Dental Treatment Data in Children Living in Areas with Elevated Fluoride Content in Water

Akmaanai Kamchybekova*, Rahimat Tynalieva, Ryskul Abykeeva, Akdana Erkebaeva and Gulnar Cholokova

Department of Pediatric Dentistry, I.K. Akhunbaev Kyrgyz State Medical Academy, 92 Akhunbaev Str., Bishkek 720020, Kyrgyz Republic

Abstract: *Objectives*: This study aimed to comprehensively assess the dental status of children aged 5-11 years residing in areas with naturally fluoridated water. The study included 486 children, selected by age and permanent residence using randomisation in Kyzyl-Suu and a continuous survey in Orgochor. Dental status was assessed according to World Health Organization recommendations using the KPUp+kpp and KPUz+kpz indices, while oral hygiene was evaluated using the Fedorov-Volodkina index.

Methods: The concentration of fluorides in drinking water was determined by the potentiometric method, with multiple samples collected at different times of day. Statistical processing of the data involved the use of the standard error of the mean (m), Student's t-test, and quantile-quantile plots to assess distribution normality. The results showed that the prevalence of caries among children aged 5-11 years ranged from 93.1% to 100%, depending on age group and place of residence: in Kyzyl-Suu it reached 100% in all groups except 10-11 years (96.0%), while in Orgochor it varied from 93.1% (7 years) to 98.5% (10-11 years), with a clear age-related trend towards a decline in the incidence of deciduous teeth caries and a simultaneous increase in the intensity of damage to permanent teeth.

Findings: In Orgochor, where the fluoride concentration was 1.44 mg/l, a moderate decrease in caries activity was observed; however, the incidence of fluorosis reached 27.3%. More than 60% of children had unsatisfactory or poor oral hygiene, which further aggravated the risk of dental diseases. The relationships identified between fluoride levels, hygiene conditions, and the prevalence of pathology indicate a complex interdependence of risk factors in the study population.

Conclusions: The findings underscore the need for comprehensive sanitary control, educational programmes, and regular monitoring of drinking water quality to prevent dental diseases in paediatric populations.

Keywords: Fluorosis, Enamel hypomineralisation, Early diagnostics, Prevention, Caries, Epidemiology.

1. INTRODUCTION

The issue of caries prevention in children living in areas with naturally fluoridated drinking water is becoming increasingly relevant, underscoring the need for a comprehensive reassessment of existing approaches. Since the beginning of the 21st century, scientific interest in dental morbidity in fluoride-endemic regions has expanded steadily. This trend is explained by the paradoxical duality of fluorides' effects on dental hard tissues. Although their role in reducing caries incidence is well established, prolonged and uncontrolled intake carries the risk of fluorosis - a pathological condition characterised by impaired enamel mineralisation and marked aesthetic defects. The absence of uniform regulations on safe fluoride intake in childhood, particularly given variations in water supply and lifestyle, underscores the need to develop regionally tailored recommendations.

As emphasised by Saad *et al.* [1], prolonged exposure to fluorides in drinking water significantly increases the incidence of fluorosis, which may manifest as both aesthetically significant alterations in enamel structure and functional disturbances. The severity of the clinical picture is determined not only by the fluoride concentration in drinking water but also by several individual predisposing factors, including the child's age, general health status, diet, and use of fluoride-containing hygiene products. Mfundisi *et al.* [2] highlighted that both fluoride deficiency and excess in the environment may significantly affect the prevalence of caries and other forms of dental pathology unrelated to bacterial demineralisation.

Beyond its immediate impacts on dental health, knowledge of fluoride's role in dietary minerals (specifically, how it interacts with calcium and magnesium) is crucial to comprehending its wider effects. Excessive fluoride consumption can upset the body's delicate equilibrium of these essential minerals, particularly when enamel is developing. A lack of calcium and magnesium, which are necessary for maintaining tooth enamel, can worsen the harmful effects of fluoride and lead to dental fluorosis [3]. When fluoride intake is within the permissible limit, a diet lacking in calcium and magnesium may increase the incidence of fluorosis. Therefore, maintaining a healthy

*Address correspondence to this author at the Department of Pediatric Dentistry, I.K. Akhunbaev Kyrgyz State Medical Academy, 92 Akhunbaev Str., Bishkek 720020, Kyrgyz Republic; Tel: +996 312 545 859;
E-mail: akmaanaikamchybekov@gmail.com

E-ISSN: 1929-4247/25

balance of these minerals is essential to reduce the adverse effects of fluoride on kids' oral health, particularly in areas where drinking water naturally contains high levels of fluoride.

Research conducted by Adeghe [4] made an essential contribution to clarifying the pathogenetic mechanisms underlying fluorosis. The author demonstrated a clear correlation between the fluoride concentration in drinking water and the severity of changes in enamel structure. In particular, when recommended levels were exceeded, defects progressed from superficial changes to more profound disturbances of the mineral composition. This compromised not only the aesthetic appearance of teeth but also their resistance to external influences. Such findings emphasise the importance of continuous monitoring of water supply and sanitary conditions in endemic regions, particularly in the context of preventive measures for paediatric populations.

In evaluating the influence of fluoride on oral health, the conclusions of Sanders *et al.* [5] emphasise the need for a comprehensive approach to analysing exposure factors. The authors argue that fluoride concentrations in drinking water should not be considered in isolation from other sources of intake, such as food, hygiene products, and pharmacological preparations. This issue is particularly relevant to the development of preventive strategies for children, as it is during childhood that the mechanisms of trace element absorption and excretion are established, and the overall load may vary across social and domestic contexts.

One key aspect of dental disease prevention is educational work aimed at developing hygienic skills. In their research, Demarchi *et al.* [6] demonstrated the high effectiveness of educational initiatives implemented within school programmes designed to improve oral health. Their findings indicate the need to integrate educational components into comprehensive dental health strategies.

Nevertheless, despite numerous studies, unresolved questions remain in some regions concerning the actual impact of fluoride levels in drinking water on children's dental health, particularly when oral hygiene status is taken into account. Molczyk-Sieńczak *et al.* [7] stress that even at optimal fluoride concentrations, maintaining high levels of oral hygiene is a critical factor in preventing caries and minimising the risk of fluorosis.

The results of the global analysis by Kaur *et al.* [8] are of particular interest. The authors demonstrated that, under conditions of a moderate excess of fluoride concentration, a paradoxical effect is possible: a reduction in the prevalence of caries may be accompanied by an increase in the frequency of non-carious lesions. These findings confirm the need for local epidemiological studies to assess the actual state of dental health in specific regions. Additional data obtained by Kamchybekova *et al.* [9] indicate a high prevalence of poor oral hygiene among children living in fluoride-endemic areas, which, in combination with unfavourable sanitary and hygienic conditions, increases the risk of both carious and non-carious dental diseases.

Based on the analysis of current literature, it may be concluded that, despite the accumulation of an extensive factual base on the influence of fluoride on dental health, significant gaps remain in understanding the prevalence and structure of dental pathology among children residing in areas with naturally fluoridated water. In particular, the combined effects of fluoride concentration, oral hygiene status, and sanitary-domestic conditions on dental morbidity have not been adequately investigated.

In light of the above, the purpose of the present study was to comprehensively identify the features of dental pathology formation in children living in regions with elevated natural fluoride levels in drinking water. The study assessed the prevalence and severity of carious and non-carious lesions by fluoride concentration and examined the relationship between oral hygiene status and the structure of dental morbidity.

2. MATERIALS AND METHODS

The research was conducted in the Jeta-Oguz District of the Issyk-Kul Region of the Kyrgyz Republic. The study population comprised primary schoolchildren aged 5-11 years residing in the villages of Kyzyl-Suu and Orgochor. Only children born in and permanently living within the designated settlements were included.

A total of 486 children participated in the study: 237 from a secondary school in Kyzyl-Suu and 249 from a school in Orgochor. The sample in Kyzyl-Suu was selected by randomisation, whereas in Orgochor, all children in grades 0-4 were examined because there was only one school. Inclusion criteria were: age 5-11 years and permanent residence in the study area.

Exclusion criteria were: acute infectious diseases at the time of examination; chronic somatic diseases in the exacerbation stage; severe psychoneurological symptoms that could hinder a dental exam; and temporary residence in the settlement (less than one year). The study was conducted in accordance with the principles of the Declaration of Helsinki of the World Medical Association [10]. Before the survey, written voluntary informed consent was obtained from parents (or legal representatives), and oral consent was obtained from the children. All data were processed in compliance with the principles of confidentiality, depersonalisation and non-disclosure of personal information.

A team of trained examiners conducted dental examinations, and calibration sessions were held before the study to ensure consistent assessment. A subset of 20 children was used to investigate inter-rater reliability, and the results showed high agreement amongst examiners with an intraclass correlation coefficient (ICC) of 0.95. This high efficiency means that the examiners' assessments were nearly identical, ensuring that the results are reliable and that the data collected reflects an accurate and consistent measurement of the children's dental health.

To assess stomatological status, the WHO (2013) child dental examination chart was used [10]. The survey recorded the presence of caries, fillings, teeth indicated for extraction, and teeth removed due to complicated caries. The intensity of the carious process was assessed using the KPUz+kpz and KPUp+kpp indices for temporary and permanent teeth.

The hygienic condition of the oral cavity was assessed using the Fedorov-Volodkina Index (1971). During data registration, attention was paid to the quantitative characteristics of plaque and tartar on the teeth. Standard dental instruments were employed for the clinical examination, including a dental mirror for detailed inspection of tooth surfaces and dental forceps with a probe for detecting carious lesions and other defects.

Drinking water samples were collected three times from each source at different times of the day, allowing for daily fluctuations in fluoride concentration to be accounted for and ensuring the representativeness of the average values obtained. Samples were stored in polyethylene containers at +4°C and delivered to the laboratory within 48 hours of collection, in compliance with ISO 5667-3:2018 [11], which regulates the conditions for transport and storage of water samples for analytical studies.

Fluoride concentration was determined by the potentiometric method using a fluoride-selective electrode in the presence of a Total Ionic Strength Adjustment Buffer (TISAB II) containing sodium acetate, acetic acid, sodium chloride and Cyclohexane Diamine Tetraacetic Acid (CDTA). This composition ensured stable ionic strength, maintained pH at 5.0-5.5, and eliminated the interference of multivalent ions capable of forming complexes with fluoride. Electrode calibration was performed using standard sodium fluoride solutions at concentrations of 0.2, 0.5, 1.0, 2.0, and 5.0 mg/L, prepared in TISAB II. Construction of the calibration graph confirmed the linearity of the electrode response, which corresponded to the theoretical value of -59.2 mV per decade at 25°C [12]. All measurements were performed at 22±2°C with temperature control to minimise thermal effects on accuracy.

To ensure reliability, each measurement was repeated five times, and final values were calculated as the arithmetic mean with standard deviation. Equipment calibration was conducted weekly and after every 20 measurements, in accordance with ISO 10359-1:1992 and the technical recommendations of analytical system manufacturers [12]. Internal laboratory quality control included regular stability checks, monitoring of deviations and technical maintenance of equipment. These procedures ensured the reliability, accuracy and reproducibility of data on fluoride content in drinking water [13].

Statistical data processing was carried out using SPSS Statistics and Microsoft Excel. Normality of distribution was assessed with quantile-quantile plots. Ninety-five percent confidence intervals for sample means were calculated. Differences between groups were analysed using Student’s t-test and the standard error of the mean (m). Results were considered statistically significant at $p<0.05$.

3. RESULTS AND DISCUSSION

3.1. Indicators of Dental Morbidity in Children of Different Ages

Analysis of dental status in the villages of Kyzyl-Suu and Orgochor revealed an extremely high prevalence of caries in the study population. Carious lesions of temporary or permanent teeth were detected in the vast majority of children examined, with prevalence rates by age group ranging from 93.1% to 100%. In Kyzyl-Suu, the prevalence reached 100% in all age categories, except among children aged 10-11 years (96.0±0.8%). In Orgochor, values ranged from 93.1±0.6% to 98.5±0.2%, indicating that the pathology was almost universal. In Kyzyl-Suu, younger children (5-6 years) showed higher intensity values (31.7±3.1, kpz index) for damage to temporary teeth compared with children from Orgochor. At the same time, with increasing age, a natural decrease in lesion intensity in temporary teeth was observed, attributable to physiological tooth replacement.

Conversely, the intensity of damage to permanent teeth (KPUz index) increased with age. Among children in Orgochor, the level of permanent tooth damage was lower at certain stages (18.0±2.4) than in Kyzyl-Suu, which may be related to the higher fluoride concentration in Orgochor drinking water (1.44 mg/l). Nevertheless, indices of permanent tooth damage remained high in both locations. In addition, the findings showed that younger age groups had a high proportion of complicated caries, characterized by deep carious cavities, pulpitis, and periodontitis. Characteristically, lesions were most pronounced in the upper anterior teeth and first molars. Overall, the results indicate significant dental morbidity in children, irrespective of the conditions of natural water fluoridation, with pronounced age-related dynamics in the damage to temporary and permanent teeth. Table **1** presents the distribution of children by age group and the leading indicators of carious process prevalence and intensity.

The obtained data are consistent with the findings of Shende and Wagh [14], who reported a peak in caries prevalence in primary teeth at 3-4 years, followed by a decline in older age groups. According to the authors, this decrease is associated with the physiological replacement of teeth and the development of independent oral hygiene skills. A similar trend was observed in the present study: in children aged 5-6 years, the intensity of primary tooth damage reached maximum values (31.7±3.1 in Kyzyl-Suu), but subsequently declined with age. However, the study population showed a significantly higher initial lesion intensity than reported by Shende and Wagh. This is likely due to the socio-hygienic conditions in Kyzyl-Suu and Orgochor, including limited access to early prevention and weak family involvement in developing children's hygiene habits.

At the same time, the data of Kostenko *et al.* [15] emphasise that, alongside the decline in primary tooth damage, the prevalence of caries in permanent teeth increases, particularly under inadequate preventive conditions. This conclusion was directly confirmed in the present study: with increasing age, a natural decline in the kpp index was recorded, while the intensity of permanent tooth damage (KPUz+kpz) increased, reaching its highest levels in children aged 10-11 years. In Orgochor, the rate of increase was less

Table 1: Caries Prevalence and Hygienic Status in Children of Different Age Groups

Age group	Settlement	Number of children	Caries prevalence (%)	Hygiene index according to Fedorov-Volodkina (mean ± SD) and its interpretation
5-6 years old	Kyzyl-Suu	38	100	1.6±0.1 (Satisfactory level of hygiene)
	Orgochor	40	97.5±0.4	1.9±0.1 (Satisfactory level of hygiene, closer to unsatisfactory)
7 years old	Kyzyl-Suu	46	100	2.0±0.2 (Borderline between satisfactory and unsatisfactory)
	Orgochor	44	93.0±0.6	2.0±0.2 (Borderline between satisfactory and unsatisfactory)
8 years old	Kyzyl-Suu	27	97.2±0.4	1.5±0.2 (Satisfactory level of hygiene)
	Orgochor	30	97.2±0.4	1.8±0.1 (Satisfactory level of hygiene, but there is a clear tendency for it to deteriorate)
9 years old	Kyzyl-Suu	71	100	1.9±0.2 (Satisfactory level of hygiene)
	Orgochor	65	96.0±0.8	1.9±0.2 (Satisfactory level of hygiene)
10-11 years old	Kyzyl-Suu	55	98.5±0.2	2.2±0.1 (Poor hygiene)
	Orgochor	70	98.5±0.2	2.0±0.1 (Borderline between satisfactory and unsatisfactory)

Note: HI - hygiene index, SD - standard deviation.
Source: compiled by the authors.

pronounced than in Kyzyl-Suu, which may be associated with higher fluoride content in drinking water. Despite this moderate difference, the level of permanent tooth damage in both locations remained high. These results suggest that the patterns described by Kostenko *et al.* are partially confirmed. Still, under regional conditions characterised by high initial cariogenicity, insufficient systemic prevention, and widespread hygienic deficiencies, the age effect is weakened and more difficult to fully realise.

An analysis of the structure of carious lesions by Godovanets and Kotelban [16] confirmed that the pathological process progresses from the initial stages of demineralisation to deep carious cavities with increasing age. According to their findings, the mean number of severe lesions in 15-year-old children reached 2.83±0.22 teeth on the International Caries Detection and Assessment System (ICDAS) II 4-6 scale. Although the ICDAS scale was not used in the present study, an age-related increase in complex caries was also observed, especially in children aged 8-11 years, among whom multiple cases of pulpitis and periodontitis were recorded. In addition, a considerable proportion of children exhibited predominant lesions in the first permanent molars and anterior teeth, consistent with the clinical picture described by Godovanets and Kotelban. At the same time, in the rural regions under study, such lesions were diagnosed at younger ages, suggesting an earlier onset and accelerated progression of the disease. This difference is most likely linked to the lack of preventive infrastructure, the infrequent frequency of dental examinations, and the absence of established hygiene practices within families.

An essential finding of this study is the high prevalence of complex caries among younger children. As emphasised by Kozma *et al.* [17], the so-called “bottle caries” causes predominant damage to the anterior teeth of young children due to prolonged enamel contact with carbohydrate-rich foods and liquids. The present study fully confirmed this observation: a significant proportion of children aged 5-6 years, particularly in Kyzyl-Suu, exhibited multiple lesions of the upper front teeth. However, unlike Kozma *et al*., who focused primarily on children under 3 years of age, severe lesions were observed in this study among preschool-and primary school-aged children. This may reflect delayed detection of pathology, low awareness among parents and teachers, and the absence of early dental monitoring in rural schools. Thus, while the clinical picture is similar, differences in the timing and age of manifestation point to the influence of organisational and behavioural factors specific to the regional context.

The differences between Kyzyl-Suu and Orgochor also warrant attention. Despite similar overall caries prevalence, the level of permanent tooth damage in Orgochor was somewhat lower. This can be attributed to the preventive effect of higher fluoride concentrations in drinking water, which aligns with current understanding of fluoride's protective role against caries development.

Nevertheless, as shown by both this study and the literature, a high level of natural fluoridation alone does not protect against dental disease in the absence of comprehensive hygienic training, health education and regular preventive examinations. The analysis of dental morbidity under elevated fluoride conditions underscores the need for an integrated approach to childhood dental disease prevention. This approach should combine health education, systematic monitoring of drinking water quality, correction of hygiene practices, and access to preventive dental care.

An assessment of oral hygiene status among children in the villages of Kyzyl-Suu and Orgochor revealed significant deficiencies in the study population. The application of the Fedorov-Volodkina Index provided objective quantitative data demonstrating an unsatisfactory level of individual hygiene among a large proportion of children.

Of the 486 children examined, only 151 (31.07%) had good hygiene status (index < 1.2). A satisfactory level was recorded in 38 children (7.82%). In contrast, 196 children (40.33%) had unsatisfactory hygiene, 66 (13.58%) poor hygiene, and 35 (7.20%) deplorable hygiene.

The distribution of hygiene categories indicated that most children with unsatisfactory, poor, or abysmal scores lacked access to regular preventive dental care and had inadequate oral self-care skills. A particularly unfavourable situation was noted in Orgochor, where the proportion of children with poor and very poor hygiene exceeded that in Kyzyl-Suu. Overall, 101 children (20.78%) demonstrated pronounced hygiene violations according to the Fedorov-Volodkina Index, reflecting a high prevalence of inadequate oral self-care. This trend in Orgochor correlated with less favourable sanitary and living conditions, as well as limited access to preventive dental measures.

Table 2: Intensity of the Carious Process in Children of Different Age Groups

Age group	Settlement	Intensity of KPUp+kpp (mean±SD)	Intensity of KPUz+kpz (mean±SD)
5-6 years old	Kyzyl-Suu	31.7±3.1	12.8±0.8
	Orgochor	18.0±2.4	8.7±0.7
7 years old	Kyzyl-Suu	14.8±2.4	5.7±0.5
	Orgochor	19.2±2.2	5.8±0.7
8 years old	Kyzyl-Suu	11.8±2.2	7.5±0.8
	Orgochor	13.6±1.6	8.7±0.6
9 years old	Kyzyl-Suu	10.8±1.0	6.9±0.4
	Orgochor	14.4±1.4	4.6±1.1
10-11 years old	Kyzyl-Suu	8.2±0.8	6.6±0.4
	Orgochor	10.7±0.9	6.0±0.0

Source: compiled by the authors.

Analysis of age-related dynamics showed a moderate tendency towards improved hygiene indicators with increasing age, likely due to the development of motor skills and the acquisition of basic hygiene habits. However, even in older age groups, the proportion of children with unsatisfactory hygiene remained high. Thus, the findings demonstrate a pronounced prevalence of poor hygiene among children in both populations studied. Despite the natural fluoridation of drinking water, this factor contributes to persistently high caries levels. For a more detailed analysis of children's dental status, data on caries prevalence are summarised in Table **2**.

The results of this study are consistent with those of Kaskova and Sadovski [18], who reported that in cases of compensated caries, children generally maintain a satisfactory level of oral hygiene. In contrast, in subcompensated and decompensated forms, hygiene deteriorates markedly. The present data confirm this pattern, showing that the majority of children with pronounced caries activity demonstrated average or unsatisfactory hygiene levels. Similar trends were observed in the study by Mania *et al.* [19], in which only 29.5% of children had good hygiene according to the Simplified Oral Hygiene Index (OHI-S), while the remainder had average or unsatisfactory scores. This points to a global problem of inadequate hygiene among children and underscores the universality of the observed patterns.

The findings of Jaiswal *et al.* [20] reinforce this view: brushing teeth twice daily was associated with significantly better hygiene indicators, whereas irregular hygiene practices were associated with substantially higher plaque index values and, consequently, a higher risk of caries. Their study also demonstrated a direct correlation between poor hygiene and higher caries incidence.

Equally important are the conclusions of Syarah Rulifa and Asia [21], who noted that even when children reported relatively high self-assessed dental status, hidden dental disorders often remained due to a mismatch between self-assessment and objective oral health status. In rural areas such as Orgochor, this problem is exacerbated by parents' limited dental education.

The study by Celepkolu *et al.* [22] emphasises the importance not only of regular toothbrushing but also of ensuring the sanitary safety of personal hygiene products. The use of chlorhexidine solution to disinfect toothbrushes reduced pathogenic microflora colonisation fourfold within four weeks. This finding highlights the necessity of additional educational interventions on hygiene, directed at both children and their parents.

Particular attention should also be paid to the phenomenon of the “fluoride paradox”, described by Kaskova and Sadovski [18] and Shalini *et al.* [23]. Even when fluoride-containing toothpastes are used, poor hygiene can neutralise fluoride's preventive effect. The present results confirm this observation: children with decompensated caries exhibited deplorable hygiene despite the presence of environmental fluoride sources.

Taken together, the findings from the analysis of children's oral hygiene status point to an urgent need for a systemic approach to dental disease prevention. This should include not only the correction of individual oral care skills but also the implementation of health education programmes aimed at parents and teachers. The development of comprehensive preventive strategies must incorporate regular oral health monitoring, structured hygiene training, disinfection of hygiene products, and optimisation of fluoride prophylaxis in accordance with the population's actual hygiene culture.

3.2. Frequency and Nature of Non-Carious Lesions of Teeth

In assessing the dental status of children living under conditions of natural water fluoridation, particular attention was given to the frequency and clinical characteristics of non-carious lesions, with a focus on fluorosis as one of the most common forms of pathology.

In Orgochor, clinical signs of fluorosis were observed in 27.3% of children. The severity of lesions ranged from mild to moderate and correlated with the fluoride concentration in drinking water (1.44 mg/l). By contrast, in Kyzyl-Suu, where the fluoride content was lower, fluorosis was much less common and generally subclinical.

The most pronounced enamel changes in children from Orgochor were expressed as opalescent inclusions and areas of reduced gloss, predominantly on the labial surfaces of incisors and molars. In some cases, small areas of enamel gloss loss were noted, reflecting early signs of hypomineralisation. Clinical manifestations of fluorosis were recorded mainly among children aged 5-9 years, suggesting the influence of excess fluoride during critical periods of permanent tooth amelogenesis.

Analysis of lesion distribution showed that fluorosis severity did not consistently correlate with oral hygiene status or caries intensity, underscoring the distinct mechanism by which fluoride affects enamel mineralisation. Comparison of clinical findings with water fluoride concentrations supports the conclusion that fluoridation directly influences the severity of non-carious changes in children.

Similar findings were reported by Shruthi and Anil [24], who demonstrated that exceeding the threshold of 1.5 mg/l increases the risk of fluorosis several-fold. These data are consistent with the results of the present study, confirming that even slight deviations from recommended standards can exert a chronic toxic effect on developing enamel.

Pathogenetic aspects of enamel fluorosis were explored by Mihalas *et al.* [25], who emphasised disturbances during the active morphogenesis of hard dental tissues. The authors noted that excess fluoride during critical periods of tooth development can disrupt the activity of cells responsible for mineralisation. Such dysregulation, according to their findings, leads to areas of insufficient mineralisation and marked microporosity, which clinically appear as chalky discolouration. The changes observed in this study - specifically, enamel gloss loss and characteristic opalescent zones in young children - are morphologically and topographically similar to those described by Mihalas *et al*., suggesting a shared pathogenetic mechanism.

The study by Stepco *et al.* [26] provides further evidence, conducted in a region with exceptionally high fluoride levels in drinking water (up to 16.2 mg/L), demonstrating a clear association between fluoride concentration and fluorosis severity. Although the fluoride concentration in Orgochor was considerably lower, the detection of clinically expressed fluorosis in 1 in 4 children indicates a high sensitivity of the paediatric population even to a moderate excess above the permissible limit.

Additional evidence is provided by Pandora *et al.* [27], who emphasised that the risk of fluorosis can increase even at fluoride concentrations above 1.0-1.2 mg/l, particularly in the presence of aggravating factors such as insufficient dietary intake of calcium and magnesium. These findings are consistent with the present study and highlight the importance of an integrated approach: monitoring of fluoride levels should be complemented by assessment of mineral status, especially in vulnerable age groups.

Martignon *et al.* [28] described a characteristic clinical manifestation of fluorosis as “snow capping” of the incisal edges of anterior teeth, which was also observed in children from Orgochor. In more severe cases, localised zones of hypomineralisation with loss of enamel gloss were recorded, consistent with previously described mechanisms of structural disturbance. Additional data from Sidhu and Boobalan [29] confirmed that severe forms of fluorosis are accompanied not only by enamel discolouration but also by structural weakness, significantly increasing the risk of secondary carious processes. These findings suggest that even relatively mild forms of fluorosis require careful dental monitoring and preventive measures.

Taken together, the literature review and the present study support the conclusion that even a moderate excess of fluoride above the optimal level in drinking water adversely affects enamel formation and increases the risk of non-carious changes. On this basis, regular monitoring of drinking water quality and the implementation of early fluorosis diagnostic programmes in endemic regions are advisable.

3.3. Effect of Fluoride Concentration in Drinking Water on Children's Dental Health

Analysis of fluoride concentrations in drinking water in the studied settlements revealed significant differences affecting children's dental health. In Orgochor, the fluoride level was 1.44 mg/L, almost twice the recommended level for children (optimal range: 0.7-1.0 mg/L). In Kyzyl-Suu, the fluoride content was considerably lower and within the range recommended for preventive standards (0.7-1.0 mg/l), indicating no risk of fluorosis.

The data demonstrate a clear relationship between drinking water fluoride concentration and children's dental health. In Orgochor, the elevated fluoride level was associated with a lower caries intensity than in Kyzyl-Suu. At the same time, the prevalence of non-carious dental lesions, particularly clinical forms of fluorosis, was significantly higher in Orgochor. Clinical analysis showed that an increase in the frequency and severity of fluorotic enamel changes accompanied the reduction in caries intensity in Orgochor. This highlights a paradox: exceeding the safe fluoride threshold reduces cariogenicity but also increases the risk of enamel damage.

Comparative analysis revealed that oral hygiene quality in both villages remained poor and did not account for the differences in caries intensity. Statistically significant differences in the carious, filled and extracted permanent teeth + carious and filled primary teeth index were identified between Kyzyl-Suu and Orgochor in the age groups 5-6 years ($p<0.001$), 8 years ($p<0.001$), 9 years ($p<0.001$) and 10-11 years ($p<0.001$), confirming the effect of fluoride concentration differences. In the 7-year age group, differences were not statistically significant ($p=0.411$), possibly reflecting compensatory factors or features of occlusal development. These findings confirm the leading role of fluoride concentration in determining dental pathology under natural fluoridation conditions. They also emphasise the delicate balance between fluoride's preventive and toxic effects, disruption of which shifts the structure of dental morbidity in the child population.

The results obtained are consistent with the findings of Vasisth *et al.* [30], who demonstrated that the optimal fluoride concentration in drinking water - ranging from 0.7 to 1.2 mg/l - provides a marked caries-preventive effect with minimal risk of fluorosis. The authors emphasised the importance of maintaining this narrow range, as even minor upward deviations may disrupt the balance between fluoride's benefits and potential toxicity. In the present study, the fluoride concentration in Orgochor was 1.44 mg/l, exceeding the upper limit of the optimal range defined by Vasisth *et al.* and approaching a level considered conditionally acceptable but already associated with risk.

This finding is supported by the observations of Taher *et al.* [31], who reported that at fluoride concentrations above 1.5 mg/l the likelihood of developing non-carious lesions, particularly clinically evident fluorosis, increases several-fold. Although the concentration recorded in Orgochor did not exceed the critical threshold, its proximity to the limit may explain the observed 27.3% prevalence of fluorosis among children. Importantly, unlike the studies of Vasisth *et al.* [30] and Taher *et al.* [31], which primarily examined urbanised regions with controlled water supply systems, the present study concerns natural, uncontrolled fluoridation. Under such conditions, the exposure experienced by children can vary within ranges not captured by a single water analysis but exert systemic effects over extended periods. Consequently, even when parameters formally comply with permissible standards, children remain vulnerable to chronic fluoride exposure, as confirmed by clinical observations [32, 33].

The study by Pontigo-Loyola *et al.* [34] also highlights that even moderate increases in drinking water fluoride levels can lead to paradoxical outcomes: a reduction in caries incidence accompanied by a rise in non-carious lesions, chiefly fluorosis. This dual dynamic was fully reproduced in the present study. In Orgochor, where the water fluoride concentration was 1.44 mg/L, a decrease in the intensity of permanent tooth damage was observed compared with Kyzyl-Suu; however, the proportion of children with clinical signs of fluorosis rose markedly (27.3%). Thus, the findings confirm the results of Pontigo-Loyola *et al*., while extending them through field observations in the context of moderate excess natural fluoridation. Unlike most studies conducted in countries with artificial fluoridation, the present data reflect the impact of natural, uncontrolled exposure, which heightens risks and underscores the need for systematic monitoring.

The data of Collantes Acuña *et al.* [35] indicate that fluoride concentrations in drinking water exceeding 1.5 mg/l increase the risk not only of dental alterations but also of systemic disturbances in mineral metabolism, particularly during childhood. In the context of the present study, this highlights the need for regular monitoring and adjustment of water supply in endemic regions.

The mechanism of fluorosis development, described in detail by Chaqqanov [36], also warrants attention. According to this model, excess fluoride during active enamel mineralisation disrupts the functional activity of ameloblasts, the cells responsible for forming the enamel layer. As a result, the organisation of the crystal lattice is impaired, leading to the formation of a porous, hypomineralised layer with reduced strength and resistance to external factors [37]. The clinical signs of fluorosis observed in Orgochor children - chalky spots, localised loss of enamel lustre, and elements of hypoplasia on the labial surfaces of incisors and molars - directly reflect these pathogenetic changes. Such manifestations were most pronounced in children aged 5-9 years, indicating that fluoride exerts its effect during the critical period of permanent tooth germ formation.

Unlike studies in regions with artificial fluoridation, the situation in Orgochor reflects chronic, low-dose, uncontrolled background exposure. Here, even "moderate" concentrations of fluoride (1.4-1.5 mg/l) can trigger destructive mechanisms in the absence of compensatory factors such as adequate calcium intake, regular dental monitoring, and preventive remineralisation therapy. Thus, clinical observations not only confirm the pathogenetic model described by Chaqqanov [36] but also demonstrate its realisation in an endemic context, where a combination of chemical, social, and behavioural factors predisposes children to a persistent reduction in dental health reserves.

The current data of Alamoudi *et al.* [38] highlight the importance of the body's overall mineral balance - primarily calcium and magnesium concentrations - as a key modifying factor in the pathogenesis of fluorosis. The authors noted that calcium and magnesium act as buffers, regulating fluoride bioavailability, thereby reducing its penetration into biologically active zones of the mineralising matrix. In cases of deficiency, not only does fluoride delivery to ameloblasts increase, but compensatory mechanisms for enamel tissue restoration are also impaired. This is particularly critical during childhood, when the permanent dentition forms and mineral strength is established [39].

In the context of the present study, the findings of Alamoudi *et al.* [38] are particularly relevant. Although the fluoride concentration in Orgochor drinking water was only slightly above the recommended level (1.44 mg/L), clinical signs of fluorosis were observed in 27.3% of children. The discrepancy between this relatively moderate exposure and the severity of non-carious changes may indicate dietary deficiencies in calcium and magnesium, which heighten vulnerability to fluorotoxic effects. Since the study did not include a targeted nutritional assessment, this explanation remains hypothetical but warrants attention in future investigations. In rural regions of Kyrgyzstan, where dietary diversity is often limited, latent mineral deficiencies may develop even with adequate caloric intake. Integration of nutritional monitoring into epidemiological studies of dental health would therefore expand the understanding of risk factors and strengthen the evidence base for preventive strategies.

A comprehensive analysis of the literature and the present results indicates that optimal dental health is achievable only by balancing the preventive benefits of fluoride with monitoring of its potential toxicity [40-43]. However, even where fluoride levels in drinking water were within or near the recommended range, oral hygiene among the examined children remained unsatisfactory, increasing their vulnerability to both carious and non-carious dental lesions. These findings underscore the urgent need to improve hygienic behaviours and establish sustainable oral care skills beginning in primary school. Effective prevention requires implementing comprehensive hygiene education programs in schools. These should include regular training for children and parents in personal hygiene, the involvement of health workers in educational activities, and the use of visual and behavioural methods such as demonstrations, interactive sessions, and adapted materials.

An essential component of preventive work is the organisation of systematic dental examinations for schoolchildren, which enable not only the early identification of disease but also the assessment of the development of self-care skills and parental control. Equally significant is the availability of high-quality hygiene products, particularly in socially vulnerable groups [44, 45]. Under conditions of limited resources, targeted provision of toothbrushes, toothpaste, and supplementary care products - selected with regard to individual dental status and local water fluoride concentrations - becomes especially relevant. In settlements with elevated fluoride levels in drinking water, the use of fluoride-containing toothpastes should be avoided in favour of calcium-based or remineralising agents, with recommendations for product selection developed jointly by the school paediatrician and dentist [46-48].

An additional element of the prevention system could be the introduction of electronic dental health passports, enabling the monitoring of examination results, hygiene levels, the effectiveness of preventive measures, and family compliance with professional recommendations. The formation of a culture of oral health requires coordinated efforts by medical and educational professionals, alongside active parental involvement [49, 50]. Only through interdisciplinary cooperation, sustained health education and adaptation of approaches to the specific features of the local context can a sustainable reduction in dental disease among children in regions with natural water fluoridation be achieved.

Although this study offers insights into the relationship between fluoride levels in drinking water and dental health outcomes, it is crucial to note that causal inference is not possible given the cross-sectional research design. The correlations between fluoride levels, caries prevalence, and fluorosis identified are based on a single point in time and do not account for the possible impact of other dynamic factors, including genetic predispositions, nutrition, and hygiene habits. To better understand the long-term effects of fluoride exposure on oral health and to demonstrate causal relationships, future longitudinal studies would be helpful, especially in areas with different fluoride concentrations.

4. CONCLUSIONS

The study provided a comprehensive assessment of the dental status of children aged 5-11 years living under conditions of natural water fluoridation in the settlements of Kyzyl-Suu and Orgochor, Jeti-Oguz District, Issyk-Kul Region. The prevalence of caries among the examined children was extremely high, ranging from 93.1% to 100% across all age groups and regardless of place of residence. Maximum values were observed in younger children: among those aged 5-6 years, prevalence reached 100% in Kyzyl-Suu and 97.5% in Orgochor. In children aged 7 years, the prevalence was 100% and 93.1%, respectively; at 8 years, 100% and 97.2%; at 9 years, 100% and 98.1%; and at 10-11 years, 96.0% and 98.5%. Clear age-related trends were identified: with increasing age, the intensity of damage to temporary teeth decreased due to physiological replacement, reflected in a reduction of the KPUp+kpp index from 31.7±3.1 in children aged 5-6 years in Kyzyl-Suu to 8.2±0.8 in those aged 10-11. At the same time, the severity of permanent tooth damage (KPUz+kpz) increased, especially among children aged 8-10 years, underscoring the need for early, systematic preventive measures throughout all stages of childhood.

Assessment of oral hygiene revealed that a substantial proportion of children had unsatisfactory or poor hygiene, with the worst indicators recorded in Orgochor. Only about one-third of children demonstrated satisfactory hygiene, indicating a low level of development of individual oral care skills. Importantly, even under conditions of elevated fluoride concentrations in water, inadequate hygiene remained the most significant risk factor for dental disease.

The concentration of fluoride in drinking water had a marked effect on the structure of dental pathology. In Orgochor, with a fluoride level of 1.44 mg/L, caries intensity in permanent teeth was lower than in Kyzyl-Suu ($p<0.001$), but the prevalence of non-carious lesions increased. Clinical signs of fluorosis were identified in 27.3% of children, mainly of mild severity, ranging from whitish chalky spots to initial areas of enamel hypomineralisation. It is also crucial to consider nutritional interventions, such as ensuring adequate calcium and magnesium intake, which may help mitigate the adverse effects of fluoride on dental health, particularly in areas with high fluoride concentrations in drinking water. These findings confirm the existence of a delicate balance between the preventive and toxic effects of fluoride: moderate excess above optimal concentrations reduces cariogenicity but increases the risk of enamel mineralisation disorders.

The scientific and practical significance of this study lies in substantiating the need for comprehensive control of drinking water quality, regular monitoring of children's dental health in regions with natural fluoridation, and the development of educational programmes to establish sustainable hygiene skills from an early age. The findings can be applied to strengthen public health preventive strategies.

The limitations of the study include the absence of nutritional status analysis, particularly of calcium and magnesium intake, and the inability to precisely account for all additional sources of fluoride exposure (e.g., food, hygiene products, medications). These factors may have influenced the severity of both carious and non-carious processes and should be addressed in future research. Further studies should incorporate nutritional indicators and consider concomitant fluoride sources to improve the accuracy of interpretations.

FUNDING

None.

ETHICAL APPROVAL AND CONSENT TO PARTICIPATE

All procedures performed in the study were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments.

Informed consent was obtained from all individuals included in this study.

CONFLICTS OF INTEREST

The authors confirm that they have no conflicts of interest to disclose.

ACKNOWLEDGEMENTS

None.

AUTHORSHIP

Conception and Design

Akmaanai Kamchybekova, Ryskul Abykeeva

Data Acquisition

Rahimat Tynalieva, Akdana Erkebaeva

Analysis and Interpretation of Data

Ryskul Abykeeva, Gulnar Cholokova

Writing the Initial Draft of the Manuscript

Rahimat Tynalieva, Akdana Erkebaeva

Review

Akmaanai Kamchybekova, Rahimat Tynalieva

Review and Editing

Ryskul Abykeeva, Akdana Erkebaeva,

Final Approval of the Manuscript

Akmaanai Kamchybekova, Gulnar Cholokova

All authors approve the final version and agree to be accountable for all aspects of the work.

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