Title:

A retrospective view on the viability of water fluoridation in South Africa to prevent dental caries

Key words:
Caries, Economics, Fluoridation, Prevention

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Abstract
Objectives: Despite a Commission of Inquiry into water fluoridation recommending the fluoridation of public water supplies to the optimal fluoride concentration of 0.7 ppm, as well as regulations for the introduction of water fluoridation which compel water providers to fluoridate public water supplies, no artificially fluoridated water scheme exists in South Africa. In view of concerns expressed by South African local authorities about cost and reports urging further investigation into the effectiveness of water fluoridation, the aim of this study was to determine whether water fluoridation is still a viable option to reduce dental caries in South Africa. *Methods:* A model based on a cost evaluation of 44 communities in Florida, United States and applied to South Africa was used as the basis for this study. Twenty-three input variables were used to create a computerized model which was populated with 2006 and 2011 data. Per capita cost, cost-effectiveness ratio and cost-benefit ratio were calculated as economic outputs to facilitate decision making for projected caries reductions of 15%, 30% and 50%. *Results:* The average per capita cost of water fluoridation for all category water providers combined is US$0.28 in 2006 and US$0.35 in 2011, an increase of 23.2% over this period. The average cost-effectiveness for all water providers combined varies from US$3.32 for a 50% to US$11.08 for a 15% caries reduction. Despite higher cost-effective values for some cities and towns, the cost per person per year to save one DMFT at a projected caries reduction of at least 15% as a result of the introduction of water fluoridation, is at least 48.4% less than the cost of a two surface restoration. The average cost-benefit for all water providers combined varies from 0.1 at a 50% to 0.34 at a 15% caries reduction. For both cost-effectiveness and cost-benefit ratio better results are achieved when the projected caries reduction increases. *Conclusions:* The results of this study show that water fluoridation is still a viable option to prevent dental caries in communities in South Africa along with the reduction in the prevalence of dental caries and increases in economically driven variables.

Introduction

Prior to 1996, the history of water fluoridation in South Africa can be categorised into three phases (1). During Phase 1 (1935-1968) the presence of fluorosis in children in high fluoride areas, delineation of areas of endemic fluorosis, recording levels of fluoride in different areas in South Africa and the observation of dental caries in these areas were reported (2-5). This led to a report by the Council for Scientific and Industrial Research (CSIR) which recommended the addition of fluoride to community water supplies as a preventive health measure to reduce dental caries (6). In view of the divergence of opinions between those who supported and those with objections to water fluoridation, a Commission of Inquiry was appointed by the State President. The report was overwhelmingly in favour of fluoridation of drinking water and recommended inter alia that local authorities should be encouraged, advised and assisted to fluoridate the water supplies of their communities as soon as possible (7). No action was however taken by the then government of the day to implement water fluoridation.

Phase 2 (1978-1989) was characterised by a number of reports and symposia (1). A publication on the views of the profession and the Department of Health triggered public debate from those opposed to water fluoridation (8). This prompted a National Symposium on Water Fluoridation which ended inconclusively with no clear mandate to government to implement water fluoridation (9). During this phase considerable research was conducted into the levels of fluoride in drinking water as well as research supported by the Medical Research Council (MRC) on alternative sources of fluoride (10-16).

Phase 3 (1990-1996) occurred during major political change in South Africa (1). Water fluoridation was discussed at a National Medical and Dental Association (NAMDA) workshop and another MRC symposium (17-18). The National Health Plan of the African National Congress (ANC) included water fluoridation as a primary health care measure (19). In the mid nineties, a number of journal articles also reported on the potential effectiveness of water fluoridation in South Africa (20-22). In 1995 the Ministry of Health’s Oral Health Committee recommended that government implement water fluoridation as part of its Reconstruction and Development Programme (23).

The Oral Health Committee set up a National Fluoridation Committee (NFC) to oversee the implementation of water fluoridation and to draft regulations for the fluoridation of water supplies. On 8 September 2000 the Minister of Health approved these regulations as part of Health Act No. 63 of 1977 which compelled every water supplier to initiate fluoridation unless exempted thereof (24). An advisory committee to the NFC, called the Joint Fluoridation Implementation Committee (JFIC), drafted criteria for the identification of “front runner sites” for the safe implementation of water fluoridation (25). Four coastal regions (Cape Town, Port Elizabeth, East London and Durban) were identified (26). A new Health Act (Act No. 61 of 2003) for South Africa necessitated an amendment to the regulations on fluoridating water supplies (27). Consultation on the amended regulations is ongoing and they are yet to be finalised and approved. Despite all the evidence in favour of water fluoridation, several recommendations and draft regulations to facilitate its implementation, no artificially fluoridated water scheme currently exists in South Africa.

A review of caries trends between 1953 and 2003 from several countries reports a decline in both fluoridated and non-fluoridated communities. These declines came to an end when low or very low levels of caries prevalence are reached. For the majority of industrialised countries this occurred during the mid-nineties (28). The reason for this decline could be attributed mainly to the introduction of fluoridated toothpaste in the early 1970's, but other fluoride-containing products are also considered to have contributed substantially. A more recent review of epidemiological data from several countries since 2000 expresses a concern about a possible increase in caries prevalence and emphasises that dental caries remains a serious health problem (29). This review also lists twenty-one countries from across the world who have not achieved the WHO goal of a DMFT of less than 3.0 for 12-year-olds post 1995. The authors call for a return to the basics of prevention to address this public health concern, which includes a renewed campaign for water fluoridation.

Both the United Kingdom's MRC and University of York reports into water fluoridation identified a need to extensively research the economic impact of water fluoridation, especially in times of exposure to other fluoride products (30-31). It is estimated that with current levels of dental caries community water fluoridation could reduce caries prevalence by an additional 15% (32).

In view of concerns expressed by South African local authorities about cost and reports urging further investigation into the effectiveness of water fluoridation, the aim of this study was to determine whether water fluoridation is still a viable option to reduce dental caries in South Africa taking into consideration fluctuations in economic variables over a four year period between 2006 and 2010.

Materials and Methods

A model based on a cost evaluation of 44 communities in Florida, United States (33) and applied to South Africa (34) was used as the basis for this study. Details of this model are presented in the Appendix.

Twenty-three input variables (Table 1) were used to create a computerized model which was populated with 2006 and 2011 data. Information on these variables was provided by water providers, municipalities, the chemical industry, South African Department of Water Affairs and Forestry and the 1999-2002 National Children's Oral Health Survey of South Africa (NCOHS) (35-36). Economic analysis requires a range of assumptions to be made for several of the input variables used in this study. These assumptions are listed in Table 1. Sixteen of the input variables relate to either chemical cost, labour cost, cost of maintenance of infrastructure, opportunity cost and capital depreciation. Operating cost was expressed as the sum of chemical cost, labour cost and maintenance cost. Total cost consists of the sum of operating cost, opportunity cost and capital depreciation. The remaining seven variables relate to the calculation of the economic outputs of this model.

The following economic outputs were calculated to facilitate decision making:

1. Per capita cost per year
2. Cost-effectiveness ratio: Cost per person per year to save 1 DMFT
3. Cost-benefit ratio: Cost of implementation of water fluoridation divided by the savings in cost of treatment. A program should be considered for implementation if cost-benefit is less than one.

Cost-effectiveness and cost-benefit ratios were calculated for projected caries reductions of 15%, 30% and 50%.

Water boards, cities and towns included in this study (Figure 1) were classified into three categories based on their total daily water purification rate: Category A: more than 700 Mega litre/day (Ml/d); Category B: less than 700 Ml/d, but more than 100 Ml/d; Category C: less than 100 Ml/d. The 2011 South African mid-year population estimates indicate the total population as 50.59 million people (37). Water purification plants managed by municipalities and water boards included in this study serve 27.08 million people. This represents 53.5% of the total population of South Africa.

For the purpose of this study fluoride levels of community water supplies for all municipalities and water boards were adjusted to 0.7 ppm (variable [3]) which is in line with the recommendation for the optimal fluoride concentration as published in the South African regulations for the fluoridation of water supplies (24).

Although this study was conducted based on South African data, results are presented in United States Dollars (US$). All resources and requirements for the implementation for water fluoridation in South Africa can be sourced locally with no need for any imports. To eliminate the impact of any fluctuation in the exchange rate on results the average exchange rate between the South Africa Rand (ZAR) and US$ over the five year period of the study (1 January 2006 to 31 December 2011) of ZAR 1 = US$ 0.1345 was used for the currency conversions in this study (38).

The average cost of a two surface restoration was calculated from the South African 2009 National Health Reference Price List (NHRPL) fee for a two surface amalgam (Variable [22]), anterior resin (Variable [23]) and posterior resin (Variable [24]) restoration (39). The

2009 fees were adjusted by 7.9% for 2010 and a further 6.3% for 2011. The average fee for a 2 surface restoration in 2011 amounted to $32.52.

Results

Per capita cost

Table 2 presents the per capita cost of water fluoridation for the population included in this study for 2006 and 2011 data. The average per capita cost of water fluoridation for all category water providers combined is $0.28 in 2006 and $0.35 in 2011, an increase of 23.2% over this period. For 2011 data the per capita cost ranges from $0.12 (Botshabelo) and $0.15 (Polokwane) at the lower end to $0.60 (Kimberley) and $0.63 (Mbombela) at the higher end. The average per capita cost is higher for Category A providers ($0.39) compared to Category B ($0.33) and Category C ($0.29) providers.

Cost-effectiveness ratio

Table 3 presents results for cost-effectiveness ratio for the total population for Category A, B and C water providers using 2011 data. As expected cost-effectiveness results are more favourable when the projected caries reduction increases. For the total population the average cost-effectiveness for all water providers combined varies from $3.32 for a 50% to $11.08 for a 15% caries reduction. When comparing different categories of water providers, it is slightly more cost-effective to introduce water fluoridation for Category C compared to Category A and B providers for all three projected levels of caries reduction. For individual providers cost-effectiveness ratio varies from $1.40 for a 50% caries reduction for Amatola Water to $16.78 for Mbombela for a 15% caries reduction. For Mbombela this is still 48.4% less than the average cost of a two surface restoration of $32.52.

Cost-benefit ratio

The average cost of $32.52 for a two surface restoration (Table 1) was used to calculate cost-benefit ratio. Table 4 presents results for cost-benefit ratio for Category A, B and C water providers for 2011 data. Similar to cost-effectiveness, cost-benefit ratio results are more favourable when the projected caries reduction increases. For the total population the average cost-benefit ratio for all water providers combined varies from 0.1 at a 50% to 0.34 at a 15% caries reduction. For all projected caries reductions cost-benefit ratio was similar for Category A, B and C water providers, although some degree of variation was noted between municipalities and water boards in each category. Cost-benefit ratio varies from 0.04 for two water providers (Amatola Water and Botshabelo) at a 50% caries reduction to 0.52 for Mbombela at a projected caries reduction of 15%. The lowest values at a 15% caries reduction are 0.14 for Amatola Water and 0.15 for Botshabelo while the highest values were found for Mbombela (0.52), Pietermaritzburg (0.49) and Polokwane (0.46).

Discussion

Water fluoridation is generally regarded as one of the ten greatest public health achievements of the 20th century (40). Before 1980 communities with fluoridated water supplies typically experienced 50% less dental caries compared to non-fluoridated communities during which time economic evaluations of water fluoridation revealed this measure to be highly cost-effective (41). Despite fluoride being available in various delivery systems, only 20% of the world's population benefits from an appropriate exposure to fluoride (42).

Caries prevalence for 12-year-old South African children declined from a mean DMFT of 1.73 in the 1988/89 National Oral Health Survey (NOHS) to 1.05 in the 1999-2002 NCOHS (43). These levels are considered to be very low to low according to the WHO classification (44). The 1999-2002 NCOHS report recommended that the implementation of water fluoridation be evaluated for South Africa taking into account current caries levels and the cost of water fluoridation (35).

Despite all this evidence in favour of water fluoridation and a Commission of Inquiry into water fluoridation recommending the fluoridation of public water supplies to the optimal fluoride concentration of 0.7 ppm (7), as well as regulations for the introduction of water fluoridation which compel water providers to fluoridate public water supplies (24), no artificially fluoridated water scheme exists in South Africa. This can mainly be ascribed to concerns raised by South African local authorities about costs and reports urging further investigation into the effectiveness of water fluoridation.

The model for this study to determine per capita cost, cost-effectiveness ratio and cost-benefit ratio of the implementation of water fluoridation for seventeen major metropolitan cities, towns and water boards from all nine South African provinces, serving 53.5% of the total population, was based on the principles described in previously published studies (33-34, 45).

Per capita cost for the population served by all water providers is $0.35 (Table 2). The highest per capita cost is $0.63 (Mbombela) and the lowest $0.12 (Botshabelo). Based on these results there can be no doubt that water fluoridation remains the cheapest fluoride vehicle to reach more than 50% of the South African population.

Although the actual cost of water fluoridation cannot and should not be ignored, estimates of saving in treatment cost may be more important than per capita cost. Health economists at the conclusion of a 1989 workshop in Michigan concluded that water fluoridation was one of only a few public health measures where it actually saved more money than it costs to operate (46).

As would be expected both cost-effectiveness ratio and cost-benefit ratio indicate more favourable results when the projected caries reduction increases. In this study results were calculated for 2011 data for projected caries reductions of 15%, 30% and 50% as a result of the introduction of water fluoridation. Water fluoridation is most effective in preventing dental caries on the interproximal, buccal and lingual surfaces with limited effect on occlusal surfaces (47). For this study it was estimated that a saving of one DMFT equalled the cost of a two surface restoration (45). The average cost to restore a two surface restoration at the time of this study is $32.52.

At a projected caries reduction of 15% cost-effectiveness ratio (expressed as the cost per person per year to save 1 DMFT) for all categories of water providers combined is $11.08 (Table 3). It is slightly more cost-effective to introduce water fluoridation for Category C ($10.42) compared to Category A ($11.74) and B ($10.86) providers. The highest cost-effectiveness ratio was calculated for Mbombela ($16.78). An estimated decrease in caries per child per year calculated from the DMFT increment per year and linked to the per capita cost of introducing water fluoridation are determining variables to calculate cost-effectiveness ratio. DMFT values for 15-year-olds, as reported in the 1999-2002 NCOHS (35-36) were used in this study. The combined effect of these two variables leading to a less favourable cost-effectiveness ratio can clearly be seen for Cape Town (DMFT for 15-year-olds of 4.05), Buffalo City and Amatola Water (both with a DMFT value of 2.01), and Botshabelo (DMFT of 1.53). Per capita cost for the introduction of water fluoridation is $0.36 for Cape Town, $0.16 for Amatola Water, $0.18 for Buffalo City and $0.12 for Botshabelo. The opposite is also true where a different combination of DMFT at age fifteen and per capita cost leads to a more favourable cost-effectiveness ratio for Mbombela (DMFT 2.25; $0.63), Pietermaritzburg (DMFT 1.26; $0.34) and Johannesburg (DMFT 1.81; $0.39).

Despite more favourable cost-effective ratio results for some cities and towns, the cost per person per year to save one DMFT for all municipalities and water boards, provided a caries reduction of at least 15% can be achieved as a result of the introduction of water fluoridation, is at least 48.4% less than the cost of a two surface restoration of $32.52.

Similar to cost-effectiveness ratio, cost-benefit ratio was also calculated for an anticipated caries reduction of 15%, 30% and 50% as a result of the introduction of water fluoridation. Should the cost-benefit ratio (expressed as the cost of implementing the procedure divided by the savings in the cost of treatment) approach one or be larger than one, the measure should not be considered.

At an anticipated caries reduction of 15%, the average cost-benefit ratio for all categories of water providers combined is 0.34 (Table 4) with little variation between the different categories of water providers. The lowest values were found for Amatola Water (0.14), while the highest value was found for Mbombela (0.52). The latter is still way below the benchmark cost-benefit ratio of 1 for any program to be implemented.

Similar to cost-effectiveness ratio an estimated decrease in DMFT per child per year calculated from the DMFT increment per year and linked to the per capita cost of introducing water fluoridation, are determining variables to calculate cost-benefit ratio. The same cities and towns with the lowest and highest cost-effectiveness therefore also present with the lowest and highest cost-benefit ratios. The results of this study indicate that if a caries reduction of at least 15% can be achieved through the introduction of water fluoridation, cost-benefit ratio does not exceed 0.52 for any municipality or water board included in this study.

One of the limitations of modelling is that assumptions need to be made. Assumptions for this study are listed in Table 1 and include the number of operators required per water plant, capital cost per Mega litre of water processed, assuming that the DMFT increment per year is identical for all ages and that the savings in cost of treatment as a result of the introduction of water fluoridation is considered to be equal to the average fee for a two surface restoration.

A further limitation is linked to cost-benefit analysis itself where an attempt should be made to express all costs and benefits linked to an intervention in monetary terms. This would then allow for a comparison between different programmes to assist in deciding which program resources should be allocated to. Due to the complexity of this certain immeasurable, intangible or indirect benefits are often ignored (48).

The benefits of water fluoridation in this model are only measured in terms of caries averted and many of the intangible benefits which are difficult to measure are not accounted for. Some of these are freedom from pain, a dentition free of any decay, improved occlusion, social acceptability, psychological value of retaining teeth, fewer unsightly restorations, less time missed from school or work and avoidance of extractions and operative procedures (48). Others include savings in the cost of dental treatment and saving in oral health workers' time or salaries as a result of less complex treatment required due to a delay in the progression of caries in the presence of fluoride. Health is almost impossible to express in monetary terms and this should always be kept in mind when the cost-benefit ratio of water fluoridation is used to argue in its favour, especially when immeasurable, intangible or indirect benefits are ignored.

It can also be argued that some of these benefits can be achieved through other means such as a well established and organised public dental service with an emphasis on primary preventive measures and early and minimal restorative intervention. Improved oral health for the South Africa population younger than 15, estimated to be 31.3% of the total population in 2011 (37), can unfortunately not rely on the latter as this will only be possible with huge expansions of the public oral health sector in South Africa.

Since cost-effectiveness analysis does not take into account the cost of intangible or indirect benefits it should be preferred in deciding among different options to prevent dental caries. When cost-benefit ratio is used as well the limitations associated with this analysis should be well understood.

The aim of this study was to determine whether water fluoridation is still a viable option to reduce dental caries in South Africa based on economic outputs such as per capita cost per year, cost-effectiveness and cost-benefit. Results confirm conclusions from several studies published over the last ten years that water fluoridation leads to significant cost savings and remains a cost-effective measure for reducing dental caries, even when the caries-preventive effectiveness is modest (49-53).

Despite worldwide fluctuations in caries prevalence, water fluoridation may still be a relevant public health measure in populations where oral hygiene conditions are poor, lifestyle habits result in high caries incidence and access to a well-functioning oral health care system is limited (54). The results of this study show that water fluoridation is still a viable option to prevent dental caries in communities in South Africa along with the reduction in the prevalence of dental caries and increases in economically driven variables.

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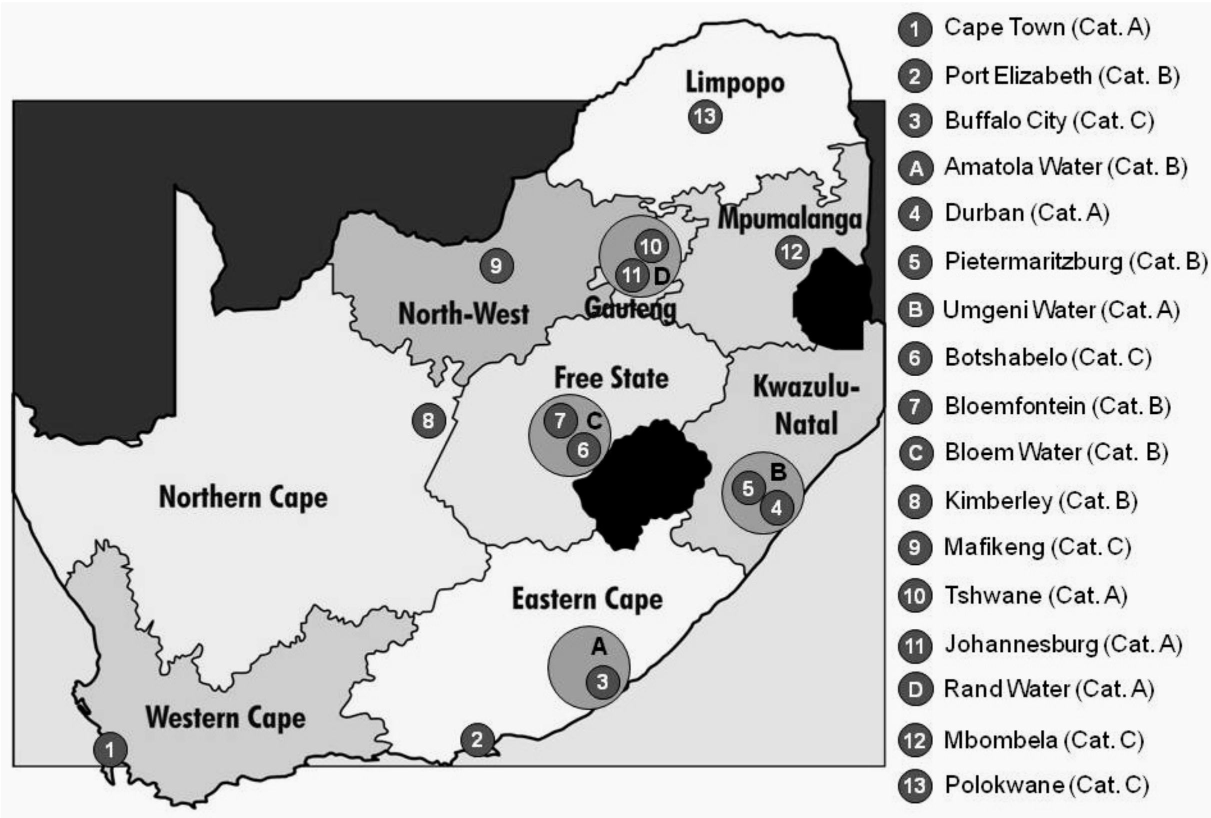

Fig. 1. Regions, cities and towns included in study

Table 1. Input variables, source of information and assumptions made

Input variable	Source of information	Assumptions
Chemical cost:		
[1] Daily water purification rate (litre per day)	Water providers	Fluorosilic acid is used as the chemical of choice since it is produced in South Africa, is relatively inexpensive, requires a simple dosing technique and it is suitability for both large and small water plants One company to handle and deliver the chemicals to all water providers, cities and towns
[2] Natural fluoride content of water (mg F per litre)	Grobler (55)	
[3] Adjustment of fluoride level to 0.7 mg F/litre	Regulations on fluoridating water supplies (24)	
[4] Cost of chemical (per metric tonne)	Pelchem	
[5] Percentage handling fee by agent	Süd-Chemie	
[6] Delivery cost (per metric tonne)	Süd-Chemie	
Labour cost:		
[7] Average operator salary	Water providers	The number of plant operators required is based on water purification rate of plant: >250 Ml/day: 4 operators 100-249 Ml/day: 3 operators 50-99 Ml/day: 2 operators <50 Ml/day: 1 operator
[8] Number of operators needed	Water providers	
[9] Number of hours needed per operator per day	Ringelberg (33)	
Maintenance cost:		
[10] Capital cost per Mega litre of water processed daily	Rand Water (56-57); Van Wyk (34)	The capital cost of buildings, storage, mechanical and electrical plant is based on a calculation for Rand Water and Gauteng Province, adjusted to Ml/day of water purified and Category A, B and C Water providers
[11] Percentage cost of buildings and storage	Category A: 21% Category B: 29% Category C: 36%	
[12] Percentage cost of mechanical and electrical plant	Category A: 79% Category B: 71% Category C: 64%	
[13] Maintenance as a % of capital cost	Ringelberg (33)	
Opportunity cost:		
[14] Prime Overdraft Rate of Banks	South African Reserve Bank (58)	
Capital depreciation:		

[15] Years for building and storage [16] Years for mechanical and electrical plant	Ringelberg (33) Van Wyk (34)	
Operating cost: Chemical cost + Labour cost + Maintenance cost		
Total cost: Opportunity cost + Capital depreciation + Operating cost		
Per Capita Cost:		
[17] Population served by water provider	Water providers	
Caries data:		
[18] DMFT [19] Age for DMFT score used	Department of Health (26); Van Wyk (36) As for input variable [18]	The DMFT increment per year is identical for all ages, mainly due to a lack of recent epidemiological data for the adult population
Cost-effectiveness ratio:		
[20] Anticipated percentage decrease in caries	Projected at 15%, 30% and 50%	
Cost-benefit ratio:		
[21] Cost of a two surface amalgam restoration [22] Cost of a two surface anterior resin restoration [23] Cost of a two surface posterior resin restoration	Council for Medical Schemes (39) and adjusted for 2010 and 2011	The savings in cost of treatment as a result of the introduction of water fluoridation was considered to be equal to the average fee for a two surface restoration
Average cost of a two surface restoration	Calculated from [21], [22], [23]	

Table 2. Per capita cost per year

	2006	2011
Cape Town	$0.30	$0.36
Umgeni Water	$0.37	$0.45
Durban	$0.36	$0.44
Rand Water	$0.28	$0.29
Johannesburg	$0.37	$0.39
Tshwane	$0.33	$0.35
Category A Average	**$0.34**	**$0.39**
Port Elizabeth	$0.29	$0.41
Amatola Water	$0.11	$0.16
Pietermaritzburg	$0.27	$0.34
Bloem Water	$0.17	$0.24
Bloemfontein	$0.18	$0.26
Kimberley	$0.55	$0.60
Category B Average	**$0.26**	**$0.33**
Buffalo City	$0.13	$0.18
Botshabelo	$0.08	$0.12
Mafikeng	$0.25	$0.39
Mbombela	$0.52	$0.63
Polokwane	$0.12	$0.15
Category C Average	**$0.22**	**$0.29**
Category A, B, C Average	**$0.28**	**$0.35**
% change from 2006		**23.2%**

Table 3. Cost-effectiveness ratio for 2011 data

	50% caries reduction	30% caries reduction	15% caries reduction
Cape Town	$1.58	$2.64	$5.27
Umgeni Water	$4.38	$7.30	$14.59
Durban	$4.07	$6.78	$13.55
Rand Water	$2.91	$4.85	$9.69
Johannesburg	$3.89	$6.49	$12.97
Tshwane	$3.48	$5.80	$11.59
Category A Average	**$3.52**	**$5.87**	**$11.74**
Port Elizabeth	$3.65	$6.08	$12.17
Amatola Water	$1.40	$2.34	$4.67
Pietermaritzburg	$4.81	$8.02	$16.05
Bloem Water	$2.86	$4.76	$9.53
Bloemfontein	$3.06	$5.09	$10.19
Kimberley	$3.77	$6.28	$12.57
Category B Average	**$3.26**	**$5.43**	**$10.86**
Buffalo City	$1.58	$2.63	$5.27
Botshabelo	$1.46	$2.43	$4.86
Mafikeng	$3.07	$5.12	$10.23
Mbombela	$5.03	$8.39	$16.78
Polokwane	$4.48	$7.47	$14.94
Category C Average	**$3.12**	**$5.21**	**$10.42**
Category A, B, C Average	**$3.32**	**$5.54**	**$11.08**

Table 4. Cost-benefit ratio for 2011 data

	50% caries reduction	30% caries reduction	15% caries reduction
Cape Town	0.05	0.08	0.16
Umgeni Water	0.13	0.22	0.45
Durban	0.13	0.21	0.42
Rand Water	0.09	0.15	0.30
Johannesburg	0.12	0.20	0.40
Tshwane	0.11	0.18	0.36
Category A Average	**0.11**	**0.18**	**0.36**
Port Elizabeth	0.11	0.19	0.37
Amatola Water	0.04	0.07	0.14
Pietermaritzburg	0.15	0.25	0.49
Bloem Water	0.09	0.15	0.29
Bloemfontein	0.09	0.16	0.31
Kimberley	0.12	0.19	0.39
Category B Average	**0.10**	**0.17**	**0.33**
Buffalo City	0.05	0.08	0.16
Botshabelo	0.04	0.07	0.15
Mafikeng	0.09	0.16	0.31
Mbombela	0.15	0.26	0.52
Polokwane	0.14	0.23	0.46
Category C Average	**0.10**	**0.16**	**0.32**
Category A, B, C Average	**0.10**	**0.17**	**0.34**

Appendix. A model to calculate total cost, per capita cost, cost-effectiveness ratio and cost-benefit ratio of the implementation of water fluoridation

Variable	Formula	Assumptions
Chemical cost:		
Chemical used % available fluoride % purity		
[1] Daily water purification rate (litre per day)		
[2] Natural fluoride content of water (mg F/litre)		
[3] Adjustment of fluoride level (mg F/litre) to:		
[4] Fluoride needed per day (metric tonne)	[1] x ([3] - [2]) / (1 x 10^9)	
[5] Fluoride needed per year (metric tonne)	[4] x 365	
[6] Chemical needed per year (metric tonne)	[5] / (% available fluoride x % purity)	
[7] Cost of chemical (per metric tonne)		
[8] Percentage handling fee by agent		
[9] Delivery cost (per metric tonne)		
[10] Total delivery cost of chemical	[7] + ([7] x [8] / 100) + [9]	
(A) Cost of chemical per year	[6] x [10]	
Labour cost:		
[11] Average operator salary		
[12] Number of operators needed		
[13] Annual operator salary for number of operators needed	[11] x [12]	
[14] Number of hours		1 hour per day

needed per operator per day		(or 8 hour shift) (33)
(B) Annual labour cost for number of hours needed per day	[13] / 8 x [14]	
Maintenance cost:		
[15] Capital cost per Mega litre of water processed daily		
[16] Percentage cost of buildings and storage		Expressed as a % of capital cost
[17] Cost of buildings and storage	[1] / 1,000,000 x [15] x [16] / 100	
[18] Percentage cost of mechanical and electrical plant		Expressed as a % of capital cost
[19] Cost of mechanical and electrical plant	[1] / 1,000,000 x [15] x [18] / 100	
[20] Total capital cost	[17] + [19]	
[21] Maintenance as a % of capital cost		2.4% (33)
(C) Maintenance cost	[20] x [21] / 100	
Opportunity cost:		
[22] Prime Overdraft Rate of Banks		Rate at which finances for capital cost would be obtained
(D) Opportunity cost as a percentage of total capital cost	[20] x [22] / 100	
Capital depreciation:		
[23] Years for building and storage		15 years (33)
[24] Capital depreciation of buildings and storage	[17] / [23]	
[25] Years for mechanical and electrical plant		8 years (34)
[26] Capital depreciation of mechanical and	[19] / [25]	

electrical plant **(E) Total capital depreciation per annum**	[24] + [26]	
Operating cost:		
(F) Operating Cost = Chemical cost + Labour cost + Maintenance cost	(A) + (B) + (C)	
Total cost:		
(G) Total cost = Opportunity cost + Capital depreciation + Operating cost	(D) + (E) + (F)	
Per Capita Cost:		
[27] Population served by water provider [28] **Per capita cost for total population**	 (G) / [27]	
Caries data:		
[29] DMFT [30] Age for DMFT score used [31] DMFT increment per year	 [29] / ([30] - 6)	It is assumed that the annual caries increment will be identical for all ages
Cost-effectiveness ratio: **(the cost per person per year to save 1 DMFT)**		
[32] Anticipated percentage decrease in dental caries [33] Decrease in DMFT per child per year **Cost-effectiveness ratio for total population**	 [32] / 100 x [31] [28] / [33]	
Cost-benefit ratio: **(the cost of the implementation of water fluoridation divided by the savings in cost of treatment)**		

[34] Cost of a two surface amalgam restoration **[35]** Cost of a two surface anterior resin restoration **[36]** Cost of a two surface posterior resin restoration **[37]** Average cost of a two surface restoration **Cost-benefit ratio for total population**	([34] + [35] + [36]) / 3 [28] / ([33] x [37])	It is assumed that the savings in cost of treatment as a result of the introduction of water fluoridation is equal to the average fee for a two surface restoration