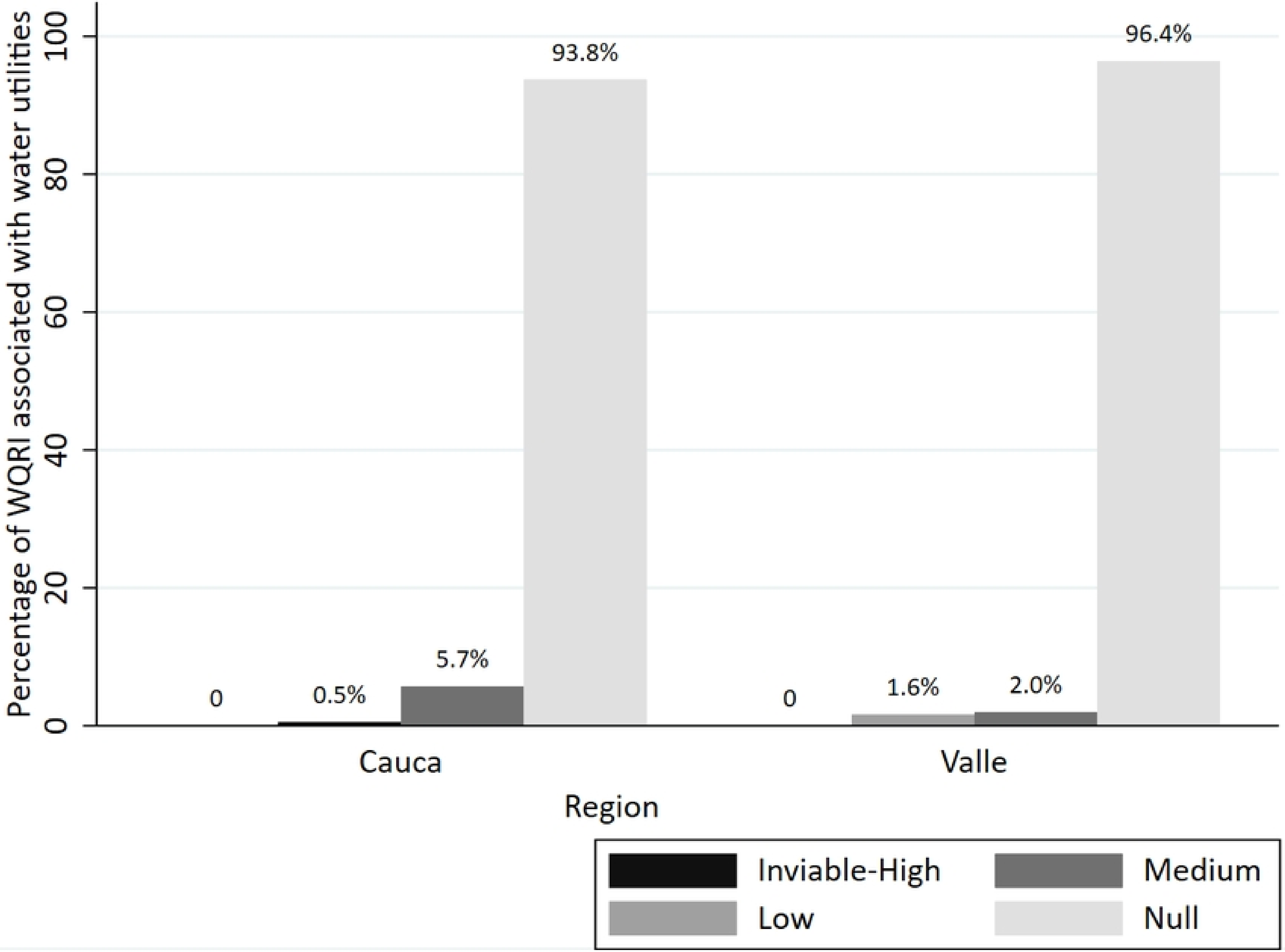
Percentage of WQRI associated with water utilities
0
20
40
60
80
100
0
0.5%
5.7%
93.8%
0
1.6%
2.0%
96.4%
Cauca
Valle
Region
Inviable-High
Medium
Low
Null

Figure2a

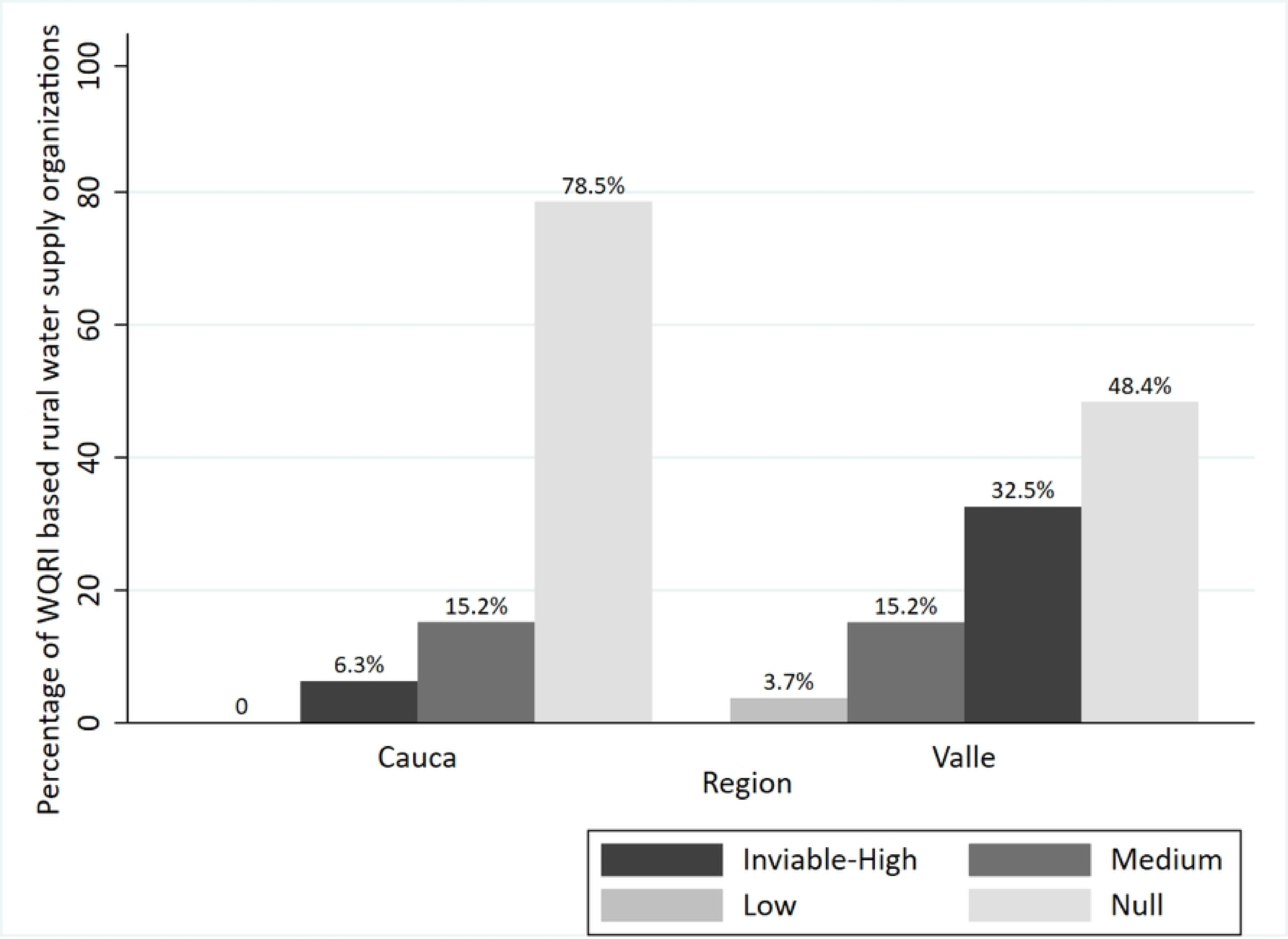
Percentage of WQRI based rural water supply organizations
100
80
60
40
20
0
78.5%
48.4%
32.5%
15.2%
15.2%
6.3%
3.7%
0
Cauca
Valle
Region
Inviable-High
Medium
Low
Null

Figure2b

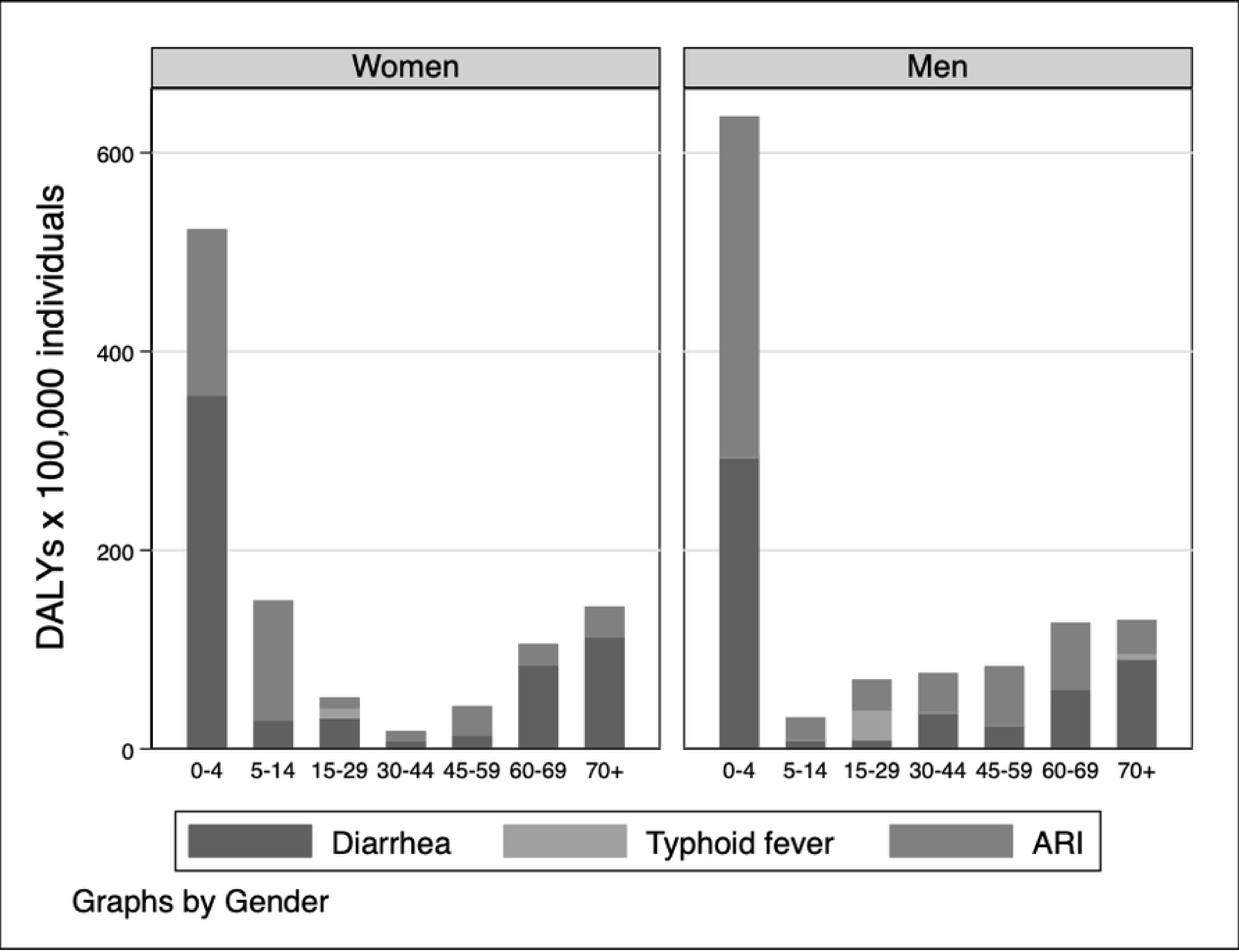
Women
Men
DALYs x 100,000 individuals
600
400
200
0
0-4
5-14
15-29
30-44
45-59
60-69
70+
Diarrhea
Typhoid fever
ARI
Graphs by Gender

Figure3

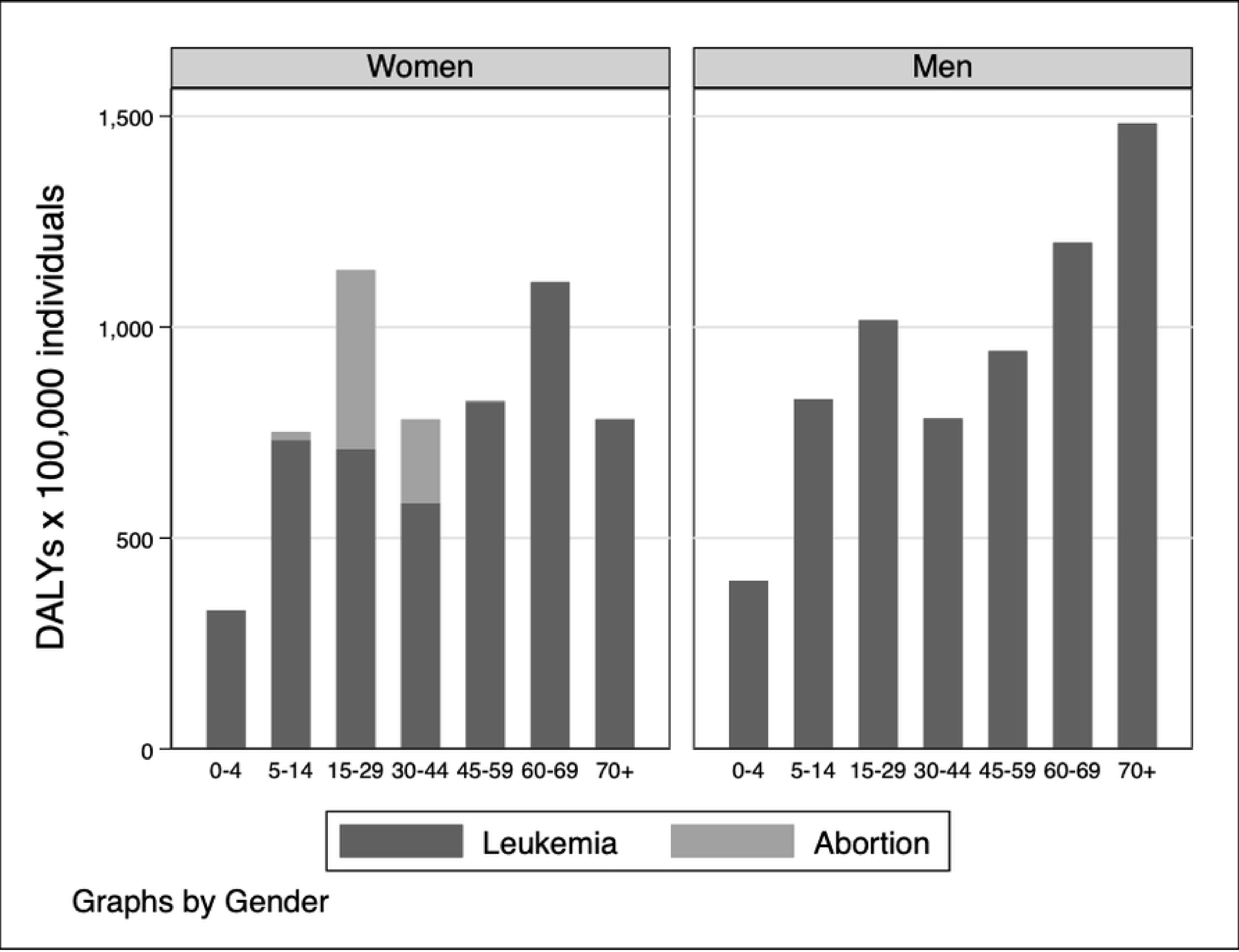
Women
Men
1,500
1,000
500
0
DALYs x 100,000 individuals
0-4
5-14
15-29
30-44
45-59
60-69
70+
Leukemia
Abortion
Graphs by Gender

Figure4