Science of the Total Environment 490 (2014) 301–312

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Examining the influence of urban definition when assessing relative safety of drinking-water in Nigeria

Elizabeth Christenson [a], Robert Bain [a], Jim Wright [b], Stephen Aondoakaa [c,d], Rifat Hossain [e], Jamie Bartram [a,*]

[a] The Water Institute at UNC, University of North Carolina at Chapel Hill, NC, USA
[b] Geography and Environment, University of Southampton, Southampton, UK
[c] Geography and Environmental Management, University of Abuja, Abuja, Nigeria
[d] School of Geography, University of Nottingham, Nottingham, UK
[e] World Health Organization, Geneva, Switzerland

HIGHLIGHTS

- Urban improved sources of a given type are no more contaminated than rural ones.
- Fecal contamination is 1.6–2.3 times more likely in rural areas, combining sources.
- We find no evidence to justify different urban and rural water quality standards.
- Comparisons of urban and rural areas are sensitive to definitions of urban extent.

ARTICLE INFO

Article history:
Received 19 February 2014
Received in revised form 2 May 2014
Accepted 2 May 2014
Available online xxxx

Editor: D. Barcelo

Keywords:
Drinking water quality
Urban
Rural
Geographic Information Systems
Water Supply

ABSTRACT

Reducing inequalities is a priority from a human rights perspective and in water and public health initiatives. There are periodic calls for differential national and global standards for rural and urban areas, often justified by the suggestion that, for a given water source type, safety is worse in urban areas. For instance, initially proposed post-2015 water targets included classifying urban but not rural protected dug wells as unimproved. The objectives of this study were to: (i) examine the influence of urban extent definition on water safety in Nigeria, (ii) compare the frequency of thermotolerant coliform (TTC) contamination and prevalence of sanitary risks between rural and urban water sources of a given type and (iii) investigate differences in exposure to contaminated drinking-water in rural and urban areas. We use spatially referenced data from a Nigerian national randomized sample survey of five improved water source types to assess the extent of any disparities in urban–rural safety. We combined the survey data on TTC and sanitary risk with map layers depicting urban versus rural areas according to eight urban definitions. When examining water safety separately for each improved source type, we found no significant urban–rural differences in TTC contamination and sanitary risk for groundwater sources (boreholes and protected dug wells) and inconclusive findings for piped water and stored water. However, when improved and unimproved source types were combined, TTC contamination was 1.6 to 2.3 times more likely in rural compared to urban water sources depending on the urban definition. Our results suggest that different targets for urban and rural water safety are not justified and that rural dwellers are more exposed to unsafe water than urban dwellers. Additionally, urban–rural analyses should assess multiple definitions or indicators of urban to assess robustness of findings and to characterize a gradient that disaggregates the urban–rural dichotomy.

1. Introduction

The World Health Organisation (WHO) and UNICEF monitor progress to Millennium Development Goal 7, Target 7c to "halve by 2015 the proportion of people without access to safe drinking water" (UN Development Group, 2003) through the Joint Monitoring Programme (JMP). International monitoring efforts have relied on classifying households according to their "use of an improved source" for drinking water, employing data derived from nationally-representative household surveys and censuses (Table 1). Not all improved sources are safe, however,

Abbreviations: AP, AfriPop; BH, Boreholes; E-GEO, E-geopolis; GLOB, Globcover; GRUMP, Global Urban–Rural Mapping Project; GPS, Global Positioning System; HH, household sample; JMP, Joint Monitoring Programme; LS, LandScan; MDG, Millennium Development Goal; NAT, National; PDW, protected dug wells; RADWQ, Rapid Assessment of Drinking-water Quality; TT, tanker truck; TTC, thermotolerant coliform; *E. coli*, *Escherichia coli*; WHO, World Health Organisation; UN, United Nations; UP, utility piped water.

* Corresponding author at: The Water Institute at UNC, Gillings School of Global Public Health, The University of North Carolina at Chapel Hill, Rosenau Hall, 135 Dauer Drive, Chapel Hill, NC 27599-7431, USA. Tel.: +1 919 966 3934.
E-mail address: jbartram@unc.edu (J. Bartram).

http://dx.doi.org/10.1016/j.scitotenv.2014.05.010
0048-9697/© 2014 Published by Elsevier B.V.

Table 1
WHO and UNICEF improved source classification (www.wssinfo.org).

Source class	Type of source
Unimproved drinking-water source	Unprotected dug well, unprotected spring, cart with small tank or drum, surface water (e.g. river, dam, lake, pond, stream, canal or irrigation channel) and bottled water
Improved drinking-water source	Piped water connection located inside the user's dwelling, plot or yard, public taps or standpipes, tube wells or boreholes, protected dug wells, protected springs and rainwater collection

as judged by health guidelines and national water quality standards (Bain et al., 2014). WHO recommends testing for *Escherichia coli* (*E. coli*) or alternatively thermotolerant coliform (TTC) (WHO, 2011); both indicators are strongly associated with fecal contamination of drinking-water and their absence is a minimum standard of most drinking-water regulations, including those in Nigeria (Standards Organisation of Nigeria, 2007).

WHO and UNICEF commissioned studies in eight countries to investigate the safety of improved sources between 2004 and 2005. The Rapid Assessment of Drinking-water Quality (RADWQ) studies found widespread contamination in improved water source types for four of the five countries for which data have been made available to the public (Aldana, 2010; Aliev et al., 2010; Ince et al., 2010; Properzi, 2010; Tadesse et al., 2010); the principal type of contamination was found to be microbial contamination as indicated by TTC and many sources were found to have multiple sanitary risks. The results of these studies have been used to estimate the impact of adjusting coverage figures for contamination and the impact on MDG progress in these countries (Bain et al., 2012), to extrapolate findings globally (Onda et al., 2012; Wolf et al., 2013), and to investigate whether the improved source metric captures inequalities in safe access between the rich and poor (Yang et al., 2013). None of these analyses have explored differences in safety between rural and urban areas.

Definitions of "urban" are not consistent and there is considerable variation in the definitions between, and even within, countries (Panel on Urban Population Dynamics, 2003; UN Statistics Division, 2013). Our study discusses the implications of urban definition on microbial water quality, however identification of urban extent and allowing for an urban-rural gradient is important for other environmental assessments of urban impact as well such as changes in precipitation patterns (Rosenfeld, 2000; Shepherd et al., 2012), air quality and climate (Arnfield, 2003), deforestation and loss of biodiversity (Hahs et al., 2009) among others (Seto et al., 2011). Additional implications of identifying urban and rural areas include looking at health disparities, and assessing equity in the distribution of resources within and between the urban and rural environments (Dahly and Adair, 2007; Fotso, 2007; Günther and Fink, 2010; Ruel et al., 2010).

Disparities in access to drinking-water services between rural and urban areas are pronounced (Bain et al., submitted for publication-b). Rural dwellers are less likely to use an improved source of drinking water with a reported gap of 12% globally and 28% in Nigeria in 2011 (WHO/UNICEF, 2013b). Furthermore community-managed water services which are primarily found in rural areas globally, including sub-Saharan Africa, often fall into disrepair (Foster, 2013).

Despite this, there are periodic calls to set higher targets in urban areas to address unequal access to safe water by the urban poor (Schäfer et al., 2007). In comparing the safety of different source classes, it has been argued that groundwater from springs and dug wells in urban areas ought to be classed as "unimproved" and this was reflected in the initially-proposed post-2015 sustainable development targets (WHO/UNICEF, 2013b). Such an approach would focus greater attention on urban areas and may run counter to efforts to reduce national inequalities between urban and rural areas. The JMP reported that only 4% of the global urban population used an unimproved source of drinking-water in 2011 whereas 19% of the rural population relied on these source types. This trend in inequality is consistent globally, for all MDG regions and for the overwhelming majority of countries (WHO/UNICEF, 2013b). It is unclear whether different targets can be justified on the basis of greater risk to health. On the one hand, population density, industrial activity and de-centralized solid waste management might be expected to result in more frequent contamination in urban areas. On the other hand, factors including better access to sanitation facilities, removal from agricultural activities, higher service levels and a more informed public with access to disinfectants could mean that those in urban and peri-urban (i.e. areas on the urban perimeter such as slums or suburbs) areas are at lower risk.

In Nigeria, one of the five countries that took part in the RADWQ study, Global Positioning System (GPS) coordinates were collected for each water source investigated. These data offer the possibility to disaggregate water quality data by various definitions of "rural" and "urban" populations in Nigeria as well as explore the relationships between water quality, sanitary risks and spatial information such as population density. Using these data, the objectives of this study were: (i) to examine the influence of urban extent definition on water safety between rural and urban areas in Nigeria, (ii) to compare the frequency of thermotolerant coliform (TTC) contamination and prevalence of sanitary risks between rural and urban water sources of a given type and (iii) to investigate differences in exposure to contaminated drinking-water in rural and urban areas.

2. Materials and methods

2.1. Study area

The study was conducted in Nigeria, a country with a large difference in access to improved sources between rural and urban areas. In 2010, 74% of urban households had access to an improved source of drinking-water compared with 36% in rural areas (WHO/UNICEF, 2013b). Household surveys contemporary with the RADWQ study show that the main water sources used by households in Nigeria are boreholes and piped water in urban areas, and protected dug wells and unimproved sources in rural areas (WHO/UNICEF, 2013a). Federal regulation is strongest for utility piped water and in some instances is responsible for dug wells. Non-governmental organizations and individuals are responsible for construction of boreholes. The regulatory agency that is responsible for piped water and other sources is the Federal Ministry of Water Resources which develops state and local government steering committees on sanitation (Department of Water Supply and Quality Control, 2004).

2.2. Data sources

This analysis combines spatially referenced RADWQ survey data with two population density map layers, four urban map layers (see Table 2), and the UN 2005 urban population data (UN Department of Economic and Social Affairs Population Division, 2012) (Table 2).

Water quality and sanitary risk data are from the RADWQ Nigeria dataset containing 1768 analyses of microbial quality (TTC) collected using a portable Wagtech membrane filtration kit supplied by WHO/UNICEF and sanitary inspections as part of a stratified cluster survey of water safety in Nigeria (Ince et al., 2010). A further 73 replicate samples were tested as a quality control measure. Household water quality was assessed for a smaller number of sources (~10%, n = 160) and a single cluster (n = 31) was included to evaluate the quality of water from tanker trucks. Neither subset was a random sample. Sanitary risk was assessed using a standardized observational checklist of 10 contamination hazards at each source type (WHO, 2012). Hazards included proximity of onsite sanitation, animals and industry, as well as failings in a source's structural integrity (Ince et al., 2010). An overall sanitary risk score was calculated by summing the total number of hazards observed