Investigation on Fluoride Concentration in Well Water and Its Health Implications: A Case Study of Gwagwalada, Gwagwalada Area Council, FCT, Abuja

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Abstract

This study focuses on determining the concentration of fluoride ions in selected hand-dug wells and investigating its health implications in Gwagwalada Area Council, Federal Capital Territory, Abuja. The necessity for this investigation arose from observed health issues, including dental and skeletal fluorosis among the residents in the area. Fifteen sampling points (well water sources) were chosen in the study area, and a total of forty-five samples (three per sampling point) were collected. The calorimetric water quality analysis method was employed to analyze these samples in the laboratory. Additionally, the Inverse Distance Weighting (IDW) interpolation method was used to generate a spatial variation map for fluoride ion concentration using ArcMap. The results indicate a concentration range of 0.122 mg/L to 1.910 mg/L across the study area. When compared with the recommendations for fluoride ion concentration in the Nigeria Industrial Standard (NIS) for drinking water (0.1 – 1.0 mg/L), approximately 67% of the sampling points (10 out of 15) fall within the recommended values, while 33% fall outside. The areas with higher fluoride ion concentrations include Dupa 1, Dupa 2, Tunga Maje 1, Tunga Maje 2, and Old Kutunku 2. The study concludes that the observed dental and skeletal fluorosis in these areas can be attributed to the consumption of water with high fluoride concentrations. Consequently, the study recommends increased attention from both local and federal authorities to provide potable water for human consumption in these areas to address the associated health challenges.

key words

Fluoride ion

Inverse Distance Weighting

Dental Issues

Skeletal fluorosis

Spatial Variation

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1 Background of the Study

Approximately 780 million people around the world have no access to safe potable water [1] with about 2.5 billion people worldwide largely dependent on groundwater for their daily water needs [2,3,4]. Groundwater quality is a substantial global environmental concern that necessitates the monitoring of various physicochemical parameters, encompassing both cations and anions [5,6]. The presence of fluoride in groundwater is particularly noteworthy, as it is established that fluoride strengthens tooth enamel and serves as a preventive measure against dental issues such as caries, tooth decay, tooth loss, and cavities [7]. The use of fluoride in dental products is therefore viewed as an important means to improve dental health. Furthermore, countries such as Brazil, Malaysia, the United Kingdom, and the United States artificially fluoridate drinking water for public health reasons so that people are continuously exposed [8]. The Centers for Disease Control and Prevention [9] considers water fluoridation as one of the ten great public health achievements of the 20th century.

Fluoride is known to occur at elevated concentrations in several parts of the world and such circumstances can have, and often have, a significant adverse impact on public health and well-being [10]. Elevated fluoride concentrations are likely in groundwaters sourced from calcium-poor aquifers and regions where fluoride-bearing minerals are prevalent. Additionally, fluoride concentrations may increase in groundwaters where cation exchange, involving the substitution of sodium for calcium, takes place. Understanding these geological and hydrochemical factors is crucial for assessing and managing fluoride levels in groundwater to safeguard public health [11].

Fluoride is commonly associated with volcanic activity and fumarolic gases. Thermal waters, especially those of high pH, are also rich in fluoride [12]. Fluorides are found at significant levels in a wide variety of minerals, including fluorspar, rock phosphate, cryolite, apatite, mica, hornblende, and others [13]. Fluoride ions have the same charge and nearly the same radius as hydroxide ions and may replace each other in mineral structures [14]. Fluoride tends to occur in areas where fluoride-bearing minerals such as fluorspar (CaF_2), cryolite (Na_3AlF_6), apatite ($Ca_5(PO_4)3F$), and hornblende [$(Ca, Na)_2(Mg, F, Al)_5(Si, Al)8O_{22}(OH)_2$] are most abundant [15]. Fluoride indeed has beneficial effects on teeth at low concentrations in drinking water, prompting several countries to fluoridate their water supplies to achieve optimal levels. However, both concentrations below and above the World Health Organization's recommended levels can pose serious health challenges, as evident in the health conditions observed in the study area. Consequently, research into the concentration of fluoride in well water and its health implications is crucial and cannot be overstated. This type of research is essential for informed decision-making and effective public health interventions to address issues related to fluoride exposure[38].

The occurrence of fluoride in water has also been considered to result from water-rock interaction through weathering of fluoride-rich rocks and circulation processes of water in soils and rocks [16]. As a result, fluoride is leached out and dissolves in groundwater and thermal gases [17]. Some of the important rocks bearing fluoride minerals include volcanic, gneissic, and granitic rocks [18] Although, fluorine is reported to be the most abundant halogen in sedimentary rocks, it is generally low except in areas with specific mineralization [19]. High fluoride concentrations have been observed in groundwaters, especially in arid and semi-arid sedimentary aquifers [20].

A meta-study conducted by researchers from the Harvard School of Public Health [21] reviewed several earlier papers and concluded that exposure to high dosages of fluoride is associated with a reduction of almost half of a standard deviation in IQ among children. It is noteworthy that many of these studies investigated very high levels of fluoride, surpassing the World Health Organization's (WHO) recommendation that fluoride should not exceed 1.5 mg/l in drinking water [22]. However, it's important to acknowledge that some studies reporting negative effects on cognitive development [23] have found evidence that people tend to be concerned with fluoridation. This highlights the complexity of the issue and the need for further research to understand the potential impacts of fluoride exposure on cognitive function.

The advantages of fluoride ingestion to human health are limited to fluoride levels of about 1.0 mg/l in potable water; such levels of fluoride are said to improve skeletal and dental health [24]. The science behind the beneficial effects of fluoride on the skeletal structure is based on the ion exchange reactions between hydroxide and fluoride ions in the calcium hydroxy-phosphate as

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indicated in Equation 1 [15]. From Equation 1, an acid-resistant structure, fluorapatite is formed due to the replacement of hydroxide with fluoride ions [15]. Fluorapatite prevents dental caries since it is more resistant to acid attack compared to hydroxyapatite [25].

$$Ca_5(PO_4)3OH^+ F^- \rightarrow Ca_5(PO_4)3F + OH^- \quad \text{[Eq. 1]}$$

Drinking water with high fluoride levels above 1.5 mg/l results in negative health impacts [26]. For example, fluoride in water between 1.5 and 3.0 mg/l is likely to cause mottling and browning of teeth which is referred to as dental fluorosis [27], this makes the teeth brittle and very hard [28]. Similarly, the science behind the negative effects of fluoride on the skeletal structure is based on the ion exchange reactions whereby the reaction goes beyond the replacement of hydroxide during excess fluoride intake as shown in Equation 2.

$$Ca_5(PO_4)3F + 9F^- \longrightarrow Ca_5F_{10} + 3PO_4^{3-} \quad \text{[Eq. 2]}$$

From Equation 2, ion exchange takes place between fluoride and phosphate ions which results in very hard and brittle material (Calcium decafluoride). This compound is not suitable for the skeletal structure [29]. The levels of fluoride between 4 to 8 mg/l are likely to result in skeletal fluorosis whereas crippling fluorosis occurs when fluoride levels greater than 10 mg/l are consumed for an extended period [30]. Skeletal fluorosis is a condition that results in bone malformation that brings about movement difficulties while crippling fluorosis is characterized by weakening of the bone junctions and bones causing immobility [27].

Rural areas often grapple with a lack of basic amenities, particularly in healthcare, leading to various challenges. In specific regions of Gwagwalada Local Council, FCT, Abuja, issues related to dental fluorosis and skeletal fluorosis have been observed. This study aims to evaluate the fluoride ion concentration in well water in the study area, assess the health implications of current fluoride ion concentrations on consumers, and investigate the various causes of dental and skeletal fluorosis observed among the villagers.

The findings from this research are crucial for local authorities to identify the root causes of these health issues and develop effective solutions to mitigate them. Understanding the fluoride ion concentrations and associated health implications will contribute to informed decision-making and the implementation of measures to improve the overall well-being of the affected communities.

2 MATERIALS AND METHODS

2.1 Description of the Study Area

The study area is Gwagwalada town. Gwagwala-

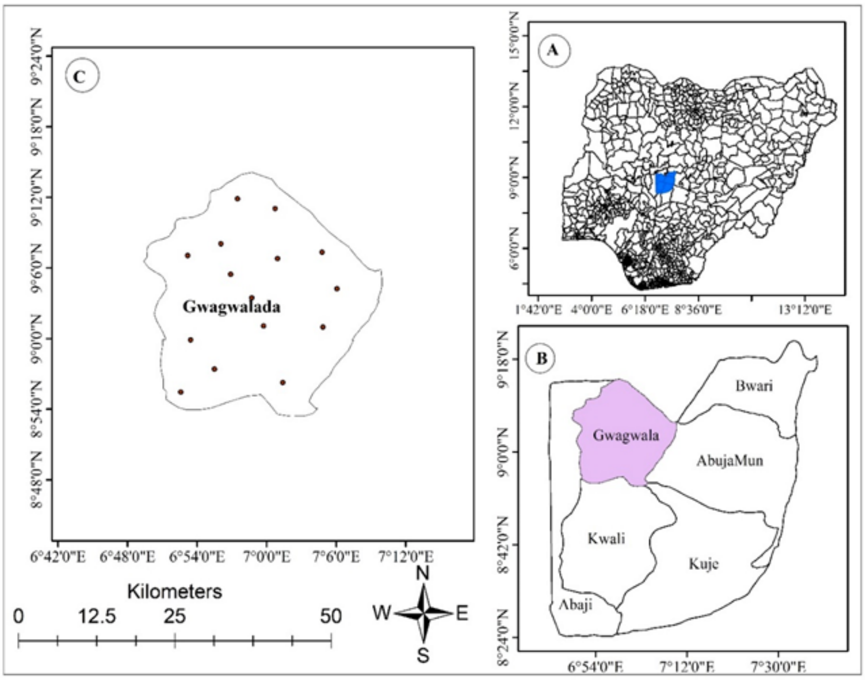

Figure 1: Study Area Location Map: (a) Map of Nigeria showing all the states and LGAs; (b) Map of FCT showing all the Council areas; (c) Map of Gwagwalada with 15 Sampling Points

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da town is one of the largest satellite towns and the third-largest urban center in the Federal Capital Territory. It is one of the most densely populated areas in the Federal Capital Territory (FCT) and the headquarters of one of the oldest councils in the Federal Capital Territory, Abuja [31]. Figure 1 shows the map of the study area.

2.2 Data Collection Method

Water samples were systematically collected from fifteen distinct dug wells in Gwagwalada, Gwagwalada Area Council, FCT Abuja. Rigorous cleaning of the sterile containers was carried out before utilization to ensure the samples' integrity. The labeling of each water sample was meticulously performed, adhering to the locations where they were collected, to facilitate accurate identification throughout the study. This careful sampling process is essential for maintaining the reliability and traceability of the collected data.

2.3 Method of Data Analysis

The possible analytical methods for fluoride determination include:

- Ion-chromatography (IC) Method
- Ion-selective electrode (pH meter) Method
- Colorimetric Method

The type of methodology used to test the level of fluoride in water is the colorimetric method. The colorimetric method involves mixing a reagent with a sample to form a colored compound. The intensity of the color corresponds with the concentration of the Fluoride in the sample.

2.3.1 Materials Required

- Water
- Standard Excess – Aluminum (Al) procedure
- A – Z tablets (acid alizarin-zirconium mixture)
- Excess – Al tablet (containing aluminum sulfate)
- Container
- Distilled water
- Nesslériser with a comparator
- Nessler tubes (50mls).
- Comparator discs for fluoride.

2.3.2 Laboratory Procedure

Standard Excess Aluminum (AL) procedure starts by placing 50ml of the sample in a Nessleriser tube glass and add 2g of an excess- Aluminum (AL) tablet with the flattened end of a glass rod and stir until dissolved. Any turbidity appearing at this stage can be ignored. Subsequently, a further 50 of the sample in another Nessleriser glass, and 2 g of A-Z tablet (acid alizarin-zirconium mixture) was added after crushing and stirring rapidly until it dissolves. Parallelly, another 50ml of sample in a third Nessleriser glass in the left-hand compartment of the Nessleriser.

After treating the samples, We allowed them to stand until the colors of both samples align within the range of the color standard on the disc. This waiting period typically ranges from 15 to 60 minutes. Subsequently, the glasses were places in the right-hand compartment of the Nessleriser, positioning the instrument for a consistent light source (such as the eight north windows of a Nessleriser lighting unit). The disc were then rotated until color matches are achieved. The disparity between the fluoride concentrations of the treated samples provides both the fluoride concentration of the treated sample and the fluoride content of the original sample. This meticulous process ensures accurate determination of fluoride levels in the water samples. Extended delay before taking readings in 15-60 minutes is more desirable for discs. The reading should not be delayed more than an hour, it should be within the range of 15-60 minutes to get an accurate reading.

3 RESULTS AND DISCUSSION

3.1 Study Area Fluoride Concentration

A total number of forty-five samples were collected from the selected fifteen sampling points across the study area for laboratory study. About three 500ml water samples from each well were collected in a clean plastic bottle, labeled accordingly, and transported to Mozuk Scientific and Analytic Laboratories where the analysis was carried out. The sampling points' geographical and elevations were summarized in Table 1 while the average results of the analysis are summarized in Table 2. In addition, the results are better presented in a bar chart shown in Figure 2.

As shown in Figure 1, Tunga Meje 1 well has the highest fluoride concentration (1.910 mg/L) which is far about the recommended value in the Nigerian Standard for Drinking Water while Phase 3B has the lowest fluoride concentration (1.22 mg/L). Similarly, Nwankwoala et al., [32]; Danbature et al., [17]; Ankidawa et al., [10] & Lar et al., [12] studied the fluoride ion concentrations in groundwater in Katsina State, Gombe State, Adamawa State, and Benue State, Nigeria respectively.

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Table 1: Summary of the Fifteen Sampling Points, Geographical Locations (deg), and Elevations (m)

S/N	Sampling Point	Latitude (deg)	Longitude (deg)	Elevation (m)
1	Gwako 1	9.0028	7.1542	250
2	Gwako 2	9.0033	7.1542	250
3	Dupa 1	9.0608	7.1950	330
4	Dupa 2	9.0594	7.1978	350
5	Zuba 1	9.1139	7.2236	400
6	Zuba 2	9.0897	7.2178	390
7	Tunga maje 1	9.0608	7.1950	330
8	Tunga Maje 2	9.0594	7.1978	350
9	Phase 3A	8.9978	7.1517	450
10	Phase 3B	8.9967	7.1500	240
11	Old Kutunku 1	8.9967	7.1500	240
12	Old kutunku 2	9.0036	7.1547	240
13	Bako 1	9.0039	7.1547	240
14	Bako 2	9.0042	7.1550	240
15	Dawaki 1	8.9775	7.1761	280

Table 2: Summary of Average Fluoride Ion Concentrations (mg/L)

S/N	Sampling Point	Sample A	Sample B	Sample C	Avg Fl- Conc. (mg/L)
1	Gwako 1	0.820	0.780	0.800	0.800
2	Gwako 2	0.830	0.770	0.890	0.830
3	Dupa 1	1.100	1.080	1.060	1.080
4	Dupa 2	1.100	1.140	1.120	1.120
5	Zuba 1	0.880	0.860	0.900	0.880
6	Zuba 2	0.620	0.640	0.630	0.630
7	Tunga maje 1	1.900	1.920	1.910	1.910
8	Tunga Maje 2	1.005	1.010	1.015	1.010
9	Phase 3A	0.610	0.630	0.590	0.610
10	Phase 3B	0.123	0.122	0.121	0.122
11	Old Kutunku 1	0.900	1.100	1.000	1.000
12	Old kutunku 2	1.800	1.780	1.820	1.800
13	Bako 1	0.851	0.852	0.850	0.851
14	Bako 2	0.839	0.840	0.841	0.840
15	Dawaki 1	0.663	0.665	0.661	0.663

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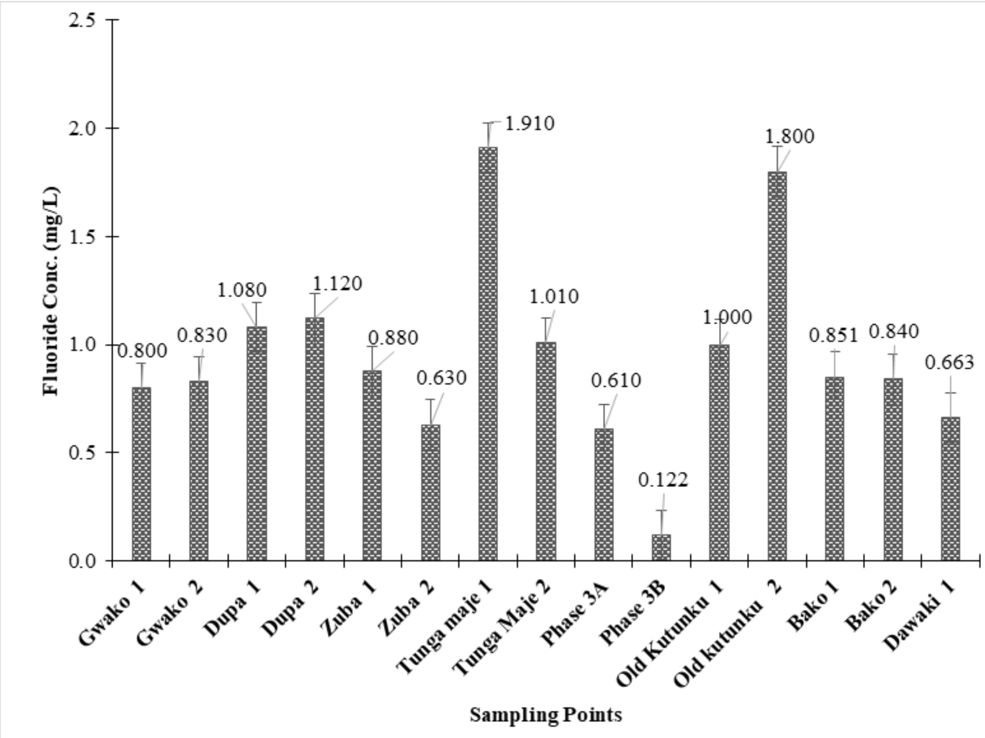

Figure 2: A Bar Chart Showing the Summary of Fluoride ion Concentrations (mg/L) across the Fifteen Sampling Points

3.2 Spatial Variation of Fluoride Concentration

Fluoride concentration variations across the study area were modeled using the Inverse Distance Weighting (IDW) technique, and the resulting map was generated in ArcGIS, as depicted in Figure 3. The map illustrates that high fluoride concentrations are predominantly observed in the central and eastern parts of Gwagwalada, aligning with areas where dental fluorosis appears to be notable. This outcome parallels findings from a study conducted by Rohana et al. [15] in Sri Lanka. The spatial representation provided by the map aids in visualizing and understanding the distribution of fluoride levels across the studied region.

3.3 Health Implications of Study Area Fluoride Concentration

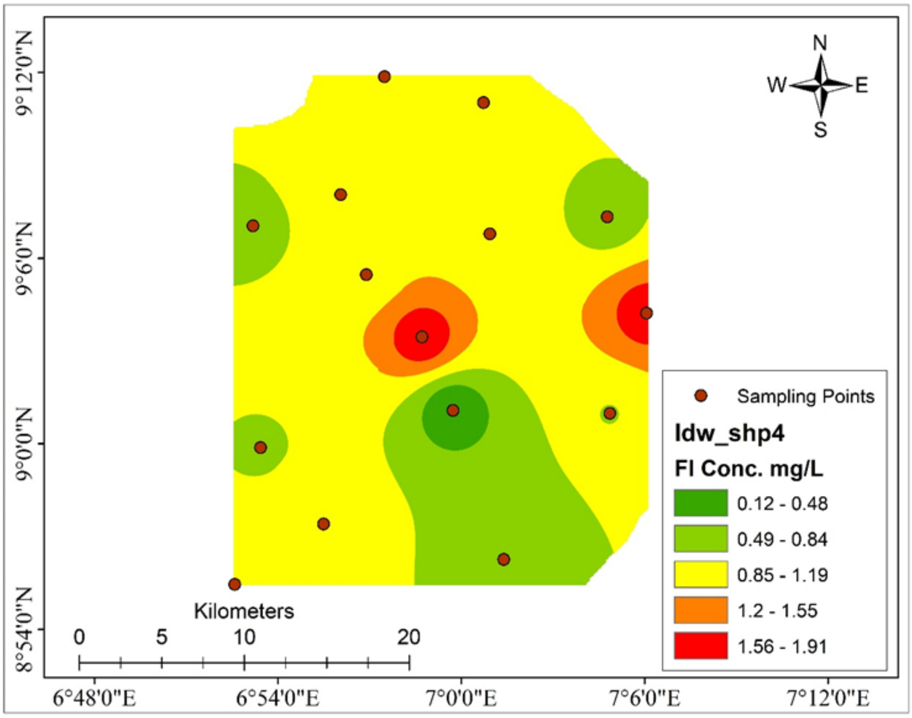

Figure 3: An IDW Map Showing the Spatial Variation of Fluoride Ion Concentrations (mg/L) in Gwagwalada

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Fluoride contamination of groundwater can have direct or indirect impacts on humans, animals, healthcare, and the agricultural sector [33]. As indicated in the results above, the maximum allowable level of fluoride in water is 1.0 mg/L. Exposure to concentrations above this threshold can result in health issues such as joint pains, restricted mobility, and skeletal and dental fluorosis [34].

Among the fifteen samples analyzed, only ten meet the Nigeria Industrial Standard, where the fluoride concentration ranges from 0-1.0 mg/L, making it acceptable for human consumption. However, the remaining five samples exhibit a high concentration of fluoride, exceeding the maximum allowable value for human consumption. Consuming water with fluoride concentrations higher than the recommended level may lead to various health issues, including skeletal deformation, cancer, dental fluorosis, and other adverse effects. This underscores the importance of monitoring and addressing fluoride levels in groundwater to ensure the well-being of the population.

Similarly, the fluoride ion concentration in Al-Dhala Basin comprises 71% of the water used for drinking purposes. Dental and skeletal fluorosis are present in people in the area who receive their drinking water sources from high levels of fluoride from the wells. The population of the study area is at high risk because of the excessive intake of fluoride, especially in the absence of knowledge of fluoride consumption [35].

3.4 Cause of Dental and Skeletal Fluorosis Noticeable in the Study Area

Human exposure to naturally existing dissolved contaminants ions in groundwater and surface water has been identified as the world's biggest mass poisoning in human history [36]. Fluoride is among the most hazardous elements contaminating groundwater resources [37]. Groundwater pollution of arsenic and fluoride is a serious issue [37]. From the laboratory experimental results, it was discovered that five samples contain high Fluoride concentrations, and these are the areas where Dental and Skeletal Fluorosis are most noticeable. Therefore, this study may conclude that these diseases (dental and skeletal fluorosis) are most likely associated with high Fluoride concentration intake from the available groundwater sources (dug wells).

4 CONCLUSIONS

The findings presented above clearly indicate that well water in certain regions exhibits elevated concentrations of fluoride, making it unsuitable for consumption. The Nigeria Industrial Standard sets the permissible fluoride concentration in water to be below 1.0 mg/L to prevent fluoride-related afflictions, such as dental and skeletal fluorosis. As a result, this investigation concludes that residents in the affected areas, including Gwagwalada Local Government and the broader Abuja region, should prioritize conducting water analyses to determine the chemical composition, with a particular focus on fluoride content, before using it for ingestion. This precautionary measure is crucial for safeguarding the health of the community members.

Drawing insights from laboratory outcomes and the observed prevalence of diseases in locales characterized by heightened fluoride levels, this study advocates for remedial actions. Specifically, it recommends that either the local government authority or the residents within the affected areas institute a miniature water treatment facility dedicated to mitigating fluoride concentrations. Furthermore, this initiative proposes a comprehensive assessment of the water quality in any accessible water sources, either conducted by the relevant authorities or the community residents. This proactive measure aims to determine the level of portability or contamination in the available water sources, thereby averting potential disease outbreaks within the communities.

5 Acknowledgement

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6 Data Availability Declaration

All the data used are contained in this submission.

7 Conflict of Interest Declaration

The authors declare no known conflict of interest

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