Community Dental Health (2019) **36,** 214–220
Received 28 January 2019; Accepted 8 June 2019

doi:10.1922/CDH_4549Razafimamonjy07

Fluoride in drinking water in Madagascar and the development of a strategy for salt fluoridation

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Objective: To update current knowledge of the distribution of drinking water fluoride content in Madagascar, in an effort to develop a strategy for the distribution of fluoridated salt to prevent tooth decay. ***Basic research design:*** In accordance with a strict protocol, water samples were collected from all the country's 22 regions. Fluoride concentration in ppm fluoride (F) was determined by use of a F ion-selective electrode coupled with a pH/ion meter. ***Results:*** A total of 651 sources of drinking water were sampled, of which 94% were found to have fluoride concentrations ≤ 0.7 ppm. The two regions with the highest number of water supplies with fluoride concentrations > 0.7 ppm are situated in the south and south-west of Madagascar. 87% of thermal springs have fluoride levels > 0.7 ppm, with a mean value of 2.21 ± 1.64 ppm. ***Conclusions:*** These findings confirm that, with the exception of certain districts in the extreme south of Madagascar, fluoridated salt distribution would be appropriate for most regions in the country. This could be achieved by encouraging salt producers in the north and west of Madagascar, who are responsible for over 88% of national salt production, to fluoridate their salt. Most of this salt is distributed throughout the north and centre of the country, whereas very little is distributed to the extreme south.

Keyword: *Madagascar, fluoride, water, salt fluoridation, health policy*

Introduction

With a population close to 26 million, Madagascar rates as one of the ten poorest countries in the world, with 70% of its population living below the poverty line (World Bank, 2017, 2018). The prevalence of dental caries is high, affecting approximately 80% of 6 year-olds and 60% of 12 year-olds. By the age of 15 years, 90% of the country's inhabitants are affected, with this figure rising to 98% by the age of 35-44 years (Petersen, 2002). Access to dental care is extremely limited, due to the implicit cost and the shortage of oral health personnel. As a result, most decayed teeth are eventually lost.

Given the high levels of caries and the very limited health resources in Madagascar, efforts need to focus on prevention, in order to reduce caries to more manageable levels in the long term. In many countries, tooth brushing with fluoride toothpaste twice a day is the main method used to ensure the prevention of caries (FDI, 2018). However, in poorer countries and communities, fluoride toothpaste is often too expensive for the majority of the population (Goldman *et al*., 2008).

More economically accessible options for the prevention of dental caries are the fluoridation of water or salt, each having its advantages and disadvantages. Water fluoridation is used in some developed countries, where large urban populations have access to piped and treated water supplies. In Madagascar, as in many other poorer countries with a large rural population, this is not a viable solution since only 7% of the population has access to domestic water supplies (WHO / UNICEF, 2015). A more realistic and equitable option would be to implement salt fluoridation (Sampaio and Levy, 2011), given that Madagascar has several large-scale salt producers, thus making it largely self-sufficient in terms of the supply of salt (WHO, 2014a). In addition, salt fluoridation is relatively easy to implement, can be complementary to salt iodisation, and incurs a relatively small increase in production cost. Lastly, salt has the significant advantage of being consumed by the entire population, and of requiring a relatively simple distribution network (PAHO, 2005).

In Madagascar, salt iodisation has been mandatory since 1995, for the prevention and control of iodine deficiency disorders (IDD), including impaired cognitive development in children and goitre (Ministry of Health, 1995). Salt fluoridation, in combination with iodisation, was introduced in 2003 (WHO, 2014b). However, an assessment of the salt iodisation / fluoridation program, commissioned by the WHO in 2013, revealed that 84% of samples contained less than 10 ppm iodine (the standard concentration is 40-60 ppm) and 82% contained less than 3 ppm fluoride (standard concentration 250 ppm), which are well short of the levels required to effectively prevent IDD or caries (WHO, 2014b).

Based on two WHO reports (WHO, 2014a,b), the Ministry of Health published a decree making salt iodisation and fluoridation obligatory (Ministry of Health, 2014). As part of the re-launch of the salt iodisation / fluoridation program it was necessary to identify regions where the

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drinking water has naturally high levels of fluoride, for which the distribution of fluoridated salt could potentially lead to unacceptable levels of dental fluorosis. Although a national survey of fluoride in water was carried out in the 1990's, the methods used and the detailed results are no longer available (Petersen and Razanamihaja, 1996). In addition, the possibility of newly introduced and/or modified water supplies justified the revision and updating of the national map of fluoride concentrations in drinking water.

The aim of this study is thus to update the national mapping of the fluoride content in Madagascar's drinking water and to develop a strategy for the distribution of fluoridated salt, in an effort to maximise the prevention of dental caries and minimise the risk of unacceptable dental fluorosis.

Materials and Methods

Selection of sampling sites

Madagascar has 22 regions, which in turn are divided up into a total of 119 districts. In each district, the local authorities were contacted to identify all sources of water used by the population. Sampling took place in two localities in each district, one in the main town and one in a rural area. The criteria used to select a suitable rural locality were: a distance of at least 20 km from the main town, a water supply that was independent from that of the main town and accessibility by car. Additional samples were collected from known thermal springs, and from the three closest sources of water in the vicinity of these springs.

Collection of water samples

The samples were collected in 2016-2017, following a strict protocol, by teams from the Malagasy Ministry of Health, Aide Odontologique Internationale (AOI), and in some instances by trained government dentists.

Duplicate samples, with volumes ranging between 125 and 250 ml, were collected from each drinking-water source, in plastic containers labelled with an identity number, the date of collection and the name of the district. Photographs of the water source were taken, and the name of the locality, the type of source, as well as the regularity and periods of use during the year were recorded. Water supplies were classified according to five categories: surface water (lakes and rivers), natural springs, thermal springs, wells including boreholes, and piped water including standpipes. In the case of the latter, the water was allowed to run for approximately one minute, and the container rinsed two or three times prior to collection of the sample. For all other types of source, the samples were collected 20 to 30 cm below the surface, in order to avoid the collection of any sediment from the bottom.

Analysis of fluoride levels

One of the two samples taken from each water source was analysed in the laboratory of the "Service de la Nutrition" (SNUT) of the Madagascan Ministry of Health, by two technicians who had received training in fluoride analysis from an international expert. These analyses were carried out in batches, between two and four weeks after sampling. The fluoride concentration in each sample was determined by the use of a fluoride (F) ion-selective electrode (Orion 9609BNWP) coupled with a Thermo Scientific™ Orion Star™ A214 pH/ion meter. Serial dilution was used to prepare standard fluoride solutions of 0.1, 0.5, 1, 2, 10 ppm F^- from a stock solution of sodium fluoride (100 ppm F^-). A linear regression (calibration curve) of the fluoride standards was constructed by plotting electrode response against concentration, using Microsoft Excel™ Software. Each sample was mixed with an equal volume of TISAB II buffer solution and stirred. From the calibration curve, the electrode response obtained with each sample was then used to determine the corresponding fluoride concentration.

Independent control tests were made for ten of the duplicate water samples, drawn at random. These were submitted for fluoride concentration analysis, based on ionic chromatography, at the Lab'eau laboratory in Le Pecq, France.

Data entry and analysis

All of the data was recorded using Microsoft Excel™ software and analysed using R statistical software (R Foundation). All fluoride concentrations > 0.7 ppm were considered to be high.

Results

A total of 651 sources of drinking water were sampled in 222 towns, located in 111 districts, thus providing data from all of Madagascar's 22 regions (Figure 1). For reasons of security, it was not possible to sample the water in eight districts. The samples were taken from the following types of source: surface water, 116 samples (17.8%); springs, 96 (14.7%); thermal springs, 8 (1.2%); wells and boreholes, 248 (38.0%); and piped water including standpipes, 183 (28.1%). The category of one sample was not recorded.

The fluoride analyses undertaken with duplicate samples in the French and Malagasy laboratories revealed similar results. Two of the ten water samples submitted for duplicate analysis had fluoride levels > 0.7 ppm, but the difference between the results from the duplicate samples obtained with these two laboratories was < 0.2 ppm. The remaining eight samples were all found to have fluoride concentrations < 0.2 ppm, and all of the corresponding duplicate results were consistent, within differences in fluoride concentration not more than 0.1 ppm.

Throughout Madagascar, 94% of the sampled water sources were found to have fluoride levels ≤ 0.7 ppm (Table 1). Only 6% (N=37) had fluoride levels > 0.7 ppm, of which six are either infrequently used, or are not used for drinking water at all.

The two regions with the highest numbers of water sources with fluoride levels > 0.7 ppm were located in the south and south-west of Madagascar, namely Androy and Atsimo Andrefana, with respectively 9 and 11 sources (corresponding to 43% and 18% of the sources tested in each of these regions). In the region of Androy, the water from 8 of the 9 sources was frequently consumed, with 5 sources being located in the district of Bekily (Figure 1).

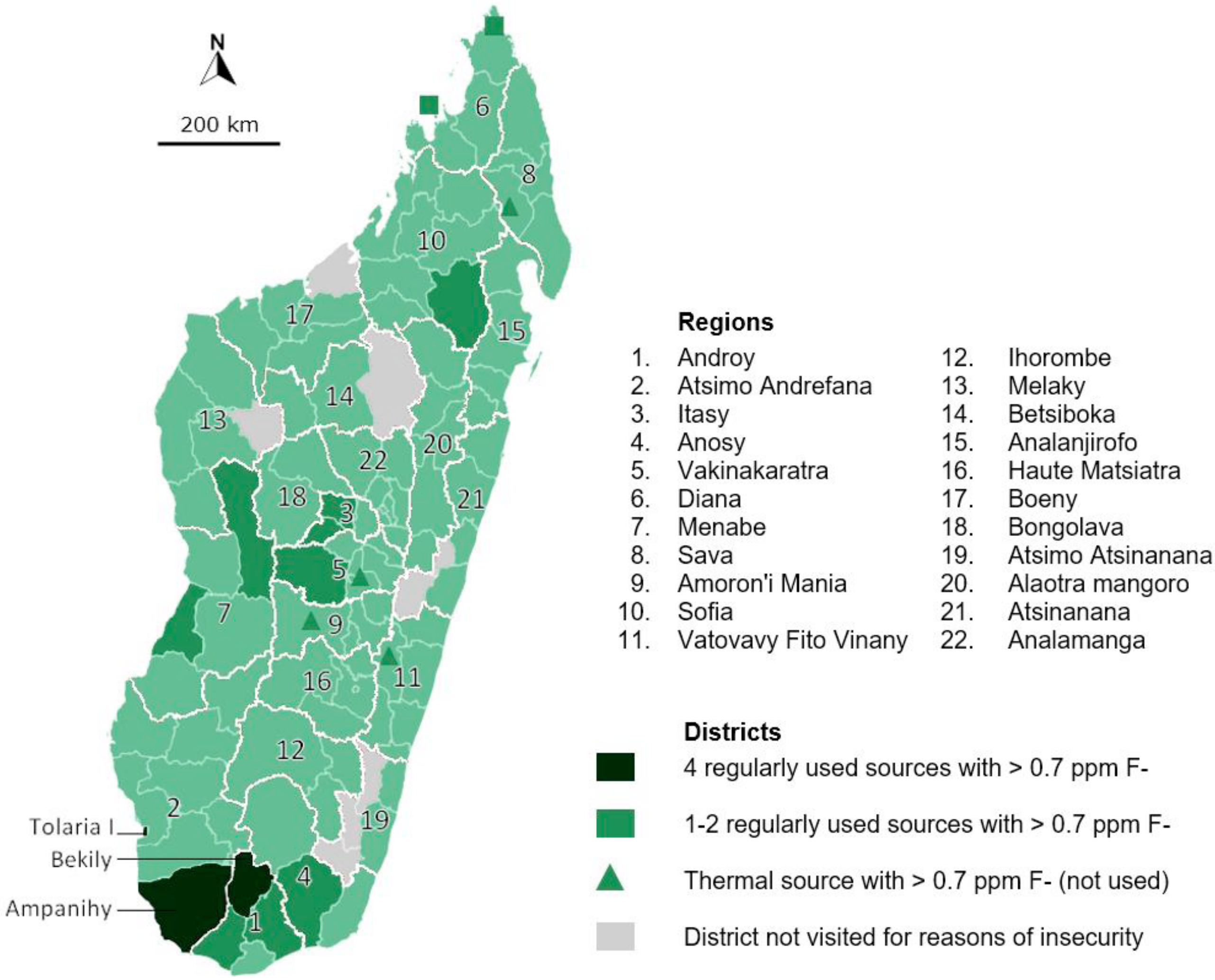

Figure 1. Distribution of water sources with fluoride concentrations > 0.7 ppm across Madagascar's 22 regions

Table 1. Distribution of fluoride concentrations of water sources per region, with regions ranked according to severity.

		Fluoride levels (ppm) (%)					
	Regions	*No. sources*	*0.00–0.35*	*0.36–0.70*	*0.71–1.05*	*1.06–1.40*	*≥ 1.41*
1.	Androy	21	29	29	24	5	14
2.	Atsimo Andrefana	62	61	21	3	5	10
3.	Itasy	21	81	5	5	10	
4.	Anosy	16	63	25	13		
5.	Vakinakaratra	35	89		3	3	6
6.	Diana	40	63	33	3		3
7.	Menabe	38	82	13	3		3
8.	Sava	33	94	3			3
9.	Amoron'i Mania	31	97				3
10.	Sofia	40	90	8	3		
11.	Vatovavy Fito Vinany	43	98				2
12.	Ihorombe	14	79	21			
13.	Melaky	14	79	21			
14.	Betsiboka	8	88	13			
15.	Analanjirofo	35	94	6			
16.	Haute Matsiatra	42	95	5			
17.	Boeny	26	96	4			
18.	Bongolava	13	100				
19.	Atsimo Atsinanana	14	100				
20.	Alaotra mangoro	19	100				
21.	Atsinanana	30	100				
22.	Analamanga	56	100				
	Total	651	85	9	2	1	3

In Atsimo Andrefana, fluoride concentrations in excess of 0.7 ppm were found in only two, non-adjacent districts: Toliara I (N=4) and Ampanihy (N=7). The water from these sources was consumed regularly. The regions of Androy and Atsimo Andrefana account for more than half of all Madagascan sources with fluoride levels > 0.7 ppm; the sources located in other regions are clustered in a small number of districts in the centre-west and north of the country.

Nationwide, the following mean values of fluoride concentration were found: 0.18 ± 0.23 ppm in surface water; 0.07 ± 0.14 ppm in natural springs; 0.19 ± 0.35 ppm in wells and boreholes; and 0.15 ± 0.34 ppm in standpipes and piped water. Almost all thermal springs had fluoride levels > 0.7 ppm, with a mean value of 2.21 ± 1.64 ppm. The highest fluoride concentration in the country was 5.4 ppm, observed in a single thermal spring in the Andapa district of the Sava region. In the Vakinankaratra region, situated in the centre of the country, all samples with fluoride levels higher than 0.7 ppm (12%, n=4) were from thermal springs located in the districts of Antsirabe and Betafo.

The box and whisker plot of fluoride levels (Figure 2), according to water source, shows that for the thermal springs, the median was 2.19 ppm F (range 0.08 to 5.4 ppm F). The other types of water source had a low median fluoride levels with few outliers that exceeded 0.7 ppm F.

Thermal springs are not often used for drinking water, since alternative sources are preferred by the population. One exception was found in the Betafo district of the Vakinankaratra region, where two thermal springs with high fluoride concentrations (2.86 and 2.99 ppm) are regularly used for drinking water.

Discussion

This present investigation was instigated following the findings of a WHO-commissioned study, which reported that existing salt iodisation and fluoridation programs in Madagascar did not meet the required standards for iodine and fluoride (WHO, 2014b). The finding concerning iodine was corroborated by a 2013 UNICEF survey (UNICEF, 2017) showing that the Malagasy population experienced a moderate degree of iodine deficiency, associated with a very low iodised salt coverage (21.3%). In view of these results, an integrated strategy for salt iodisation and fluoridation was launched by the Madagascan Ministry of Health. The present study of fluoride levels in drinking water was thus considered to be an essential step, needed to identify regions in the country where high natural levels of fluoride in drinking water might lead to unacceptable levels of dental fluorosis, if fluoridated salt was also consumed.

Despite the complexity of undertaking a study of this magnitude, in a country as large as Madagascar, which is affected by an often poorly maintained network of roads and problems of insecurity, samples of drinking water were collected from all regions and almost all districts of the country. The districts where sampling was not possible were generally sparsely populated, and represented less than 4% of the total population. The results of this study can therefore be considered to provide an excellent representation of national levels of fluoride concentration in drinking water, which can be used for the planning of distribution networks for fluoridated and iodised salt.

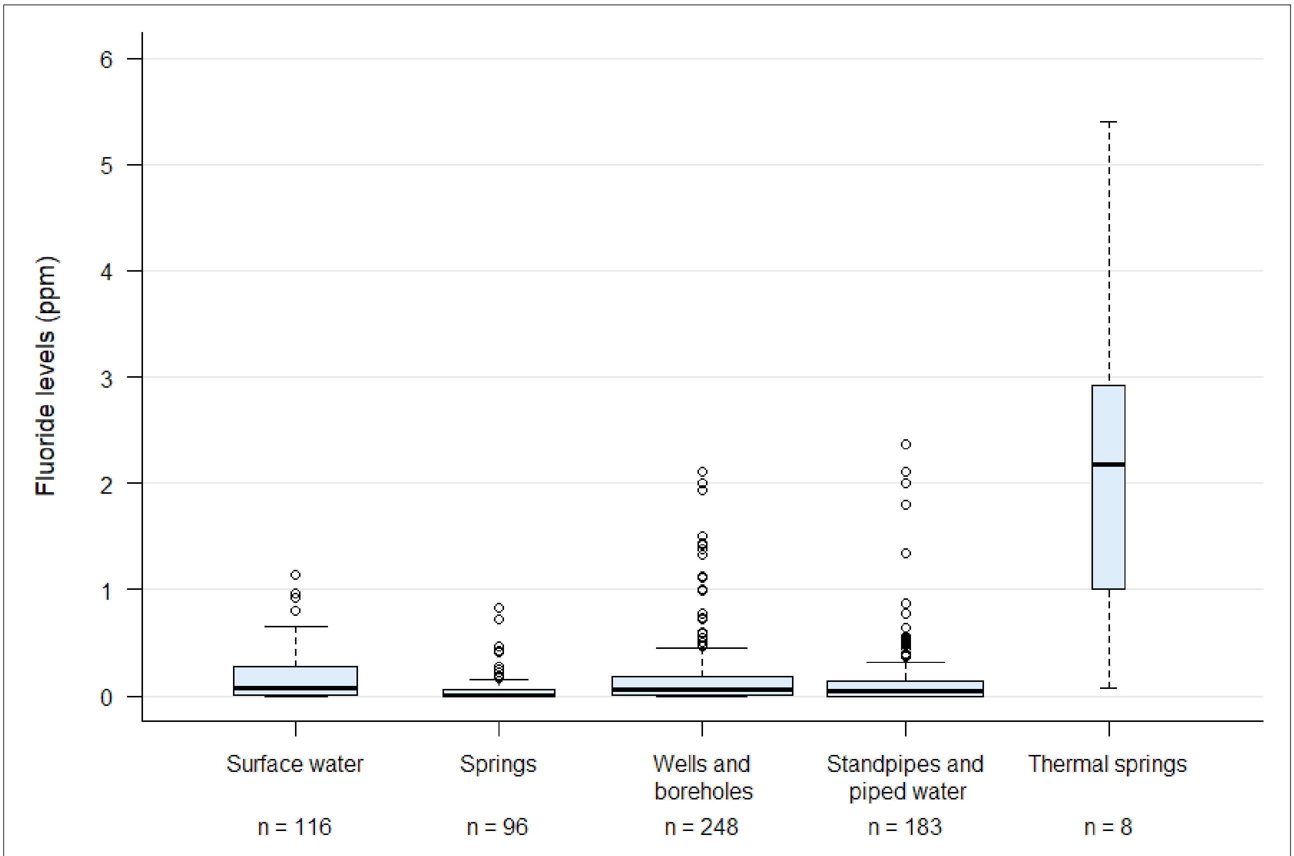

Figure 2. Fluoride levels, according to type of water source

The fluoride concentrations in drinking water were measured locally, using a fluoride ion-selective electrode. This is a proven, reliable, and low-cost method, which is well-adapted to the conditions encountered in Madagascar (Fawell *et al*., 2006). Several technicians from the local governmental nutrition laboratory (SNUT) followed a dedicated training course, providing them with the skills needed to implement the water sample analyses. Although the sample duplicates analysed in France relied on the use of ion chromatography, rather than a fluoride ion-selective electrode, both techniques produced very similar results, confirming the accuracy of the local SNUT analyses. In addition, the results of the present study are largely consistent with the rather limited results derived from analyses carried out by Petersen and Razanamihaja (1996).

The drinking water fluoride concentrations that can lead to undesirable levels of fluorosis tend to vary between countries and regions. In countries with warm climates, such as Madagascar, individual water consumption is usually higher than in countries with a temperate climate (Fawell *et al*., 2006). According to the Galagan and Vermillion (1957) formula, which is widely used to determine the optimal concentration of fluoride in water as a function of temperature, 0.7 ppm provides maximum protection, with a minimal risk of fluorosis, when the maximum average temperature exceeds 26°C. This is the case in certain regions of Madagascar. However, this value must be adapted, whenever there are other potential sources of fluoride, such as the inadvertent ingestion of fluoride toothpaste by young children (Cochran *et al*., 2004). In the absence of fluorosis data for Madagascar, and since fluoride toothpaste is rarely used in this country, water fluoride concentrations > 0.7 ppm were considered to be high, potentially predisposing the population to an increased risk of unacceptable fluorosis.

Our study has confirmed that the proportion of water sources with fluoride concentrations > 0.7 ppm is low (6%). The sources with high concentrations were located mainly in the extreme south (Figure 1). The inhabitants of the Bekily, Toliara I and Ampanihy districts, in the regions of Androy, Atsimo Andrefana and Anosy, respectively, are the populations most exposed to relatively high levels of fluoride in drinking water. These inhabitants would be at a higher risk of undesirable levels of dental fluorosis if fluoridated salt were to be consumed in their districts. However, it would be relatively straightforward to restrict the sale and use of fluoridated salt in these areas (Figure 3), since most of their salt consumption originates from local, small-scale producers. In practice, for technical reasons related to production and quality control it is difficult for these producers to iodise and fluoridate their salt. In Mexico, where salt fluoridation has been used as a public health measure since 1991 (Casanova-Rosado *et al*., 2013), the sale of fluoridated salt is restricted to regions with low levels of fluoride in the local drinking water.

In the case of Madagascar, it is interesting to note that salt producers in the north and west of the country are responsible for 88% of national salt production (WHO, 2014a,b). Most of this salt is distributed in the north and the centre, with very little is distributed to the extreme south (Figure 3). Furthermore, two of the major salt producers in Madagascar already have the capacity to iodise and fluoridate their salt to specified standards and to ensure quality control.

As there are relatively few districts in the north and centre with water fluoride levels > 0.7 ppm, one obvious approach would be to distribute fluoridated and iodised salt everywhere in the country, except in the extreme south. As a further step to limit dental fluorosis, local populations, especially children younger than 6 years, should be advised not to drink water from the few sources identified as having naturally high levels of fluoride. Although thermal springs are not commonly used for drinking water, alternative sources of water would need to be identified in the Betafo district of the Vakinankaratra region, where two thermal springs with high fluoride concentrations are currently used for drinking water.

In conclusion, assessment of the fluoride concentrations in Madagascar's drinking water has allowed a strategy to be developed for the distribution of fluoridated salt, with the aim of maximising the prevention of dental caries and minimizing the risk of unacceptable dental fluorosis in the country's population. The distribution of fluoridated salt would be appropriate for most of the country, with the exception of certain districts in the extreme south.

Recommendations

When re-launching the fluoridated and iodised salt program in Madagascar, considerable effort should be focused on the large and middle-sized salt manufacturers in the north and west of the country, since they already have the capacity to produce iodised and fluoridated salt that complies with the current standards, their salt is consumed by more than 80% of the population, and is distributed predominantly in regions of the country where the concentrations of fluoride in the drinking water are generally ≤ 0.7 ppm.

The distribution of fluoridated salt to regions in the south, where the drinking water fluoride concentration is > 0.7 ppm, should be avoided until any future study demonstrates the level of fluoride in drinking water that would lead to undesirable levels of fluorosis. This approach could be combined with the collection of baseline data on caries and fluorosis before the reinstatement of the fluoridated and iodised salt program.

In districts where drinking water sources have a fluoride concentration > 0.7 ppm, the local population, especially children under the age of 6, should be advised to use other sources of drinking water. When this approach is not feasible or is not heeded, de-fluoridation should be considered.

Acknowledgements

The authors wish to thank all of those who contributed to the realisation of this study, especially those who took part in the collection of water samples in the numerous districts throughout Madagascar. They also extend their gratitude to those who performed the laboratory analyses of the water samples, in particular: Dr Maminirina Fidelis Andrianomenjanahary, Department of Eyes, Hearing and Oral Health (SSOABD) and M. Delphin Rakotonirina, Department of Nutrition (SNUT), Ministry of Public Health, Madagascar.

Declarations

Consent for publication

All authors have approved the final version for its publication.

Competing interests

The authors declare that they have no competing interests.

Funding

Funding for this research was provided by the French Development Agency.

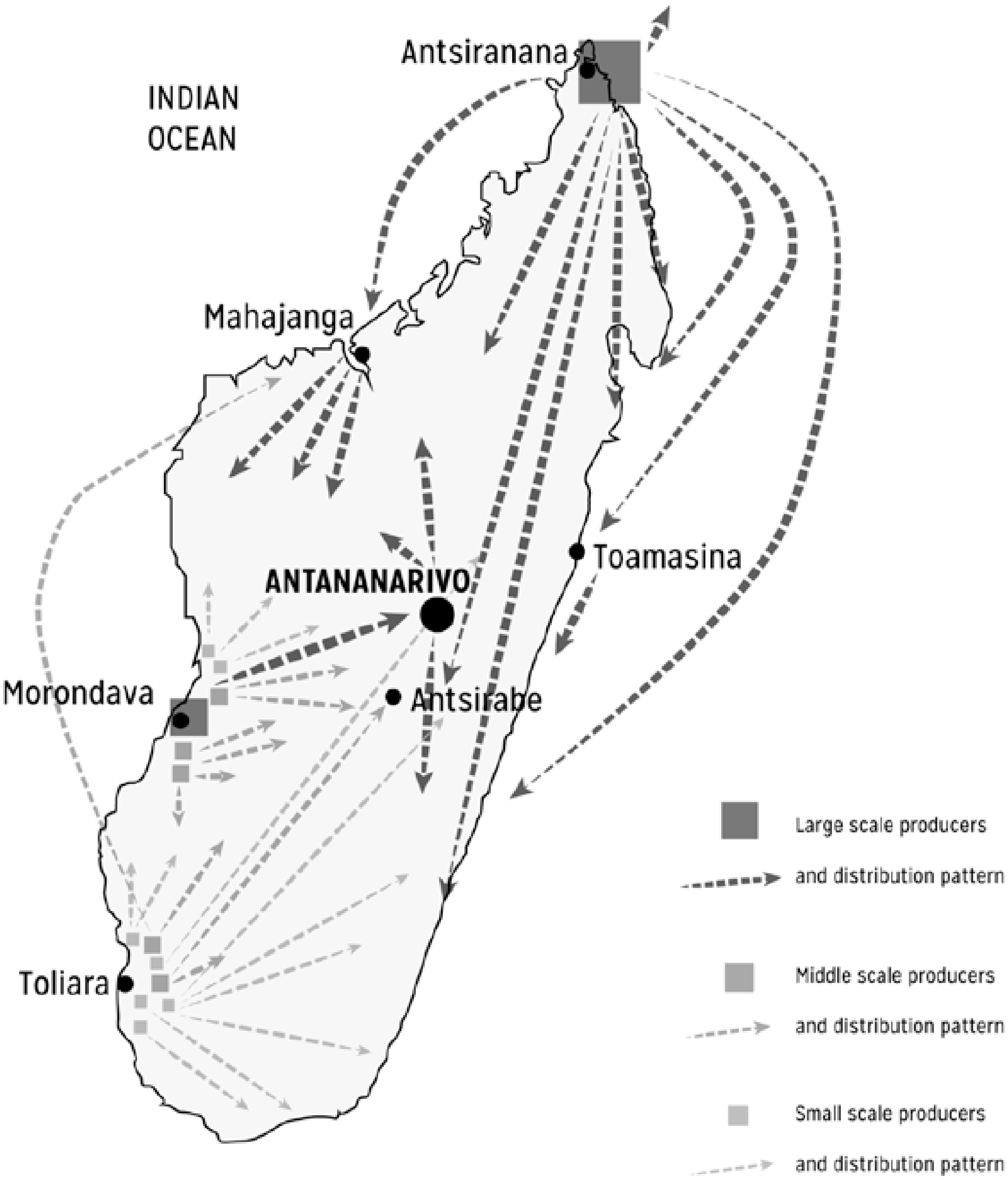

Figure 3. Salt production and distribution circuits in Madagascar

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