NO-FEE OPEN ACCESS JOURNAL indexed in Scopus

Bulletin of the International Association for Paleodontology

Volume 19, Issue 2, 2025

Established: 2007

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We thank all the reviewers for their effort and time invested to improve the papers published in this journal.

Fluorosis and caries in prehistoric populations of Papua Indonesia*

• Marlin Tolla (1), Taufiqurrahman Setiawan (1), Hari Suroto (2), Bau Mene (3), Restu Budi Sulistiyo (1) •

1 – Research Center for Archaeometry, National Research and Innovation Agency, Republic of Indonesia
2 – Research Center for Environmental Archaeology, Maritime Archaeology and Cultural Sustainability, National Research and Innovation Agency, Republic of Indonesia
3 – Rsearch Center for Prehistoric and History Archaeology, National Research and Innovation Agency, Republic of Indonesia

Address for correspondence:

Marlin Tolla
BRIN KST Ir. Soekarno Cibinong, Jl. Raya Bogor No.970, Cibinong, Bogor, 16915, Indonesia
Email: marl011@brin.go.id

Bull Int Assoc Paleodont. 2025;19(2):109-120.

Abstract

This study examines the prevalence and association of two major dental pathologies-fluorosis and caries- in prehistoric populations from Papua Indonesia. A total of 73 teeth from 55 individuals were analyzed using the Tooth Surface Index of Fluorosis (TSIF) alongside standard diagnostic methods for detecting caries. The study involved examining the teeth using Novex Holland, and Bresser microscopes, followed by the application of statistical methods, such as Spearman's correlation and linear regression, to analyze the relationship between fluorosis and caries. The findings revealed high rates of fluorosis, whereas caries appeared less frequently. These outcomes suggest a potential inverse correlation, likely resulting from prolonged fluoride intake through naturally sourced water. This research offers valuable insights into the oral health of ancient populations and highlights the importance of further studies on how environmental and biological elements influence dental diseases in tropical climates.

Keywords: dental fluorosis; caries; prehistory; Papua

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Introduction

Dental enamel is composed of nearly 87 % crystalline calcium phosphate in the form of hydroxyapatite (1,2). During the mineralization process, fluoride enters dental tissues and accumulates on the enamel surface (3). The fluoride occurs naturally as the fluoride ion, F- (fluorine), in food, air, and drinking water (4,5). Fluoride enters the human system through digestive and respiratory systems. Its ingestion benefits human bones and teeth through biological mechanisms (6). Following ingestion, ions from various sources rapidly enter the bloodstream (7). This process contributes to the development of dental fluorosis. Dental fluorosis is a tooth pathology characterized by a developmental disruption of dental enamel, caused by excessive fluoride exposure during the enamel formation period (8,9). Dental fluorosis is a condition in which the mineral content of the hard tissues of teeth is altered due to prolonged fluoride intake during tooth development, typically occurring within the first eight years of life for most permanent teeth, excluding the third molars (10). The different ranges of fluorosis, categorized as mild, moderate, or severe, may be associated with the timing of fluoride exposure during prenatal, infancy, and childhood periods (11). Fluoride, the factor responsible for dental and skeletal fluorosis in the human body, is mostly found in water and in water-containing foods. Naturally occurring fluoride in water plays a key role in supporting the human body; however, excessive intake can lead to dental and skeletal fluorosis (12,13).

The correlation between fluoride and human health was first investigated in the late nineteenth century, when researchers discovered varying concentrations of fluorine in human tissues including teeth (14). Dental fluorosis in human teeth is characterized by white, brown spots and lines on the enamel, caused by excessive fluoride intake (15,16). The primary sources of fluoride originate from natural processes, including the weathering of fluoride-rich minerals in rocks and volcanic eruptions, which are mostly found in the tropical environments like Indonesia (17,18). Research on fluorosis in tropical islands underscores the need to manage fluoride exposure and highlights challenges such as geographical isolation, reliance on natural water sources, and the unique geological characteristics of this region. Tropical regions, including Papua Indonesia, contribute to high levels of water consumption, which may increase health risks such as dental and skeletal fluorosis due to dependence on groundwater sources.

The severity of fluorosis depends on both the concentration of fluoride in the water and the duration of exposure, particularly during tooth development. From a chemical standpoint, water is a basic compound represented by H2O. Groundwater chemistry, however, is influenced by the relationship between the chemical properties of the water and its suitability, based on the geological formations present in the local and regional context (19). Groundwater sources contaminated with fluoride (F-) are known to be associated with the risk of dental and skeletal fluorosis (20). Prolonged exposure to high fluoride levels in drinking water can result in these conditions, as fluoride accumulates in the body over time. More than half of the global population relies on groundwater as their primary source of drinking water (21). Globally, regions with high natural fluoride concentrations in groundwater show the greatest health risk (22).. Populations in Africa are most at risk of fluoride exposure from drinking water, followed by those in Asia, Australia/Oceania, Europe, and the Americas (23).

Dental caries is known as the most common infectious disease in the world (24,25). The development of caries in human teeth is promoted by multiple disturbance in the balance between the oral environment and the teeth (26). Dental caries refers to the localized destruction of tooth tissue caused by bacterial activity, involving complex interactions between the tooth structure, high concentrations of sugars and carbohydrates, genetic and salivary factors (27,28). Carious lesions form on the surface of the enamel and can eventually lead to tooth loss if left untreated (29). The prevention of caries has been studied by researches over the years, with fluoride ions playing a major role in reducing dental caries for several decades (9,30,31). Fluoride application for dental caries prevention has been widely implemented through both collective and individual measures, achieving remarkable success, as seen in the reduction of dental caries in many countries (32,33,34).

Dental fluorosis and caries are well-documented in modern populations, often linked to diet and fluoride exposure. Studies on contemporary humans show that both conditions are especially common in communities with highly processed diets and elevated fluoride levels. By contrast, prehistoric people had no access to modern fluoride products, instead they may obtain fluoride solely from their environment, primarily through drinking water and natural food sources. In this study, the prehistoric environment was characterized by regional metamorphic rocks, which may have contributed to the occurrence of dental fluorosis. For instance, in the lowland areas of northern Papua, including the Sentani area, metamorphic surrounded the watershed, such as lakes and rivers. Additionally, the freshwater in this region is influenced by volcanic breccia, ultramafic rocks, alluvial deposits, and various types of siliciclastic and carbonates sediment (35,36). Ultramafic rocks and specific types of limestone typically have fluoride levels between 100 mg/kg and 1,000 mg/kg, while alkaline igneous rocks contain around 1,000 mg/kg of fluoride (37).

In prehistoric populations, however, dental fluorosis and caries are less studied, particularly in tropical islands like Papua Indonesia and surrounding areas. Studying dental fluorosis and caries in prehistoric human populations is important for several reasons, including providing insight into ancient diets and environments, such as fluoride and caries exposure. Carious lesions in past populations offer valuable information on human adaptation to their physical and cultural environments (38). While this research originated in dissertation work (39), this paper represents the first dedicated publication of these results. The current study highlights important insights into dental health, allowing for comparisons with modern populations to better understand how prehistoric lifestyles influenced oral health. Additionally, this study can provide a baseline for understanding how natural diets affected the health of early human communities, especially in tropical island like Papua Indonesia.

Materials

For this study, 73 adult teeth from 55 individuals across five different sites were examined for the presence of fluorosis and caries. These teeth consist of 46 teeth from Srobu, 10 teeth from Mamorikotey, 8 teeth from 2 individuals from Namatota, 5 teeth from Karas site, 4 teeth from 2 individuals from Yomokho. Figure 1 one shows the locations of these 5 sites across Papua Indonesia. The archaeological findings indicate that a total of 73 teeth were analyzed, consisting of 45 posterior teeth and 28 anterior teeth. These teeth were excavated from archaeological sites from the Holocene period, ranging from 3400 to 1100 BP, and were obtained through archaeological fieldwork conducted in the lowland regions of Papua Indonesia (39).

Methods

In this study, the human teeth found in each of the five sites were analysed using microscopes, to detect fluorosis and caries marks on various parts of the teeth. The tooth pathology was then classified using numerical standardization methods. A Bresser microscope was used to detect marks of fluorosis on each tooth. The Tooth Surface Index of Fluorosis (TSIF) developed by Horowitz et al. (Horowitz HS, Heifetz SB, Driscoll WS, et al., 1984) presents distinct criteria for analyzing fluorosis on the tooth surface. It was applied to classify the severity with a scoring system ranging from 0 to 7, where higher scores indicate more severe fluorosis (40). The criteria include: score 0 = no evidence of fluorosis; score 1-2 = small white areas of opaque spots covering less than one-third of the surface; score 3-4 = white opacity covering more than one-third to two-thirds of the surface; score 5 = staining and pitting present; score 6-7 = severe pitting, staining, and loss of enamel structure.

A Novex Holland microscope was used to detect carious lesions in each tooth from the five sites. Since human teeth recovered from archaeological sites often present challenges during the observations process, a simplified classification system developed by Hillson (Hillson, 2001) was applied, with scores ranging from 0 to 3, where higher scores indicate more severe caries (41). To explore the relationship between the fluorosis and caries patterns in this study, statistical methods were used, specifically Spearman’s correlation, using an online calculator (42), and linear regression. The goal is to determine whether there is a significant statistical relationship between fluorosis and caries, and to derive a mathematical model. Prior researches and literature give no reason to assume that a possible correlation would be different between the sites analysed in this study. But to see whether results are consistent, correlation factors as well as linear regression lines were additionally calculated for each site separately, where possible.

Results

Most Srobu samples show moderate to severe fluorosis, indicating high fluoride exposure. Severe fluorosis (score 7) was found in 7 canines including, Srb/22/UC, Srb/23/UC, Srb/28/UC, Srb/30/LC, Srb/31/UC, Srb/32/LC, and Srb/33/LC. While score 6 appeared in multiple premolars and molars including, Srb/627/LP1, Srb/622/LP2, Srb/413/LLM1, and Srb/35/UP1. Moderate fluorosis (scores 4-5) was common

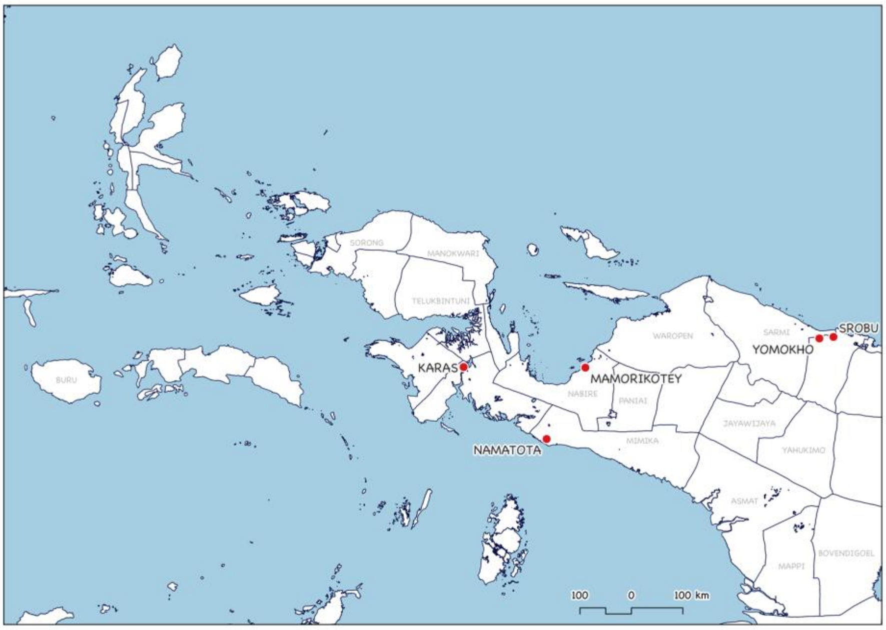

Figure 1. This map shows Papua Indonesia with the locations of the 5 sites of this study.

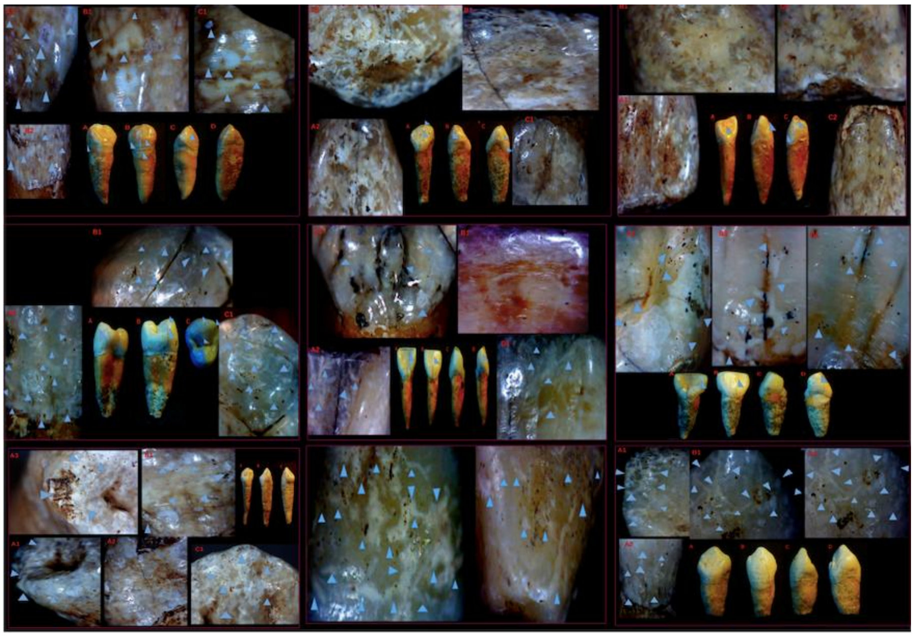

Figure 2. Human teeth from Srobu site. First row (left to right): Upper Canine: fluorosis (white to dark-brown) on lingual, buccal, distal, and mesial surfaces (blue arrows). Lower Canine: fluorosis (white to dark-brown) with incisal abrasion and plaque on tooth surfaces. Lower Canine: fluorosis (white) on crown surfaces; buccal aspect shows fluorosis and plaque. Second row (left to right): Upper first premolar: fluorosis associated with cracks on mesial, distal and occlusal crown surfaces. Upper first incisor: fluorosis (white, yellow to dark brown) affecting nearly all surfaces. Upper first incisor: fluorosis (white and dark yellow) distributed on crown surfaces. Third row (left to right): Lower first premolar: fluorosis (white to dark-brown) on tooth surface; occlusal abrasion present. Lower canine: fluorosis (white) on tooth surface in both images. Upper canine: fluorosis (white to dark-brown) on lingual, buccal, mesial, and distal surfaces (blue arrows).

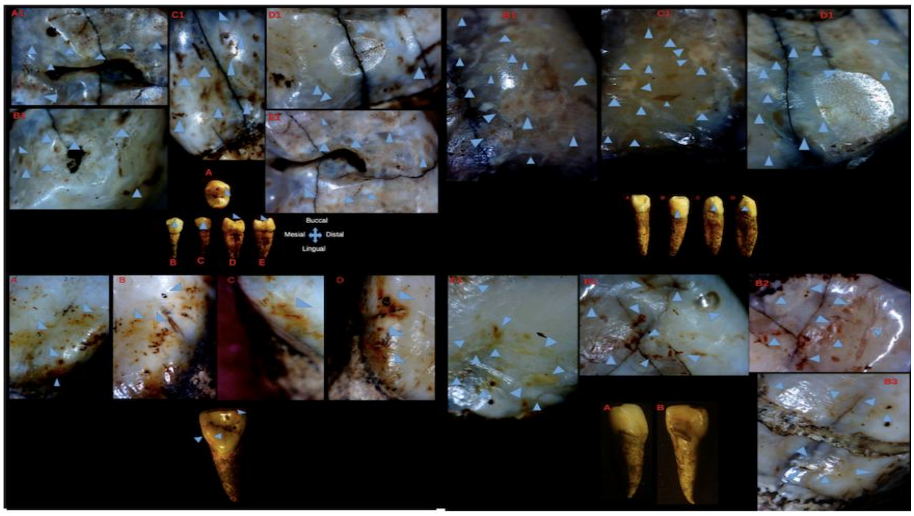

Figure 3. Human teeth from Mamorikotey site: First Row (left to right): Upper first premolar: fluorosis (white to dark-brown) on all surfaces, with abrasion and cracks on the crown. Lower canine: fluorosis (white) on lingual, buccal, and mesial surfaces, with abrasion and cracks on the distal crown. Second row (left to right): Upper first incisor: fluorosis (yellow-brown) on all surfaces. Upper second incisor: fluorosis (yellow to brown, dark) with cracks on buccal and lingual surfaces, and plaque on the crown.

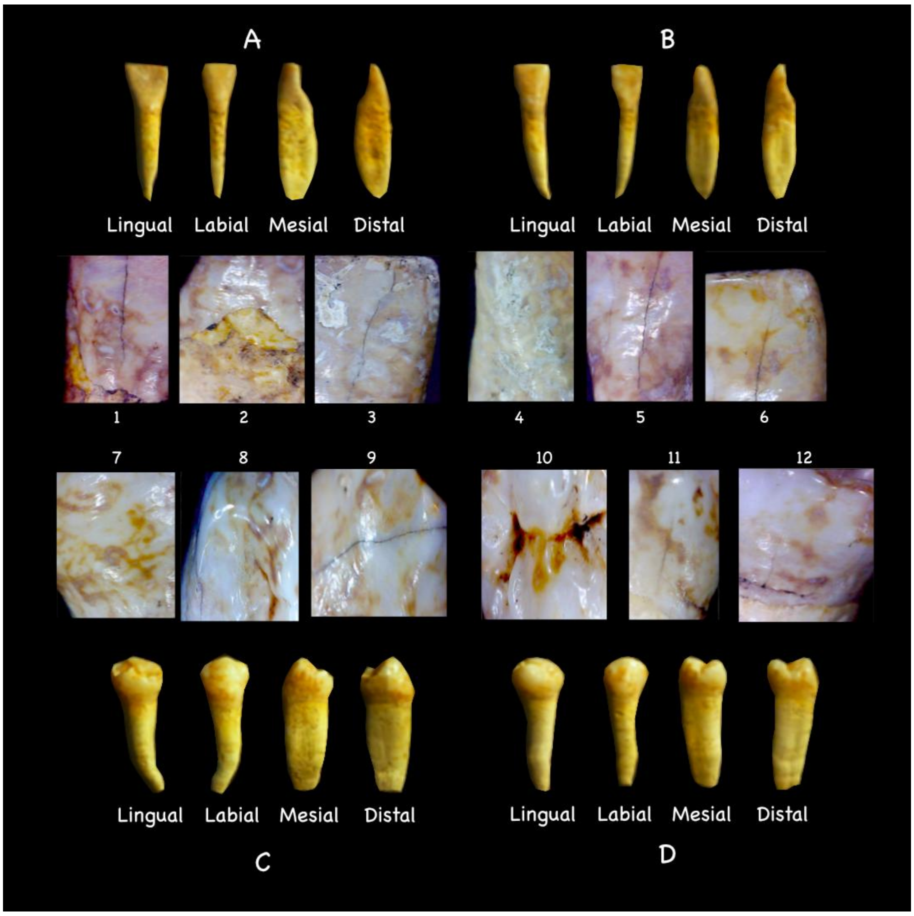

Figure 4. Human teeth from Namatota site. Fluorosis (white-milk, yellow to dark brown) is present on the surfaces of the lower first incisor (A), lower second incisor (B), lower first premolar C, and lower second premolar (D). Fluorosis affects the lingual, buccal, mesial and distal surfaces (number 1-12).

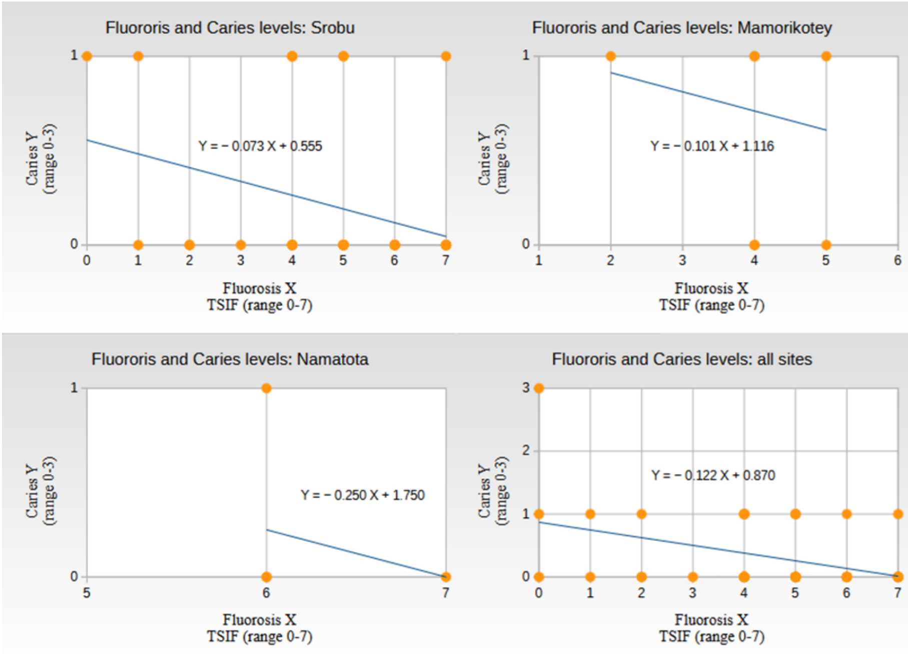

Figure 5. Linear regression functions for the sites Srobu, Mamorikotey, Namatota and combined, using the TSIF fluorosis score as domain X and the caries score as codomain Y. The orange-colored data points can represent multiple samples each.

across various teeth, and mild fluorosis (scores 1-3) was observed in a four incisor and premolar teeth including, Srb/624/LP1, Srb/403/LP2, Srb/67/LI2, Srb/20/LP2 (Figure 2). From the Mamorikotey site, ten teeth show fluorosis, with scores of 4 displaying white and dark brown discoloration, while scores of 5 show yellow and dark brown staining (Figure 3). Other teeth from Karas with scores 2 to 4, show colors varying from white and yellow to dark brown. All teeth from the Karas site have fluorosis scores of 4 or 5. Analysis of fluorosis in two individuals from the Namatota site revealed that it falls within the severe category, marked by irregularly shaped brownish flecks on the enamel of three posterior and anterior teeth (Figure 4). The fluorosis is visible on the labial, lingual, and buccal surfaces, as well as the mesial-distal and occlusal areas of the posterior teeth.

The analysis of caries, assessed using the Hillson scale (Hillson, 2001), showed scores ranging from 0 to 1 for all teeth from all sites, with a single exception: one tooth from Yomokho exhibited caries covering more than 50% of the tooth surface, resulting in a score of 3. Caries at stage one were observed in the following teeth: Srb/489/ULM1, Srb/489/ULM2, Srb/636/LM2, and Srb/ABC/UM1. At the Mamorikotey site, caries with a score of one were recorded in MMK/42/UP, MMK/49/UC, MMK/78/UI1, MMK/79/UI2, and MMK/640/LP1/ At the Yomokho site, a score of three was observed in the lower first molar (Ymk/1/LM1).

Two contrasting observations were made regarding the dental health of the human group in this study. Firstly, tooth decay was rare among this population, suggesting that high fluoride exposure, along with a diet low in refined carbohydrates, may have prevented caries development. Secondly, the teeth exhibited high levels of fluorosis. To examine the relationship between fluorosis and caries, Spearman correlation and linear regression analyses were applied to all samples. The results for the Srobu samples show a Spearman correlation coefficient r of -0.307, indicating a moderate negative correlation between caries and fluorosis. This suggests that as the severity of fluorosis increases, the severity of caries tends to decline. The r-value and the number of samples give a p–value of 0.0379. When using a significance level of 0.05, this suggests that there is indeed significant relationship between caries and fluorosis among the Srobu samples.

In other words, the observed negative correlation is unlikely to have occurred by chance, due to natural statistical variations of samples. For the 10 samples from Mamorikotey, a Spearman correlation coefficient of -0.130 was derived, and p-value of 0.719. The samples from Namatota give a correlation coefficient of -0.378, with a p-value of 0.356. For these two sites, this suggests a weak to moderate negative correlation, but not statistically significant, as the p-values are greater than the chosen significance level of 0.05. The indicated correlation has a high chance to originate from random variations. For the samples from Karas and Yomokho, a Spearman coefficient cannot be calculated. The number of samples from these two sites is too low: those from Karas all show no sign of caries, while those from Yomokho all have a fluorosis score of 0. The combination of values from all 5 sites gives a correlation coefficient of -0.359 with a p-value of 0.00209, indicating a moderate very significant negative correlation between fluorosis and caries.

To derive a mathematical model about how fluorosis and caries levels correlate with each other, a linear regression was applied for all the samples in this study (Figure 5). The fluorosis score was used as domain X, while the caries score was used as codomain Y. For the Srobu samples the regression equation is $Y=-0.073*X+0.555$. The negative slope of -0.073 indicates an inverse relationship between caries and fluorosis, meaning that in average the severity of caries decreases with increasing severity of fluorosis. This is consistent with the negative correlation coefficient for these samples. Every score point of fluorosis decreases the caries score by 0.073. The intercept of 0.555 can be mathematically interpreted as average caries score, if the fluorosis score is zero. For the samples from Mamorikotey the linear regression results in the equation $Y=-0.101*X+1.116$. Since most of its samples show traces of caries, the negative slope as well as the intercept are higher, compared to those for the samples of Srobu. For Namatota, the linear regression results in the equation $Y=-0.250*X+1.750$. It is, however, based on 8 samples, all of which have elevated fluorosis scores of 6 or 7, with only one showing traces of caries. For the Karas and Yomokho, the number of samples and variation of caries respectively fluorosis levels is too low for a meaningful linear regression. Combining data from all sites, the linear equation is $Y=-0.122*X+0.869$.

Discussion

The analysis of human teeth in this study provides evidence of severe fluorosis. Because dental fluorosis is caused by an abnormal fluoride intake, it is critical to understand what factors influence the range of fluorosis in human teeth for the five groups in this study: Srobu, Mamorikotey, Namatota, Karas and Yomokho. Most of the teeth in this study were affected by fluorosis indicated by colored markings located on the enamel surfaces of both anterior and posterior teeth. These patterns suggest that fluoride exposure likely affected the development of permanent teeth during childhood, highlighting the long-term impact of environmental fluoride on these groups. Consuming high levels of fluoride from drinking water can lead to the removal ions (OH-) from hydroxyapatite, which in turn causes the formation of fluorapatite (43). The mild form of fluorosis appears as white lines along the perikymata, which may merge to form irregular areas. With increasing severity, the affected area is larger and can cover the whole surface of the tooth. Severe fluorosis may be characterized by brownish staining and even minute pitting on the enamel surface. The severity of fluorosis is linked to several factors including the fluoride concentration in drinking water, the fluoride daily intake, the length of exposure as well as the geology and the climatic conditions (44). Fluoride can be beneficial at low concentrations but can cause dental fluorosis when levels are too high (45). Besides anthropogenic contaminants, groundwater typically contains naturally occurring toxic elements, including fluoride, which dissolve into the water from soil or geological formations (46).

Granite group of rocks contain muscovite, amphiboles and hornblende which have a high content of fluoride. These minerals, by weathering, enrich fluoride in groundwater (47). In hydrothermal vein deposits fluorite commonly exists as fluorspar (48). Coal contains fluoride, around 295 mg/kg, which also contributes to environmental fluoride (49). Water is a necessary component of any living creature; it is required for the various organ systems and physiologic activities (50). It containing chemical ions such as fluoride plays a vital function in human teeth and bones, particularly in improving enamel tooth resistance to acid assault, avoiding cavities, and being an essential component in the remineralization process (51).

One significant factor that could contribute to dental fluorosis in the prehistoric population examined in this study is the consumption of water from natural sources with high levels of fluoride. These freshwater sources, including rivers, lakes, ponds and groundwater, were likely utilized for drinking. Given the limitations in water management during prehistoric times, the use of groundwater for daily drinking likely played a significant role in the prevalence of dental fluorosis in this study. Studying fluorosis in prehistoric groups can help locate high-fluoride water sources and provide geological insights into their settlements. For instance, people living close to volcanic areas or in regions with high fluoride in groundwater are more prone to show signs of dental fluorosis (52). Geological conditions, such as the presence of fluoride-rich minerals in the soil and rock formations, can result in elevated fluoride concentrations in local water sources. This happens because regions rich in fluoridated minerals release elevated fluoride levels into the groundwater (53). The region of Papua Indonesia, is unique in its geological formation, which is closely related to medical geological features, primarily consisting of volcanic rocks and sediments formed through subduction-related processes. The accreted arc and fore arc parts of the northwestern extension of the Melanesian Arc terrane resulted from two distinct phases of volcanism that have taken place since the Eocene (54). Given the location of the sites near karstic cave systems and lowland zones, it is possible that prehistoric communities relied primarily on groundwater for drinking water. In this context, the individuals in this study may have experienced dental fluorosis as a result of chronic fluoride exposure. The consumption of natural groundwater may have had further health effects, such as skeletal fluorosis (55).

Fluorosis and caries patterns relationships

Comparing the fluorosis scores with caries rates might help to uncover whether fluorosis acted as a protective factor against decay, as some studies suggests an association between fluorosis and dental caries (56,57,58). Some evidence suggests that fluorosis may help protect against caries, although this idea remains debated. Several studies have reported a negative correlation between severity of fluorosis and the occurrence of caries, especially in regions with different levels of fluoride exposure. Studies show a mixed relationship between fluorosis and caries. In Turkey and Lithuania, children with fluorosis tended to have fewer cavities, suggesting that moderate fluoride exposure may offer some protection (59,60). However, research in South Africa found higher caries rates in children from high-fluoride areas, likely because severe fluorosis weakened their enamel (61).

Based on the statistical calculations presented in this study, it can be concluded that, aside from the Karas and Yomokho samples, there is a connection between the rate of fluorosis and caries. The Spearman correlation factors indicate at least a moderate negative correlation between fluorosis and caries. While the sample size for individual sites other than Srobu is too low to derive a significant correlation, the factors were all consistently negative. And the combination of all samples gives a very significant correlation of -0.359 is observed, with a p-value of 0.00209. This as well aligns with the negative slope of all linear regression equations. The combined linear regression line of all samples from all five sites suggests that individuals without fluorosis have an average caries level close to 1, which is roughly halved between the scores of 3 to 4, and reaches an average close to 0 at a fluorosis score of 7. Further studies with more samples would be needed to verify and narrow down such quantitative relationship. The qualitative relationship, however, complements previous studies by researchers on the effect of fluoride use in prevention of dental caries.30,62 But excessive intake of this anion, particularly at concentrations above 1.5 mg/L, can lead to dental and skeletal fluorosis (62,63).

Even though fluorosis may act as a protective factor for teeth against caries, it does not completely eliminate the occurrence of caries in this study. Individual samples with caries lesions have the highest fluorosis score of 7. Caries is a multifactorial disease, influenced by the interaction of intrinsic factors, such as saliva flow rate, pH, and dental morphology, along with extrinsic factors like fluoride exposure and diet behaviors that increase risk (64). The presence of lesions in posterior and anterior teeth may be related to the morphology of the teeth. For the posterior teeth, such as molars, the lesions are present in areas likely affected by pits, fissures or grooves on the occlusal surface. This can be seen as the lesions mostly appear on the occlusal surfaces of the molar teeth from samples of the Srobu group. In some teeth from Mamorikotey and Yomokho, early lesions are also present on the occlusal surfaces. The occlusal pits/fissures lesions on these teeth initially appear as tiny brown to black discoloration. The lesions, mainly located on the occlusal surfaces of the molar teeth, are likely related to the function of this area in the chewing process, as it serves as the surface where all types of food, including sugary items, are processed. The occlusal surface is characterized by deep grooves and fissures that

separate the tooth into cusps and ridges, where saliva and bacteria frequently accumulate. As food is chewed in this area, the risk of decay increases.
According to this study, both occlusal and proximal wear facets exhibited carious lesions. Once the enamel of a tooth is damaged or lost due to hard foods or objects, lesions can easily form in the worn teeth through demineralization caused by bacterial acids from dietary sugars, salivary dysfunction, and other factors (64). The lesions were located on the worn tooth surfaces in the posterior teeth, such as premolar and molar, from several samples of the Srobu and Mamorikotey groups. For the several anterior teeth, caries lesions were present in the incisal part of the incisors and canines. In this study, hard tissue such as enamel and dentin worn down or lost from the teeth may have occurred due to several factors, including an abrasive diet and mechanical stress performed on the teeth. Since the human group in this study primarily depended on hunting and foraging for food (39), their diet was dominated by coarse or gritty items, which could gradually erode the surface of their teeth over time. Numerous factors can contribute to the tooth wear, including the consumption of hard foods, as evidenced by the wear patterns observed in this study (39). These patterns, such as cupping and pitting on the teeth surfaces, were often followed by the development of caries. Once teeth tissue, such as enamel and dentin, is lost from the tooth body, bacteria can penetrate these areas, leading to the formation of lesions.

Limitations

The sample size is relatively small to represent the population affected by fluorosis and caries in this region. Additionally, the lack of environmental data, especially the measurement of fluoride concentrations in drinking water sources, highlights the importance of conducting future research. Such data would be valuable for modern populations in this region due to their significant dependence on natural water for daily needs. The combined data from all sites of this study is enough to derive a significant correlation between fluorosis and caries, which matches expectations from past studies and the known caries preventive effect of fluoride. However, the sample size of the individual sites, with the exception of Srobu, is too small to derive this correlation with sufficient significance or differences between them. Future studies with more samples from individual sites or areas can help to identify differences between them and relationships between fluoride intake and environmental characteristics. Besides that, examining fluorosis and caries in relation to other pathological conditions can provide a more comprehensive understanding of oral health in prehistoric populations, although this remains challenging due to issues of preservation and post-burial alteration of human remains.

Conclusion

The human teeth in this study exhibited severe fluorosis, which may have played a role in reducing the development of caries due to fluoride's protective effect against caries. Severe fluorosis could be attributed to groundwater consumption and inadequate water management by prehistoric people in this study. The geological features of the Papua region may contribute to the elevated fluoride levels in freshwater sources, including groundwater, which have become a major factor in fluoride contamination. Further investigations are need to explore the intricate relationship between fluorosis and caries and to identify the factors contributing to varying outcomes. Additionally, future research into water composition and fluoride contamination is essential, especially in tropical regions like Papua, where natural water consumption is high. This factor can have a significant impact on human health, contributing to the development of skeletal and dental fluorosis, as well as other pathologies in the region.

Declaration of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author Contributions

All authors contributed to the study conception and design. Marlin Tolla initiated this study, performed the teeth descriptions and statistical calculation, conducted analytical calculations, and wrote the manuscript. Taufiqurrahman Setiawan: drafted, designed and finalized the figures and manuscript. Hari Suroto and Bau Mene: participated in the archaeological fieldwork, gathered the teeth samples from the sites, and contributed to the teeth descriptions. Restu Budi Sulistiyo: contributed to clarifying the manuscript.

Statement on the use of artificial intelligence in manuscript preparation

Artificial intelligence was not used in the preparation of this manuscript.

Funding
The authors declare that no funds, grants or other support were received during the preparation of this manuscript.

Ethics statement
The study was conducted in accordance with ethical guidelines for archaeological fieldwork and carried out with permission from relevant authorities, particularly the local Papuan community where the study took place. Throughout the research process, the principles of respectful treatment of human remains, including the teeth, were meticulously upheld.

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