BKM Public Health & Community Medicine
Berita Kedokteran Masyarakat

Volume 40 **Number** 6, 2024, **Pages** e10964
DOI: 10.22146/bkm.v40i06.10964

The correlation between the levels of fluoride, $CaCO_3$, and pH in clean well water with the calculus index

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Submitted :
November 27th, 2023
Accepted:
June, 25th 2024
Published:
June, 30th 2024

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Abstract

Background: The fluoride, $CaCO_3$, and pH levels in clean well water are chemical requirements that must be considered to ensure water quality. In terms of dental and oral health, fluoride, $CaCO_3$, and pH in clean well water can increase the risk of dental calculus. Dental calculus contributes to the prevalence of periodontal diseases due to bacteria and plaque. **Objective:** This study aims to determine, analyze, and explain the correlation between the levels of fluoride, $CaCO_3$, and pH in clean, well water that is consumed among the people of Wukirsari Ward, Imogiri Subdistrict, Bantul Regency, the Special Region of Yogyakarta with the calculus index. **Methods:** This is an analytical observational study with a cross-sectional design. The subjects were 169 individuals aged between 20 and 44 years who consumed well water. Primary data were obtained directly from interviews, assessments of the calculus index, and measurements of the chemical parameters of water quality. Meanwhile, secondary data were obtained from Imogiri 1 Community Health Center. Data were analyzed using univariate, bivariate, and multivariate analyses with multiple linear regression. **Results:** Results showed significant variations in moderate fluoride levels, hard $CaCO_3$, and alkaline pH. The predominant correlation was found between low fluoride levels, high $CaCO_3$ levels in clean well water, and age with the calculus severity index. **Conclusion:** $CaCO_3$ levels in clean well water were the most strongly correlated variable and stood out as a key factor. A potential solution includes increasing fluoride levels by drinking water fluoridation and reducing $CaCO_3$ levels by boiling water. Education about water quality and dental hygiene is key to reducing the prevalence of periodontal diseases and improving public health.

Keywords: $CaCO_3$; calculus index; fluoride; pH; water

INTRODUCTION

The availability of clean water is a fundamental necessity for the survival of all beings. According to the Regulation of the Minister of Health (1990), clean water emphasizes water quality that meets health standards and can be consumed after boiling [1]. Ikhtiar supports the importance of clean water and sanitation as prerequisites for health, arguing that water quality that meets health requirements is essential to prevent human diseases [2].

In the environmental context, water quality standards include physical, biological, and chemical parameters that should be checked regularly according to the regulation [3]. Clean water and sanitation are crucial elements in the community, especially for drinking and cooking. Therefore, the quality must be considered. However, there are real challenges to the availability of clean water suitable for consumption. The Ministry of National Development Planning (2018) highlights that these challenges are part of the 2030 Sustainable Development Goals (SDGs), with a universal target of up to 100% access to decent drinking water and sanitation. A number of regions in Indonesia face these challenges, including Wukirsari Ward, Imogiri Subdistrict, Bantul Regency, and the Special Region of Yogyakarta [4].

In this region, clean water is obtained from sources such as well water. However, its predominantly choppy topography and geographical conditions are significant factors in the need for clean water. The topography of an area dramatically influences groundwater, with lowlands tending to have more water content than highlands [5]. Due to these limitations, the health of the water in Wukirsari Ward must be considered. A preliminary study on April 4, 2023, in the Regional Health Laboratory of Bantul Regency showed significant variations in the chemical parameters of healthy water, such as fluoride, $CaCo_3$, and pH, in several areas of Wukirsari Ward. For example, in the Karangtalun Cluster, the fluoride, pH, and $CaCo_3$ levels were 0,33 mg/L, 7.1 mg/L, and 195 mg/L, respectively. Meanwhile, in the Karangkulon Cluster, the fluoride, pH, and $CaCo_3$ levels were 0,44 mg/L, 6,9 mg/L, and 220 mg/L, respectively. These data suggested that the fluoride levels were below the safety limit, while the levels of pH and $CaCo_3$ were above the safe consumption limit.

This poor water quality can seriously impact public health, especially dental and oral health. Periodontal diseases due to plaque and dental calculus are increasingly spread across Indonesia [6]. These diseases develop from inflammation caused by bacteria that can result from environmental factors, including water quality [7]. Fluoride is one of the chemical water parameters that significantly affects dental health. Fluoride exposure can affect the severity of periodontal diseases [8]. The World Health Organization (WHO) determined that optimal fluoride levels to prevent tooth decay is 0,5-1,0 mg/L, while the safe consumption limit ranges between 0,7-1,5 mg/L [9].

Geographical conditions in the highlands, including in Wukirsari Ward, cause the area to have low fluoride levels. The higher an area is, the lower the fluoride levels will be. This suggests that groundwater resources are influenced by climatic and geographical factors, which result in significant differences in fluoride levels [10]. In addition to fluoride, minerals such as $CaCO_3$ can affect dental health. The number of Ca^{2+} and Mg^{2+} in water can affect water hardness [11]. WHO (2010) determined that the water hardness level safe for human consumption is 50-150 mg of $CaCO_3$/L [12]. Hard water can form calculus, an important factor in dental and oral health [13]. Another chemical parameter that affects dental and oral health is pH. Water with a high pH level reacts with saliva to form sediment that causes dental calculus [14].

Environmental factors, including water quality, are crucial for dental and oral health. The people of Wukirsari Ward who consume well water of varying qualities have a high risk of developing periodontal diseases and other related dental health problems. Dental and oral health is not an isolated problem. It affects the overall health. The WHO Global Oral Health (2022) stresses that periodontal diseases are a significant global health burden. The distribution and severity of these diseases vary, especially among underprivileged groups in many countries [15].

Studies on the quality of clean water, especially well water used by the people of Wukirsari Ward, revealed significant problems related to chemical parameters such as fluoride, $CaCO_3$, and pH. Previous studies have highlighted similar problems. For example, Artawa and Swastini found significant differences in calculus formation between the people who consumed well water and those who did not [16]. Wungkana et al. also studied the formation of calculus in a community consuming dug well water [17]. In addition, Setiawan et al. found a correlation between the alkalinity of water sources and altitude and the severity of periodontal diseases [18]. Meanwhile, Sannidhya highlighted the correlation between fluoride and calcium levels in drinking water with periodontal diseases in children aged 6 and 8 [19].

The fundamental difference with previous studies lies in the focus on independent and dependent

variables and the characteristics of the population, age, and research site. Previous studies used specific sampling techniques, such as cross-sectional surveys, analytical observational, and geographic mapping. Studies that correlate fluoride, $CaCO_3$, and pH in well water with the calculus index in the people of Wukirsari Ward have never been conducted. As a result, this study aims to fill this gap by measuring the chemical parameters of well water and correlating them with the calculus index in the local community. It is important to note that although previous studies are partly related to the variables investigated in this study, they did not specifically explore the correlation between the levels of fluoride, $CaCo_3$, and pH in well water with the calculus index in the people of Wukirsari Ward. Therefore, this study is novel in terms of exploring this correlation in the context of specific populations and locations to provide a deeper understanding of dental health and the impact of water quality on the area.

Given these problems, this study focuses on the correlation between the levels of fluoride, $CaCO_3$, and pH in well water consumed by the people of Wukirsari Ward with the calculus index. The main objective of this study is to explore and analyze the correlation between the chemical parameters of well water consumed by the people of Wukirsari Ward and the calculus index, which is the focus of this study. By understanding this correlation, the relationship between water quality and dental and oral health problems experienced by the people in the area can be revealed.

This study was encouraged by the urgent need to understand the direct impacts of water quality on dental and oral health. Practically, this study is a real contribution to a deep scientific understanding of dental and oral health problems caused by water quality in Wukirsari Ward. This study can also be an important source of information for future academics and researchers who want to understand holistic dental health.

Currently, data on dental and oral health at the Imogiri 1 Community Health Center in 2022-2023 shows that periodontal diseases, especially acute periodontitis, have a high incidence rate in the 20-44 age group, reaching 49% of diagnosed cases, with more than 344 cases of calculus. However, the World Dental Federation (FDI) stated that public awareness of the importance of oral hygiene and understanding of periodontal diseases remains low [20].

Therefore, this study aims to identify and analyze the correlation between the levels of fluoride, $CaCO_3$, and pH in clean, well water consumed by the people of Wukirsari Ward with the calculus index. This study also presents related chemical parameters of clean water, describes the calculus index in the people who consumed well water and analyzes the correlation between fluoride, $CaCO_3$, and pH with the calculus index. This study aims to comprehensively understand water quality and its impacts on dental and oral health. This study is significant in two domains. Practically, the results of this study are an important contribution to the development of science and a valuable source of information for stakeholders in addressing dental and oral health problems related to water quality in this area. Theoretically, this study provides a broader insight for the public about the importance of understanding water quality and dental and oral health.

METHODS

This is an analytical observational study with a cross-sectional design. This study was conducted in Wukirsari Ward, Imogiri Subdistrict, Bantul Regency, the Special Region of Yogyakarta, between September and October 2023. Respondents who became the research subjects were those of Wukirsari Ward who consumed well water, with a total sample of 169 individuals. The sample was taken from 16 clusters in the area using a convenience sampling technique. The inclusion criteria included individuals affiliated with the research site, in their productive age (20-44 years), who had never received scaling or periodontal treatments. Meanwhile, the exclusion criteria included individuals who did not consume well water for daily needs in the past five years, had chronic diseases, were active smokers, and were pregnant. The operational definition of the characteristics of the subjects is presented in Table 1.

Variables included exposure to well water, such as the levels of fluoride, $CaCO_3$, and pH as independent variables and the calculus index as a dependent variable [8,11]. Data were collected from interviews, examinations of the calculus index by dental health workers, and measurements of the chemical parameters of clean water at the Regional Health Laboratory of Bantul Regency.

Table 1. Operational definition of the characteristics of the subjects

Characteristics	Operational Definition	Criteria	Scale
Sex	Biological differences between men and women since birth Data obtained from the identity card of the subject	Male Female	Nominal dichotomy
Age	Age is calculated from birth until now. Data obtained from the identity card of the subject	20-44 years 1. Late teens (17-25) 2. Early adults (26-35) 3. Late adults (36-44) (MoH, 2009)	Ordinal
Economic status	The position in the community is based on monthly family income. Data obtained from short interviews	1. Very high income (>3,500,000/month) 2. High income (2,500,000-3,500,000/month) 3. Moderate income (1,500,000-2,500,000/month) 4. Low income (<1,500,000) (Statistics Indonesia, 2014)	Ordinal
Tooth brushing habit	Accuracy and way of brushing teeth in a day by the subject Data obtained from short interviews	1. Accurate (at least twice a day, after meals and before bed) 2. Inaccurate (less than twice a day, not after meals nor before bed)	Ordinal dichotomy
Education level	The highest formal education level was completed (Nasution et al., 2014). Data were obtained from short interviews.	1. Low (not attending school, elementary school, junior high school) 2. High (senior high school, university)	Ordinal

Data were analyzed using univariate, bivariate, and multivariate analyses with multiple linear regression to identify variables' correlations. Research ethics are guided by the ethical clearance from the Health Medicine Research Ethics Committee, Faculty of Medicine, Gadjah Mada University (UGM), permission from the Imogiri 1 Community Health Center, and informed consent from the research subjects to ensure the security and confidentiality of the data.

RESULTS

This study focuses on the correlation between the levels of fluoride, $CaCO_3$, and pH in well water with the calculus index among the people of Wukirsari Ward, Imogiri Subdistrict, Bantul Regency, the Special Region of Yogyakarta. This study was conducted on 169 individuals in 16 clusters who used well water as a water source. Figure 1 shows that Bantul Regency has a hilly topography with dominant soil types, including regosol, lithosol, Mediterranean, and latosol. Imogiri Subdistrict in the southeastern part of Bantul Regency consists of lowlands and highlands.

Table 2 shows that the average fluoride level in 16 clusters was moderate (0.7-1.5), 0.74 mg/L. Of 169 samples, 30.8% had moderate fluoride levels. An assessment of $CaCO_3$ showed that 30.8% of the samples had moderate $CaCO_3$ levels, 168.80 mg/L for hard water. In addition, 65.1% of the samples had relatively high pH levels, 7.12 mg/L for alkaline water.

In this study, 169 subjects comprised 63 males (37.3%) and 106 females (62.7%). Most of the subjects (26.1%) were 36-45 years. The majority of subjects (63.3%) had higher levels of education, namely senior high school and bachelor's degree, while the rest (36.7%) had lower levels of education (not attending school, elementary school, and junior high school). Economically, most subjects (40.8%) had moderate income (regional minimum wage, 1,500,000 - 2,500,00 / month). Regarding tooth brushing habits, most subjects (60.4%) brushed their teeth properly (at least twice a day after breakfast and before bed), while 39.9% did not have the habit.

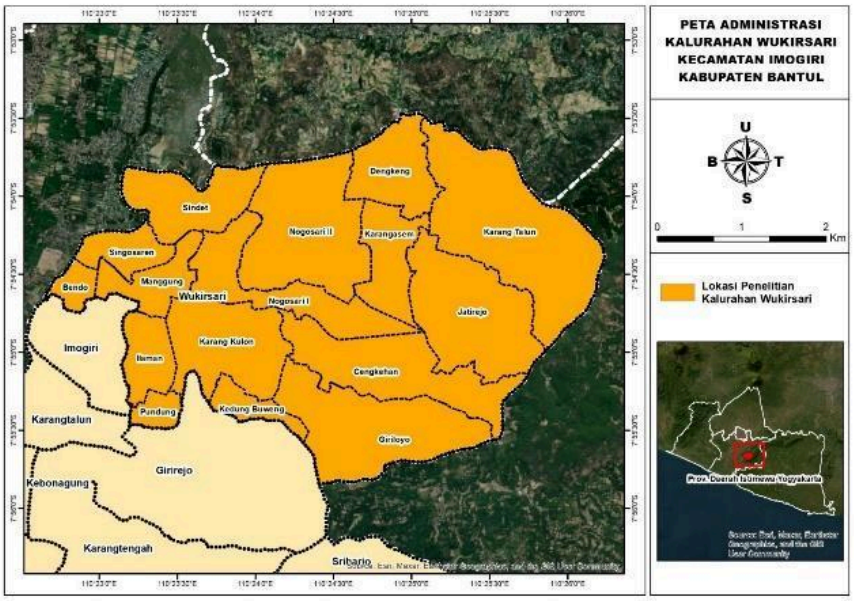

Figure 1. Administrative map of Imogiri Subdistrict [21]

Table 2. Average levels of fluoride, $CaCO_3$, and pH

Parameters of clean well water	n (%)	Average levels
Fluoride		
Very low	49 (29)	0,74 mg/L
Low	51 (30.2)	
Moderate	52 (30.8)	
High	17 (10.1)	
$CaCO_3$		
Soft	9 (5.3)	162,80 mg/L
Moderate	93 (55)	
Hard	38 (22.5)	
Very hard	29 (17.2)	
pH		
Acid	31 (18.3)	7,12 mg/L
Neutral	28 (16.6)	
Alkaline	110 (65.1)	

The study on the calculus index in 16 clusters in Wukirsari Ward, Imogiri Subdistrict, Bantul Regency, showed that the severity of calculus was correlated with several factors, including well water consumed by the people and dental health behavior. The findings suggested that fluoride levels in well water were significantly correlated with the calculus index. The lower the fluoride level, the more severe the calculus index. Most well water with low fluoride levels led to bad severity of the calculus (69.4%). In addition, the findings suggested that $CaCO_3$ levels in well water were correlated with the calculus index. The higher the $CaCO_3$ level, the more severe the calculus index. Most well water with moderate $CaCO_3$ levels led to moderate severity of the calculus (46.2%).

Finally, the pH levels of well water also influenced the calculus index. The more alkaline the well water is, the more severe the calculus index will be. The majority of well water with alkaline pH levels led to bad severity of the calculus (66.4%); moreover, other factors such as age and tooth brushing habits were correlated with the calculus index. The older the subject is, the more severe the calculus index will be. Inaccurate tooth brushing habit was also associated with the severity of the calculus index. Although sex, education level, and socioeconomic status did not show any significant correlations with the calculus index, these factors give an overview of the severity of the calculus index in the community under investigation. The average scores of the examination of the calculus index are presented in Table 3.

Table 3. Average score of the calculus index

Severity	n (%)	Average score of the calculus index
Good	13 (7.7)	1,91
Moderate	53 (31.4)	
Bad	103 (60.9)	

The results of multivariate analysis using multiple linear regression were used to identify factors that influenced the severity of the calculus index in Wukirsari Ward, Bantul Regency, and are presented in Table 4. The initial stage involved entering variables with a p-value of less than 0.25 from the bivariate analysis into the multivariate analysis. The selected variables included fluoride level, $CaCO_3$ level, age, socioeconomic status, and tooth brushing habit. After the backward LR, variables such as pH, socioeconomic status, and tooth brushing habit were excluded because the p-value was more than 0.25. The

variables selected for the second stage were fluoride level, $CaCO_3$, and age.

The results of the second stage of the analysis highlighted factors that significantly correlated with the severity of the calculus index.

a. Flouride level: A negative correlation with the severity of the calculus index was found (p = 0.007), meaning that the lower the fluoride level in clean well water, the more severe the calculus index will be. An odds ratio of -2.718 indicated that fluoride in clean, well water posed a two-times greater risk to the severity of the calculus index.
b. $CaCO_3$ level: There was a positive correlation with the severity of the calculus index (p = 0.000), meaning that the higher the CaCO3 level in well water is, the more severe the calculus index will be. An odds ratio of 7.803 indicated that $CaCO_3$ level in clean, well water posed seven times greater risk on the severity of the calculus index.
c. Age: This variable also positively correlated with the severity of the calculus index (p = 0.034), meaning that the older the subject is, the more severe the calculus index will be. An odds ratio of 2.138 indicated that age posed two times greater risk to the severity of the calculus index.

Table 4 shows that fluoride level, $CaCO_3$ level, and age were significant factors in determining the severity of the calculus index in the area. If the fluoride level decreases, the $CaCO_3$ level increases, or the subject ages, the severity of the calculus index is likely to increase.

Table 4. Multivariate analysis

Variable	B	OR	P	CI (95%)
Fluoride Level	-0.112	-2.718	0.007**	-0.194 – -0.031
$CaCO_3$ Level	0.381	7.803	0.000***	0.285 – 0.478
Age	0.113	2.138	0.034*	0.009 – 0.218

Notes: *p = < 0,05, **p = < 0,01, *** p = < 0,001

DISCUSSION

This study was conducted in Wukirsari Ward, Imogiri Subdistrict, Bantul Regency, the Special Region of Yogyakarta. This study investigates the correlation between the quality of well water consumed by the people and the severity of the calculus index. This is important because the high calculus index is associated with an increase in the prevalence of periodontal diseases. The bivariate analysis revealed a correlation between several factors, such as fluoride level, $CaCO_3$ level, and pH level, in well water and the severity of the calculus index. Moderate fluoride levels (0.74 mg/L) in Wukirsari Ward's wells raised a question about its effectiveness in preventing dental calculus. Although still within the safety limit according to the WHO, the results showed that the severity of the calculus index remained high. As a result, the Government should consider fluoride in drinking water as a further preventive measure, as recommended by Khatkar and Nagpal. It is also worth considering that the geological characteristics and type of well water can influence the fluoride level.

In addition, it is interesting to note the positive correlation between $CaCO_3$ level in well water and the severity of the calculus index. Although still below the maximum limit, this high level is associated with the formation of dental calculus. This can be attributed to the research site's topography, soil, and rock types. Measures such as boiling water using clay pots can help reduce $CaCO_3$, as suggested by Maran and Pare. In addition, the pH of well water, which tends to be alkaline (7.14), was correlated with the severity of the calculus index. Alkalinity affects the ionization of enzymes in saliva and the formation of calculus. This emphasizes the importance of understanding the quality of well water consumed by the people about dental and oral hygiene.

Multivariate analysis showed that $CaCO_3$ level is a variable most strongly correlated with the severity of the calculus index, followed by fluoride level and age. This can be a basis for the government and community efforts in prioritizing handling $CaCO_3$ levels to reduce the risk of dental calculus. In relation to public health, the results of this study highlight the importance of access to clean water that meets environmental health standards. Better water quality can help lower the risk of periodontal diseases and improve the dental health of the overall community. The Government can take measures such as drinking water fluoridation, education about dental hygiene, and technicalities such as boiling water to reduce $CaCO_3$ levels. This is a preventive measure and a pillar in realizing the universal health coverage that the Sustainable Development Goals indicate. Better dental health also directly impacts the quality of life and reduces the burden of healthcare costs. It is expected that through a deep understanding of the factors that affect dental and oral health in Wukirsari Ward, the Government can formulate more targeted and effective policies to improve the quality of life and overall public health.

CONCLUSION

This study was conducted in Wukirsari Ward, Imogiri Subdistrict, Bantul Regency. This study reveals an important correlation between the quality of well water consumed by the people and the severity of calculus. Although fluoride levels in well water were within the safety limit according to the WHO, they significantly correlated with the severity of calculus. Therefore, the Government should consider drinking water fluoridation as a preventive measure. The positive correlation between $CaCo_3$ levels and the severity of calculus highlights the importance of managing $CaCO_3$ levels in well water to reduce the risk of dental calculus. Multivariate analysis confirmed that handling $CaCo_3$ levels should become the top priority, followed by fluoride levels and age, to improve people's quality of life and dental health. In this context, measures like drinking water fluoridation, education about dental hygiene, and technicalities like boiling water can become concrete efforts to reduce the risk of periodontal diseases and improve people's dental health.

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