

## ORIGINAL ARTICLE

# Geographic Information System (GIS) Mapping of Fluoride Levels in Reticulated Water System and Dental Caries Experience in Pahang Preschool Children

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## ABSTRACT

**Introduction:** This study identified the range of fluoridation levels, mapped the spatial pattern of the fluoridated public water supply, and correlated by mapping it with the caries trends of preschool children in Pahang. **Materials and methods:** Secondary data on fluoride level readings in water supply from reticulation points of water treatment plants (WTP) and dental caries experience of preschool children in Pahang from 2015 to 2019 was obtained from the Ministry of Health's Health Information System. Each WTP's Global Positioning System (GPS) coordinates were verified in Google Maps and Google Street View and further analysed using Quantum Geographic Information System (QGIS). **Results:** All WTPs have had a suboptimal fluoride range (below 0.4 ppm) since 2018. Areas without fluoride in the water supply were in Kuantan, Bera, Rompin, and Cameron Highlands. Caries prevalence in preschool children in Pahang from 2015 to 2019 increased (42.1% to 42.9%). In 2019, the preschool children's mean caries index of 'dmft' (the sum number of decayed, missing, filled deciduous teeth per individual) was 2.45 (SD=±1.29). Rompin had the highest mean dmft (3.74) compared to others, with a dmft mean of 2.45 in the same year. Higher severity nationwide was reported in the National Oral Health Preschool Survey Malaysia (NOHPS) 2015 (dmft 4.8). **Conclusion:** All WTPs in Pahang have the suboptimal range of fluoride. With the decreasing trend of fluoride levels in the water supply, the caries experience among preschool children in Pahang increased by 0.8%.

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## INTRODUCTION

Exposure to fluoride in public water fluoridation proved to be highly protective against dental caries (1). For decades, evidence has demonstrated that water fluoridation is an effective method for preventing caries at the population level as it remains a relevant and robust upstream approach to public health intervention (2).

Globally, higher caries incidences have been reported in areas where public water fluoridation has ceased (3). The cessation of public water fluoridation has increased the variety of treatment modalities for caries, resulting in significantly higher costs and frequency of procedures (4).

Despite a long history of evidence supporting the effectiveness of water fluoridation, challenges to installing the necessary infrastructure persist, even in developed countries (5). Water fluoridation faces challenges including political opposition, costs, geographical access equity issues and ethical concerns (6).

In addition, the difficulties in operating and maintaining the complex water treatment plant system for water fluoridation result in the water plant companies' hesitancy in providing such services to remote populations in geographically challenged areas due to higher setup costs (7).

Malaysian school children have benefited positively from the water fluoridation programme and the government's school incremental dental programme that synergistically contributes to improving the oral health of the schoolchildren (8). From 2013 to 2018,

however, there was a reduction of 80% to 75% in the coverage of the Malaysian population that received fluoridated water supply (9). Three states achieved less than 15% population coverage of fluoridated water: Kelantan, Sabah and Pahang, with Pahang being the lowest at 0.8%. Kelantan and Sabah achieved a population coverage of 12.5% and 5.2 % respectively (10). Notably, in the state of Pahang, a considerable reduction of the coverage compared with other states in Malaysia was solely due to the privatisation of the water treatment plant in which the company has ceased the procurement of fluoride ingredients for the fluoride feeder (11).

Geographic Information Systems (GIS) have been used to study disease patterns, determine geographic accessibility of health facilities, and assess health inequities among different populations (12)(13). Furthermore, GIS can be used to map the water supply distribution in relation to fluoride availability as geo-mapping with colour coding provides a visual tool depicting variation in the distribution of any important indicators, such as dental caries, across different geographical borders (14).

This study aimed to identify the spatial pattern of the fluoridated public water supply and to correlate it with the caries experience of preschool children in Pahang, Malaysia.

## **MATERIALS AND METHODS**

This study has been registered with the Medical Research and Ethics Committee (MREC), Ministry of Health Malaysia (MOH), with the Registration number NMRR-21-311-58118 (IR). It was conducted in adherence to ethical standards, and approval was obtained from the MREC through the National Medical Research Register (NMRR). The research utilised secondary data, ensuring no personal or identifiable information about individual children was collected or processed. The data focused on aggregated metrics, such as the mean dental caries experience within specific schools in each district. Furthermore, no individual-level data, including names, addresses, or other identifying information, was part of the dataset. Demographic details like age and gender were not used in this study.

The type of secondary data obtained from the relevant authorities include:

### **Water treatment plant (WTP) locations and distributions**

The researchers collected the addresses of each water treatment plant (WTP) in all the districts from Pahang's private water supply company. The exact coordinates of the addresses were obtained from the official list of WTP for 2019, and the corresponding coordinates were received from the Department of Environment of the Ministry of Natural Resources and Environment Malaysia's official website. Google Maps and Google Street View are used to verify each location to ensure

the mapping on QGIS is correctly done on the QGIS map layer. The WTP distribution (length) was obtained formally from the water supply company, Perbadanan Air Pahang (PAIP). The fluoride feeder status and the water supply pipe distribution length were verified with them.

### **Fluoride level in the water supply**

The unit of fluoride measurements used for the data was parts per million units (ppm) as recommended by the guideline set by the Ministry of Health (15). In Malaysia, water fluoridation was officially instituted in 1972, with an initial fluoride concentration set at 0.7 parts per million (ppm) as mandated by a specially appointed Commission (16). This public health initiative was primarily aimed at reducing the incidence of dental caries across the population, a goal that continued to be realised over the subsequent decades due to the sustained efforts of water fluoridation. Recognising the dynamic nature of dietary habits and other sources of fluoride exposure among the Malaysian population, the Ministry of Health (MOH) undertook a comprehensive review in the early 2000s. The objective was to evaluate the efficacy and safety of the existing fluoride concentration in public water supplies, considering the changing patterns of fluoride intake from other sources (16). This review was prompted by the recognition that various forms of fluoride are now commonly used in dental products such as toothpaste and mouth rinses, which contribute to the overall fluoride exposure of individuals.

As a result of the study and ongoing monitoring of dental health outcomes and fluoride exposure levels, the MOH adjusted the recommended optimal fluoride level in public water supplies. This adjustment was based on the findings that a slightly lower range of fluoride concentration, specifically between 0.4 to 0.6 ppm, would be adequate to maintain the caries-preventive benefits while minimising the risk of dental fluorosis, a condition caused by excessive fluoride intake during tooth development (16). Recently, in 2009, the recommended fluoride level was further refined to 0.5 ppm, a decision supported by the Malaysian Dental Council, and this adjustment reflects an ongoing commitment to evidence-based public health practices, aiming to optimise the balance between maximising dental health benefits and minimising health risks associated with fluoride exposure (15). The continuous monitoring and adjustment of fluoride levels in Malaysia underscore the country's proactive approach to managing fluoride as a critical component of its public health strategy. This approach ensures the effectiveness of caries prevention programs and aligns with international best practices for fluoride use, thereby safeguarding the oral health of the Malaysian population.

To effectively monitor fluoride levels in the water supply at reticulated points, oral health personnel must

undergo rigorous training and briefing sessions to ensure the accurate collection and testing of water samples (15). These samples are typically obtained from facilities within the distribution area of a specific water treatment plant, thereby providing representative readings of fluoride levels across the supply network. In regions lacking a fluoridated water supply, collecting water samples at least once a month is mandatory to monitor fluoride concentrations (16). The optimum range of fluoride in the therapeutic range was between 0.4 to 0.6 ppm (17). Furthermore, fluoride values below 0.4 ppm were considered not beneficial to oral health (18). Similarly, in this study, fluoride measurements lower than 0.4 ppm were categorised as below the suboptimal range of fluoride in the water supply.

The fluoride levels in the water supply were measured fortnightly by trained oral health personnel from the Oral Health Division, Pahang Health State Department, at each district's water treatment (19). The values below 0.4 parts per million (ppm) were considered below the beneficial range for oral health, as reported by previous studies (18). A reading of 0.4 ppm to 0.6 ppm was considered to be the optimal fluoride level (17). In this study, fluoride measurements lower than 0.4 ppm were categorised as below the suboptimal range of fluoride in the water supply.

#### **Preschool children's primary dentition caries prevalence data**

The sampling frame for this study includes public-funded and registered private kindergartens that were monitored by the state of Pahang Oral Health Division. The total population of preschool children from 2015 to 2019 was based on the enrolment reports of the school dental services by the Oral Health Division of Pahang Health State Department. The caries experience measured were the decay status; filled and extracted (dfx) teeth of the primary dentition of the preschool children, which were routinely collected and kept by the Oral Health Division (20). The dmft (decayed, missing, filled teeth) index is an essential tool in dental epidemiology, particularly for assessing the oral health status of children (21). It is specifically designed for use with deciduous (primary) teeth, providing a reliable measure of dental caries prevalence and severity in young populations (22). The importance of the dmft index lies in its ability to offer a straightforward yet comprehensive assessment of a child's dental health by recording the number of decayed, missing due to caries and filled primary teeth (23). The dmft index is highly valued in comparative studies across countries and populations. Its simplicity and ease of use make it the preferred choice for large-scale epidemiological surveys (24). Caries prevalence was calculated by the number of carious primary teeth divided by the number of 6-year-old children in Pahang. The mean dfx was calculated by adding the total dfx of all the preschool children divided by the total number of preschool children in Pahang.

#### **Local district border and population density data**

The data were obtained from the Population and Housing Census of Malaysia, 2019 by the Department of Statistics, Malaysia, from their official website, [www.dosm.gov.my](http://www.dosm.gov.my). The administrative borders of all the 11 districts of Pahang were obtained from the [www.data.gov.my](http://www.data.gov.my) website, which is an open-access data-sharing platform from the official portal of the public sector in Malaysia.

#### **Data Integration and Mapping Process**

Firstly, the administrative state and district borders of Pahang were mapped. As the data was obtained from [www.data.org.my](http://www.data.org.my), the relevant data layer was readily available for all districts in Malaysia. Thus, removing all the unwanted study areas was necessary by deselecting them and saving them as another layer as a shapefile to retain the map for analysis. The individual layers of the district-level area have also been created in the shapefile format to allow the analysis, specifically for each district in Pahang. The second type of layer used in the study was the OpenStreetMap layer, which incorporated the geographical and landmark characteristics of the surrounding areas of each plotted administrative border in Pahang. It allows more map characteristics to be utilised and analysed in the spatial analysis regarding the primary physical terrain surrounding the water treatment plant locations.

All water treatment plants in all districts of Pahang were also incorporated in the third type of layer in the analysis. The data used were the coordinates extracted from the geo-tagged location in the Google Maps application and then were recorded in Microsoft Excel. The data file from each water treatment plant was converted to the delimited text layer (CSV) format before being exported into the Quantum Geographic Information System (QGIS) application.

The data in the QGIS application had to be converted into a shapefile to allow the coordinates to be interpreted as the spatial feature in the analysis. All the water treatment plants were mapped, and those either equipped with fluoride feeders or not were labelled. The fluoride level measurement of each water treatment plant of all districts in Pahang was created as another layer of input in QGIS. The readings were the mean value of fluoride levels from 2015 to 2019. The reading for each year was recorded separately for the facilities and further categorised into two groups, with fluoride level mean values below 0.4 ppm and those within the range of 0.4-0.6 ppm. These mean values were integrated with the distribution radius of the water supply for each water treatment plant and were displayed together in the same layer. The mean number of fx index (filled, extracted primary deciduous teeth) for each district was also integrated into the map.

#### **Validation and Refinement**

Ensuring the reliability and robustness of the analysis was

a critical step, as the results were thoroughly reviewed to identify any discrepancies or unexpected patterns. This review involved checking the spatial data's accuracy and the analysis parameters' correctness with the subject matter expert and the custodian of the data. Any issues identified during this review were addressed by refining the analysis parameters and rerunning the analyses as necessary.

For instance, if the buffer distance did not align with the expected reach of the reticulated water system, it was revised to reflect the real-world conditions better. This iterative validation and refinement process was crucial for ensuring that the conclusions drawn from the analysis were accurate and meaningful.

### RESULTS

Buffer analysis for fluoride levels in water supply distribution is carried out, as shown in Figures 1 and Figure 2. Data from 74 WTPs in eleven districts in Pahang were collected. Sixty-six per cent (49 WTP) of WTP have fluoride feeders. The districts involved were Kuantan, Pekan, Rompin, Maran, Raub, Bentong, Bera, Temerloh, Jerantut, Kuala Lipis and Cameron Highlands. The districts of Jerantut had the most WTP, with Kuantan and Bentong having the most significant number of fluoride feeders in the WTP. All fluoride feeders Pahang's WTPs were inactive in 2019, with a mean fluoride level of 0.05 ppm, which was below the optimal level of between 0.4 and 0.6 mg/L.

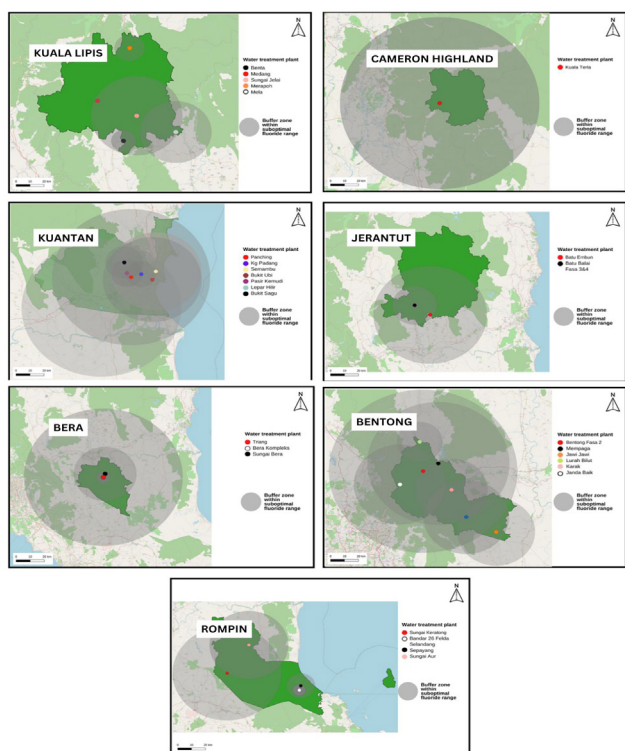


Figure 1: Map of buffer analysis from seven districts of Pahang that have not reach optimal fluoride levels at reticulation point from WTPs from 2015 to 2019

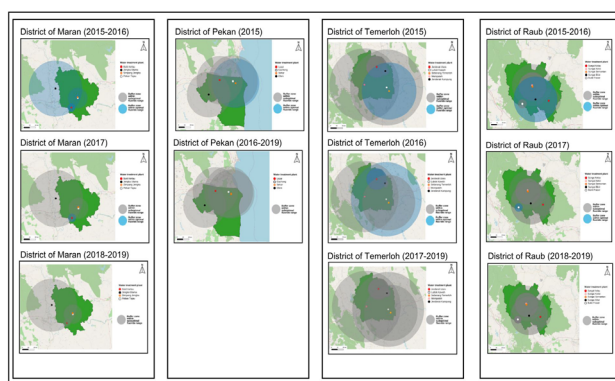


Figure 2: Map of buffer analysis for four districts of Pahang, which still had optimum fluoride levels (0.4-0.6 ppm) initially at reticulation point from WTPs with fluoride from 2015 to 2019, according to the trend of diminished fluoride concentration.

In Figure 1 for Kuala Lipis, the buffer zone (in grey) shows the radius of the water distribution in Kuala Lipis from the reticulation point of the WTP of Benta (16.44km), Medang (0.53km), Sungai Jelai (60.63km), Merapoh (20.17km) and Mela (47.41km). Medang WTP has a very short distribution of the water supply to the surrounding areas in the Kuala Lipis district; therefore, the grey area is not shown on the map. The map of Cameron Highlands water treatment plants (WTP) with fluoride feeders from year 2015 to 2019 and its radius of distribution shows the buffer zone (in grey) radius of the water distribution in Cameron Highlands from the reticulation point of the WTP of Kuala Terla is 96.66km. The buffer zone (in grey) shows the radius of the water distribution in Kuantan from the reticulation point of the WTP of Panching (109.36km), Kg. Padang (17.02km), Semambu (51.59km), Bukit Ubi (55.93km), Pasir Kemudi (17.98km), Lepar Hilir (90.46km) and Bukit Sagu (21.22km) respectively. The buffer zone (in grey) shows the radius of the water distribution in Jerantut from the reticulation point of the WTP of Batu Embun (8.04km), Batu Balai Fasa 3 (8.54km) and Batu Balai Fasa 4 (44.11km). The buffer zone (in grey) shows the radius of the water distribution in Bera from the reticulation point of the WTP of Triang (169.44km), Bera Kompleks (66.99km) and Sungai Bera (14.80km). In the map, WTP Bera Kompleks (white dot image) is located near WTP Sungai Bera, which is located underneath the black dot. The buffer zone (in grey) shows the radius of the water distribution in Bentong from the reticulation point of the WTP of Bentong Fasa 2 (96.80km), Mempaga (73.04km), Jawi Jawi (39.96km), Lurah Bilut (23.59km), Karak (37.09km) and Janda Baik (47.47km). The buffer zone (in grey) shows the radius of the water distribution in Bentong from the reticulation point of the WTP of Sungai Keratong (96.35km), Bandar 26 Felda Selandang (11.60km), Sepayang (25.92km) and Sungai Aur (71.14km).

Figure 2 shows that in Maran district, all the WTPs initially had optimal fluoride ranges (0.4 to 0.6 ppm) in the water supply distribution (0.53 to 0.55 ppm) in 2015 and 2016. In 2017, the mean fluoride range of all

WTPs was reduced to a suboptimal mean range except for WTP Bukit Kertau, which still was in the range of optimal fluoride (0.4 ppm) marked by blue radius. Consequently, in 2018 and 2019, all the WTPs had a suboptimal mean range of fluoride levels marked by a grey radius in all Maran water supply (0 to 0.13 ppm).

Additionally, Figure 2 showed that Pekan district that initially, in 2015, all the WTPs in Pekan had suboptimal fluoride levels in the water supply distribution (ranging from 0 to 0.21 ppm) except for WTP Sekor, which had optimal fluoride (0.43 ppm). From 2016 to 2019, all WTPs had suboptimal fluoride levels ranging from 0 to 0.39 ppm.

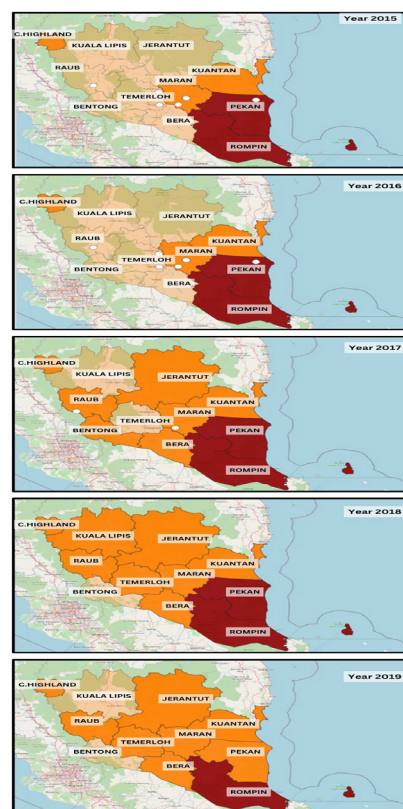
Temerloh, in 2015, all WTPs had suboptimal fluoride levels in the water supply distribution, which ranged from 0.02 to 0.2 ppm, except for Seberang Temerloh WTP (1.6 ppm). In 2016, all WTPs had suboptimal fluoride levels of 0.13 to 0.18 ppm except for Jenderak Utara and Lubok Kawah WTPs, with 0.63 and 0.78 ppm, respectively. From 2017 to 2019, all the WTPs had suboptimal fluoride levels in the water supply distribution, which ranged from (0 to 0.2 ppm).

Raub, initially from 2015 until 2016, all WTPs in Temerloh had suboptimal fluoride levels in the water supply distribution, which ranged from 0.02 to 0.2 ppm except for Sungai Bilut WTP 1.6 ppm). In 2017 and 2018, all WTPs had suboptimal fluoride levels of 0.13 to 0.18 ppm, except for Bukit Fraser, with 0.63 ppm. From 2018 to 2019, all the WTPs had suboptimal fluoride levels in the water supply distribution, which ranged from (0 to 0.2 ppm).

This study captures the dental caries data (from 2015 to 2019) of 222,245 preschool children in Pahang. A total of 48,318 preschool children represented 2.80% of Pahang's population in 2019. Additionally, Kuantan is the most populated district, comprising 30.7% of Pahang's population. Caries experience of preschool children in Pahang between 2015 and 2019 can be viewed as a layer of time series and the trend of heat map analysis of changing along the year, as can be seen in Figure 3.

Figure 3 shows the trend of caries in Pahang in 2015 and the mean dfx index (decayed, filled, extracted) range, which is represented by different colours: mean dfx 0.00 to 1.50 (faded orange), 1.51 to 3.00 (orange) and 3.01 to 4.50 (brown). The white dots were the location of WTPs that have the optimal fluoride concentration range between 0.4 to 0.6 ppm. These WTPs were in districts of Pekan (WTP Sekor), Maran (WTP of Jengka Utama, Pekan Tajau, Bukit Kertau and Simpang Jengka), Temerloh (WTP Seberang Temerloh) and Raub (WTP Sungai Bilut). In 2016, as depicted in Figure 2, white dots are WTPs in districts of Maran (WTP of Jengka Utama, Pekan Tajau, Bukit Kertau and Simpang Jengka),

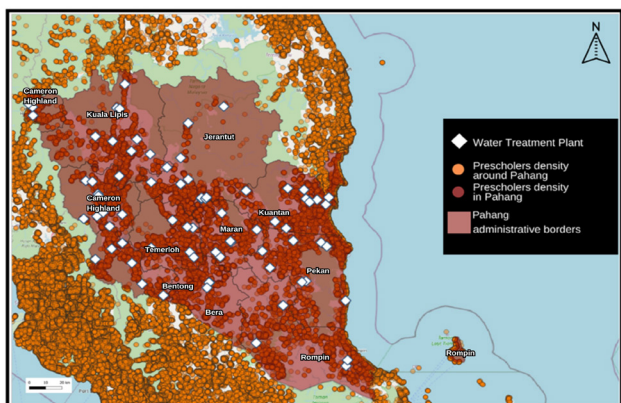
Temerloh (WTP of Jenderak Utara and Lubok Kawah) and Raub (WTP Sungai Bilut). Bera was visualised as having a higher incidence of caries, as depicted in orange. Consequently, in the year 2107, Bentong, Raub and Jerantut districts visually changed into orange-coloured areas, indicating increased mean dft of preschool children in 2017 with WTPs with optimal fluoride concentration, which in districts of Maran (WTP Bukit Kertau) and Raub (WTP Bukit Fraser). In the subsequent years until 2018, there was no WTP with the optimal range of fluoride. Almost all districts have the mean dfx index (decayed, filled, extracted primary teeth) in the range of 1.5 to 4.5, except for the district of Kuala Lipis and Bentong, with mean dfx in the range of 0.00 to 1.50, as shown in the year 2018. Lastly, in 2019, all districts retained their mean dfx range from last year except for Kuala Lipis, which has a reduction of mean dfx into the value in the range of 0 to 0.15.



**Figure 3: Heatmap of mean dfx of preschool children and the WTPs with fluoridated water supply in Pahang from 2015 to 2019**

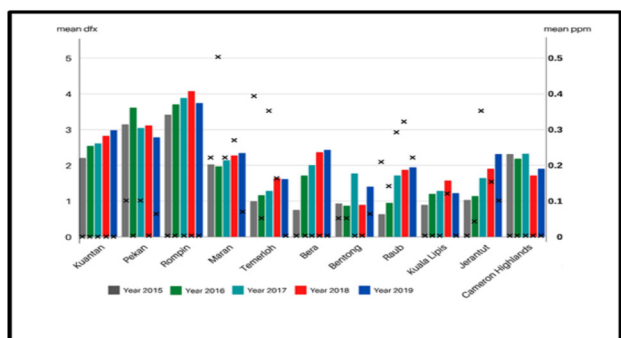
Figure 4 shows the distribution of the preschool children population in Pahang in relation to the Water Treatment Plants (WTP) in 2019. The population of preschool children in Pahang were located mainly around areas without rugged terrains (outside the greenish area with thick forestry in the high-altitude area, range of Titiwangsa), mostly around regions developed in small towns for each district. It is symbolised in the figure as round maroon dots. The WTPs in Pahang were also located near the densely populated areas. The population and WTPs in Pahang were well distributed on the map

except in the northeast region, particularly in the district of Jerantut. Each orange and maroon dot represents ten preschool children, and the WTPs are depicted as white rectangular objects in the Figure 4.



**Figure 4: GIS Distribution of preschool children population in Pahang in relation to the WTPs in 2019**

Figure 5 shows the mean dfx index (decayed, filled, extracted primary teeth) (presented in bars according to year) and mean ppm fluoride values (plotted in crosses) for each district from 2015 to 2019. Not included in Figure 5 is the overall mean dfx index of the preschool children for the state of Pahang, which was 2.45. It is a comparison graph of the caries experience and fluoride level in water supply across districts in Pahang in 5 years (2015-2019). The districts that showed an increasing trend of mean dfx index (decayed, filled, extracted primary teeth) within the five years were Kuantan, Bera, Raub, and Jerantut. In addition, Rompin consistently had the highest mean dfx index compared to the other districts throughout the years. From the context of water fluoridation, Rompin had no fluoride in the water supply from 2015 to 2019. The districts that showed a decrease in the mean dfx index between 2015 and 2019 were Pekan, Rompin, Bentong and Kuala Lipis. However, the mean dfx index ranged from 1.22 to 3.74 from 2015 to 2019. All the districts had a lower mean dfx index in 2015 than in 2019, except for Pekan and Cameron Highlands. Only Maran had the optimum level of fluoride in the water supply in 2016, which was 0.5 ppm. All the other districts had suboptimal fluoride levels in the water supply since 2015.



**Figure 5: Graph of the mean dfx and mean fluoride level (ppm) of each district in Pahang from 2015 to 2019**

**DISCUSSION**

**Reduction in fluoride concentration of water fluoridation scheme in Pahang to suboptimal range**

In 2012, the annual report from the Oral Health Division MOH reported that Sabah had reinstated public water fluoridation for the population but still needed help with the budget and technical issues of fluoridating the water supply. In Malaysia, it is reported that 26 out of 298 WTPs with fluoride feeders were inactive due to a lack of resources to purchase fluoride supplies, including in Pahang (25). Furthermore, the water distribution management differs across states, each adhering to local standards and protocols (26). A decade ago, most of Pahang's residents enjoyed access to fluoridated water that was rigorously maintained within the optimal range for preventing dental caries, as per the Ministry of Health recommendation in 2019. However, our research indicates a significant reduction in fluoride concentration in Pahang by 2019, as seen in buffer analyses of Figures 1 and 2.

Several areas in the Pahang districts have fluoridated public water supply. These areas were North and West of Kuala Lipis, North of Jerantut, East of Rompin, East of Maran and South of Pekan. Due to the partial distribution of fluoridated water supply from WTPs that catered to the entire Pahang population, some districts rely on the nearest WTPs with fluoridation located in neighbouring districts. In such cases, residents may have experienced the 'halo effect' from adjacent fluoridated areas, akin to a study conducted in Alaska (4).

Buffer analysis as a means of determining whether the population have accessibility to fluoridated water supply This research builds on and extends the geospatial analysis methods used in previous studies, such as the one conducted in Western Australia, which examined school water fluoride levels to identify areas with suboptimal fluoride levels for targeted oral health interventions (7). The novel approach of this study lies in applying buffer analysis to assess the distribution of fluoridated water from Water Treatment Plants (WTPs) to the general population in Pahang, Malaysia. While the Western Australia study focused on fluoride levels at specific points (schools), this research expands the scope by analysing water fluoridation coverage across entire populations, using buffer zones to estimate the spatial reach of reticulated water systems.

Buffer analysis provides an innovative method to map potential fluoridated water distribution and evaluate its relationship with dental caries prevalence among preschool children. This technique offers a more comprehensive assessment of water fluoridation programs at a population level rather than limiting the analysis to individual institutions like schools. Furthermore, the study contributes a novel application of geographic information systems (GIS) in dental

public health, especially in resource-limited settings where detailed infrastructure data may be limited. By integrating this approach with insights from the Western Australia study, this research sets a new standard for understanding the spatial distribution of fluoridated water and its impact on dental health, facilitating more targeted and efficient public health interventions.

#### **Feasibility of WTP location in geodiversity country**

Water fluoridation planning and execution in Pahang is highly complicated due to the geographic complexity of the area, similar to the situation in Western Australia (7). This has caused the number of WTPs and fluoride feeders to differ between districts in Pahang, and it is further complicated by a variety of population densities in each area. Water treatment plants in Pahang were built in less complicated terrains of deep forests and mountains. The western part of Pahang, the natural backbone of the Titiwangsa Range, runs from the upper part of Cameron Highlands downwards to Bentong and consists of mountainous forests of varying heights. On the east side of Pahang, the difficult terrains consist of thick forestry of national reserves in Jerantut. The complexity of the geography in Pahang may contribute to the complicated setup of WTPs and fluoride feeders in certain areas (27). In this study, the rural areas were affected mainly by the lack of fluoridated water supply, which might suggest that they tend to find other resources of water supply that could be similarly seen in Australia, whereby most indigenous communities residing in remote areas tend to use self-collected tanks water without being process (28). Furthermore, populations scattered sparsely around the jurisdiction and added geographical complexities made the fluoridation scheme challenging to execute (7).

#### **Caries Experience (dft) and fluoride level in water fluoridation system**

In the non-fluoridated areas in Pahang, a study has found that the prevalence of caries was 61.6% despite the fact that more than 80% of the Indigenous population practised tooth brushing twice daily with fluoridated toothpaste in a remote district, such as Cameron Highlands (29). Other studies also supported these findings, showing that water fluoridation cessation leads to tooth decay (3,4,30). Aside from Cameron Highlands, all the districts in Pahang had a consistent mean level of fluoride of 0 with an increasing trend of caries prevalence. Rompin was the district that recorded the highest mean dft value (3.41 to 4.07).

In terms of socioeconomic background, comparing Kuantan to Seremban, which has almost similar household income status, Kuantan has a lower mean dft status, although it is a non-fluoridated area (31). This could be attributed to a higher household income and education level, which contributes to parents having better attitudes towards their child's oral health care (32). However, in nations with low-income and high-income

inequality, the DMFT and per capita sugar intake show a substantial positive connection (33). In another district from a different state, such as Pasir Mas, which was similar to Kuantan in terms of zero water fluoridation, Pasir Mas recorded a high mean dft with  $11.1 \pm 4.8$ , with additional factors such as low household income. This provides the possibility that low household income is associated with higher caries prevalence apart from fluoridation status (34). Another study in Kota Bharu found that the mean dft in private preschool children for affluent residents was only half of that in Pasir Mas, with  $5.27(\pm 5.22)$ , despite having no public water fluoridation (35).

#### **Key findings**

The distribution of fluoridated water supply to the population of Pahang is no longer optimal for potentially beneficial effects for caries prevention at the population level. The majority of the Pahang preschool children resided within the distribution zone of reticulated water supply that potentially can be fluoridated. Caries trends of the preschool children of Pahang were seen increasing from 2015 to 2019 when there was no fluoridated water supply. With the decreasing fluoride levels in the water supply, the caries experienced by preschool children in Pahang increased.

#### **Study Limitations**

The data on the distribution of reticulated water supply from the Water Treatment Plants (WTPs) in Pahang were provided by the private water supply company in the form of the total length (in kilometres) of all types of piping systems. These pipe lengths were converted into a radius for mapping in QGIS, assuming that the piping follows the major roadside routes until the end of the distribution network. However, this method may only partially capture the actual spatial distribution of the water supply network. The study's reliance on pipe length rather than detailed spatial data limited the precision of the geospatial analysis. Furthermore, buffer zones around the reticulated water supplies overlapped in some areas, which introduced uncertainties in estimating the exact boundaries of water usage, especially in cases where the community may be using water indirectly from nearby facilities such as schools or eateries rather than from households.

Additionally, confounding variables, such as socioeconomic status (SES) and alternative sources of fluoride (e.g., fluoridated toothpaste or dietary sources), could have significantly impacted the study's outcomes. Unfortunately, the secondary data used in this study did not provide sufficient details to account for these variables. As a result, while the study acknowledges the potential influence of SES and other fluoride sources on dental caries prevalence, the lack of readily available data for these variables in the group of samples studied meant that their effects could not be fully controlled for in the analysis. This limitation reduces the ability

to accurately assess the isolated impact of water fluoridation on oral health outcomes.

Moreover, the study predominantly used secondary data provided by the relevant authorities, which could have discrepancies due to variations in record-keeping practices. Some of the data were incomplete or contained excessive, irrelevant information, such as distribution patterns that did not fully contribute to the analysis. Despite focusing on secondary data regarding the prevalence of water fluoridation and dental caries among preschool children, the study's findings suggested that higher household income may partially mitigate the negative effects of a lack of water fluoridation. Nevertheless, these insights are drawn from limited data, and more comprehensive primary data would enhance the accuracy of future studies.

### **Implication for Policy**

The findings from this research underscore the critical need for a reassessment of water fluoridation policies in Malaysia, particularly in states like Pahang, where fluoridation practices are not consistently implemented. The observed increase in dental caries prevalence among preschool children during periods without fluoridated water highlights the public health consequences of inadequate water fluoridation. To address this issue, policymakers should prioritize the consistent and effective delivery of fluoridated water as a preventive measure against dental caries, especially in regions where alternative sources of fluoride may be less accessible or unaffordable. In cases where reinstating water fluoridation proves to be financially impossible, other sustainable alternatives such as targeted fluoride varnish programme in schools or subsidized fluoridated toothpaste distribution in schools.

Furthermore, the innovative use of buffer analysis in this study provides a new perspective for public health planning by mapping the potential reach of fluoridated water from Water Treatment Plants (WTPs). This method enables authorities to identify gaps in the current water distribution network and better understand which communities may be at higher risk of dental health issues due to inadequate fluoride exposure. By integrating such geospatial data into water fluoridation strategies, health agencies can make informed decisions about where to focus resources and interventions, ensuring that the benefits of fluoridated water reach all communities, including those in remote or underserved areas.

Lastly, this research emphasizes the need for collaboration between governmental bodies including universities, water supply companies, and health organizations, to address the technical and logistical challenges of water fluoridation. Policymakers should facilitate partnerships that ensure reliable data sharing and infrastructure improvements, enabling more precise monitoring and management of water fluoridation levels across different

regions. By adopting these evidence-based strategies, Malaysia can strengthen its water fluoridation policy framework and achieve better dental health outcomes for its population.

### **Future Research**

To improve the accuracy and reliability of future studies, it is recommended to use more detailed and real-time spatial data, similar to a study conducted in Western Australia in 2017, to better represent the actual distribution of reticulated water systems. Such data would allow for more precise mapping and analysis, leading to more accurate interpretations of the areas affected by water fluoridation programs. This would also reduce the uncertainty introduced by assumptions regarding the location of water pipelines.

Moreover, conducting an economic evaluation of water fluoridation programs in Malaysia is strongly recommended to justify the long-term sustainability of such initiatives. This would provide valuable insights into the cost-effectiveness of these programs and offer policymakers data-driven evidence to support future investments. Further studies should also consider incorporating more comprehensive data sources, such as spatial distribution patterns of water usage and more precise socioeconomic indicators, to capture the complex interactions between household income, access to fluoridated water, and dental health outcomes. These efforts would contribute to a more robust understanding of the effectiveness of water fluoridation as a public health measure in Malaysia.

### **CONCLUSION**

The study highlights that the distribution of fluoridated water in Pahang has become suboptimal for caries prevention, with an increase in dental caries among preschool children from 2015 to 2019 corresponding to the absence of fluoride in the water supply. Despite most preschool children residing in areas with potential access to fluoridated water, the lack of consistent fluoridation has likely contributed to the rising prevalence of caries. Alternative fluoridation modes should be implemented to provide a more practical solution for the cessation of community water fluoridation.

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## REFERENCES

1. Roberts DJ, Massey V, Morris J, Verlander NQ, Saei A, Young N, et al. The effect of community water fluoridation on dental caries in children and young people in England: an ecological study. *Journal of Public Health*. 2023;45(2):462-9. doi: 10.1093/pubmed/fdac066
2. Matsuo G, Aida J, Osaka K, Rozier RG. Effects of community water fluoridation on dental caries disparities in adolescents. *International journal of environmental research and public health*. 2020;17(6):2020. doi: 10.3390/ijerph17062020
3. McLaren L, Singhal S. Does cessation of community water fluoridation lead to an increase in tooth decay? A systematic review of published studies. *J Epidemiol Community Health*. 2016;70(9):934-40. doi: 10.1136/jech-2015-206502
4. Meyer J, Margaritis V, Mendelsohn A. Consequences of community water fluoridation cessation for Medicaid-eligible children and adolescents in Juneau, Alaska. *BMC Oral Health*. 2018;18:1-10. doi: 10.1186/s12903-018-0684-2
5. Zokaie T, Pollick H. Community water fluoridation and the integrity of equitable public health infrastructure. *Journal of public health dentistry*. 2022;82(3):358-61. doi: 10.1111/jphd.12480.
6. Senevirathna L, Ratnayake HE, Jayasinghe N, Gao J, Zhou X, Nanayakkara S. Water fluoridation in Australia: A systematic review. *Environmental Research*. 2023;116915. doi: 10.1016/j.envres.2023.116915
7. Al-Bloushi N, Trolio R, Kruger E, Tennant M. High resolution mapping of reticulated water fluoride in Western Australia: opportunities to improve oral health. *Australian Dental Journal*. 2012;57(4):504-10. doi: 10.1111/j.1834-7819.2012.01727.x
8. Masood M, Yusof N, Hassan MI, Jaafar N. Longitudinal study of dental caries increment in Malaysian school children: a 5-year cohort study. *Asia Pacific Journal of Public Health*. 2014;26(3):260-7. doi: 10.1177/1010539511420704
9. MOH. Annual Report 2018 Oral Health Programme, Ministry of Health Malaysia. 2018.
10. Abdul Karim F, Yuzadi Mohd Yusof Z, Azlida Mohd Nor N. Dental caries among 12-year-old children after discontinuation of water fluoridation in Pahang, Malaysia. *Makara Journal of Health Research*. 2020. doi: 10.7454/msk.v24i3.1221
11. Khashoggi BF, Murad A. Issues of healthcare planning and GIS: a review. *ISPRS International Journal of Geo-Information*. 2020;9(6):352. <https://doi.org/10.3390/ijgi9060352>
12. Tokatlı C, Güner Ş. Fluoride Levels in Drinking Water and Assessment of Water Quality in Terms of Teeth Health in a Significant Watershed in Thrace Region: Ergene River Basin. *Acta Aquatica Turcica*. 2020;16(2):238-45. <https://doi.org/10.22392/actaquatr.644087>
13. MOH O. Guidelines for Water Fluoridation Programme in Malaysia. In: Oral Health Programme MoH, Malaysia, editor. 2024.
14. Karim FA, Yusof ZYM, Nor NAM. Water Fluoridation And Oral Health In Malaysia: A Review Of Literature: *Journal of Health and Translational Medicine (JUMMEC)*. 2020;23(2):76-91. <https://doi.org/10.22452/jummec.vol23no2.12>
15. Mohd Nor NA, Chadwick BL, Farnell DJ, Chestnutt IG. The impact of a reduction in fluoride concentration in the Malaysian water supply on the prevalence of fluorosis and dental caries. *Community dentistry and oral epidemiology*. 2018;46(5):492-9. doi: 10.1111/cdoe.12407
16. Desai P, Kruger E, Trolio R, Tennant M. Western Australian schools access to dentally optimal fluoridated water. *Australian dental journal*. 2015;60(1):112-8. doi: 10.1111/adj.12260
17. MOH. Annual Report 2012 Oral Health Programme, Ministry of Health Malaysia. 2012.
18. Saimy IS, Yusof NAM. The need for better water policy and governance in Malaysia. *Procedia-Social and Behavioral Sciences*. 2013;81:371-5. doi: 10.1016/j.sbspro.2013.06.445
19. Schuch HS, Dantas RVF, Seerig LM, Santos IS, Matijasevich A, Barros AJ, et al. Socioeconomic inequalities explain the association between source of drinking water and dental caries in primary dentition. *Journal of dentistry*. 2021;106:103584. doi: 10.1016/j.jdent.2021.103584
20. Duangthip D, Gao SS, Lo ECM, Chu CH. Early childhood caries among 5-to 6-year-old children in Southeast Asia. *International dental journal*. 2017;67(2):98-106. doi: 10.1111/idj.12261
21. Masood M, Yusof N, Hassan MI, Jaafar N. Longitudinal study of dental caries increment in Malaysian school children: a 5-year cohort study. *Asia Pacific Journal of Public Health*. 2014 May;26(3):260-7. DOI: 10.1177/1010539511420704
22. Nor NAM, Chadwick B, Farnell D, Chestnutt I. The prevalence of enamel and dentine caries lesions and their determinant factors among children living in fluoridated and non-fluoridated areas. *Community Dent Health*. 2019;36(3):229-36. DOI: 10.1922/CDH\_4522Nor08
23. Berhan Nordin EA, Shoaib LA, Mohd Yusof ZY, Manan NM, Othman SA. Oral health-related quality of life among 11–12 year old indigenous children in Malaysia. *BMC Oral Health*. 2019;19:1-10. DOI: 10.1186/s12903-019-0833-2
24. Clarkson J, Macey R, Alam R, Tugwell P, Welch V, Glenny A. Water fluoridation for the prevention of dental caries. *Cochrane Database Syst Rev*. 2015. DOI: 10.1002/14651858.CD010856.pub2
25. Lee ZL, Gan WY, Lim PY, Hasan R, Lim SY. Associations of nutritional status, sugar and second-hand smoke exposure with dental caries among 3-to 6-year old Malaysian pre-schoolers: a cross-sectional study. *BMC Oral Health*. 2020;20:1-9.

- doi: 10.1186/s12903-020-01152-0
26. Saldūnaitė K, Bendoraitienė EA, Slabšinskienė E, Vasiliauskienė I, Andrukevičienė V, Zūbienė J. The role of parental education and socioeconomic status in dental caries prevention among Lithuanian children. *Medicina*. 2014;50(3):156-61. doi: 10.1016/j.medici.2014.07.003
  27. Ruhaya H, Jaafar N, Jamaluddin M, Ismail AR, Ismail NM, Badariah TC, et al. Nutritional status and early childhood caries among preschool children in Pasir Mas, Kelantan, Malaysia. *Arch Orolfac Sci*. 2012;7(2):56-62.
  28. Dolah S, Eusufzai SZ, Alam MK, Ahmad WMAW. Factors influencing oral health-related quality of life among preschool children in district of Kota Bharu, Malaysia: a cross-sectional study. *Pesquisa Brasileira em Odontopediatria e Clínica Integrada*. 2020;20:e5052. <https://doi.org/10.1590/pboci.2020.008>
  29. Elmer T, Langford J, Morris A. An alternative marker for the effectiveness of water fluoridation: hospital extraction rates for dental decay, a two-region study. *British Dental Journal*. 2014;216(5):E10-E. doi: 10.1038/sj.bdj.2014.180
  30. Griffin SO, Gooch BF, Lockwood SA, Tomar SL. Quantifying the diffused benefit from water fluoridation in the United States. *Community dentistry and oral epidemiology*. 2001;29(2):120-9. doi: 10.1034/j.1600-0528.2001.290206.x.
  31. Cronin J, Moore S, Harding M, Whelton H, Woods N. A cost-effectiveness analysis of community water fluoridation for schoolchildren. *BMC Oral Health*. 2021;21:1-12. doi: 10.1186/s12903-021-01490-7
  32. Marico R, Zaror C. Economic evaluations in water-fluoridation: a scoping review. *BMC oral health*. 2020;20:1-12. DOI: 10.1186/s12903-020-01100-y