# COST ANALYSIS OF COMMUNITY WATER FLUORIDATION IN KERIAN, PERAK

***Gnanapragasam SS[1,2], Tengku Hamzah TNN[3], Wan Puteh SE[4], and Mohd Nor NA[1].***
*[1]Department of Community Oral Health & Clinical Prevention, Faculty of Dentistry, Universiti Malaya, 50603 Kuala Lumpur, Malaysia.*
*[2]Oral Health Programme, Ministry of Health Malaysia, Level 5, Block E10, Parcel E, Precinct 1, Federal Government Administrative Centre, 62590 Putrajaya, Malaysia.*
*[3]Department of Paediatric Dentistry & Orthodontics, Faculty of Dentistry, Universiti Malaya, 50603 Kuala Lumpur, Malaysia.*
*[4]Department of Community Health, Faculty of Medicine, Universiti Kebangsaan Malaysia, 56000 Kuala Lumpur, Malaysia.*

***Correspondence:***
*Nor Azlida Mohd Nor,*
*Department of Community Oral Health & Clinical Prevention,*
*Faculty of Dentistry,*
*Universiti Malaya,*
*50603 Kuala Lumpur, Malaysia*
*Email: azlida@um.edu.my*

***Abstract***
There is limited information available regarding the cost of community water fluoridation (CWF) in Malaysia. Issues related to the cessation of CWF since 2012 in one of the states in Malaysia, were due to the cost of fluoride chemical and the privatisation of water treatment facilities (WTF). Hence, this study aims to estimate the total and per capita cost of the CWF programme in Kerian, Perak, from 2015 to 2019. This was a retrospective record review, analysing CWF expenditure data in two WTF and two dental clinics in Kerian, Perak, from 2015 to 2019, using a healthcare provider perspective. The data on the population coverage of CWF in Kerian was obtained from the Perak Dental Division. Activity-based costing followed CWF guidelines for implementation, operation and maintenance, monitoring, and evaluation activities. All cost items (capital, manpower, safety, maintenance, chemical, and transportation) were presented in MYR with a 3.0% discount rate. Over the five-year period, the cost of the CWF programme was estimated as follows: MYR 242,644.33 (20.4%) for programme implementation, MYR 796,627.93 (66.9%) for programme operation and maintenance, MYR 147,542.05 (12.4%) for programme monitoring, and the remaining MYR 3,508.20 (0.3%) for programme evaluation. The highest contributor to the CWF programme cost was the fluoride chemical; sodium fluorosilicate, at MYR 450,364.53 (37.8%). The population that received fluoridated water was 189,015. From 2015 to 2019, the CWF programme in Kerian, Perak, incurred an estimated total cost of MYR 1,190,322.51, with a cost per capita of MYR 6.30. This cost analysis enables oral health policymakers and WTF authorities to make informed decisions about investing in the CWF programme.

***Keywords*****:** Community Water Fluoridation; Cost Analysis; Activity-Based Costing

## *Introduction*

Dental caries can significantly impact the overall quality of life, leading to pain, discomfort, social and functional limitations, and time lost from school and work (1). Moreover, dental caries imposes a substantial economic burden on healthcare providers, especially in a country with a public health system where treatment costs are heavily subsidised. While there is no published data specifically on the global economic burden of dental caries, a recent opinion article estimated it to be as high as United States Dollar (USD) 245 billion, comprising USD 161 billion in direct treatment costs and USD 84 billion in indirect productivity losses (2). However, it is important to note that dental caries is experienced disproportionately by different populations within society, with high-income countries bearing a lower burden and, consequently, a reduced economic impact (3). This could be attributed to the effective use of fluorides, including community water fluoridation (CWF), improved living conditions,

changing lifestyles, better education and enhanced self-oral care practices (4).

In Malaysia, there has been a decline in caries prevalence among 12-year-old children based on 2007 and 2017 epidemiological data (5, 6). However, it should be noted that the decline in caries prevalence was not consistent across the states in Malaysia. Some states, such as Pahang, have experienced an increasing trend associated with the cessation of CWF, in contrast to Perak, which has consistently implemented CWF (7). The cessation of CWF in Pahang was mainly attributed to financial constraints in purchasing fluoride compounds by the Pahang water treatment company after its privatisation (8). Despite the presence of clinical preventive programmes like fissure sealant and fluoride varnish in Malaysia, their implementation at the individual level in a resource-limited setting poses challenges and significant costs. On the other hand, evidence regarding alternative systemic fluoride methods such as fluoridated salt, fluoridated milk or fluoride dietary supplements shows low compliance rates and limited targeting, often focusing on specific age groups (9). Considering the caries burden and oral health inequality in Malaysia, a population-based caries prevention strategy like CWF remains relevant (10).

In general, countries that adopt CWF as a national policy must adhere to a code of practice governing the implementation, operation and maintenance, monitoring, and evaluation of the CWF programme. This adherence entails additional costs, particularly for the water treatment facilities (WTF) authorities, beyond the standard water treatment processes, including coagulation, flocculation, sedimentation, filtration, and disinfection (11-13). Economic data, such as the cost of the CWF programme, aids decision-makers, including WTF authorities, in making well-informed decisions to allocate limited resources efficiently. The cost of implementing CWF can vary depending on various factors, such as community size, the number of fluoride injection points, the amount and type of fluoride feeders and monitoring equipment used, the type and quantity of fluoride compounds used, and the level of expertise among personnel at the WTF (14).

Although Malaysia has a long-standing history of a CWF programme, only one published study conducted in Johor state assessed the cost of CWF, and this study is a quarter of a century old. According to the previous study in 1996, the estimated per capita cost of fluoride compound was Malaysian Ringgit (MYR) 0.18 per year, with a recurrent expenditure of MYR 0.45 per head of the population served annually in Johor (15). However, it is essential to note that this study had some limitations, including outdated data and insufficient cost analysis for the CWF programme.

Due to the lack of available local evidence, Malaysian authorities often rely on international studies analysing CWF costs, primarily conducted in developed countries and with varying methodological quality due to cost data obtained from various sources such as WTF, engineering companies, government reports, and previously published studies (16-19). These studies have demonstrated a wide range of annual per capita costs for CWF, from as low as USD 0.11 or Euro Currency (€) 0.54 to as high as USD 24.38 or € 39.18 for communities serving populations ranging from over 100,000 to less than 1,000. Factors contributing to these cost variations among different population sizes may include the type of fluoride feeders and ancillary equipment used, the employed technology, and the types of monitoring devices utilised (20).

It is pertinent to ensure that our national oral health policymakers, state and local decision-makers, and relevant WTF authorities are committed to maintain recommended fluoride levels in water by allocating adequate funding and fostering a culture of safety and continuous improvement to ensure the long-term success of the CWF programme. Therefore, recognising the importance of generating local evidence regarding the costs of implementation, operation and maintenance, monitoring, and evaluation of the CWF programme, this study aims to estimate the total and per capita costs of the CWF programme in Kerian, Perak, from 2015 to 2019 (a five-year period).

## *Materials and Methods*

### *Study design, time horizon, setting, perspective and discounting*

This was a partial economic evaluation study using cost analysis of the CWF programme in Kerian, Perak. This study was part of a more extensive CWF study that examined the cost-effectiveness of the CWF programme in Malaysia by the water treatment facilities authorities. The assessment of CWF costs in Kerian, Perak was based on good compliance with

recommended fluoride concentration in water (0.5 ± 0.1 parts per million (ppm)) over five years and the availability of costing data. The time horizon chosen in this study was five years (2015-2019). This study included all WTF: Jalan Baru WTF and Gunung Semanggol WTF with active fluoride feeders in Kerian, Perak, from 2015 to 2019 for implementation, operation and maintenance, and monitoring of the CWF programme. The Parit Buntar Dental Clinic and Kerian Dental Clinic which were responsible for monitoring and evaluation of the CWF programme in Jalan Baru WTF and Gunung Semanggol WTF respectively were also included in the study. The costing analysis was conducted from the healthcare provider's perspective. The healthcare provider's perspective chosen in this study included the Ministry of Health (MOH) Malaysia and local WTF authorities for the costing of the CWF programme. All costs were presented in Malaysian Ringgit (MYR) in 2015, with a 3.0% discount rate applied beyond 2015, starting from 2016 to 2019, for the cost of the CWF programme, in accordance with the pharmacoeconomic guidelines in Malaysia (21). For comparison, the estimated conversion rate is USD 1 = MYR (2015) 3.90.

### *Cost identification, measurement, and valuation of the CWF programme*

All the resources used for activities related to the indicators of implementation, operation and maintenance, monitoring, and evaluation of the CWF programme for deriving the cost components in Kerian, Perak, were based on the 2006 guidelines for the implementation of the water fluoridation programme in Malaysia and its addendum, which was revised in 2015, as illustrated in Figure 1 (11).

The costing information was obtained from the available retrospective CWF expenditure data held in the general ledger and accounting management system of WTF and dental clinics in the Kerian district, as well as through observations at the WTF and interviews with WTF operators and the CWF programme coordinator of the Kerian district dental office, conducted by the researcher in 2022. Activity-based costing (ABC) was used for the cost estimation of the CWF programme in Kerian, Perak. Costs were allocated to each activity based on resource consumption, and cost drivers such as frequency, duration, or volume of each activity were used to estimate the cost. These resources were categorised into different groups, such as capital cost, manpower cost, safety cost, maintenance cost, chemical cost, and transportation cost, for the implementation, operation and maintenance, monitoring, and evaluation activities of the CWF programme. The costing and valuation methods are detailed in Table 1.

### *Cost of CWF programme implementation*

This involved capital costs for the initial installation of the building and equipment for the CWF programme in each WTF. The capital cost included fluoride equipment and a materials storage room, two wet fluoride feeders, ancillary work and equipment, transportation, technical consultancy, and installation. Using the straight-line method, the capital cost depreciated over its useful life of 15 years with no salvage value (21).

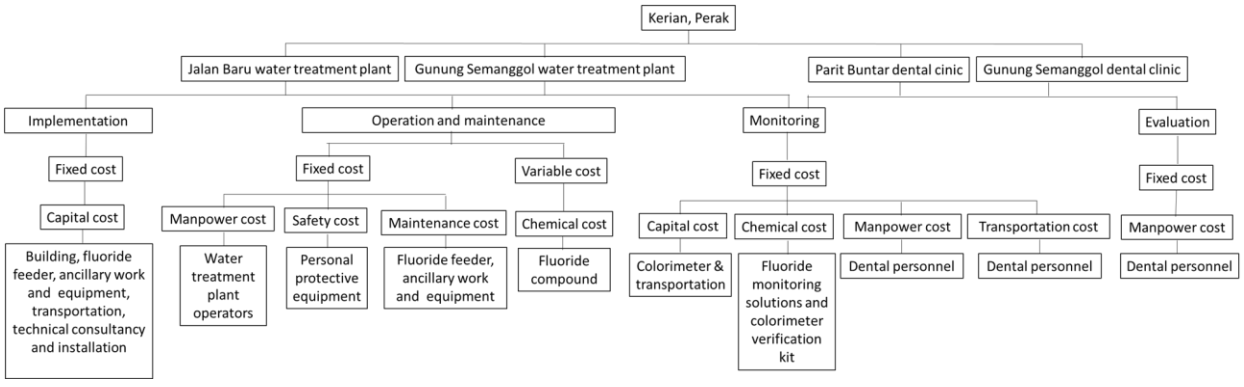


**Figure 1:** Indicators of the CWF programme and the respective cost components in Kerian, Perak

**Table 1:** Costing and valuation method of cost items for CWF programme

| Indicator | Cost item | Costing method | Valuation method |
|---|---|---|---|
| Implementation | Capital | Activity-based costing | Unit cost for fluoride equipment and materials storage room, two fluoride feeders, ancillary work and equipment, transportation, technical consultancy, and installation estimated using EAC |
| Operation and maintenance | Manpower | Activity-based costing | The hourly manpower cost was multiplied by the total hours spent for CWF programme operation in a year |
| | Safety | Activity-based costing | The unit cost for each PPE used by WTF operators was multiplied by the quantity used in a year |
| | Maintenance | Activity-based costing | The unit cost for maintenance of indicated fluoride feeder, ancillary work, and equipment inclusive of transportation performed in a year |
| | Chemical | Activity-based costing | The cost per kg of sodium fluorosilicate multiplied by the total amount of sodium fluorosilicate used in a year |
| Monitoring | Capital | Activity-based costing | The unit cost of the colourimeter multiplied by the quantity and estimated using EAC |
| | Chemical | Activity-based costing | The unit cost of chemical; SPADNS solution, TISAB solution, colorimeter verification kit, SPADNS ampules and fluoride solution multiplied by the quantity used in a year |
| | Manpower | Activity-based costing | The hourly manpower cost was multiplied by the total hours spent monitoring CWF in a year |
| | Transportation | Activity-based costing | The unit cost per km multiplied by the total distance covered to the reticulation point and WTF for monitoring fluoride level in water. |
| Evaluation | Manpower | Activity-based costing | The hourly manpower cost was multiplied by the total hours spent evaluating CWF in a year |

WTF = water treatment facilities, PPE = personal protective equipment, EAC = equivalent annual cost, SPADNS = 4,5-Dihydroxy-3-(4-sulfophenylazo)-2,7-naphthalene Disulfonic Acid, Trisodium Salt, TISAB = total ionic strength adjustment buffer

An annualisation factor of 11.94 was used to calculate the equivalent annual cost (EAC) as shown in Equation 1:

$$\text{Equivalent annual cost (MYR)} = \frac{\text{Cost of the building \& equipment (MYR)}}{\text{Annuity factor (useful life of building and equipment at 15 years and 3.00\% discount rate )}} \quad (1)$$

The EAC was multiplied by five years, reflecting the study's time horizon, to obtain the total capital cost.

### *Cost of CWF programme operation and maintenance*

The annual manpower cost for one WTF operator was estimated by multiplying their hourly salary by the annual working time (in hours) dedicated to water fluoridation activities, as shown in Equation 2.

$$\text{Annual manpower cost for one WTF operator (MYR)} = \text{Hourly salary (MYR)} \times \text{Number of hours spent for water fluoridation works per year by 1 WTF operator} \quad (2)$$

To determine the total manpower cost for six WTF operators between 2015 and 2019, the cost for one operator was multiplied by six and summed over five years.

Safety costs included personal protective equipment (PPE) such as daily disposable National Institute for Occupational Safety and Health (NIOSH) dust masks, monthly replaced semi-leather gloves, chemical goggles, protective clothing, safety helmets (replaced yearly), and Wellington boots (replaced every three years). These costs were divided equally among the five chemicals (alum, chlorine, polymer, fluoride, and lime) handled by one WTF operator to calculate the PPE cost for water fluoridation activities. The resulting cost was then multiplied by six operators and summed to obtain the total safety cost for each

WTF over five years. Maintenance costs covered expenses related to the fluoride ion-selective electrode and probe (replaced yearly for the Orion online fluoride analyser), and repairs to the fluoride feeder, colourimeter, and ancillary equipment. All maintenance costs from 2015 to 2019 included transportation and installation expenses.

The chemical cost specifically pertained to sodium fluorosilicate, a dry fluoride chemical compound. Consumption was measured in kilograms (kg) for each WTF, and the cost for each year was calculated by multiplying the consumed amount by the respective cost per kg. The total cost of sodium fluorosilicate was then determined by summing the costs from 2015 to 2019.

### *Cost of CWF programme monitoring and evaluation*

The monitoring of the CWF programme included assessing the capital cost and chemical costs for both the WTF and dental clinics. Additionally, manpower costs and transportation expenses involving dental personnel were estimated for monitoring and evaluating the CWF programme by the dental clinics.

The capital cost of the colourimeter was converted to an EAC using a useful life of 10 years for the asset and an annuity factor of 8.53, as shown in Equation 3. The resulting EAC was then multiplied by five, reflecting the study's time horizon, to obtain the total EAC.

$$\text{Equivalent annual cost (MYR)} = \frac{\text{Cost of the colorimeter(MYR)}}{\text{Annuity factor (useful life of colorimeter at 10 years and 3.00\% discount rate )}} \quad (3)$$

The unit cost of 2-(p-sulfophenylazo)-1,8-dihydroxy-3,6-naphthalenedisulfonic acid (SPADNS) fluoride reagent solution, Total Ionic Strength Adjustment Buffer (TISAB) solution used in the Orion online fluoride analyser, colourimeter verification kits, SPADNS fluoride reagent AccuVac® Ampules, and fluoride standard solution (1.0mg/l) was multiplied by annual consumption and summed over five years to calculate the total cost.

Transportation costs were calculated for dental personnel involved in monitoring the fluoride level at the reticulation point and WTF. The distance in kilometres for a round trip between the reticulation point and WTF with the dental clinic was determined and then multiplied by the standard mileage rate (MYR 0.70 per kilometre) from 2015 to 2019.

The annual manpower cost was estimated by multiplying the hourly salary by the annual working time (in hours) spent by dental personnel for monitoring and evaluating the CWF programme. The cost of manpower for dental personnel from 2015 to 2019 was summed separately for monitoring and evaluating the CWF programme over the five-year period to obtain the total cost.

### *Cost data analysis*

All costs related to the implementation, operation and maintenance, monitoring, and evaluation of the CWF programme from 2015 to 2019 were analysed for all WTFs and dental clinics using Microsoft Excel 2019. These costs were aggregated based on the Jalan Baru WTF and its corresponding Parit Buntar Dental Clinic, as well as the Gunung Semanggol WTF and its respective Gunung Semanggol Dental Clinic. This provided an estimate of the total cost of the CWF programme from 2015 to 2019 for each WTF and its associated dental clinic. Subsequently, this cost was divided by the average population size that received fluoridated water from each individual WTF to calculate the cost per capita.

Additionally, the total cost for both the WTFs and dental clinics was combined to determine the overall cost of the CWF programme in the Kerian district from 2015 to 2019. Population data for the average number of individuals who received fluoridated water from both the Jalan Baru WTF and the Gunung Semanggol WTF between 2015 and 2019 in Kerian were obtained from the Perak Dental Division. Then, the total cost of the CWF programme was divided by the population that received fluoridated water in Kerian during the same period to estimate the cost per capita for the CWF programme, as shown in equation 4.

$$\text{Cost per capita for CWF programme in Kerian, Perak} = \frac{\text{Cost}_{\text{implementation}} + \text{cost}_{\text{operation and maintenance}} + \text{cost of}_{\text{monitoring}} + \text{cost of}_{\text{evaluation}}}{\text{Average population receive fluoridated water in Kerian, Perak}} \quad (4)$$

## *Results*

Table 2 demonstrates the quantity and estimated cost of sodium fluorosilicate consumption for both the Jalan Baru WTF and the Gunung Semanggol WTF from 2015 to 2019. The registered consumption of sodium fluorosilicate ranged from 8,350 kg to 9,300 kg for the Jalan Baru WTF, while the Gunung

Semanggol WTF recorded higher consumption levels, varying from 31,700 kg to 34,800 kg. The estimated cost in the Jalan Baru WTF exhibited a gradual decrease from 2015 (MYR 18,135.00) to 2016 (MYR 18,056.25), followed by a sharp increase until 2018 (MYR 25,980.87), and a subsequent reduction in 2019 (MYR 22,261.93). In contrast, the estimated cost of sodium fluorosilicate compound in the Gunung Semanggol WTF increased from 2015 (MYR 50,757.50) to 2017 (MYR 77,413.52), decreased in 2018 (MYR 74,845.78), and increased again in 2019 (MYR 84,583.97). The cumulative estimated cost of sodium fluorosilicate was higher in the Gunung Semanggol WTF (MYR 345,240.38) compared to the Jalan Baru WTF (MYR 105,124.15) from 2015 to 2019.

Table 3 shows the cost composition and cost per capita for the implementation, operation, maintenance, monitoring, and evaluation of the CWF programme from 2015 to 2019, as per the WTF and the corresponding dental clinics in Kerian, Perak. Under each cost item and the total cost for the implementation, operation and maintenance of the CWF programme, the Gunung Semanggol WTF had higher values compared to the Jalan Baru WTF, except for safety cost (MYR 7,731.49), which remained the same for both WTFs, and maintenance cost, which was lower in the Gunung Semanggol WTF (MYR 13,377.81).

Meanwhile, the total cost for monitoring the CWF programme was lower for the Gunung Semanggol WTF and Gunung Semanggol Dental Clinic (MYR 64,991.81) compared to the Jalan Baru WTF and Parit Buntar Dental Clinic (MYR 82,550.24). The cost item that exhibited a similar pattern under this indicator was the chemical cost, with a difference estimated at MYR 19,219.11 between the two WTFs and their corresponding clinics. A similar cost was estimated for evaluating the CWF programme in both dental clinics (MYR 1,754.10).

The cost per capita for the CWF programme was MYR 1.13 lower for the Jalan Baru WTF and Parit Buntar Dental Clinic, serving an average population of 75,000 with fluoridated piped water, compared to the Gunung Semanggol WTF and Gunung Semanggol Dental Clinic (MYR 6.89), serving an average population of 110,000 in Kerian, Perak.
Table 4 presents the estimated cost composition with proportions and cost per capita for the implementation, operation and maintenance, monitoring, and evaluation of the CWF programme from 2015 to 2019 in Kerian, Perak. The healthcare provider allocated MYR 796,627.93 (66.9%) to the operation and maintenance of the CWF programme, MYR 242,644.33 (20.4%) to the implementation of the CWF programme, MYR 147,542.05 (12.4%) to monitoring the CWF programme, and the remaining MYR 3,508.20 (0.3%) to the evaluation of the CWF programme.

A more detailed analysis of the cost composition by CWF programme indicator revealed that sodium fluorosilicate chemical cost (37.8%) and monitoring chemical cost (11.1%) were the highest contributors to the operation and maintenance cost and monitoring cost of the CWF programme, respectively. The highest expenditure in terms of manpower cost was observed for the operation and maintenance of the CWF programme, totalling MYR 278,932.55 (23.4%).

The total cost and cost per capita for the implementation, operation and maintenance, monitoring, and evaluation of the CWF programme in Kerian, Perak, from 2015 to 2019 for the population that received fluoridated water (189,015) from both the WTF were estimated to be MYR 1,190,322.51 and MYR 6.30, respectively.

## *Discussion*

This study estimated the total cost and cost per capita for the CWF programme in Kerian, Perak. In this study, the total cost and cost per capita for the CWF programme were MYR 1,190,322.51 (USD 305,210.90) and MYR 6.30 (USD 1.62) between 2015 and 2019 respectively. This cost per capita varied between MYR 5.76 (USD 1.48) and MYR 6.89 (USD 1.77) due to differences in the population served by the two WTF, namely the Jalan Baru WTF and Gunung Semanggol WTF. The cost per capita of the CWF programme over a five-year period in Kerian, Perak, appeared to be similar to other studies that covered larger populations of over 50,000 (USD 2.10) and 100,000 people with CWF (USD 1.30) (16, 17). Nevertheless, the current study offered a more comprehensive analysis of the CWF programme costs compared to prior research. Unlike other studies that relied on aggregate data from WTF, engineering companies, government reports, or previously published studies, most of the costing analysis in this study utilised real-time disaggregated data (18, 22-25). Other than that, the ABC method was utilised to estimate the costs of the CWF

**Table 2:** Estimated quantity and cost of registered sodium fluorosilicate according to the WTF in Kerian, Perak from 2015 to 2019

| Year | Sodium fluorosilicate | Jalan Baru WTF | Gunung Semanggol WTF |
|---|---|---|---|
| 2015 | Cost per kg (MYR) | 1.95 | 1.58 |
| | Registered amount(kg) | 9,300 | 32,125 |
| | Cost of registered amount (MYR) | 18,135.00 | 50,757.50 |
| 2016 | Cost per kg (MYR) | 2.00 | 1.71 |
| | Registered amount(kg) | 9,300 | 34,800 |
| | Cost of registered amount (MYR) | 18,058.25 | 57,639.61 |
| 2017 | Cost per kg (MYR) | 2.36 | 2.36 |
| | Registered amount(kg) | 9,300 | 34,800 |
| | Cost of registered amount (MYR) | 20,688.10 | 77,413.52 |
| 2018 | Cost per kg (MYR) | 3.40 | 2.58 |
| | Registered amount(kg) | 8,350 | 31,700 |
| | Cost of registered amount (MYR) | 25,980.87 | 74,845.78 |
| 2019 | Cost per kg (MYR) | 2.88 | 2.88 |
| | Registered amount(kg) | 8,700 | 32,125 |
| | Cost of registered amount (MYR) | 22,261.93 | 84,583.97 |
| Total (2015-2019) | Registered amount estimate (kg) | 44,950 | 165,550 |
| | Reported cost of registered amount (MYR) | 112,129.00 | 366,560.30 |
| | Cost of registered amount (MYR) | 105,124.15 | 345,240.38 |

WTF = water treatment facilities, MYR = Malaysian Ringgit
Registered amount: Amount of sodium fluorosilicate used by WTF for the CWF programme

**Table 3:** Estimated cost composition and cost per capita for implementation, operation and maintenance, monitoring and evaluation of CWF programme from 2015 to 2019 by WTF and their corresponding dental clinics

| Indicators | Cost item | Jalan Baru WTF & Parit Buntar Dental Clinic | Gunung Semanggol WTF & Gunung Semanggol Dental Clinic |
|---|---|---|---|
| Implementation | Capital cost (MYR) | 83,752.10 | 158,892.23 |
| Operation and maintenance | Manpower cost (MYR) | 112,904.47 | 166,028.08 |
| | Safety cost (MYR) | 7,731.49 | 7,731.49 |
| | Maintenance cost (MYR) | 38,490.06 | 13,377.81 |
| | Chemical cost (MYR) | 105,124.15 | 345,240.38 |
| Monitoring | Capital cost (MYR) | 3,610.84 | 3,441.76 |
| | Chemical cost (MYR) | 75,417.32 | 56,198.21 |
| | Manpower cost (MYR) | 2,412.62 | 2,895.18 |
| | Transportation cost (MYR) | 1,109.46 | 2,456.66 |
| Evaluation | Manpower cost (MYR) | 1,754.10 | 1,754.10 |
| | Total cost (MYR) | 432,306.61 | 758,015.90 |
| | Average population received fluoridated water | 75,000 | 110,000 |
| | Cost per capita (MYR) | 5.76 | 6.89 |

WTF = water treatment facility, CWF = community water fluoridation, MYR = Malaysian Ringgit
Total time spent by WTF operators for fluoridation work daily: 45 minutes in Jalan Baru WTF and 1 hour 7 minutes in Gunung Semanggol WTF
Total time spent by dental personnel monitoring CWF programme yearly: 30 hours by Parit Buntar Dental Clinic and 36 hours by Gunung Semanggol Dental Clinic
Total time spent by dental personnel evaluating the CWF programme: 12 hours by Parit Buntar Dental Clinic and 12 hours by Gunung Semanggol Dental Clinic
Total cost=Cost $_{\text{implementation}}$ + cost $_{\text{operation and maintenance}}$ + cost of $_{\text{monitoring}}$ + cost of $_{\text{evaluation}}$
Cost per capita= total cost / average population received fluoridated water

**Table 4:** Estimated costs composition with proportion and cost per capita for implementation, operation and maintenance, monitoring and evaluation of CWF programme from 2015 to 2019 in Kerian, Perak

| Indicators | Cost item | CWF Programme in Kerian, Perak | Cost Percentage (%) |
|---|---|---|---|
| Implementation | Capital cost (MYR) | 242,644.33 | 20.4% |
| Operation and maintenance | Manpower cost (MYR) | 278,932.55 | 23.4% |
| | Safety cost (MYR) | 15,462.98 | 1.3% |
| | Maintenance cost (MYR) | 51,867.87 | 4.4% |
| | Chemical cost (MYR) | 450,364.53 | 37.8% |
| Monitoring | Capital cost (MYR) | 7,052.60 | 0.6% |
| | Chemical cost (MYR) | 131,615.53 | 11.1% |
| | Manpower cost (MYR) | 5,307.80 | 0.4% |
| | Transportation cost (MYR) | 3,566.12 | 0.3% |
| Evaluation | Manpower cost (MYR) | 3,508.20 | 0.3% |
| | Total cost (MYR) | 1,190,322.51 | 100.0% |
| | Average population received fluoridated water | 189,015 | |
| | Cost per capita (MYR) | 6.30 | |

WTF = water treatment facility, CWF = community water fluoridation, MYR = Malaysian Ringgit
Total cost= Cost $_{implementation}$ + cost $_{operation\ and\ maintenance}$ + cost of $_{monitoring}$ + cost of $_{evaluation}$
Cost per capita= total cost / average population received fluoridated water

Programme in the present study. This approach was deemed appropriate as CWF is predominantly activity-based. It factored in implementation, operation and maintenance, as well as monitoring, and evaluation indicators. Employing the ABC method allows for more precise and transparent data, as it follows a micro-costing approach (26).

Estimating the manpower costs of WTF operators for the operation and maintenance of the CWF programme has been a challenge in previous studies (18, 25). Some studies assumed a standard labour requirement of one hour per fluoride injection point per day for WTF operators in the US and South Africa (18, 27). In contrast, this study conducted direct observations and interviews with the WTF operators to determine the actual time spent on fluoridation work accurately. The findings revealed that the time varied between 45 minutes and 1 hour and 7 minutes per day for all the six operators in the Jalan Baru WTF and Gunung Semanggol WTF, depending on the WTF's capacity. The cost was then derived from this time spent on fluoridation activities at WTF to estimate the manpower cost specifically dedicated to fluoridation work.

In addition, recent research studies examining the cost of the CWF programme have overlooked the expenses associated with PPE used by operators in WTF during programme operation, despite the significance of this aspect being emphasised in most CWF codes of practice (17, 23, 28). To address this gap, the current study estimated the cost of PPE for WTF operators over a five-year period to be MYR 15,462.98 (US$3964.87). Wearing PPE is necessary among WTF operators because fluoride chemicals are classified as dangerous goods, and this cost should be factored into the cost analysis of the CWF programme.

Most studies covered the cost of CWF programme monitoring, which involves testing fluoride levels in water to ensure compliance with the recommended standard. However, there is a lack of information on the specific monitoring equipment and solutions used, which may differ between countries. A recent study by Belotti and Frazão in 2021, focusing solely on the cost estimation of a CWF programme in Brazil, did include the expenses associated with measuring and controlling fluoride levels in water using the SPADNS colourimetric method (20). In terms of monitoring technology employed by WTF, the present study found that the Jalan Baru WTF utilised both the online fluoride analyser and colourimeter. In contrast, the Gunung Semanggol WTF used only the colourimetric method similar to the one employed in the Brazilian study. Nonetheless, in the US, England and Wales, New Zealand, Australia, and Ireland, the online fluoride analyser remained the preferred choice due to its continuous and accurate measurement

capabilities despite being more expensive (12, 13, 29-31). It is important to note that both the colourimeter and online fluoride analyser have proven to provide precise measurements if appropriately calibrated and well-maintained (12). Furthermore, the present study highlighted the cost of CWF programme evaluation, which encompasses reporting and analysing fluoride concentration in water by dental personnel in accordance with the recommended levels set by the MOH. This aspect, which was not covered in previous studies, is a necessary component of the CWF programme as outlined in the CWF guidelines in Malaysia (11).

In terms of cost composition, this study found that operation and maintenance accounted for over two-thirds of the total CWF programme cost, with the cost of fluoride chemical (sodium fluorosilicate) being the highest contributor, as also observed in the Brazil study (20). This can be attributed to the substantial quantity of sodium fluorosilicate, the primary component used annually to adjust the fluoride concentration in water to the recommended level. This cost estimation provides valuable insights for WTF facilities to understand the necessary expenditure for the ongoing CWF programme. It is important to note that any cost-reduction efforts should focus on improving efficiency rather than compromising the quality of fluoride in water.

It was observed in this study that there were variations in the registered amount of sodium fluorosilicate used between the years. Specifically, the trend of the registered amount was found to be fluctuant due to the low solubility of sodium fluorosilicate, which hindered its proper dissolution for achieving the required fluoride concentration in water. Therefore, it is recommended that the training of WTF operators in handling and mixing fluoride chemicals be enhanced, accompanied by regular supervision from supervisors (31). This step is crucial to ensure effective resource management of the CWF programme, contain costs and ensure that fluoride concentration remains at recommended levels.

This study had several limitations, and the conclusions were drawn based on these limitations. It was noted that the capital cost of the water fluoridation plant in the WTFs in Kerian, Perak, may have been overestimated due to the assumption of a 15-year lifespan for the fluoride feeder, even though some equipment functioned well beyond this period. However, most of the cost estimations were based on actual data or approximations derived from the time spent on fluoridation work, especially concerning manpower costs. The direct cost of utilities, such as electricity, for the operation, maintenance, and monitoring of the CWF programme in Jalan Baru WTF and Gunung Semanggol WTF was not included. This omission was due to the minimal electricity consumption for fluoridating water supply compared to other water treatment steps, including coagulation, flocculation, sedimentation, filtration, and disinfection, as indicated by the WTF authorities. Furthermore, the cost of training WTF operators to manage the operation and maintenance of the CWF programme in both WTFs was not factored into the cost estimation of the CWF programme. This omission was because training is typically provided to newly hired WTF operators, and it was assumed that all the operators involved in this study had already received the necessary training.

It is worth noting that the per capita estimation for the CWF programme only applied to WTFs that supplied fluoridated water to populations exceeding 75,000 individuals in West Malaysia. Consequently, the per capita cost results for the CWF programme cannot be applied to smaller WTFs that provide CWF to fewer than 75,000 individuals in Malaysia or more than 75,000 individuals in East Malaysia (Sabah, Sarawak, and the Federal Territory of Labuan). Despite these limitations, it is worth highlighting that this study is one of the first comprehensive cost analyses of the CWF programme conducted in Malaysia. Further research is recommended to analyse the cost of the CWF programme in both West and East Malaysia, considering different population coverages and geographical variations.

## *Conclusion*

Cost estimation serves as an effective tool in bridging the gap between national oral health policymakers, who prioritise the quality of fluoride levels in water, and the WTF authorities that emphasise the cost of the CWF programme. The evidence generated from this study may assist WTF authorities in making informed decisions about investing in CWF programme expenditure by allocating the necessary monetary resources for the CWF programme each year. This, in turn, could promote the reimplementation of CWF in areas where it had ceased and support the continuation of CWF in other parts of Malaysia.

## Acknowledgement

The authors express their sincere gratitude to the Principal Director of Oral Health, Ministry of Health and Faculty of Dentistry, Universiti Malaya, for their support and permission to conduct this study. Special thanks to the Director General of Health Malaysia for his permission to publish this article. Heartfelt thanks are also expressed to the Lembaga Air Perak, Syarikat Aliran Utara and Perak Dental Division for their assistance during the data collection.

## Competing interests

The authors declare that they have no competing interests.

## Ethical Clearance

Ethical approval for this study was obtained from the Medical Ethics Committee, Faculty of Dentistry, Universiti Malaya (DF CO2101/0066 (P)) and the National Medical Research Registration, Ministry of Health Malaysia (NMRR ID: 22-00311-6CX (IIR)). Permission to conduct this study was granted by the Principal Director of Oral Health Programme (OHP), Ministry of Health (MOH), Malaysia (KKM.600-56/7/2 Jld.9 (41)).

## Financial support

The authors acknowledge funding support for this project from the Faculty Research Grant, University of Malaya, Malaysia (Grant No: UMG017E-2022).

## References

1. Alvarez-Azaustre MP, Greco R, Llena C. Oral health-related quality of life in adolescents as measured with the child-OIDP questionnaire: A systematic review. Int J Environ Res. 2021; 18(24):1-6.
2. Vujicic M, Listl S. An economic perspective of the global burden of dental caries. ACFF make cavities history taskforce. 2021. Available at: https://www.acffglobal.org/wp-content/uploads/2021/03/An-economic-perspective-on-the-burden-of-dental-caries.pdf. Accessed 5 June 2023.
3. Wen P, Chen M, Zhong Y, Dong Q, Wong H. Global burden and inequality of dental caries, 1990 to 2019. J Dent Res. 2022; 101(4):392-399.
4. Crall JJ, Vujicic M. Children's oral health: Progress, policy development, and priorities for continued improvement: Study examines improvements in American children's oral health and oral health care that stem from major federal and state initiatives, and persistent disparities. Health Aff. 2020; 39(10):1762-1769.
5. Ministry of Health Malaysia. National Oral Health Survey of Schoolchildren 2007. Kuala Lumpur: Oral Health Division Ministry of Health Malaysia; 2007. Available at: https://ofa.arkib.gov.my/ofa/group/asset/1206455. Accessed 10 March 2022.
6. Ministry of Health Malaysia. National Oral Health Survey of Schoolchildren 2017. National Institute of Health, Ministry of Health Malaysia: Institute for Public Health; 2017. Available at: https://hq.moh.gov.my/ohd/images/pdf/research/NHMS%202017%20NOHSS%202017%20Vol%20II%20Oral%20Health%20Status%20of%2012%20yr%20olds.pdf. Accessed 10 March 2022.
7. Ministry of Health Malaysia. Annual report 2018. Ministry of Health Malaysia: Oral Health Programme; 2019. Available at: https://hq.moh.gov.my/ohd/images/pdf/annual_rpt/annual_rpt18.pdf. Accessed 21 October 2022.
8. Karim FA, Yusof ZYM, Nor NAM. Water Fluoridation and oral health in Malaysia: A review of literature. JUMMEC. 2020; 23(2):76-91.
9. Kargul B, Caglar E, Tanboga I. History of water fluoridation. J Clin Pediatr Dent. 2003; 27(3):213-217.
10. Goodwin M, Henshaw M, Borrelli B. Inequities and oral health: A behavioural sciences perspective. Community Dent Oral Epidemiol. 2023; 51(1):108-115.
11. Ministry of Health Malaysia. Implementation of water fluoridation in Malaysia. In: Oral Health Division, Ministry of Health Malaysia 2006. Available at: https://hq.moh.gov.my/ohd/images/pdf/xtvtnsop/Implementation-of-Water-Fluoridation-Programme-in-Malaysia-2006.pdf. Accessed 19 November 2022.
12. American Water Works Association. Water fluoridation principles and practices. In: 6th ed. United States of America; 2016.
13. Department of Health Queensland. Water fluoridation code of practice. Queensland, Australia: Department of Health; 2021. Accessed 12 July 2022.
14. Rathore B, Pallavi HN, Pushpanjali K. Community water fluoridation: Revisiting a cost-effective measure. Int J Sci Study 2015; 3(4):154-158.
15. Loh KH. Cost estimation study of water fluoridation programme in Johor. Paper

presented at: Oral Health Research Conference 2004; May 20-May 21, 2004; Bangi, Selangor.
16. Ran T, Chattopadhyay SK. Economic evaluation of community water fluoridation: A community guide systematic review. Am J Prev Med. 2016; 50(6):790-796.
17. Cronin J, Moore S, Harding M, Whelton H, Woods N. A cost-effectiveness analysis of community water fluoridation for schoolchildren. BMC Oral Health. 2021; 21(1):1-12.
18. O'Connell J, Rockell J, Ouellet J, Tomar SL, Maas W. Costs and savings associated with community water fluoridation in the United States. Health Aff. 2016; 35(12):2224-2232.
19. Mariño R, Zaror C. Economic evaluations in water-fluoridation: A scoping review. BMC Oral Health. 2020; 20(1):1-12.
20. Belotti L, Frazão P. Intervening factors in the costs of fluoridation in water supply systems: A case study in seven population sizes. Eng Sanit Ambient. 2021; 26(4):785-791.
21. Pharmacy Practice & Development Division PSP. Pharmacoeconomic guidelines for Malaysia. 2 ed. Ministry of Health, Malaysia; 2019. Available at: https://pharmacy.moh.gov.my/en/documentts/pharmacoeconomic-guideline-malaysia-2nd edition.html#:~:text=These%20guidelines%20aimed%20to%20encourage,in%20the%20Malaysian%20healthcare%20system. Accessed 15 October 2022.
22. Ciketic S, Hayatbakhsh MR, Doran CM. Drinking water fluoridation in South East Queensland: A cost-effectiveness evaluation. Health Promot J Austr. 2010; 21(1):51-56.
23. Moore D, Poynton M, Broadbent JM, Thomson WM. The costs and benefits of water fluoridation in New Zealand. BMC Oral Health. 2017; 17(1):1-8.
24. Tchouaket E, Brousselle A, Fansi A, Dionne PA, Bertrand E, Fortin C. The economic value of Quebec's water fluoridation program. J Public Health. 2013; 21(6):523-533.
25. Wright JC, Bates MN, Cutress T, Lee M. The cost-effectiveness of fluoridating water supplies in New Zealand. Aust N Z J Public Health. 2001; 25(2):170-178.
26. Sockanathan L, Kuppusamy E, Teo R, Dom TNM, Aizuddin AN, Yazid F. Activity-based costing of caries treatment done under general anaesthesia. Res Sq. 2022. Available at: https://assets.researchsquare.com/files/rs-1834310/v1/bfd071a0-66eb-413a-b9b7-a19d5efdaff6.pdf?c=1661236155. Accessed 4 March 2023.
27. Kroon J, Van Wyk PJ. A retrospective view on the viability of water fluoridation in South Africa to prevent dental caries. Community Dent Oral Epidemiol. 2012; 40(5):441-450.
28. Goodwin M, Emsley R, Kelly MP, Sutton M, Tickle M, Walsh T, et al. Evaluation of water fluoridation scheme in Cumbria: The CATFISH prospective longitudinal cohort study. J Public Health Res. 2022; 10(11):1-186.
29. Drinking Water Inspectorate England and Wales. Code of practice on technical aspects of fluoridation of water supplies 2016. England: Drinking Water Inspectorate; 2016. Available at: https://www.dwi.gov.uk/what-we-do/annual-report/drinking-water-2016/. Accessed 23 April 2022.
30. Ministry of Health New Zealand. Fluoridation of drinking-water supplies in New Zealand. New Zealand; 2014. Available at: https://www.waternz.org.nz/Folder?Action=View%20File&Folder_id=89&File=Code%20of%20Practice%20%20Fluoridation%20of%20drinking-water%20supplies.pdf. Accessed 10 July 2022.
31. The Irish Expert Body on Fluorides and Health. Code of practice on the fluoridation of drinking water. Ireland: The Irish Expert Body on Fluorides and Health; 2016. Available at: https://www.fluoridesandhealth.ie/assets/files/pdf/cop_fluoridation_of_drinking_water_2016.pdf. Accessed 18 July 2022.