Estimating the changing burden of disease attributable to unsafe water and lack of sanitation and hygiene in South Africa for 2000, 2006 and 2012

N Nannan,[1] MSc, PhD; **I Neethling,**[1,2] PhD; **A Cois,**[1,3] PhD; **R Laubscher,**[4] BComm (Maths); **E B Turawa,**[1] MSc; **R Pacella,**[2] PhD; **D Bradshaw,**[1,5] DPhil; **V Pillay-van Wyk,**[1] PhD

[1] *Burden of Disease Research Unit, South African Medical Research Council, Cape Town, South Africa*
[2] *Institute for Lifecourse Development, Faculty of Education, Health and Human Sciences, University of Greenwich, UK*
[3] *Division of Health Systems and Public Health, Department of Global Health, Faculty of Medicine and Health Sciences, Stellenbosch University, Cape Town, South Africa*
[4] *Biostatistics Unit, South African Medical Research Council, Cape Town, South Africa*
[5] *School of Public Health and Family Medicine, Faculty of Health Sciences, University of Cape Town, South Africa*

Corresponding author: *N Nannan (nadine.nannan@mrc.ac.za)*

Background. The incidence of diarrhoeal disease is closely linked to socioeconomic and environmental factors, household practices and access to health services. South African (SA) district health information and national survey data report wide variation in the incidence and prevalence of diarrhoeal episodes in children under 5 years of age. These differentials indicate potential for reducing the disease burden through improvements in provision of water and sanitation services and changes in hygiene behaviour.
Objectives. To estimate the burden of disease attributed to unsafe water, sanitation and hygiene (WASH) by province, sex and age group for SA in 2000, 2006 and 2012.
Methods. Comparative risk assessment methodology was used to estimate the disease burden attributable to an exposure by comparing the observed risk factor distribution with a theoretical lowest possible population distribution. The study adapts the original World Health Organization scenario-based approach for estimating diarrhoeal disease burden from unsafe WASH, by assigning different standards of household water and sanitation-specific geographical classification to capture SA living conditions in rural, urban and informal settlements.
Results. SA experienced an improvement in water and sanitation supply in eight of the nine provinces between 2001 and 2011, with the exception of Northern Cape Province. In 2011, 41% of South Africans lived with poor water and sanitation conditions; however, wide provincial inequalities exist. In 2012, it was estimated that 84.1% of all deaths due to diarrhoeal disease were attributable to unsafe WASH; this equates to 13 757 deaths (95% uncertainty interval (UI) 13 015 - 14 300). Of these diarrhoeal disease deaths, 48.2% occurred in children under 5 years of age, accounting for 13.9% of all deaths in this age group (95% UI 13.1 - 14.4). Between 2000 and 2012, the proportion of deaths attributable to diarrhoea reduced from 3.6% to 2.6%. Gauteng and Western Cape provinces experienced much lower WASH-attributable death rates than the more rural, poorer provinces.
Conclusion. Unsafe WASH remains an important risk factor for disease in SA, especially in children. High priority needs to be given to the provision of safe and sustainable sanitation and water facilities and promoting safe hygiene behaviours. The COVID-19 pandemic has reinforced the critical importance of clean water for preventing and containing disease.

S Afr Med J 2022;112(8b):729-736. https://doi.org/10.7196/SAMJ.2022.v112i8b.16498

The article in context

Evidence before this study. The first South African Comparative Risk Assessment (SACRA1) study estimated that the attributable burden due to unsafe water, sanitation and hygiene (WASH) ranked eleventh in terms of mortality and seventh in terms of disability-adjusted life years (DALYs) among 17 risk factors evaluated, and accounted for 2.4 - 2.7% of total deaths. The burden was especially high in children under 5 years of age, accounting for 9.3% of total deaths and 7.4% of disease burden.
Added value of this study. This study applied comparative risk assessment methodology adapted to the SA setting for three time points: 2000, 2006 and 2012. Two censuses and one large national survey were used to determine trends in diarrhoeal diseases attributed to unsafe WASH. The study demonstrates stark provincial inequalities in attributable burden, mediated through good v. poor water and sanitation supply and unequal improvement in water and sanitation supply across provinces over the study period.
Implications of the available evidence. High priority needs to be given to improving access to safe and sustainable sanitation and water supply, particularly in underserved urban and rural communities in SA. The high burden attributable to unsafe WASH, especially in children, provides a strong public health justification for prioritisation, as well as solid development, equity and human rights reasons for improving access and achieving the water-related Sustainable Development Goals (SDGs), which deal with the right to water and sanitation services for all. Policymakers need to pay attention to the promotion of handwashing with soap and other hygiene behaviours.

Unsafe water and lack of sanitation and hygiene affect health through multiple routes, of which faecal-oral transmission is considered a distinct risk factor in causing diarrhoeal disease, which remains an important cause of morbidity and mortality among SA children.[1,2] The incidence of diarrhoea, as reported in the district health information system among children under 5 years of age, was 95.9 episodes per 1 000 in 2011/2012, continuing a downward trend from a peak incidence in 2009.[3]

From another perspective, the series of SA demographic and health surveys (SADHSs) 1998,[4] 2003[5] and 2016[6] estimated that the prevalences measured by mothers reporting diarrhoeal episodes in children younger than 5 years (2 weeks prior to the survey) were 13%, 8% and 10%, respectively. Synergistically, diarrhoeal disease is a leading cause of malnutrition in children under 5, although a significant proportion of diarrhoeal disease can be prevented through safe drinking water, adequate sanitation and hygiene.

Globally, over half a million children under 5 years of age die annually owing to diarrhoeal disease,[7] and the World Health Organization (WHO) estimates that there are nearly 1.7 billion cases of childhood diarrhoeal disease every year.[7]

During the Millennium Development Goal period (1990 - 2015), deaths from diarrhoeal disease due to WASH were reduced by half, with the significant progress in water and sanitation provision playing a key role.[8] The target of SDG 6 is to ensure access to water and sanitation for all. The WHO notes as follows: 'While substantial progress has been made in increasing access to clean drinking water and sanitation, billions of people, mostly in rural areas still lack these basic services.'[9]

In the SA setting, access to adequate basic facilities is often linked to issues of human rights provided for in the Constitution and Bill of Rights, which state that 'The right to water and sanitation is a fundamental human right'.[10] In the era of the COVID-19 pandemic, the provision of clean water for safe handwashing has come into sharp focus and demonstrated the critical importance of sanitation, hygiene and adequate access to clean water for preventing and containing disease.

The first assessment to estimate the global disease burden from unsafe WASH was undertaken by Prüss *et al.*,[11] who considered various disease outcomes but principally diarrhoeal diseases. The risk factor was defined in terms of faecal-oral transmission of disease due to multiple factors, including ingestion of unsafe water, lack of water linked to inadequate hygiene, poor personal and domestic hygiene and agricultural practices, contact with unsafe water, and inadequate development and management of water resources or water systems. Access to water and sanitation was taken as a proxy for these factors and categorised into six scenarios of likelihood for faecal-oral transmission.

The SA assessment conducted by Lewin *et al.*[12] highlighted rural-urban and intra-urban differentials in access to safe WASH. We therefore investigated whether there are provincial differences. The objective was to estimate the burden of disease attributed to unsafe WASH by province, sex and age group for SA from 2000 to 2012.

Methods

Methods to assess the burden attributable to WASH build on the approach presented in Prüss *et al.*'s work,[11] which were further developed in the global estimate for 2000.[13] While SACRA1 adopted Prüss *et al.*'s (2002) method, the 2010 Global Burden of Diseases, Injuries and Risk Factors Study (GBD)[14] split the risk factor into the two dimensions of unsafe water and unsafe sanitation, and estimated their attributable burden separately using a new set of relative risks (RRs) based on systematic review of the literature. The GBD 2013[15] and GBD 2015[16] studies extended this approach by including exposure to handwashing. It is not possible to apply this approach in our analysis, as the first survey data related to handwashing were initially collected by the SADHS 2016.[4]

Therefore, we estimated the burden of diarrhoeal disease attributable to unsafe WASH using the method developed by Prüss *et al.*[11] Using this approach, the risk of diarrhoeal disease is conditioned by a typical exposure or a representative combination of risk factors at commonly encountered levels. Six scenarios based on the type of water and sanitation infrastructure and the load of faecal-oral pathogens in the environment are defined (Table 1).

- Scenario I: Ideal situation or theoretical minimum risk exposure level (TMREL), conferring lowest possible population risk for transmission, corresponding to the absence of transmission of diarrhoeal disease through WASH. The environmental faecal-oral pathogen load is very low in this scenario. It is assumed that the prevalence of this scenario is zero in all WHO regions, because even in the most developed regions cases of food poisoning occur.
- Scenario II: Typical in developed or high-income countries, this scenario has a low-to-medium faecal-oral load of pathogens in the environment. It is characterised by >98% coverage of improved water supply and sanitation and a regional incidence of diarrhoeal disease of <0.3/person/year.[17,18]
- Scenario III: This scenario is representative of various improved forms of provision that reduce risk of exposure compared with scenario IV; a transitionary scenario between high (scenario IV) and low (scenario II) environmental pathogen loads[11] (Table 1).
- Scenarios IV - VI: Representative of high faecal-oral pathogen environments typical in developing countries, this scenario is characterised by poor access to water and sanitation.

Relative risk estimates

RR estimates were based on reviews and large multi-country studies for areas with high faecal-oral pathogen loads in the environment (mostly developing countries). For the high faecal-oral pathogen group, Esrey's multi-country study[19] suggests that a mean reduction in diarrhoeal disease of 37.5% is possible following the introduction of improved water supply and sanitation in developing country environments.

The proportion of disease due to unsafe WASH in regions with low faecal-oral pathogen loads was based on analysing the relative importance of aetiological agents causing diarrhoeal diseases, supported by evidence from selected studies considered to be of high quality. A low faecal-oral pathogen load in the environment was assumed if sanitation coverage was >98%, corresponding to the situation in most developed countries. For the low faecal-oral pathogen group, data from the study by Mead *et al.*[20] suggest that in the USA the proportion of diarrhoeal illness attributable to food was ~35% (excluding those illnesses wholly transmitted by food). The global review therefore estimated that ~65% was attributable to unsafe WASH. A review by Huttly *et al.*[21] of epidemiological studies on hygiene practices in seven countries identified a median reduction of diarrhoea incidence of 35%.

The outcomes of diarrhoeal diseases are defined by ICD-10 codes A00 - A04, A06 - A09.

Exposure levels

Prevalence data and distribution of exposure were obtained from the SA censuses of 2001[22] and 2011[23] and the Community Survey 2007,[24] all reporting the main source of water supply and toilet facility in households. Due to the lack of geographical codes in the officially released 2007 Community Survey data, we merged GeoType (IBM Corp., USA) into the 2007 survey data set.

Based on these data, households were assigned to poor, intermediate or good access to water supply and sanitation facilities. These three categories of exposure were then merged with person data to yield individual exposure, and matched as best possible to the exposure scenarios (Table 1). Standard estimation techniques were used to recover the proportion of population in each exposure scenario, by province, sex and 5-year age groups (0 - 4, 5 - 9, ... ≥80 years), using the calibrated sampling weights provided with each data source to take into account the sampling design and realisation. The total population falling into each exposure category is shown in Tables S1 - S10 in the appendix (https://www.samedical.org/file/1815) for SA and each of the provinces.

Due to some population subgroups in SA not being entirely captured by the definition in scenario IV, we assigned different standards of household water and sanitation with specific geographical codes. For instance, taking the example of Census 2001 (Table 2), people in urban households with full sanitation coverage and good access to improved water supply (25.7%) were considered at low risk of diarrhoeal disease and therefore assigned to scenario II. The 21.7% of people in households with piped water and full sanitation, but in rural or urban informal settlements, were assigned to scenario IV, as were people in households with intermediate water and sanitation facilities. The residual 52.6% of people were placed in scenarios Va, Vb and VI.

Calculating the population-attributable fractions

Population-attributable fractions (PAFs) for diarrhoeal disease by age were calculated in Microsoft Excel (Microsoft Corp., USA) using the formula:

$$\text{PAF} = \frac{\sum_{i=1}^{k} p_i - (\text{RR}_i - 1)}{\sum_{i=1}^{k} p_i\,(RR_i - 1) + 1}$$

where p_i is the prevalence of exposure level i, RR_i is the RR of disease in exposure level i and k is the total number of exposure levels.

Calculating the attributable burden and uncertainty analysis

The PAFs were applied to the second South African National Burden of Disease Study (SANBD2) estimates for 2000, 2006 and 2012 (deaths, years of life lost (YLLs), years lived with disability (YLDs) and DALYs) for the single outcome of diarrhoeal disease.[25] The attributable age-standardised rates for deaths and DALYs were calculated by using the mid-year population estimates of the Centre for Actuarial Research[26] and the WHO standard population.[27]

The Monte Carlo simulation-modelling technique, implemented with Ersatz Version 1.3 for Microsoft Excel (Microsoft Corp., USA),[28] was used to estimate bounds of uncertainty around the point estimates. We drew 2 000 random samples from the distribution of the RRs, and repeated the calculation of the attributable burden.

Table 1. Scenarios categorising exposure for diarrhoeal disease*

Scenario	Description	Environmental faecal-oral pathogen load
VI	No improved water supply and no basic sanitation in a country not extensively covered by such services, and where water supply is not routinely controlled	Very high
Vb	Improved water supply and no basic sanitation in a country not extensively covered by such services, and where water supply is not routinely controlled	Very high
Va	Basic sanitation but no improved water supply in a country not extensively covered by such services, and where water supply is not routinely controlled	High
IV	Improved water supply and basic sanitation in a country not extensively covered by such services, and where water supply is not routinely controlled	High
IIIc	IV and improved access to drinking water (generally piped to household)	High
IIIb	IV and improved personal hygiene	High
IIIa	IV and drinking water disinfected at point of use	High
II	Regulated water supply and full sanitation coverage, with partial treatment of sewage, corresponding to a situation typically occurring in developed countries	Medium-low
I	Ideal situation, corresponding to the absence of transmission of diarrhoeal disease through WASH	Very low

WASH = water, sanitation and hygiene.
*Source: Prüss *et al.*[11]

Table 2. Relative risk estimates associated with exposure scenarios and distribution of population between the scenarios in South Africa for 2001, 2007 and 2011*

	Exposure scenario						
Estimates	I (TMREL)	II	III	IV	Va	Vb	VI
RR lower estimate	1	2.5	2.5	3.8	3.8	4.9	6.1
RR best estimate	1	2.5	4.5	6.9	6.9	8.7	11.0
RR upper estimate	1	2.5	4.9	10.0	10.0	12.6	16.0
RR standard error	0.00	0.00	0.26	0.25	0.25	0.24	0.25
% of persons assigned to each scenario: Census 2001 (SA 2000 estimates)	0	25.7	0	21.7	2.9	27.5	22.2
% of persons assigned to each scenario: Community Survey 2007 (SA 2006 estimates)	0	35.0	0	16.2	1.9	23.6	23.4
% of persons assigned to each scenario: Census 2011 (SA 2012 estimates)	0	38.6	0	19.0	1.5	25.5	15.5

TMREL = theoretical minimum risk exposure level; RR = relative risk; SA = South African.
*Adapted from Prüss-Üstün *et al.*[13]

We used the mean of the distribution of the replicates as the point estimate of the attributable burden, and the 2.5th and 97.5th percentiles as the bounds of the 95% uncertainty interval (UI). In drawing the samples, we assumed a modified log-normal distribution for the RRs, with means and standard deviations (SDs) from Table 2, and neglected the uncertainty associated with estimation of the exposure and the total burden.

Results

The distribution of the population into exposure scenarios by province during the three time periods is shown in Fig. 1. Increases in the proportion of the population with good water and sanitation supply occurred in all provinces. The Western Cape (70%) and Gauteng (63%) had the highest proportions, while Limpopo (9%) and North West (20%) provinces had the lowest proportions; nationally, 39% of people were exposed to good WASH in 2011. All provinces except the Northern Cape experienced improvements between 2001 and 2011 in exposure to poor water and sanitation supply; however, in five provinces in 2011, >50% of the population lived with poor water and sanitation supply. In 2011, 41% of South Africans lived with poor water and sanitation conditions.

PAFs, attributable deaths and DALYs for children and persons of all ages by period are shown in Table 3. For SA, the proportion of deaths attributable to diarrhoeal disease in children and all age groups has changed slightly over time. In 2000, 3.2% of deaths were attributable to unsafe WASH, declining to 2.6% in 2012. The burden was disproportionally higher in children, accounting for 13.2% and 13.9% of the total deaths in 2000 and 2012, respectively. In 2012,

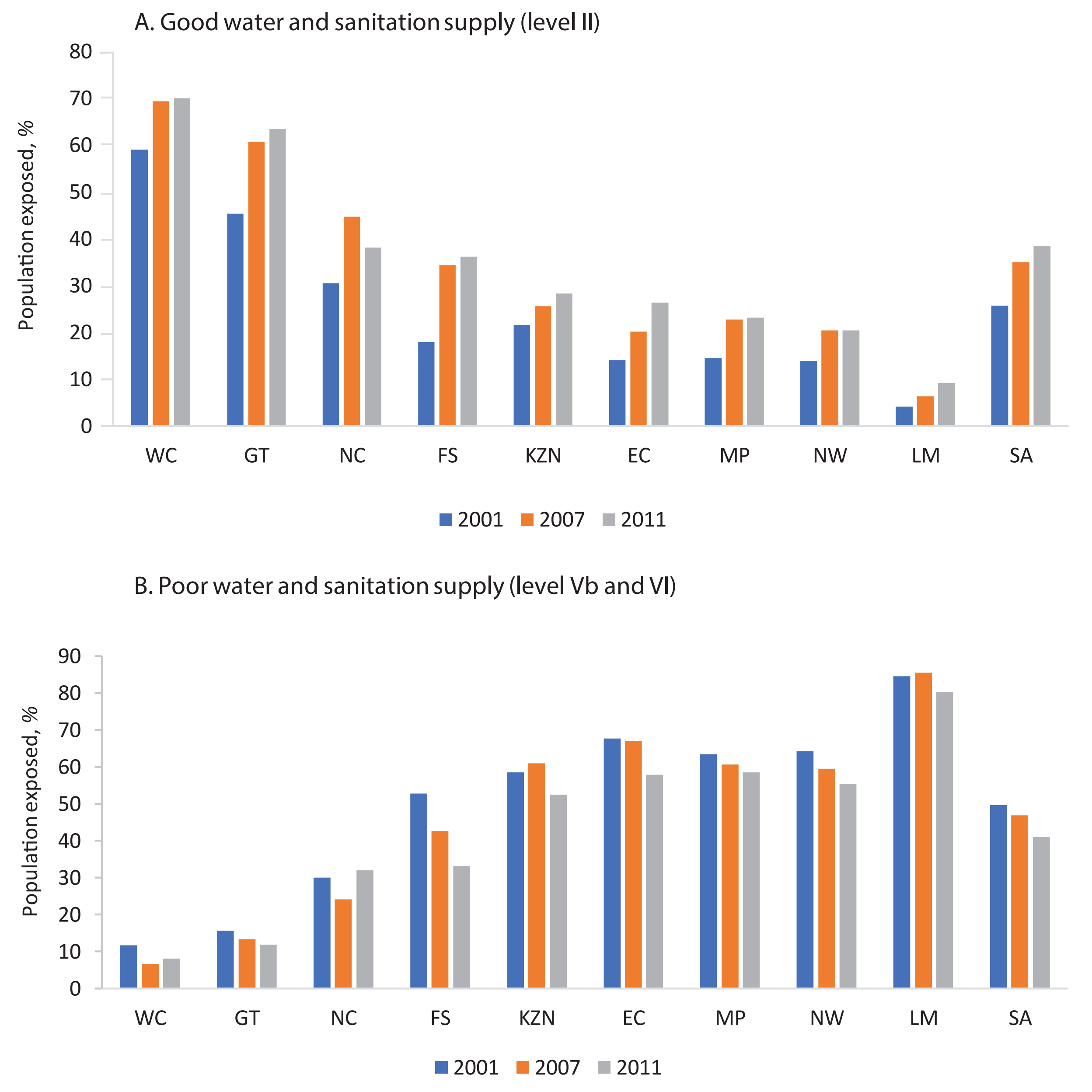

Fig. 1. Percentage population by province for 2001, 2007 and 2011, with (A) good (level II) and (B) poor (combined level Vb and VI) water and sanitation supply. (WC = Western Cape; GT = Gauteng; NC = Northern Cape; FS = Free State; KZN = KwaZulu-Natal; EC = Eastern Cape; MP = Mpumalanga; NW = North West; LM = Limpopo; SA = South Africa.)

Table 3. Burden of disease attributable to unsafe water and lack of hygiene and sanitation in children and adults in South Africa for 2000, 2006 and 2012

		Children <5 years		Males		Females		Persons	
Disease outcome	**AF, %***	**Deaths, *n***	**DALYs, *n***	**Deaths, *n***	**DALYs, *n***	**Deaths, *n***	**DALYs, *n***	**Deaths, *n***	**DALYs, *n***
2000									
Diarrhoeal disease (95% UI)	86.1	8 938 (8 483 - 9 272)	432 539 (410 477- 448 657)	7 833 (7 434 - 8 125)	296 836 (281 696 - 307 897)	8 125 (7 711 - 8 427)	290 273 (275 467 - 301 089)	15 958 (15 144 -16 553)	587 109 (557 164 - 608 986)
% of total child burden (95% UI)	-	**13.2 (12.5 - 13.6)**	**12.6 (11.9 - 13.1)**	-	-	-	-	-	-
% of total all-age burden (95% UI)	-	-	-	2.9 (2.8 - 3.0)	3.1 (2.9 - 3.2)	3.4 (3.2 - 3.5)	3.1 (2.9 - 3.2)	3.2 (3.0 - 3.3)	3.1 (2.9 - 3.2)
2006									
Diarrhoeal disease (95% UI)	85.2	9 113 (8 663 - 9 482)	441 329 (419 572 - 459 208)	7 911 (7 521 - 8 231)	292 200 (281 598 - 308 200)	8 439 (8 203 - 8 781)	301 091 (286 248 - 313 288)	16 350 (15 544 - 17 013)	597 291 (567 845 - 621 488)
% of total child burden (95% UI)	-	**11.2 (10.3 - 11.2)**	**10.8 (10.0 - 11.1)**	-	-	-	-	-	-
% of total all-age burden (95% UI)	-	-	-	2.3 (2.2 - 2.4)	2.4 (2.3 - 2.5)	2.5 (2.4 -2.6)	2.3 (2.2 -2.4)	2.4 (2.3 - 2.5)	2.4 (2.3 - 2.5)
2012									
Diarrhoeal disease (95% UI)	84.1	6 628 (6 271 - 6 890)	336 932 (318 750 - 350 215)	6 568 (6 214 - 6 827)	250 253 (236 748 - 260 119)	7 189 (6 801 - 7 473)	253 323 (239 652 - 263 309)	13 757 (13 015 - 14 300)	503 576 (476 401 - 523 428)
% of total child burden (95% UI)	-	**13.9 (13.1 - 14.4)**	**13.2 (12.5 - 13.7)**	-	-	-	-	-	-
% of total all-age burden (95% UI)	-	-	-	2.4 (2.2 - 2.5)	2.5 (2.3 - 2.6)	2.8 (2.7 - 3.0)	2.4 (2.3 - 2.5)	2.6 (2.5 - 2.7)	2.4 (2.3 - 2.5)

AF = attributable fraction based on the numbers of attributable deaths; DALY = disability-adjusted life year; UI = uncertainty interval.
*AF (%) reported for deaths.

it was estimated that 84.1% of all deaths due to diarrhoeal disease, or ~13 757 deaths, were attributable to unsafe WASH (95% UI 13 015 - 14 300). Of these diarrhoeal disease deaths, 48.2% (*n*=6 628) occurred in children, accounting for 13.9% of all deaths in this age group (95% UI 13.1 - 14.4). PAFs, attributable deaths and DALYs for children and persons of all ages by period are shown in Tables S11 - S19 in the appendix (https://www.samedical.org/file/1815) for each of the provinces.

The distinct pattern of burden, disproportionally affecting children and increasing at >60 years of age, is demonstrated in Fig. 2, showing DALYs by age group for 2000, 2006 and 2012. The drop in attributable DALYs between ages 0 - 4 years and ≥5 years is noteworthy and confirms a changing age pattern. Fig. 2 also provides further confirmation of wide geographical differences; Gauteng and the Western Cape have a lower attributable burden than the other provinces throughout the period of investigation. The ranking of provincial variation is approximately the same at both ends of the curves.

Provincial differences in age-standardised deaths attributable to unsafe WASH in 2000, 2006 and 2012 are shown in Fig. 3. The Western Cape and Northern Cape experienced most improvement (both −46%), followed by the Eastern Cape (−40%). North West (−10%) and Gauteng (−12%) experienced the lowest declines in diarrhoea-attributable deaths, whereas 3% more deaths occurred in Limpopo. Nationally there was a 25% reduction in diarrhoea-attributable deaths.

Discussion

This study found that in 2000, 3.2% of deaths were attributable to unsafe WASH, declining to 2.6% in 2012. The burden was especially high in children under the age of 5 years, accounting for 13.2% and 13.9% of the total deaths in this age group in 2000 and 2012, respectively (Table 2).

Furthermore, in 2012, child deaths from unsafe WASH demonstrate stark geographical inequalities, ranging from 21.6% in Mpumalanga Province to 6.4% in the Western Cape (not shown). The burden of diarrhoea attributable to unsafe WASH by age group (Fig. 2) shows a disproportionate burden affecting children, but also increasing in those aged >60 years. The GBD 2016 Diarrhoeal Disease Collaborators systematic review of burden between 1990 and 2016[29] established a decrease in diarrhoeal deaths in children and an increase in deaths at ages >70 years, highlighting the burden in the elderly as an increasing public health challenge requiring appropriate attention. The age-specific rates (Fig. 2) demonstrate a distinct geographical pattern, associated with poorer, more rural provinces.

A slight decline (3%) in prevalence of diarrhoeal disease in children from 1998 to 2016 (SADHS data[6]) is strongly aligned to the PAF hardly

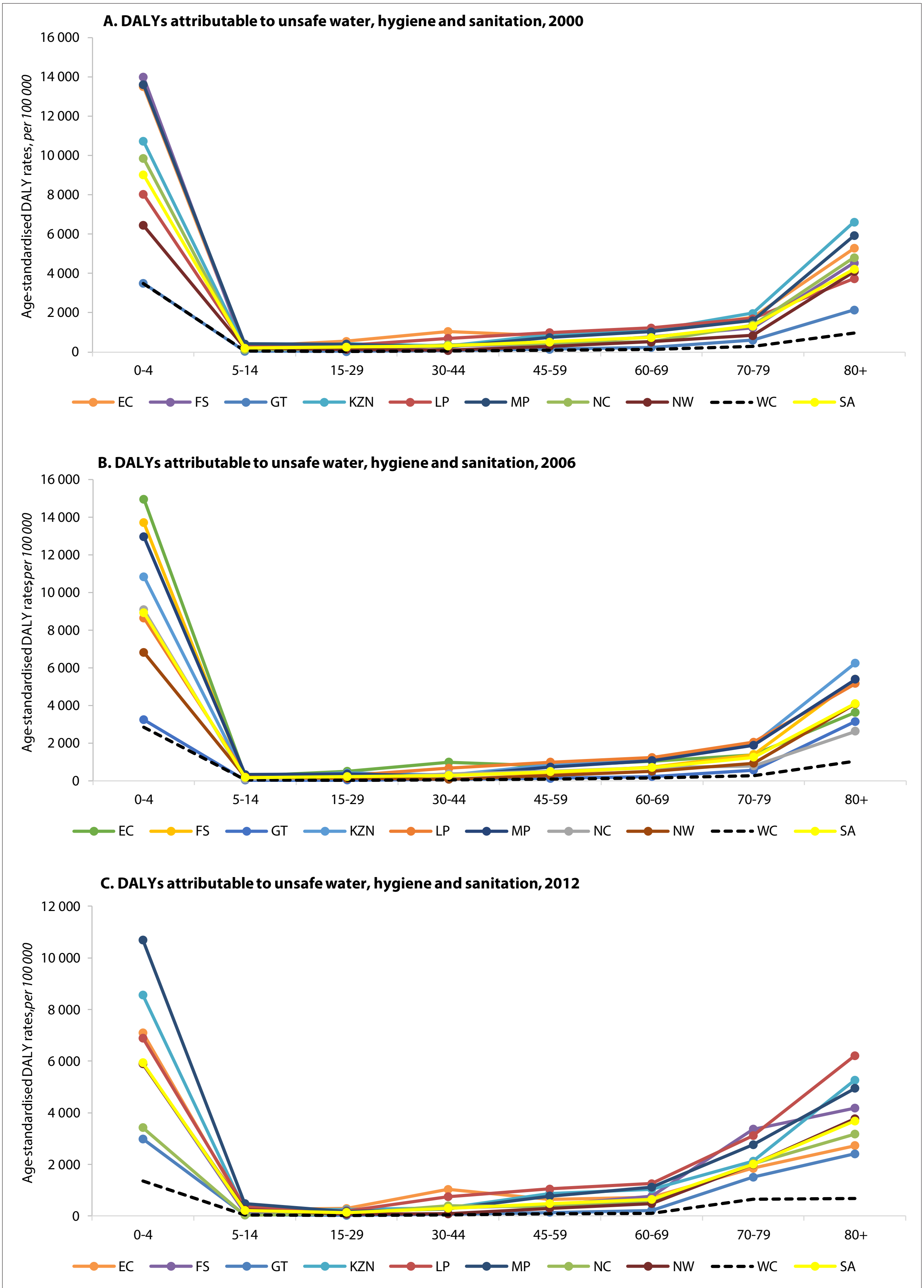

Fig. 2. DALYs attributable to unsafe WASH by age group and province, South Africa for (A) 2000, (B) 2006 and (C) 2012. (DALYs = disability-adjusted life years; WASH = water, sanitation and hygiene; WC =Western Cape; GT = Gauteng; NC = Northern Cape; FS = Free State; KZN = KwaZulu-Natal; EC = Eastern Cape; MP = Mpumalanga; NW = North West; LM = Limpopo; SA = South Africa.)

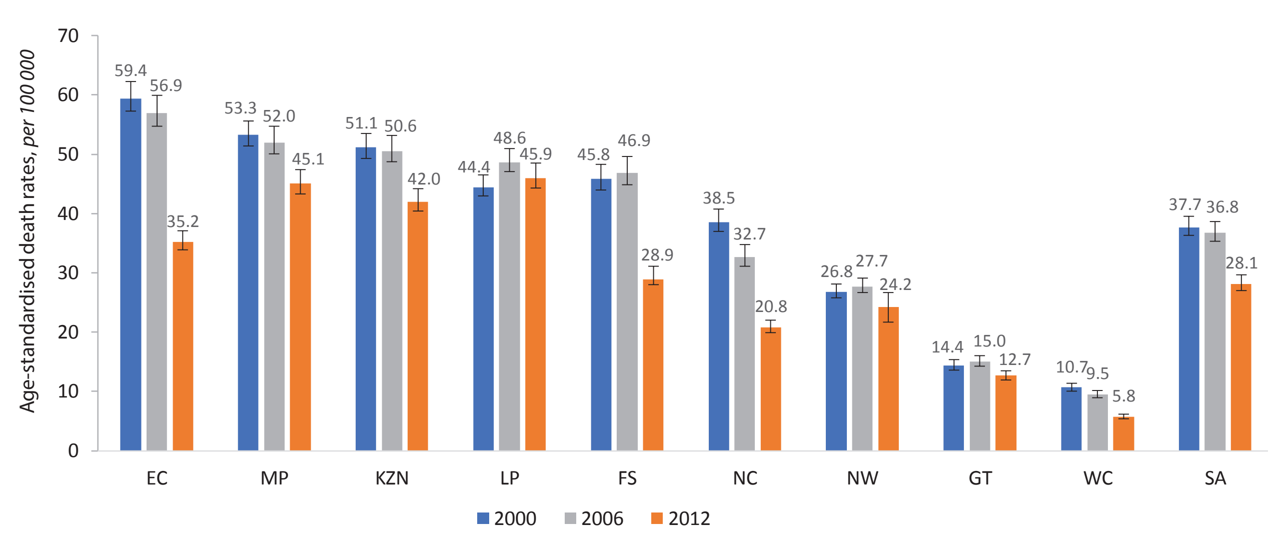

Fig. 3. Provincial change in diarrhoeal disease death rates attributable to unsafe WASH for 2000, 2006 and 2012. (WASH = water, sanitation and hygiene; WC = Western Cape; GT = Gauteng; NC = Northern Cape; FS = Free State; KZN = KwaZulu-Natal; EC = Eastern Cape; MP = Mpumalanga; NW = North West; LM = Limpopo; SA = South Africa.)

changing (86.1 - 84.1%) over the period of investigation (Table 3), indicating little change in exposure to improved water and sanitation facilities. Despite minimal improvement in the PAF, improvement in diarrhoea death rates attributable to unsafe WASH between 2000 and 2012 is evident, declining nationally by 25% (Fig. 3).

Rotavirus is the most common aetiology associated with mortality from diarrhoea at all ages.[30] Interventions to address the persistence of diarrhoeal disease as a major contributor to child mortality have shown some encouraging results from about 2010, coinciding with inclusion of the rotavirus vaccine in the expanded immunisation programme. Evaluation of the rotavirus vaccine programme in Soweto found a temporal association, with a decrease between 34% and 57% in the overall incidence of all-cause diarrhoeal hospitalisations in children under 5 years of age.[31] Despite this, diarrhoeal disease accounted for 16% of child deaths in 2012, the second largest proportion after HIV/AIDS,[2] perhaps indicating little change in the underlying causal pathways.

The method to assess unsafe WASH was extended to include exposure to handwashing since GBD 2013.[15] However, SA's first inclusion of handwashing-related questions was in SADHS 2016.[6] These survey results show that, overall, a place for handwashing was observed in 85% of households, although in 31% the place for handwashing was mobile and for 55% it was fixed. Among those households where place of handwashing was observed (rather than just reported by the respondent), 50% had soap and water, whereas 34% had only water and 14% had neither soap nor water. This is sobering in the era of the COVID-19 pandemic, when everyone worldwide has been reminded of the power of handwashing to mitigate infection.

Furthermore, in the SA context, there is a strong association between socioeconomic conditions and hygiene practice, where 67% of households have a fixed place for handwashing v. 28% of households in non-urban areas; and only 17% of households in the lowest wealth quintile v. 93% in the highest. Clearly more attention needs to be paid to the promotion of handwashing with soap, as well as other hygiene behaviours in lower socioeconomic areas.[6] As it is not yet clear how best to change hygiene behaviours in SA settings,[32] further rigorous research is needed. Water and sanitation infrastructure programmes need to include a strong hygiene behaviour component to ensure that maximum public health benefits are realised.

If access to improved WASH is to be realised for the sections of the population who most need it, government must address corruption in the water sector. In 2018, the auditor-general and Parliament's Standing Committee on Public Accounts reported that management of the National Department of Water and Sanitation had collapsed, with billions of rands of irregular expenditure, huge debts and failed projects. Many of these problems have been attributed to corruption. The report highlighted a number of cases to show the scale of systematic corruption across the sector, including how it has impacted on South Africans.[33]

Study limitations

This study has a number of limitations. First, since GBD 2013, a simpler risk factor model has been introduced to estimate the burden attributable to poor water supply and sanitation. While we consider a more detailed scenario model applicable in our setting, the multi-country studies for derivation of RR estimates were all conducted pre-2000, when conditions determining low and high faecal environmental content would have been different. According to assessment of the Millennium Development Goal targets and subsequent evaluations, there has been an improvement in the objectives.[8,29]

Second, the assignment of exposure as defined in the survey variables may not be appropriate; i.e. should households using pit latrines without ventilation be assessed as having poor or intermediate sanitation? In addition, although we attempted to capture intra-urban differences related to housing condition and location as best as possible, by further assignment to rural and urban-formal and informal settings, these may also not have been adequately captured.

Another point related to exposure is that this analysis cannot take into account interruptions in reliable water supply and delivery, although a recent report found that only 65% of South Africans have a reliable water supply.[33]

Third, we neglected the sampling error associated with the exposure estimates and the uncertainty in the burden estimated from the SANBD2 study on the basis that these were generated from national data bases and not samples.

Conclusion

Our study demonstrates that between 2000 and 2012, there were improvements in access to water and sanitation accompanied by a reduction in attributable deaths and DALYs due to diarrhoea in children and the rest of the population. Nonetheless, unsafe WASH remains an important risk factor for disease in SA, especially in children. The COVID-19 pandemic has reinforced the critical importance of clean water for preventing and containing disease, and high priority has to be given to the provision of safe and sustainable sanitation and water facilities and promoting safe hygiene behaviours.

Declaration. None.

Acknowledgements. Prof. Mike Muller and Simon Lewin are acknowledged for their valuable input when the study was initiated. Diego Iturralde and Statistics South Africa are thanked for providing the GeoType identifiers for the 2007 Community Survey. The CRA team, Rifqah Roomaney and Oluwatoyin Awotiwon, are thanked for checking the spreadsheets. The National Burden of Disease team, led by Victoria Pillay-van Wyk, was responsible for mapping the national burden of disease and GBD causes, generating YLDs and DALYs estimates for national, provincial and population groups. The following individuals are acknowledged for their contribution: William Msemburi, Oluwatoyin Awotiwon, Annibale Cois, Ian Neethling, Tracy Glass, Pam Groenewald and Debbie Bradshaw.

Author contributions. Conceived and designed the study: NN DB, RP. Analysed the data: NN, AC, RL, IN. Prepared the data for analysis: NN, IN, AC, RL, VPvW. Conducted the literature review: ET. Interrogated and interpreted the results: all authors. Drafted the manuscript: NN, DB. Critical review of the manuscript for important intellectual content: NN, RP, DB, AC. Senior authors: VPvW, DB, RP. All authors approved the final version before submission.

Funding. This research and the publication thereof were funded by the South African Medical Research Council's Flagships Awards Project (SAMRC-RFA-IFSP-01-2013/SA CRA 2). Debbie Bradshaw was the principal investigator (PI), together with Victoria Pillay-van Wyk and Jané Joubert (co-PIs).

Conflicts of interest. None.

1. Massyn N, Peer N, Padarath A, Barron P, Day C, eds. District Health Barometer 2014/15. Durban: Health Systems Trust, 2015.
2. Nannan N, Groenewald N, Pillay-van Wyk V, et al. Child mortality trends and causes of death in South Africa, 1997 - 2012, and the importance of a national burden of disease study. S Afr Med J 2019;109(7):480-485. https://doi.org/10.7196/samj.2019.v109i7.13717
3. Massyn N, Day C, Barron P, Haynes R, English R, Padarath A, eds. District Health Barometer 2011/12. Durban: Health Systems Trust, 2013.
4. National Department of Health, Medical Research Council, OrcMacro. South Africa Demographic and Health Survey 1998. Pretoria: NDoH, 2002.
5. National Department of Health, Medical Research Council, OrcMacro. South Africa Demographic and Health Survey 2003. Pretoria: NDoH, 2007.
6. National Department of Health, Statistics South Africa, South African Medical Research Council and ICF. South Africa Demographic and Health Survey 2016. Pretoria, South Africa and Rockville, USA: NDoH, Stats SA, SAMRC and ICF, 2019.
7. World Health Organization. Diarrhoeal disease. 2017. https://www.who.int/news-room/fact-sheets/detail/diarrhoeal-disease (accessed 19 May 2021).
8. World Health Organization. Water, sanitation and hygiene (WASH). https://www.who.int/health-topics/water-sanitation-and-hygiene-wash (accessed 3 February 2021).
9. United Nations. The Sustainable Development Goals Report 2020. https://sdgs.un.org/sites/default/files/2020-09/The-Sustainable-Development-Goals-Report-2020 (accessed 3 February 2021).
10. South African Human Rights Commission. Water and sanitation, revised pamphlet. 2018. https://www.sahrc.org.za/home/21/files/SAHRC%20Water%20and%20Sanitation%20revised%20pamphlet%2020%20March%202018.pdf (accessed 19 May 2021).
11. Prüss A, Kay D, Fewtrell L, Bartram J. Estimating the burden of disease from water, sanitation, and hygiene at a global level. Environ Health Perspect 2002;110(5):537-542. https://doi.org/10.1289/ehp.02110537
12. Lewin S, Norman R, Nannan N, Thomas E, Bradshaw D and the South African Comparative Risk Assessment Collaborating Group. Estimating the burden of disease attributable to unsafe water and lack of sanitation and hygiene in South Africa in 2000. S Afr Med J 2007;97(8):755-762. https://doi.org/10.1515/reveh.2010.25.2.87
13. Prüss-Üstün A, Kay D, Fewtrell L, Bartram J. Unsafe water, sanitation and hygiene. In: Ezzati M, Lopez A, Rogers A, Murray CJL, eds. Comparative Quantification of Health Risks: Global and Regional Burden of Disease Attributable to Selected Major Risk Factors. Geneva: World Health Organization, 2004:1321-1353.
14. Lim SS, Vos T, Flaxman AD, et al. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990 - 2010: A systematic analysis for the Global Burden of Disease Study 2010. Lancet 2012;380(9859):2224-2260. https://doi.org/10.1016/s0140-6736(12)61766-8
15. Global Burden of Disease 2013 Risk Factors Collaborators. Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks in 188 countries, 1990 - 2013: A systematic analysis for the Global Burden of Disease Study 2013. Lancet 2015;386(10010):2287-2323. https://doi.org/10.1016/S0140-6736(15)00128-2
16. Global Burden of Disease 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 2016;388(10053):1659-1724. https://doi.org/10.1038/sj.bdj.2015.751
17. Food Standards Agency. A Report of the Study of Infectious Intestinal Disease in England. London: HMSO, 2000.
18. Murray CJL, Lopez A, eds. Global Health Statistics: A Compendium of Incidence, Prevalence and Mortality Estimates for over 200 Conditions. Global Burden of Disease and Injury. Vol. 2. Cambridge, Mass: Harvard School of Public Health on behalf of the World Health Organization, 1996.
19. Esrey SA. Water, waste, and well-being: A multicountry study. Am J Epidemiol 1996;143(6):608-623. https://doi.org/10.1093/oxfordjournals.aje.a008791
20. Mead PS, Abdel-Moneim M, al-Erian RA, al-Amari OM. Food-related illness and death in the United States. Emerg Infect Dis 1999;5(5):607-625.
21. Huttly SRA, Morris SS, Pisani V. Prevention of diarrhoea in young children in developing countries. Bull World Health Organ 1997;75(2):163-174.
22. Statistics South Africa. Census 2001: Census in Brief. Pretoria: Stats SA, 2003.
23. Statistics South Africa. Census 2011 Statistical release – P0301.4. Pretoria: Stats SA, 2012.
24. Statistics South Africa. Community Survey, 2007 (revised version). Statistical release P0301. Pretoria: Stats SA, 2007.
25. Pillay-van Wyk V, Msemburi W, Laubscher R, et al. Mortality trends and differentials in South Africa from 1997 to 2012: Second National Burden of Disease Study. Lancet Glob Health 2016;4(9):e642-e653. https://doi.org/10.1016/S2214-109X(16)30113-9
26. Dorrington R. Alternative South African mid-year estimates, 2013. Cape Town: Centre for Actuarial Research, University of Cape Town, 2013.
27. Ahmad OB, Boschi-Pinto C, Lopez AD, et al. Age standardisation of rates: A new WHO standard. GPE Discussion Paper Series: No. 31 EIP/GPE/EBD. Geneva: World Health Organization, 2001.
28. Barendregt JJ. The effect size in uncertainty analysis. Value Health 2010;13(4):388-391. https://doi.org/10.1111/j.1524-4733.2009.00686
29. Troeger C, and the Global Burden of Disease 2016 Diarrhoeal Disease Collaborators. Estimates of the global, regional, and national morbidity, mortality, and aetiologies of diarrhoea in 195 countries: A systematic analysis for the Global Burden of Disease Study 2016. Lancet Infect Dis 2018;18(11):1211-1228. https://doi.org/10.1016/S1473-3099(18)30362-1
30. Colombara DV, Khalil IA-M, Rao PC, et al. Chronic health consequences of acute enteric infections in the developing world. Am J Gastroenterol 2016;3(Suppl):4-11. https://doi.org/10.1038/ajgsup.2016.9
31. Groome MJ, Zell ER, Solomon F, et al. Temporal association of rotavirus vaccine introduction and reduction in all-cause childhood diarrheal hospitalisations in South Africa. Clin Infect Dis 2016;62(Suppl 2):S188-S195. https://doi.org/10.1093/cid/civ1204
32. Jagals P, Nala NP, Tsubane TJ, Moabi M, Motaung KC. Measuring changes in water-related health and hygiene practices by developing-community households. Water Sci Technol 2004;50(1):91-97. https://doi.org/10.2166/wst.2004.0027
33. Muller M, Erasmus J. Money down the drain: Corruption in South Africa's water sector. Corruption Watch and the Water Integrity Network, 2020.

Accepted 4 March 2022.