

Active trachoma prevalence among Yemeni children in previously highly endemic districts following three rounds of mass drug administration: progress toward eliminating trachoma as a public health problem

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Abstract

Background

This study estimated the prevalence of trachomatous inflammation–follicular among children aged 1–9 years (TF_{1–9}) in previously highly endemic districts of Yemen following three rounds of mass drug administration (MDA) and identified its predictors.

Methods

A household-based cross-sectional study using a two-stage cluster sampling design was conducted among 1290 children from randomly selected households across six districts with a baseline trachoma prevalence exceeding 10% in Ibb and Hodeidah governorates. These districts were targeted by three rounds of MDA from 2021 to 2024. A structured questionnaire was used to collect data on children's sociodemographic characteristics, as well as the availability and status of water, sanitation, and hygiene (WASH) conditions. The children's eyes were also examined for trachoma using the World Health Organization (WHO) simplified trachoma grading system. Univariate analysis was performed to assess the association between independent variables and TF_{1–9}, while multivariable binary logistic regression was used to identify predictors of TF_{1–9} at a statistical significance level of < 0.05 .

Results

TF_{1–9} was prevalent among 0.9% (11/1290) of children in previously highly endemic districts of Ibb and Hodeidah governorates, with reductions ranging from 83.5% to 95.2%. Multivariable binary logistic regression analysis showed that households lacking improved sanitation facilities (AOR = 10.2, 95% CI: 1.70–61.19, $P = 0.011$) and the presence of nasal and/or ocular discharge on a child's face (AOR = 60.0, 95% CI: 6.16–584.54, $P < 0.001$) were independent predictors of TF_{1–9}.

Conclusions

The decline in the prevalence of TF_{1–9} in previously highly endemic districts of Ibb and Hodeidah governorates below the WHO threshold of 5% indicates substantial progress toward meeting the active-trachoma criterion for elimination as a public health problem and suggests that further MDA is not currently required for TF_{1–9} in these districts. However, surveillance surveys should be conducted to monitor potential recrudescence of trachoma. Poor household sanitation and facial uncleanness with nasal and/or ocular discharge can independently predict TF_{1–9} among children. Therefore, strengthening access to adequate sanitation and promoting facial cleanliness are key strategies for preventing trachoma recrudescence after MDA cessation.

Background

Trachoma, a bacterial eye infection caused by *Chlamydia trachomatis*, is a leading preventable cause of visual impairment and blindness [1]. It ranks as the second most common cause of blindness in Africa, Asia, and the Middle East [2]. Nevertheless, the World Health Organization (WHO) categorizes trachoma as one of the preventable neglected tropical diseases (NTDs) [3]. The infection is primarily transmitted through contact with the ocular discharge of infected individuals, contaminated hands, or contaminated objects, as well as via eye-seeking flies [4]. Overcrowded living conditions and poor sanitation further exacerbate the transmission. Repeated conjunctival infections may cause corneal scarring [1]. If left untreated, this condition may progress to trachomatous trichiasis (TT), resulting in corneal opacity and potentially irreversible blindness [5].

In 2024, the WHO estimated that 1.9 million individuals suffer from moderate-to-severe visual impairment or blindness due to trachoma across 39 countries [1]. Moreover, about 103 million people lived in trachoma-endemic areas and were therefore at risk of blindness [1]. The WHO recommends the strategy of Surgery, Antibiotics, Facial cleanliness and Environmental improvements (SAFE), as outlined in the 1998 World Health Assembly resolution WHA51.11 [6]. The "S" component of SAFE involves eyelid surgery to correct in-turned eyelashes and prevent them from damaging the cornea and eyeball, which is considered a form of tertiary prevention. The "A" component focuses on distributing antibiotics to achieve coverage of at least 80% of the population in communities where TF prevalence exceeds 5% through annual mass drug administration (MDA) with azithromycin and 1% tetracycline eye ointment (TEO). The "F" and "E" components are primary prevention measures that address personal hygiene and environmental sanitation [7].

Under the WHO framework for eliminating trachoma as a public health problem, the prevalence of TT among individuals aged 15 years and older should be reduced to below 0.2% and the prevalence of trachomatous inflammation–follicular (TF) in children aged 1–9 years (TF_{1-9}) should fall below 5% [8]. Significant progress has been made in the Eastern Mediterranean Region toward eliminating trachoma as a public health problem, with Oman, Morocco, and Iran having achieved this milestone [8]. In Yemen, trachoma remains a major public health concern. Interest in trachoma control has increased over the past few years because of its heavy burden on public health in the country [9].

As part of the Global Trachoma Mapping Project (GTMP), baseline mapping was conducted in four Yemeni governorates (Hodeidah, Ibb, Marib, and Al Jawf) from 2013 to 2015 [10]. Of the 15 evaluation units (EUs) surveyed in the first phase in 2013, six EUs (25 districts) exhibited a TF prevalence of $\geq 5\%$. Among these, two EUs comprising six districts required three annual rounds of MDA, while four EUs comprising 19 districts required a single round of MDA [10]. In the second phase, conducted between 2013 and 2015, two additional EUs comprising five districts in Hajjah were identified as needing MDA [10]. Based on the findings from the baseline surveys, a single round of MDA was conducted in six districts in Ibb and Hodeidah governorates in 2018 [5]. According to the results of population-based surveys conducted in 42 EUs across nine governorates in 2018, TF_{1-9} prevalence was $\geq 10\%$ in two EUs

comprising seven districts and ranged from 5.0 to 9.9% in six EUs comprising 24 districts, while the TT prevalence in adults was $\geq 0.2\%$ in five EUs comprising 19 districts [5]. Recently, TF was found to be prevalent among 10.9% of primary schoolchildren in Bajil district, Hodeidah [11] and among 9.1% of primary schoolchildren in Sana'a city [12]. From February 2021 to April 2024, three rounds of MDA with azithromycin were conducted in highly affected areas of Ibb and Hodeidah, targeting all eligible individuals. Therefore, this study aimed to estimate the prevalence of TF₁₋₉ in previously highly endemic districts of Ibb and Hodeidah governorates following three rounds of MDA conducted between 2021 and 2024, compared to the 2013 baseline mapping, and to identify TF₁₋₉ predictors.

Methods

Study design, population and setting

A household-based cross-sectional study was conducted among children aged 1 to 9 years in six randomly selected districts in September 2024. These districts were selected based on the following criteria: documented high endemicity for trachoma in the 2013 baseline survey, with TF prevalence exceeding 10%; implementation of three rounds of MDA with azithromycin in 2021, 2023, and 2024; and mean programmatic MDA coverage exceeding the WHO-recommended threshold of 80% across the three rounds. The selected districts included As Sabrah, As Sayyani, and Dhi As Sufal in Ibb governorate, as well as Al Qanawis, Alluheyah, and Az Zuhrah in Hodeidah governorate (Fig. 1). These districts were targeted with three rounds of MDA with azithromycin in 2021, 2023, and 2024. Children of either sex were eligible for inclusion if they resided in the survey districts and their heads of households or legal representatives provided informed consent. Children without permanent residence in the study districts were excluded.

Sample size calculation

Based on the WHO-recommended design parameters for population-based trachoma surveys [13], a sample size of 970 children was calculated, assuming a TF prevalence of 4%, a confidence level of 95%, a precision of 2%, and a design effect of 2.63. The sample size was subsequently increased to 1290 using an inflation factor of 1.33.

Sampling strategy

As in the 2013 survey, a two-stage cluster sampling approach was employed. In the first stage, 30 clusters were selected using systematic random sampling. Villages served as the primary sampling units in the study districts, which were grouped into clusters according to the WHO definition of EUs for trachoma surveys [13], while households were considered the secondary sampling units.

In the second stage, compact segment sampling was used to select households from the lists within these clusters, with the number of households selected from each cluster proportional to its population size. A household was defined as all individuals residing in a dwelling unit as their usual residence, regardless of whether the household comprised one or more marital units. The lists of households with eligible children were obtained from the Neglected Tropical Disease Program at the Ministry of Public Health and Population. Households were selected using simple random sampling from these lists. According to WHO criteria [13], 602 (46.7%) children were recruited from Ibb governorate (129 from As Sabrah, 172 from As Sayyani, and 301 from Dhi As Sufal), while 688 children (53.3%) were recruited from Hodeidah governorate (172 from Al Qanawis, 215 from Alluheyah, and 301 from Az Zuhrah). The heads of the selected households, or their adult representatives, were then informed about the study's purpose, and their consent to voluntary participation was obtained. If more than one eligible child was present in a household, a single child was selected using simple random sampling.

Data collection and trachoma examination

The household head was interviewed using a structured questionnaire to collect children's sociodemographic data and assess the availability and status of water, sanitation, and hygiene (WASH). The questionnaire was developed after reviewing the relevant literature from Yemen and comparable endemic settings [5, 11, 12, 14–16]. It was prepared directly in Arabic and reviewed by the study team to ensure clarity, cultural appropriateness, and consistency with the intended concepts. Before data collection, the questionnaire was pilot-tested with 20 households in a neighboring district not included in the final study sample, and minor modifications were made based on the pilot findings. Household interviews to collect sociodemographic and WASH data were conducted by trained field enumerators who were independent of the clinical assessment team.

Facial cleanliness was assessed by ophthalmologists through direct visual observation and recorded as a binary variable according to the presence or absence of nasal and/or ocular discharge. A child's face was classified as unclean if visible nasal and/or ocular discharge was present at the time of examination and as clean if no such discharge was observed. This assessment followed a standardized field definition used by the survey team, although photographic grading was not performed. In addition, the ophthalmologists performing clinical examinations did not administer the questionnaire or use the collected sociodemographic and WASH information during clinical grading.

The eyes of children were subsequently examined for TF using the WHO simplified trachoma grading system [17–19] by qualified ophthalmologists with prior experience in national trachoma surveys, who underwent standardized training and certification in accordance with WHO and International Trachoma Initiative (ITI) guidelines. The training included an initial theoretical review of the WHO trachoma grading system, followed by practical sessions using WHO-recommended image sets for grading TF. Certification was granted only after examiners achieved a minimum inter-rater agreement, expressed as a kappa statistic of ≥ 0.80 , compared with an expert gold-standard grader. During the survey, random inter-observer consistency checks were performed in the field to maintain diagnostic accuracy and

minimize the risk of misclassification.. TF was defined as the presence of five or more follicles, each measuring at least 0.5 mm in diameter, in the central part of the upper tarsal conjunctiva [17]. To prevent the cross-infection among participants, the investigators wore disposable gloves or sanitized their hands with 70% alcohol after each examination. All children diagnosed with TF were immediately treated and provided with two tubes of 1% TEO and azithromycin tablets at no cost, and referred to the nearest primary healthcare center for continued monitoring and follow-up. Household contacts of these children were also screened and treated according to the national trachoma control guidelines. In addition, those with suspected advanced ocular disease or complications were referred to the nearest secondary ophthalmic care facility.

Data analysis

Data were initially entered into Microsoft Excel spreadsheets to check for duplicates and inconsistencies and then analyzed using IBM SPSS Statistics, version 26.0 (IBM Corp., Armonk, NY, USA). Categorical data were presented as frequencies and percentages, while continuous data were summarized using the mean and standard deviation (SD) for normally distributed variables and the median and interquartile range (IQR) for non-normally distributed variables. The prevalence of TF₁₋₉ was calculated, along with the corresponding 95% confidence interval (CI).

Univariate analysis was performed to assess associations between the independent variables and TF₁₋₉ using either the chi-square test or Fisher's exact test, as appropriate. The odds ratios of these associations, along with their corresponding 95% confidence intervals (CIs), were reported. Additionally, all variables with *P* values < 0.25 in the univariate analysis were included in a multivariable binary logistic regression model to identify independent predictors of TF₁₋₉, along with adjusted ORs (AORs) and 95% CIs. Before fitting the multivariable binary logistic regression model, collinearity among candidate variables was assessed using the variance inflation factor (VIF) and cross-tabulation with Phi coefficients. Variables showing severe collinearity were not entered together into the final model to avoid unstable estimates. Severe collinearity was detected between "availability of latrine facilities" and "cleanliness of the child's face from nasal and/or ocular discharge" (VIF > 25; phi coefficient = 0.976, *P* < 0.001). Therefore, "availability of latrine facilities" was excluded from the final model. Statistical significance was set at *P* < 0.05.

Results

Characteristics of the study population

Table 1 shows that more than half of the children included in this study were males (54.7%) and aged 5 years or younger (58.8%), with a mean age of 5.0 ± 2.4 years. The median household size was 7 members (IQR: 4), and 50.8% of the households had 7 members or fewer. More than half of the heads of households for these children were females (54.4%), and the majority were aged 40 years or younger

(61.4%), with a mean age of 40.5 ± 11.4 years. Most of the children's fathers were literate (65.6%), while most of their mothers were illiterate (79.4%).

Table 1
Characteristics of children enrolled in the study*

Characteristics	<i>n</i>	(%)
Sex of the child		
Male	706	(54.7)
Female	584	(45.3)
Age of the child (years)		
≤ 5	759	(58.8)
> 5	531	(41.2)
Mean ± SD: 5.0 ± 2.4		
Household size (members)		
≤ 7	655	(50.8)
> 7	635	(49.2)
Median (IQR): 7.0 (4)		
Sex of the household head		
Male	588	(45.6)
Female	702	(54.4)
Age of the household head (years)		
≤ 40	792	(61.4)
> 40	498	(38.6)
Mean ± SD (range): 40.5 ± 11.4 (21–90)		
Father's literacy status		
Literate	846	(65.6)
Illiterate	444	(34.4)
Mother's literacy status		
Literate	266	(20.6)
Illiterate	1024	(79.4)
Father's employment status		
Farmer	537	(41.6)
Unemployed	374	(29.0)

Characteristics	<i>n</i>	(%)
Sex of the child		
Employed	192	(14.9)
Daily laborer	187	(14.5)

* The total number of children was 1290. *SD* standard deviation; *IQR* interquartile range.

Prevalence of TF

Table 2 shows that the overall prevalence of TF_{1–9} in the previously highly endemic districts of Ibb and Hodeidah governorates was 0.9% (11/1290). In Ibb, the overall prevalence of TF_{1–9} was 0.8% (5/602), with district-level rates of 1% (3/301) in Dhi As Sufal, 0.8% (1/129) in As Sabrah and 0.6% (1/172) in As Sayyani. In Hodeidah, the overall prevalence was 0.9% (6/688), with the highest district-level prevalence observed in Al Qanawis (1.7%; 3/172), followed by 0.7% (2/301) in Az Zuhrah and 0.5% (1/215) in Alluheyah.

Table 2

Prevalence of TF_{1–9} following three rounds of MDA in previously highly endemic districts of Ibb and Hodeidah governorates, Yemen, 2024

Governorate	Districts	<i>N</i>	TF _{1–9} prevalence after three rounds of MDA <i>n</i> (%; 95% CI)
Ibb	As Sabrah	129	1 (0.8; 0.02–4.24)
	As Sayyani	172	1 (0.6; 0.01–3.20)
	Dhi As Sufal	301	3 (1.0; 0.21–2.88)
	All districts	602	5 (0.8; 0.27–1.93)
Hodeidah	Al Qanawis	172	3 (1.7; 0.39–5.01)
	Alluheyah	215	1 (0.5; 0.01–2.56)
	Az Zuhrah	301	2 (0.7; 0.08–2.38)
	All districts	688	6 (0.9; 0.32–1.89)
Overall prevalence		1290	11 (0.9; 0.43–1.52)

N, number of children examined; *n*, number of children with trachoma; TF_{1–9} trachomatous inflammation–follicular among children aged 1–9 years; MDA mass drug administration; CI confidence interval.

District-level TF_{1–9} prevalence following three MDA rounds

Table 3 shows that the reduction in TF_{1–9} prevalence across all surveyed districts was 93.7% in Ibb and 91.3% in Hodeidah, with an overall reduction of 92.6%. The prevalence of TF_{1–9} decreased by 95.2% in As Sayyani, followed by reductions of 95.1% in Alluheyah, 93.7% in As Sabrah, 93.2% in Az Zuhrah, and 92.1% in Dhi As Sufal. The smallest district-level reduction of 83.5% was observed in Al Qanawis.

Table 3

TF_{1–9} prevalence following three rounds of MDA between 2021 and 2024 in highly endemic districts of Ibb and Hodeidah governorates, Yemen

Governorate	Districts	TF _{1–9} prevalence (%)		Percentage Reduction
		2024 (following 3 MDA rounds)	2013 (baseline) ^a	
Ibb	As Sabrah	0.8	12.6	93.7
	As Sayyani	0.6	12.6	95.2
	Dhi As Sufal	1.0	12.6	92.1
	All districts	0.8	12.6	93.7
Hodeidah	Al Qanawis	1.7	10.3	83.5
	Alluheyah	0.5	10.3	95.1
	Az Zuhrah	0.7	10.3	93.2
	All districts	0.9	10.3	91.3
Overall prevalence		0.9	11.5	92.6

TF_{1–9} trachomatous inflammation–follicular among children aged 1–9 years; MDA mass drug administration. ^a Pooled 2013 baseline for the evaluation units comprising the corresponding districts.

Association of TF_{1–9} with sociodemographic characteristics

Table 4 shows that having a household head aged older than 40 years (OR = 7.3, 95% CI: 1.56–33.79; *P* = 0.004) was significantly associated with TF_{1–9}. However, no significant associations were found between TF_{1–9} and children's sex or age, household size, the sex of the household head, parental literacy, or the father's unemployment status.

Table 4
Association of TF₁₋₉ with sociodemographic characteristics in previously highly endemic districts of Ibb and Hodeidah governorates, Yemen, 2024

Characteristics	N	Presence of TF _{1–9}				P-value
		n	(%)	OR	(95% CI)	
Sex of the child						
Male	706	6	(0.8)	1.0	(0.30–3.27)	1.000
Female	584	5	(0.9)	Reference		
Age of the child (years)						
≤5	759	9	(1.2)	3.2	(0.68–14.75)	0.138
> 5	531	2	(0.4)	Reference		
Household size (members)						
≤7	655	3	(0.5)	Reference		
> 7	635	8	(1.3)	2.8	(0.73–10.50)	0.117
Sex of the household head						
Male	588	5	(0.9)	1.0	(0.31–3.31)	0.993
Female	702	6	(0.9)	Reference		
Age of the household head (years)						
≤40	792	2	(0.3)	Reference		
> 40	498	9	(1.8)	7.3	(1.56–33.79)	0.004
Father's literacy status						
Literate	846	7	(0.8)	Reference		
Illiterate	444	4	(0.9)	1.1	(0.32–3.74)	1.000
Mother's literacy status						
Literate	266	3	(1.1)	Reference		
Illiterate	1024	8	(0.8)	0.7	(0.18–2.62)	0.706
Father's employment status						
Unemployed	1098	7	(0.6)	Reference		

Characteristics	N	Presence of TF _{1–9}				P-value
		n	(%)	OR	(95% CI)	
Sex of the child						
Employed	192	4	(2.1)	3.3	(0.96–11.44)	0.067

N, number examined; *n*, number positive; *TF*₁₋₉ trachomatous inflammation–follicular among children aged 1–9 years; *OR* odds ratio; *CI* confidence interval.

Association of TF₁₋₉ with WASH factors

Table 5 shows that the absence of latrine facilities in the household (*OR* = 147.9, 95% *CI*: 18.70–1169.64; *P* < 0.001), the presence of unimproved sanitation facilities (*OR* = 23.7, 95% *CI*: 4.87–115.02; *P* < 0.001) and the presence of nasal and/or ocular discharge on a child’s face (*OR* = 65.7, 95% *CI*: 13.96–309.00; *P* < 0.001) were significantly associated with TF₁₋₉. In contrast, no significant associations were found between TF₁₋₉ and the source of household water, the distance to the household water source, the source of household water used for washing faces, or self-reported regular washing of hands and faces with water and soap.

Table 5

Association of TF₁₋₉ with WASH factors in previously highly endemic districts of Ibb and Hodeidah governorates, Yemen (2024)

Variables	N	Presence of TF _{1–9}				P-value
		n	(%)	OR	(95% CI)	
Availability of latrine facilities in the household						
Yes	1199	1	(0.1)	Reference		
No	91	10	(11.0)	147.9	(18.70–1169.64)	< 0.001
Source of household water						
Unimproved	800	6	(0.8)	0.7	(0.22–2.42)	0.757
Improved	490	5	(1.0)	Reference		
Distance to water source (minutes)						
> 30	348	6	(1.7)	3.3	(1.00–10.84)	0.079
≤ 30	942	5	(0.5)	Reference		
Source of household water used for washing faces						
Unimproved	800	5	(0.6)	0.5	(0.15–1.67)	0.350
Improved	490	6	(1.2)	Reference		
Sanitation facilities in the household ^a						
Unimproved	160	7	(4.4)	23.7	(4.87–115.02)	< 0.001
Improved	1037	2	(0.2)	Reference		
Self-reported regular washing of hands and faces with water and soap						
No	644	8	(1.2)	2.7	(0.71–10.21)	0.129
Yes	646	3	(0.5)	Reference		
Cleanliness of a child's face from nasal and/or ocular discharge						
No	91	9	(9.9)	65.7	(13.96–309.00)	< 0.001
Yes	1199	2	(0.2)	Reference		

N, number examined; *n*, number positive; *TF*_{1–9} trachomatous inflammation–follicular among children aged 1–9 years; *WASH* water, sanitation and hygiene; *OR* odds ratio; *CI* confidence interval. ^a There were 93 missing cases: 91 children from households without latrine facilities for whom the variable was not applicable, and two children from households with latrines for whom the sanitation facility type was missing.

Independent predictors of *TF*_{1–9}

Multivariable binary logistic regression analysis showed that unimproved household sanitation facilities (AOR = 10.2, 95% CI: 1.70–61.19, *P* = 0.011) and the presence of nasal and/or ocular discharge on a child's face (AOR = 60.0, 95% CI: 6.16–584.54, *P* < 0.001) were independent predictors of *TF*_{1–9} (Table 6).

Table 6
Independent predictors of *TF*_{1–9} in previously highly endemic districts of Ibb and Hodeidah governorates, Yemen, 2024

Predictors	AOR	(95% CI)	P-value
Unimproved sanitation facilities in the household	10.2	(1.70–61.19)	0.011
Presence of nasal and/or ocular discharge on a child’s face	60.0	(6.16–584.54)	< 0.001

N, number examined; *n*, number positive; *TF*_{1–9} trachomatous inflammation–follicular among children aged 1–9 years; *AOR* adjusted odds ratio; *CI* confidence interval.

Discussion

The present study revealed that the three rounds of MDA with azithromycin from 2021 to 2024 were followed by a marked reduction in the prevalence of *TF*_{1–9} in the districts of Ibb and Hodeidah governorates, which were highly endemic at baseline in 2013. Notably, the overall prevalence in the study districts decreased from 11.5% in 2013 to 0.9% in 2024, representing a 92.6% reduction. When the 2024 district-level prevalence estimates were compared with the corresponding pooled 2013 EU baseline estimates, the estimated reductions exceeded 90% in all districts except Al Qanawis, where the estimated reduction was 83.5%. However, these comparisons should be interpreted cautiously because district-specific baseline prevalence estimates were unavailable. The comparatively smaller reduction in Al Qanawis may reflect district-specific differences in baseline endemicity, MDA participation, *WASH* conditions, access to healthcare services, or conflict-related population movement. Overall, these findings support the plausibility that MDA contributed substantially to the observed decline in *TF*_{1–9} prevalence. Nevertheless, because this was a cross-sectional rather than a longitudinal study, the reduction cannot be attributed exclusively to MDA. Other factors, including secular trends, population movement, access to healthcare, and unmeasured changes in *WASH* conditions, may also have contributed to the observed decline. The first MDA round in 2021 also coincided with the coronavirus disease 2019 (COVID-19) pandemic, which may have affected drug-distribution logistics, community

participation, access to routine health services, and household hygiene practices. However, COVID-related disruptions were not systematically documented, and their potential influence on MDA implementation and the observed reduction in TF₁₋₉ prevalence could not be assessed. Moreover, the approximately two-year interval between the first and second MDA rounds deviated from the WHO-recommended annual MDA schedule for districts with TF₁₋₉ prevalence above 10% [20]. This irregular timing likely reflected conflict-related access barriers, displacement, logistical constraints, disrupted public health activities, and the effects of the COVID-19 pandemic. The extended interval may have prolonged transmission and delayed the effects of treatment. Although TF₁₋₉ fell below 5% in all districts, the independent effect of this interval on the overall reduction remains uncertain.

In comparison, the prevalence of TF₁₋₉ was 12.6% in the three districts of Ibb and 10.3% in the three districts of Hodeidah in 2013 [19]. The prevalence of TF₁₋₉ in the present study is also lower than that documented in Ibb (3.1–7.6%) and Hodeidah (2.3–3.1%) in impact surveys conducted in 2019 [5], indicating a steady decrease in prevalence over time. Higher prevalence rates were also reported among primary schoolchildren aged 7–12 years in Bajil district, Hodeidah, in 2020 (10.9%) and among schoolchildren aged 6–12 years in Sana'a city in 2021 (9.1%) [11, 12]. The previously endemic districts included in this study achieved reductions in TF₁₋₉ prevalence to below the WHO threshold of 5%, indicating substantial progress toward meeting the active trachoma component of the elimination criteria [8]. Based on these findings, no additional rounds of antibiotic MDA for active trachoma are currently indicated in the surveyed districts, while strengthened surveillance for recrudescence and continued implementation of the F and E interventions remain essential. However, elimination of trachoma as a public health problem also requires a TT prevalence below 0.2% among adults aged 15 years and older. Because TT was not assessed in the present study, these findings should not be interpreted as confirmation that full elimination has been achieved and assessment of TT among adults is needed to confirm progress toward meeting all WHO elimination targets. Surveillance surveys are required two years after MDA cessation to monitor potential recrudescence of active trachoma [21, 22]. MDA can significantly reduce community transmission by reducing the human reservoir of infection, which is crucial for controlling NTDs like trachoma. The substantial decline in prevalence observed in the present study is comparable with the progress achieved in several other countries [14, 22, 23].

In the present study, neither the sex nor the age of children was significantly associated with TF₁₋₉, which is inconsistent with those of studies involving children aged 1–9 years in Papua New Guinea and Zimbabwe [24, 25], where younger age was identified as an independent predictor of TF. The present findings suggest that the dynamics of trachoma transmission following substantial reductions achieved through MDA are influenced more by environmental and socioeconomic factors than by the children's sex or age. However, the small number of TF₁₋₉ cases may partly explain the lack of significant associations between TF₁₋₉ and the children's age or sex, as this may limit the statistical power to detect modest differences between groups.

TF₁₋₉ in the present study was significantly higher in households led by individuals aged 40 years or older in the univariate analysis; however, this association was no longer statistically significant after adjustment for potential confounders. This finding suggests that the age of the household head may have acted as a proxy for other household-level socioeconomic, sanitation, or hygiene-related factors rather than having an independent effect. In addition, the small number of TF-positive cases may have reduced the statistical power of the multivariable model to identify an adjusted association. It is therefore essential to explore the underlying factors associated with the age of the household head that may account for the increased risk of trachoma among children, including their knowledge. For instance, research has shown that inadequate knowledge of trachoma among household heads and low monthly income were significantly associated with a higher risk of TF₁₋₉ [15]. Several studies have demonstrated that larger household size independently predicts TF among children [26–29], mainly because overcrowding facilitates transmission. However, the present study did not find a significant association between household size and TF₁₋₉. This lack of association aligns with that reported for Kenyan children [30], suggesting that the dynamics of trachoma transmission may vary across contexts and with differences in hygiene practices.

Regarding WASH conditions, the absence of latrine facilities, the presence of unimproved sanitation facilities, and the uncleanliness of a child's face from nasal and/or ocular discharge were significantly associated with TF₁₋₉. The association between WASH factors and trachoma among children is well documented. In line with the present findings, a significant association between trachoma and a lack of access to latrines, unimproved sanitation facilities, and other WASH-related factors has been reported in Yemen and elsewhere [16, 27, 31–40]. The significant association between unimproved sanitation facilities and TF₁₋₉ in the present study is consistent with the findings of previous studies elsewhere [16, 41, 42]. Increased use of latrines and improved sanitation have been found to significantly reduce the prevalence of trachoma [35, 37, 43, 44]. Apart from sanitation, the presence of nasal and/or ocular discharge on the face was an independent predictor of TF₁₋₉ among children in the present study, which is consistent with those of previous studies [27, 36, 41, 45–47]. Facial uncleanliness and the presence of nasal and ocular discharge can attract flies, which serve as vectors for bacterial transmission between infected and uninfected children [45, 48].

While this study identified significant associations, the small number of positive cases warrants cautious interpretation because estimates may be substantially exaggerated, as the low positivity rate and the large sample size limited the statistical power and widened adjusted CIs. AORs should therefore be viewed as exploratory associations rather than definitive independent effects, potentially identifying contributors to residual TF transmission for further confirmation. Because facial cleanliness was visually assessed without photographic grading, observer variability and misclassification remain possible. Therefore, its association with TF₁₋₉ should be also interpreted with caution. Similarly, self-reported, unverified hand and face washing was susceptible to recall and social desirability biases, potentially weakening its association with TF₁₋₉. In addition, because ophthalmologists were not masked to household information, information bias in TF grading, particularly in borderline cases, remains possible.

Although mean programmatic MDA coverage exceeded 80% across three rounds, the cross-sectional design prevents attributing observed changes solely to MDA or distinguishing its independent contribution from other possible contextual influences. A further sampling-related limitation is that, in households with multiple eligible children, selecting one child randomly may have obscured TF clustering and underestimated burden. Accordingly, future surveys should consider examining all children within selected households, with appropriate adjustment for household-level clustering.

In this study, operational and logistical constraints, including access difficulties, population mobility, and the short survey period, prevented documenting non-participation, limiting assessment of participation bias. Additionally, unmeasured environmental and socioeconomic confounders may have produced spurious associations or obscured genuine relationships between potential predictors and TF infection among children. It is noteworthy that both the 2013 and 2024 surveys were conducted using the WHO-recommended two-stage cluster sampling framework and by trained and certified ophthalmologists, making comparison between the two surveys methodologically reasonable. However, the 2013 survey preceded the 2015 conflict, whereas the 2024 survey occurred amid displacement and crisis, potentially altering sampled populations' demographic, socioeconomic, and WASH characteristics. Conflict-related movement may have altered household composition and introduced selection bias; therefore, the observed TF decline should be interpreted as a programmatic reduction, not definitive evidence of independent MDA effect. On the other hand, this study assessed TF_{1-9} but not TT among individuals aged 15 years and older, addressing only active-trachoma elimination criteria and precluding confirmation of elimination as a public health problem. Despite the limitations and caution required in interpreting the results, the study contributes to a broader understanding of trachoma control efforts and underscores the importance of MDA in reducing trachoma burden in endemic areas of the country.

Conclusions

Following three rounds of MDA, the marked reduction in TF_{1-9} prevalence to below the WHO threshold of 5% in previously highly endemic districts of Ibb and Hodeidah governorates represents substantial progress toward achieving the active-trachoma component of elimination as a public health problem. While further MDA is not currently indicated for active trachoma in the surveyed districts, TT assessment and continued post-MDA surveillance remain necessary before concluding that trachoma has been fully eliminated. Further attention should also be given to districts with comparatively smaller reductions in TF_{1-9} prevalence, particularly Al Qanawis. Poor household sanitation and unclean facial status due to nasal or ocular discharge independently could predict TF_{1-9} ; however, these findings should be interpreted cautiously because of the small number of TF-positive children. Therefore, strengthening sanitation and facial cleanliness interventions under the SAFE strategy is crucial for preventing recrudescence and sustaining progress toward elimination. Programmatic priorities should include targeted hygiene education, promotion of regular face washing, improved access to and use of sanitation facilities, and enhanced coordination between the national trachoma program and WASH services in communities where residual transmission risks persist.

Abbreviations

AOR Adjusted odds ratio

CI Confidence interval

COVID-19 Coronavirus disease 2019

EU Evaluation unit

GET2020 WHO Alliance for the Global Elimination of Trachoma by 2020

GTMP Global Trachoma Mapping Project

IQR Interquartile range

MDA Mass drug administration

NTD Neglected tropical disease

OR Odds ratio

SAFE Surgery, Antibiotics, Facial Cleanliness and Environmental Improvements

SD Standard deviation

SPSS Statistical Package for the Social Sciences

TEO Tetracycline eye ointment

TF₁₋₉ Trachomatous inflammation–follicular among children aged 1–9 years

TF Trachomatous inflammation–follicular

TT Trachomatous trichiasis

WASH Water, sanitation, and hygiene

WHO World Health Organization

Declarations

Ethics approval and consent to participate

The protocol of this study was approved by the Research Ethics Committee (RES) of the Faculty of Medicine and Health Sciences at Sana’a University, Yemen (Ethical approval No.: 1535). Given the high level of illiteracy in the rural study population, written informed consent was waived by the RES, and oral

consent was obtained from the heads of households or their legal representatives after they were briefed about the nature and purpose of the study. The privacy of participants and the confidentiality of their data were assured. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Author contributions

SAA conceived the study idea and implemented the fieldwork. SAA, YAR, MAKM and TAH designed the study. SAA, YAR, MAKM and RA analyzed the data, interpreted the results and drafted the manuscript. SAA and RA drafted the manuscript. All authors read, revised, and approved the final version of the manuscript.

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Availability of data and materials

All relevant data are included in the manuscript, and the datasets for the study are available from the corresponding author upon reasonable request.

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Figures

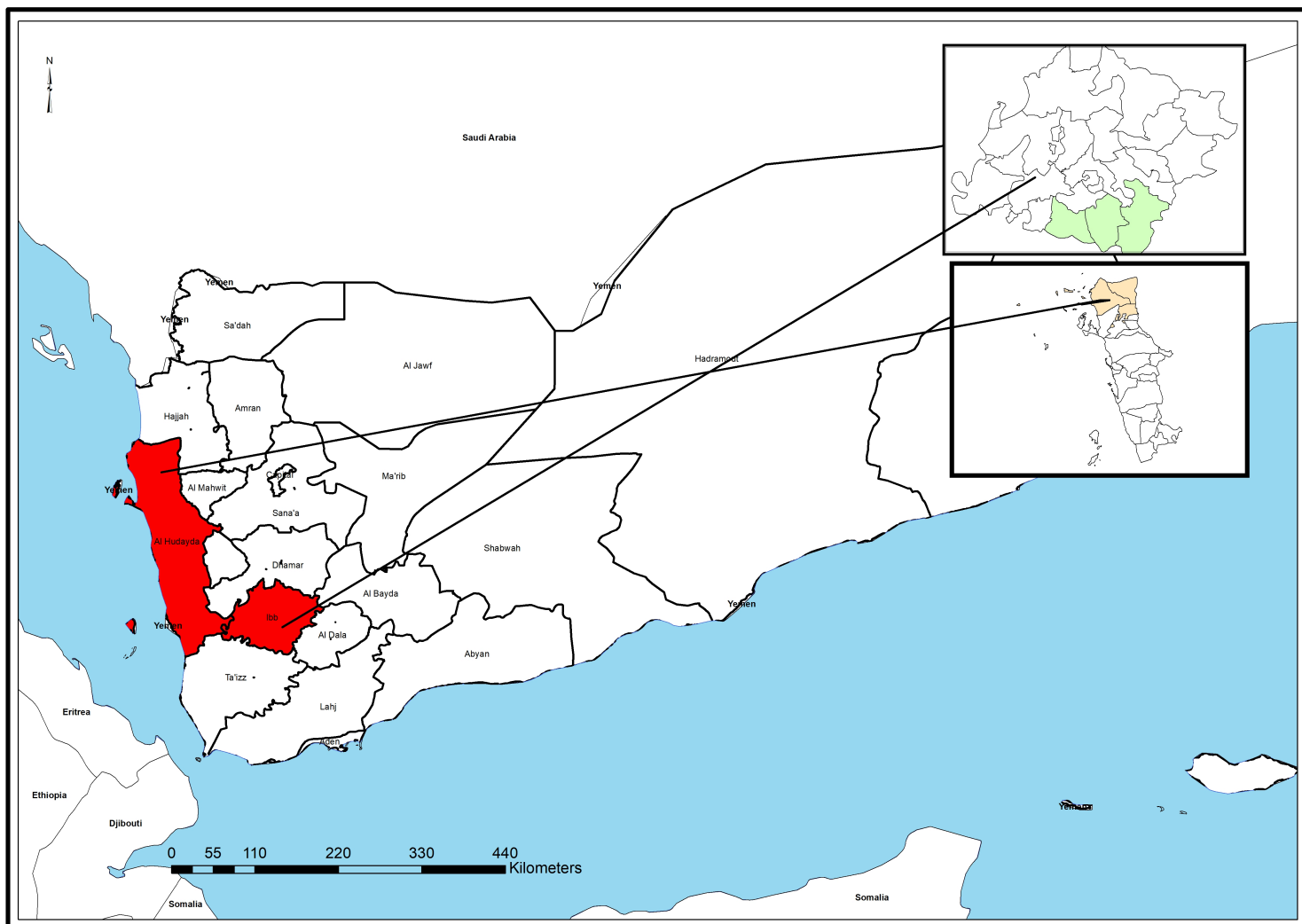


Figure 1

Map of Yemen showing the location of the survey districts in Ibb and Hodeidah governorates