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Persistent transmission of onchocerciasis in Kwanware-Ottou focus in Wenchi health district, Ghana

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Abstract

Background This study examined onchocerciasis transmission in Kwanware and Ottou in the Wenchi Health District of Ghana, where persistent onchocercal microfilariae (mf) levels have been reported since 2012.

Methods This study was conducted from 2019 to 2021 and involved the following: (i) reviewing past records of ivermectin mass drug administration (MDA); (ii) conducting a treatment coverage evaluation survey (CES); (iii) conducting key informant interviews; (iv) prospecting blackfly breeding sites; (v) collecting and dissecting blackflies; and (vi) conducting parasitological and serological surveys.

Results (i) The review indicated ongoing MDA treatment for the past 27 years, with a reported coverage of over 65% in the last 17 yearly rounds; (ii) estimated treatment coverage by the CES in 2019 was 71.3%, with most of those not taking medicine stating that they were not offered; (iii) however, the key informant interviews revealed insufficiencies in reaching a significant number of people for treatment due to remote settlement, mobility, transport logistical issues, failure to register some people for treatment, leading to a false impression of good coverage, and a short distribution time; (iv) the most productive breeding was found within 5 km of Kwanware-Ottou; and (v) blackfly daily biting rates were highest in Kwanware and Ottou, with 199 and 160 bites per day, respectively. Infection in blackflies was found only in Kwanware and Ottou, with infectivity rates of 5.9‰ (per 1000) and 6.7‰, respectively. (vi) The mf prevalence in Ottou and Kwanware, respectively, was 40.0% and 30.0% among adults aged ≥ 20 years, and the anti-(*Onchocerca volvulus*) Ov16 IgG4 antibodies seroprevalence rates were 8.3% and 13.3% among children aged 5–9 years. These values were reduced to undetectable levels at a radius of 10 km from Ottou.

Conclusions This study confirms that active onchocerciasis transmission centres on Kwanware/Ottou and is confined to a 10 km radius despite 27 yearly treatment rounds. The main contributing factors are suboptimal coverage and high biting rates. Identifying and targeting such a focus with a combination of interventions will be cost-effective in accelerating onchocerciasis elimination in Ghana.

Keywords Onchocerciasis, Ivermectin, Entomology, Parasitology, Serology, Transmission focus

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Background

Onchocerciasis, a neglected tropical disease caused by the filarial nematode *Onchocerca volvulus*, is transmitted via the bite of infected female blackflies, which breed in fast-flowing rivers and streams [1–3]. Onchocerciasis comprises of a spectrum of dermatologic and eye-related morbidities, including irreversible blindness [4, 5]. Over 240 million people in 31 sub-Saharan African countries are at risk of infection [5–7]. Annual mass drug administration (MDA) of ivermectin (IVM) for 12–15 years is recommended to eliminate onchocerciasis [6–10]. However, elimination is uncertain in areas with high endemicity and/or programmatic challenges [5, 7, 11].

In Ghana, where onchocerciasis was first described in 1875 [12, 13], approximately 8.6 million people are at risk (ESPEN, https://espen.afro.who.int/countries/ghana). Control began in 1974 with aerial larvicide spraying under the Onchocerciasis Control Programme's (OCP) mandate [14], and IVM mass treatment started in 1992 [15]. First delivered by mobile teams of health workers, the approach to delivering IVM treatments to those at risk changed in 1997 to the community-directed treatment with IVM (CDTI) approach, in which communities lead the distribution of the drug [15]. A policy of biannual CDTI was introduced in 2009 in hyper and mesoendemic areas [15].

In the Kwanware/Ottou community, situated along the Subin River in Wenchi Health District, a high baseline microfilarial (mf) prevalence of 48.1% (95% CI: 41.5–54.8%) and community mf load (CMFL) of 7.26 mf per skin snip (mf/ss) were reported in 1989 [16]. Vector control was implemented in rivers near Kwanware/Ottou, including along the section near the Tain River from Tainso to its confluence with the Black Volta River from 1976 to 1996 and the Subin River from 1988 to 1996. The annual distribution of IVM began in 1992 and switched to biannual distribution in 2018 [16]. Despite this over 27 years of IVM treatment in addition to the earlier 8 years of vector control, infection levels are still unsatisfactory. Evaluations in 2017 reported a mf prevalence of 26.7% and an anti-Ov16 IgG4 antibodies seroprevalence of 38.1%, indicating persistent infection/transmission [16]. Therefore, in Kwanware/Ottou and surrounding communities, this study aimed to do the following:

i. confirm persistent transmission.
ii. investigate the extent of infection/transmission.
iii. investigate the factors contributing to ongoing onchocerciasis transmission.

Methods

Study setting

The study took place in Ghana's Wenchi Health District, which is home to 77,454 people at risk of onchocerciasis (program data). The district is drained by a dense river network, including the Subin, Kyiridi, Akete, Tain, Yoko, and Black Volta rivers, all of which contain potential blackfly breeding sites [17]. The inhabitants of Wenchi belong to three main tribes: Akan, Dagaarti and Guan. Farming is the main occupation, and a small proportion of people engage in petty trading, fishing, and mining [17]. Figure 1 shows a map of the study area and the baseline prevalence of onchocerciasis infection. The historic profile of onchocerciasis infection in Wenchi District is presented in Table 1.

Study design

The main methods used were as follows:

1. review of treatment records,
2. key informant interviews,
3. coverage evaluation survey (CES),
4. parasitological survey via skin snip microscopy,
5. serological survey using anti-(*Onchocerca volvulus*) Ov16 IgG4 antibodies rapid diagnostic test (RDT),
6. larvae prospecting, and.
7. collection and dissection of adult blackflies.

The surveys were conducted in Kwanware-Ottou and nearby communities within a 20 km radius. In total, 15 communities were included in this work. Satellite imagery analysis was used to identify any missed communities or potential breeding sites. Communities located 5 km, 15 km, and 20 km from Kwanware-Ottou were selected to understand the geographical extent of transmission. The 20 km radius represents the likely maximum host-seeking flight range of locally breeding blackflies [15, 18–20].

The communities were categorized into three types: accessible and large areas, where the majority of people live permanently (settled communities); hamlets, which were remote and smaller settlements with a significant portion of the population being mobile or non-permanent residents; and mixed communities (a mix of settled and hamlet dwellers). The communities and survey timeline are summarized in Table 2. Figure 2 shows a spatial representation of the communities, and the surveys conducted.

Kanwar/Ottou was chosen as the primary community because of its high mf prevalence reported in 2017 (26.7%, 8/30). Akete, located in the Wenchi East subdistrict, and Kwanware, located in the Subinso subdistrict, were then selected for a review of the CDTI register and a qualitative assessment. These communities were

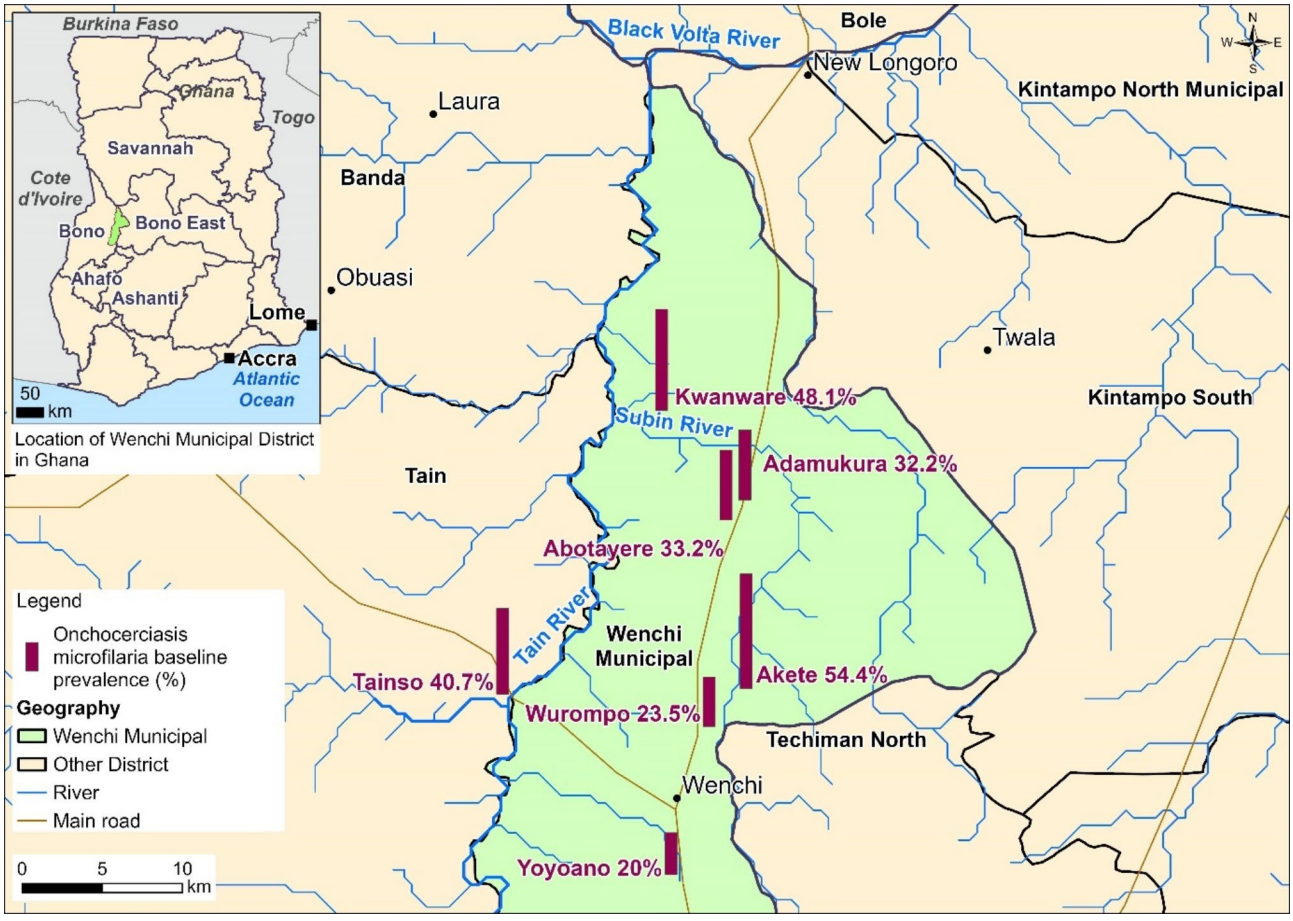

Fig. 1 Map showing microfilarial (mf) baseline prevalence in communities around Wenchi Health District. The height of the bar is proportional to the prevalence level. The baseline prevalence was established in 1980 for Akete and Tainso, now Tainano, and in 1989 for Abotereye, Adamukura, Wurompo, Yoyoano and Kwanware (including Ottou). The map was created via ArcGIS PRO® software by Esri. The data sources are as follows: (i) Fly collection, parasitology and serology results, and GPS data were collected during field activities. (ii) Hydrologic data were extracted from HydroRIVERS v1.0, available at 'https://www.hydrosheds.org/.' (iii) Road data were extracted from 'https://www.naturalearthdata.com/downloads/. (iv) administrative boundaries were extracted from Ghana Statistical Services, available at 'https://data.humdata.org/dataset/cod-ab-gha'

Table 1 Onchocerca microfilarial (mf) and anti-ov (*Onchocerca Volvulus*)16 IgG4 antibodies seroprevalence over time in selected communities within Wenchi Health District (progamme data)

Communities	Anti-Ov16 IgG4 antibodies Seroprevalence[1] (%)	Microfilarial prevalence (%)				
	2017	1980[2,3]	1989[2,3]	2000[2]	2012[2]	2017[4]
Akete	2.5 (2/80)	54.4 (153/281)	-	2.7 (6/221)	-	1.3 (1/72)
Abotereye	-	-	33.2 (88/265)		-	-
Adamukura	-	-	32.2 (38/118)		-	-
Wurompo	-	-	23.5 (104/443)		-	-
Yoyoano	-	-	20.0 (56/280)	13.4 (15/112)	-	-
Tainso	-	40.7 (127/312)		0.7 (2/290)		1.3 (2/154)
Kwanware/Ottou	38.1 (8/21)	-	48.1 (102/212)	15.6 (17/109)	5.6 (4/71)	26.7 (8/30)

[1]Among children aged 5–9 years; [2] among individuals aged ≥ 5 years; [3] before commencement of ivermectin mass drug administration; 4 among individuals aged ≥ 20 years

Table 2 Communities, surveys conducted and their implementation dates

Communities		Review of CDTI[1] records & KII[2]	CES[3]	Breeding site assessment	Blackfly catch and dissection	Parasitology and serology surveys
Name	**Type**					
Kwanware/Ottou	Hamlet	Jan. 2019	Oct. 2019	Oct. 2020	Oct. 2020	Feb-March 2021
Abotayere	Mixed	-	Oct. 2019	-	Oct. 2020	Feb-March 2021
Adamukura	Hamlet	-	-	Oct. 2020	Oct. 2020	Feb-March 2021
Subinso	Main	-	-	Oct. 2020	Oct. 2020	Feb-March 2021
Yoyoano	Main	-	Oct. 2019	Oct. 2020	Oct. 2020	Feb-March 2021
Nchiraa	Main	-	-	Oct. 2020	Oct. 2020	Feb-March 2021
Botenso	Mixed	-	-	-	Oct. 2020	Feb-March 2021
Branam	Main	-	-	-	Oct. 2020	Feb-March 2021
Tainano	Mixed	-	-	Oct. 2020	-	Feb-March 2021
Akete	Main	Jan. 2019	Oct. 2019		Oct. 2020	Feb-March 2021
Wurompo	Main	-	Oct. 2019		Oct. 2020	Feb-March 2021
Congo	Mixed	-	Oct. 2019		Oct. 2020	Feb-March 2021
Nwoase	Main	-	Oct. 2019		-	Feb-March 2021
Operator	Hamlet	-	-	Oct. 2020	-	Feb-March 2021
Krachikrom	Main & Hamlets	-	-	Oct. 2020	Feb. 2021	Feb-March 2021

[1]CDTI=community-directed treatment with ivermectin; [2]KII = key informant interview; [3]CES =coverage evaluation survey; Jan=January; Feb=February; Oct.=October. There was no mass drug treatment with ivermectin in 2020 because of COVID-19-related restrictions. Flies were collected in Tainso, near Tainano

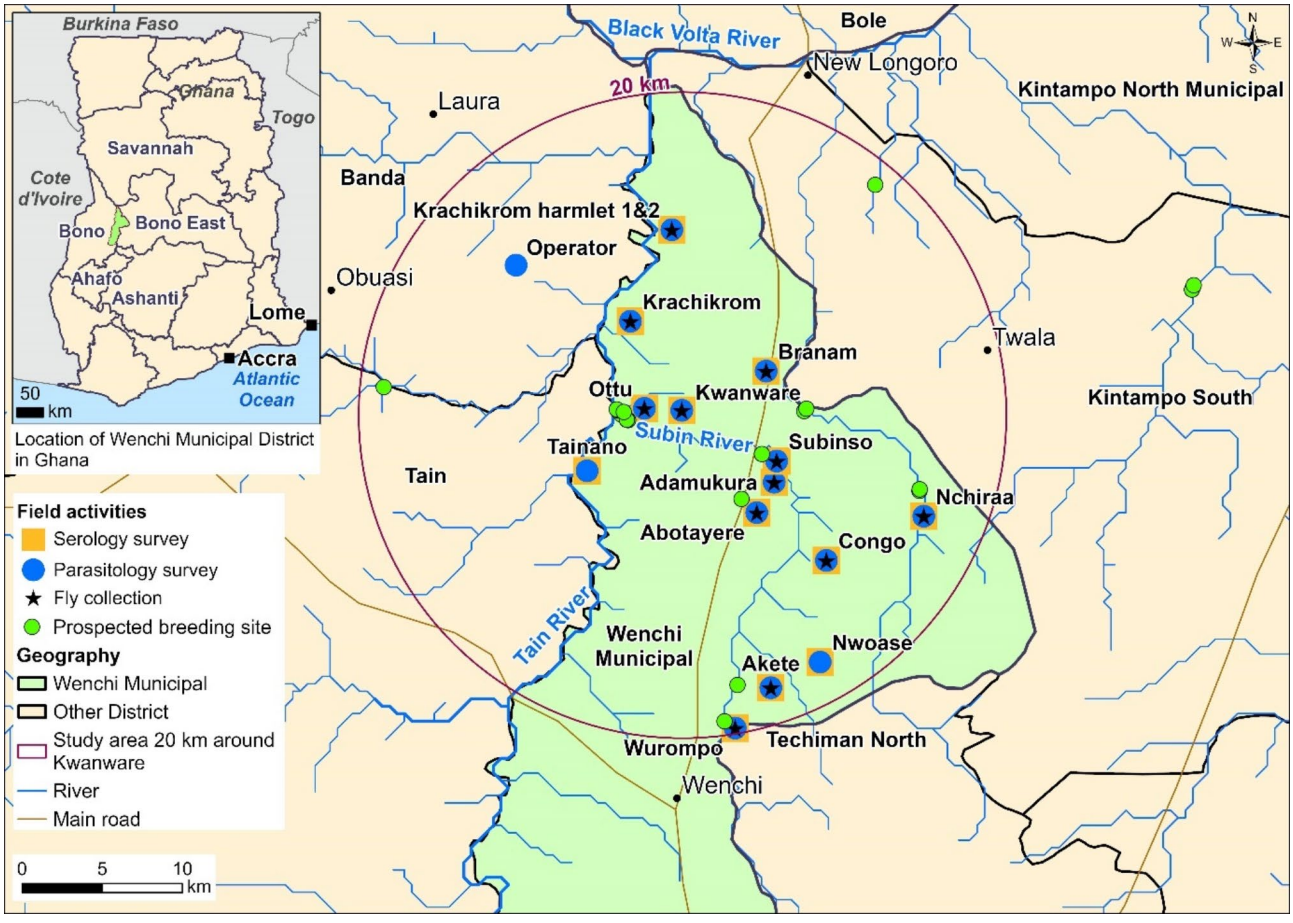

Fig. 2 Study overview: Map showing communities in which serology, parasitology, fly collection and breeding site surveys were conducted. The map was created via ArcGIS PRO® software by Esri. The data sources are as follows: (i) Fly collection, parasitology and serology results, and GPS data were collected during field activities. (ii) Hydrologic data were extracted from HydroRIVERS v1.0, available at https://www.hydrosheds.org/. (iii) Road data were extracted from https://www.naturalearthdata.com/downloads/. (iv) administrative boundaries were extracted from Ghana Statistical Services, available at https://data.humdata.org/dataset/cod-ab-gha

chosen based on their similar baseline mf prevalence and differing parasitological and serological survey results in 2017 (with Akete having a much lower prevalence). Refer to Table 1 for details. The goal was to assess the performance of the Mass Drug Administration (MDA) and compare findings between the two subdistricts in the Wenchi Health District, considering parasitological, entomological, and serological surveys.

Procedures

Treatment register review

The treatment register review involved examining the CDTI registers for the years 2017 and 2018. Additionally, historical program coverages for Akete and Kwanware communities from 1994 to 2018 were retrieved from program data/archive at the subdistricts. To assess CDTI performance, the 2017 and 2018 treatment registers were used to calculate program epidemiological mass drug administration coverages, which are calculated as the number of persons treated divided by the total population as recorded in the register.

Qualitative assessment of CDTI in Kwanware (Subinso subdistrict) and Akete (Wenchi east subdistrict)

The qualitative assessment involved seven key informant interviews (KIIs). Two interviews were conducted with opinion leaders from each of the communities, with a focus on CDTI implementation, participation, challenges, management of adverse effects, and community population dynamics (see Supplement 1 for the interview guide). Similarly, two interviews were conducted with two community drug distributor (CDDs) from each of the communities, with a focus on knowledge and the ability to distribute IVM. Furthermore, other two interviews were conducted with subdistrict programme staff—one from Subinso and the other from Wenchi East—covering programmatic issues related to the CDTI. Finally, one interview was conducted with a programme focal person staff member from Wenchi Health District covering various programmatic aspects. All the interviews were conducted in the interviewees' preferred languages (English or Twi) via an interview guide. The interviews were tape-recorded and later transcribed verbatim. The analysis followed a three-stage coding structure, including open coding, categorization, and organization into themes and subthemes supported by relevant quotes.

Coverage evaluation survey

A coverage evaluation survey (CES) was conducted to evaluate the performance of the most recent CDTI rounds in 2018—three months later. A questionnaire was used to determine whether community members were offered and swallowed IVM, and if not, why not. Key demographic information was also collected from each participant (see Supplement 2 for the questionnaire). The data were collected electronically via the Commcare application installed on an Android smartphone (https://www.dimagi.com/commcare/).

The CES was conducted in Kwanware/Ottou, and six communities located within a 20 km radius from Kwanware-Ottou. The sample size for each community was determined to be 246 individuals (50 households) via Cochran's sample size formula [21], with an expected coverage of 80%, a design effect of 1.5%, and a precision of 5%. The community population data were obtained from the Ghana Health Service and validated at the health district and community levels by the CDD and community leaders.

In each community, survey teams (four teams of two trained data collectors) selected households according to the calculated sampling interval (total number of households divided by 50). In communities where the targeted number of households could not be achieved via the sampling interval, every household was surveyed. All individuals in each selected household were enumerated, and the questionnaire was administered to all members after written consent (and assent for those younger than 18 years) was obtained. In the case of a household member being absent or unable to respond (e.g., in the case of young children), a competent household member was asked to respond on their behalf.

Prospection of blackfly breeding sites

Prospection for blackfly (*Simulium spp.*) breeding sites was conducted in rivers and streams within a 20 km radius from the Kwanware/Ottou focal community. Potential breeding sites were identified based on the experience of the researchers, use of topographical maps, analysis of satellite images, and community and district health team knowledge of rivers (Supplement 3). The global positioning system (GPS) coordinates of locations that look like potential breeding sites (rapids) along the rivers were extracted. The field team used Google Maps in Android phones to navigate to the extracted GPS locations of potential breeding sites. Community members were also asked about river points where rapids (where river flow is fast and/or noisy) were found. At the identified sites, potential breeding sites were explored by inspecting plants, twigs, debris, rocky substrata, and other attachment surfaces for the presence of blackfly larvae, pupae, and pupal cocoons of emerged blackflies, as per the World Health Organization (WHO) methodology [22, 23].

Blackfly human landing catch and dissection

The blackflies were collected in October 2020, corresponding to the peak rainy season. An additional collection was performed in Krachikrom in February. This

location was discovered through satellite imagery exploration and is close to an active breeding site. The blackfly collection employed the human landing catch (HLC) method (Table 2), in which trained catchers exposed their legs to lure blackflies and caught them in polypropylene tubes as they landed before they could bite. Two catchers were stationed at a catching point from 6 am to 6 pm, rotating hourly. Catching lasted from one to eight days at chosen points (where community members advised that they had the highest fly biting nuisance) within 15 communities (Table 2; Fig. 2). The GPS coordinates of the catching points were recorded. Flies caught were counted hourly before being stored in a cool box for later dissection.

Ninety to 100% of the hourly catches from each site were dissected individually to assess the parity rate and *O. volvulus* infection status. Each fly was anaesthetized with chloroform vapour and then placed in a drop of saline water on a microscope slide. The ninth abdominal tergite was cut to expose the ovaries and other internal organs via a pair of entomological pins. The parity of the flies was assessed by examining the ovarian follicles for ovarian relics [22, 23]. The absence of the relics signifies nulliparity. Parous flies were further dissected to separate their heads, thoraxes, and abdomens and to search for larvae. The presence and number of larval stages (L1, L2 and L3) of Onchocercal species by location (head, thorax, abdomen) were recorded.

Parasitological surveys

Human parasitological and serological surveys were conducted in the seven communities selected for the CES. Additionally, eight other communities (Adamukura, Subenso, Botenso, Nchiraa, Branam, Tainano, Karachikrom-main, and Karachikrom-hamlets 1 & 2 (also known as Adizakura and Daffarkura)) were selected because of their proximity to breeding sites and/or the number of flies collected from these communities. After sensitization, individuals in the communities were invited to a central location for a skin snip biopsy, which was examined by microscopy for the presence of onchocercal mf. The GPS coordinates of these sample collection locations were recorded.

In each of the communities, a convenience sample size of 100 adults aged 20 years and above was targeted. Two skin snips were taken from the two iliac crests of each participant (after their written informed consent was obtained) via a sterilized 2 mm Holth-corneoscleral punch. The snips were placed individually in 50 µl of normal (0.9%) physiological saline in 96-well microtiter plates and allowed to incubate. Trained laboratory technicians identified and counted emerged mf at 6 h and 30 min [24, 25].

Serological survey

The same communities included in the parasitological survey also had serological surveys conducted. Convenience samples from 80 children aged 5–9 years were targeted for the collection of dry blood spot (DBS) samples, which were analysed for the presence of anti-Ov16 IgG4 antibodies via the standard diagnostic (SD) and 16 rapid diagnostic test (RDT) laboratory protocol. The DBS samples were collected by trained laboratory technicians via a sterile single-use spring-loaded lancet that took a single prick from the finger (after being wiped with an alcohol-soaked swab). Three to five drops of blood were collected onto filter paper (Whatman paper, Grade 1) and air-dried in the shade. Once dried, the DBS samples were labelled with a barcode and individually placed in sealable bags and then stored together with desiccant in packs of 50–75 in a larger sealable bag and placed in a mobile refrigerator or ice-packed box. The packaged DBS samples were then transported to the Council for Scientific and Industrial Research (CSIR) laboratory in Accra, where they were temporarily stored before being shipped to the Centre for Research on Lymphatic Filariasis and Other Neglected Tropical Diseases (CRFilMT, now Higher Institute for Scientific and Medical Research, https://www.ismcm.org/) in Yaoundé, Cameroon, for analysis.

The RDTs used for the analysis were first validated using included controls. In brief, four SD Ov-16 RDT test kits (SD Bioline onchocerciasis IgG4, lot: 6ADE001A, expiration date: 11/10/2023) were randomly selected and validated via four antigen control methods: 0 ng/mL, 25 ng/mL, 50 ng/mL and 100 ng/mL (manufactured by Bio-Rad, https://www.bio-rad.com). Each control was evaluated twice by two different blinded laboratory technicians (for a total of 8 tests).

After successful validation of the kits, the elution buffer was prepared according to the Centers for Disease Control and Prevention (CDC) protocol (CRFilTM, personal communication). A 0.6 cm diameter disc was punched from each DBS and placed into a well of a 96-well microtitration plate. Next, 60 µL of elution buffer was added, and the plate was incubated overnight at 4 °C. The next morning, the plates and elution buffer were heated to room temperature. Next, 10 µL of elution buffer was added to the sample pad of the SD Ov16 RDT test kit previously labelled. This was followed by the addition of 10 µL of the well-mixed sample. Next, 70 µL of migration buffer (provided with the kit) was added to the buffer pad, and the samples were allowed to migrate at room temperature. The results were read after 1 h.

Data analysis

The CES data were cleaned and analysed with Stata statistical software (StataCorp. 2017. Stata: Release 15.

Statistical Software. College Station, TX: StataCorp LLC). The coverage in each community was calculated as the proportion of the total population that swallowed IVM tablets. The svyset function in Stata was used to account for household clustering, and finite population correction was used to account for small community population sizes [26]. The overall coverage for all the communities was calculated as a weighted average (the sum of the product of individual community coverages and their estimated percentage population of the total population of the surveyed communities divided by the number of communities). Coverage estimates were presented with their 95% confidence intervals (CIs) and compared (validated) with corresponding program reported and ascertained coverages. Univariate (simple logistic regression) analysis was conducted to determine whether, based on odds ratios (ORs), the variables were associated with swallowing IVM. Those variables with significant evidence of an association ($p<0.05$) were included together with age and sex in a multivariable regression model (multiple logistic regression) to determine their adjusted ORs.

The infectivity rate of (parous) blackflies was calculated as the total number of infective flies with L3 larvae in the head multiplied by 1000 and divided by the total number of parous flies. The infection rate was calculated as the number per 1000 (‰) flies with any developmental stage (L1, L2, or L3) of *Onchocerca volvulus* in any of the body parts [23]. The monthly transmission potential (MTP) was computed as the number of L3 larvae in the head divided by the number of flies dissected multiplied by the monthly biting rate (MBR; the number of days (12 h) in a month divided by the number of collection days and multiplied by the number of flies) [22, 23]. The mf prevalence was calculated at the community level as the proportion of individuals examined with mf present. The mf intensity was calculated as the community mf load (CMFL) via the geometric means for all individuals aged 20 years and above that were screened for mf. A log(x+1) transformation was performed to include zero-mf intensity counts. The seroprevalence was calculated as the proportion of all children (aged 5–9 years) with a positive anti-Ov16 RDT result. The logit function was used to estimate the confidence interval for these results.

Results

Review of treatment records

The data show the percentage of the population that received IVM treatment in different communities and years (see Fig. 3). However, there were years when data were not available or when the mass drug administration (MDA) was not delivered. At the district level, according to the ESPEN portal, coverage was 0% in 2013, 86.5% in 2014, 85.6% in 2015, 83.5% in 2016, 63.2% in 2017, 0% in 2018 (MDA not delivered/reported), 100.4% in 2019, 0% in 2020 (MDA not delivered), 75.2% in 2021, and 95.1% in 2022 (https://espen.afro.who.int/diseases/onchocerciasis). For Kwanware, coverage data were available from 1994 to 2018, but not for 2002, 2003, 2005, 2011, 2012, or 2013. In 12 out of 20 rounds, coverage was 80% or higher.

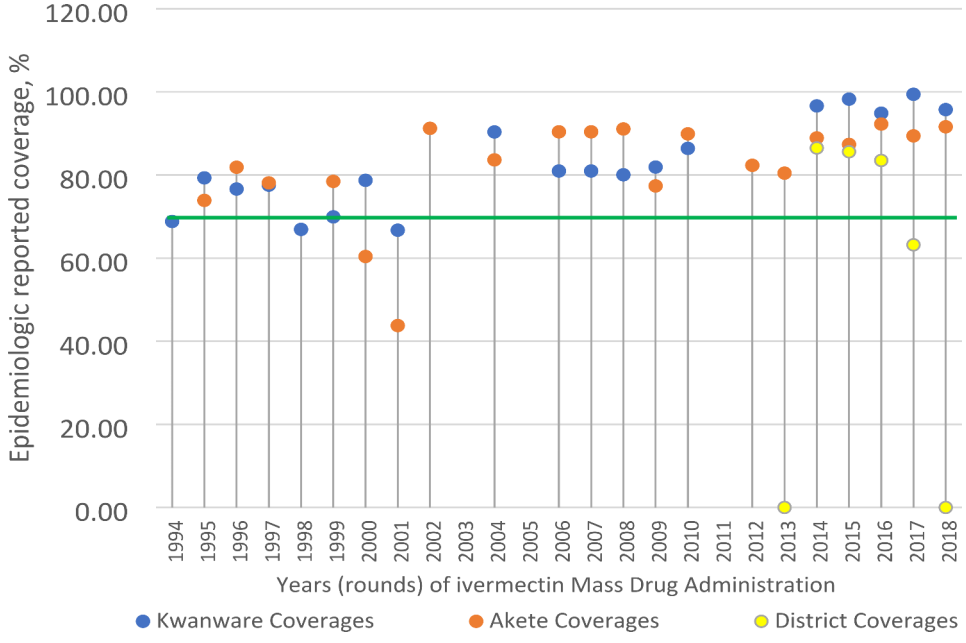

Fig. 3 The trend of the ivermectin mass drug administration programme reported epidemiological coverage in the Akete and Kwanware communities and Wenchi district. The 2018 data included here are the average of rounds 1 and 2. The green line indicates the 65% recommended minimum coverage. The district coverages were extracted from the ESPEN portal (https://espen.afro.who.int/diseases/onchocerciasis; accessed 17th December 2023)

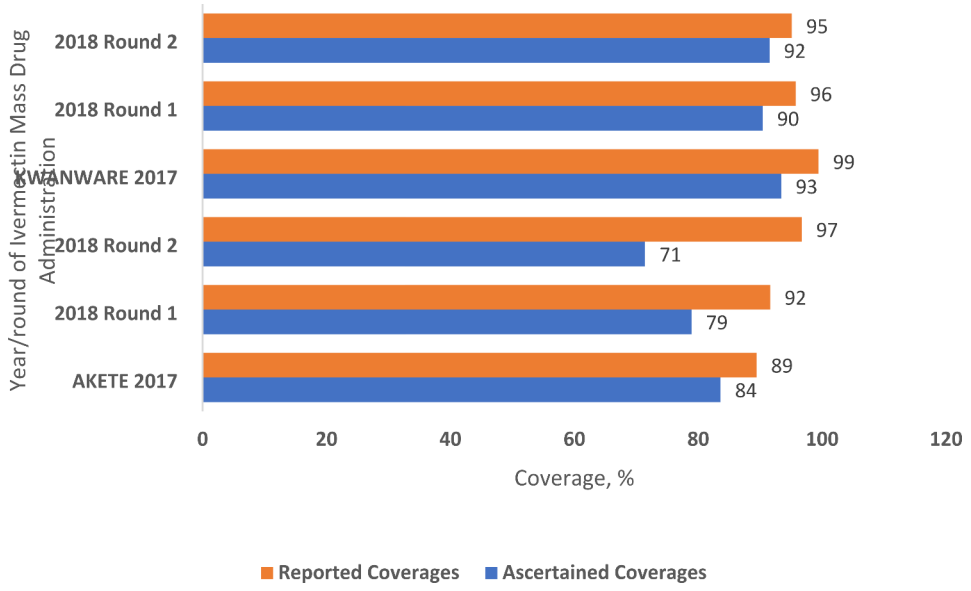

Fig. 4 Reported and ascertained coverages for 2017 and 2018 in Akete and Kwanware. Ascertained coverages were calculated as follows: 1278/1528 and 169/181 (2017); 1081/1205 and 170/188 (2018 Round 1); and 1081/1514 and 173/189 (2018 Round 2) for Akete and Kwanware, respectively

Table 3 Epidemiological coverage of ivermectin mass drug administration from the coverage evaluation survey and program report in 2019

Communities	# of HH surveyed	# individuals	# swallowed	Surveyed coverage[1]			Programme Reported coverage
Hamlet				Point	LL	UL	
Kwanware-Ottou	32	125	97	77.6%	69.5%	84.0%	94.6%
Mixed							
All	91	388	300	78.0%	72.6%	82.6%	80.1%
Abotereye	51	224	176	78.6%	72.1%	83.9%	85.7%
Congo	**40**	**164**	**124**	**75.6%**	**66.2%**	**83.1%**	**74.5%**
Main							
All	223	905	615	67.3%	62.9%	71.3%	81.8
Akete	52	267	170	63.7%	54.7%	72.7%	96.7%
Nwoase	66	224	148	65.8%	58.7%	72.2%	80.0%
Wurompu	**54**	**209**	**157**	**75.1%**	**66.9%**	**81.9%**	**77.4%**
Yoyoano	**51**	**205**	**140**	**67.6%**	**56.9%**	**76.8%**	**73.0%**

HH = household; [1]% of individuals who reported that they swallowed ivermectin; LL = lower limit; UL = upper limit; % of individuals reported being treated by the national onchocerciasis control programme. The bold rows indicate communities whose reported coverages are validated by survey results, i.e., within the surveyed LLs and ULs. Limitations of the confidence intervals

For Akete, coverage data were available for 21 rounds from 1995 to 2018 but not for 1994, 1998, 2003, 2005, 2011, 2012, or 2013. In 14 out of 21 rounds, coverage was 80% or higher.

Figure 4 displays the coverage data for two communities, Akete and Kwanware, for the years 2017 and 2018. The data show that both communities met the WHO target of 65% epidemiological coverage for IVM treatment. However, the recounted/ascertained coverage was lower than the program-reported coverage was, especially in Akete.

Coverage evaluation survey

The mean age of the participants in the CES was 23.8 (+/-19.1) years, and the median age was 19 years, indicating a young population. The gender split of the participants was 51.0% females and 49.0% males. Most participants belong to the Akan ethnic group (46%), followed by Dagaba (20.2%) and Guan (16.9%). The community IVM coverage ranged from 63.7% (95% CI: 54.7–72.7) in Akete to 78.6% (95% CI: 72.1–83.9) in Abotereye (Table 3), with an overall weighted coverage of 81.6% (95% CI: 72.8–87.9). Apart from Akete, all the surveyed communities had coverages above the recommended minimum of 65% [27]. There was no significant difference in coverage by age, sex, education, ethnicity, or occupation category for each community or when communities were considered

together. Among those who were present in the communities and were not offered medicine, 77.1% (representing 37 individuals) stated that the drug distributor did not visit them. Overall, 3.9% (38/966, aged > 10 years; CI: 2.9–5.4) of the participants stated that they had never taken IVM.

Qualitative assessment of CDTI in the subdistricts (Akete) and Wenchi East (Kwanware) subdistricts

The interviews provided insights into participation in the program and the challenges encountered during its execution.

Participation in CDTI The health district staff stated that the degree of epidemiologic coverage was usually approximately 80%. However, they admitted that the community registers, which were not regularly updated with new arrivals, might have caused inaccuracies in the reported MDA coverages.

> *"With the coverages, we've always been approximately 80%; but I think what makes the coverage look good is that those that are missed are not registered at all, ….if you compare it (coverage) to the district total population it's nowhere near that population, so we think that makes our coverage look good, but when you go into it technically, it has a problem" [Health district staff].*

Community drug distributors (CDDs) and community leaders said that the community willingly participated and showed appreciation for and appreciate the Community-Directed Treatment with IVM (CDTI) program. There were no refusals.

> *"It is a drug that is in high demand in this community. When some members hear that the drugs have arrived, they come to our houses saying, they have heard of the drug arrival and therefore are here to take theirs, even on the street when they meet me, they ask, where is my own?" [CDD].*
> *"Since I started distributing, there have never been a time when I have gone to a community household, and they had rejected the drug. In addition, when word gets out that the drugs are in, most of the community members march to my house for their drug, (even) before I begin my distribution exercise." [CDD.]*

The participants reported that the main drivers of community participation were the awareness and benefits of IVM, including its ability to cure skin rashes in the community.

> *"The drug cured people of skin rashes and diseases, which made their palms and soles very hard. When they step on the ground, they feel thrust underneath their feet, and it is difficult for them to walk. All those problems have stopped since we started distributing the drugs [Mectizan]." (CDD).*
> *"Those who took the medicine began to experience some signs; many people developed swellings all over their bodies, and we attributed that to the potency of the drug to cure us of diseases. Even all the maggots in the public toilet died, and that further convinced us of the efficacy of the drug" (Community leader).*

Challenges of CDTI implementation District staff identified key programmatic and operational challenges related to distribution during the rainy and farming seasons. Specific challenges included poor road conditions, limited distribution times, population fluctuations due to most people moving away for farm work, and logistical issues stemming from inadequate or ill-adapted means of transport.

> *"Almost every period we are to distribute, we are always behind time…We will give the volunteers a period of 5 to 10 days to use for the distribution… We can't tell the volunteer to use the whole day for the distribution without doing their own work too…. It takes about two to three weeks before an effective distribution is done, but because of the time limit you are rushed, they are rushed to do, so you see that there will be many absentees – that will be many people will be missed" [Health District staff].*
> *"Especially the first round, it's always in the rainy season, and over here, most of them are farmers…. We have a lot of cases of households that you would not be able to meet the people at home……" [Health district staff].*
> *"Our main challenge is fuel; the fuel is limited and moto-bikes. They will give you a gallon for a day or two, but the movements will require more than the gallons they gave you" [CDD].*

The district staff expressed regret that some households, particularly those recently established in the community, are not systematically included in the community registers by the CDDs. As a result, these households do not receive visits for treatment during IVM MDA.

> *"For example, what the volunteers do is that their registers have people they registered years ago, but because they don't want to take the pain to visit the new households that have just joined the community*

to register them, they just go to the old households to distribute the drugs" (District level informant).

For the CDDs and health district staff, the constant movement of the population, including immigration, along with the presence of large blackfly populations, are factors responsible for the continued transmission and the increase in mf prevalence noted in the 2017 survey.

"... so, you will have that population and then you now go back, and they tell you that most of them have moved out; then you get the people who are leaving there. Another time you get there, a lot of people are there again, so it's like the population is unstable ... you see that all the time - we keep having fluctuations; coverages keep fluctuating. It goes up, comes down [District level informant].

"Some of the people who tested positive in 2017 were natives, while others were strangers. The increase in prevalence in this community [Kwanware] may be due to the strangers who just joined the community" [CDD].

Prospection of blackfly breeding sites

A total of 35 potential breeding sites were identified across 8 communities on the rivers Kyiridi, Subin, Tain, Brumoo, Akete, and their tributaries for prospecting (Supplement 3). Among these 35 sites, six were prospected in October 2019, at the beginning of the dry season (see Table 2), and three of them were found to be productive. The remaining 29 sites were explored in October 2020, but 12 of them, all identified through satellite imagery, could not be accessed. Among the 17 sites that were reached for prospecting activities, larvae were found at 12 sites. The larval abundances varied: more than 500 at 3 sites, between 100 and 500 at 6 sites, and fewer than 100 at 3 sites (see Fig. 5 and Supplement 3 for details).

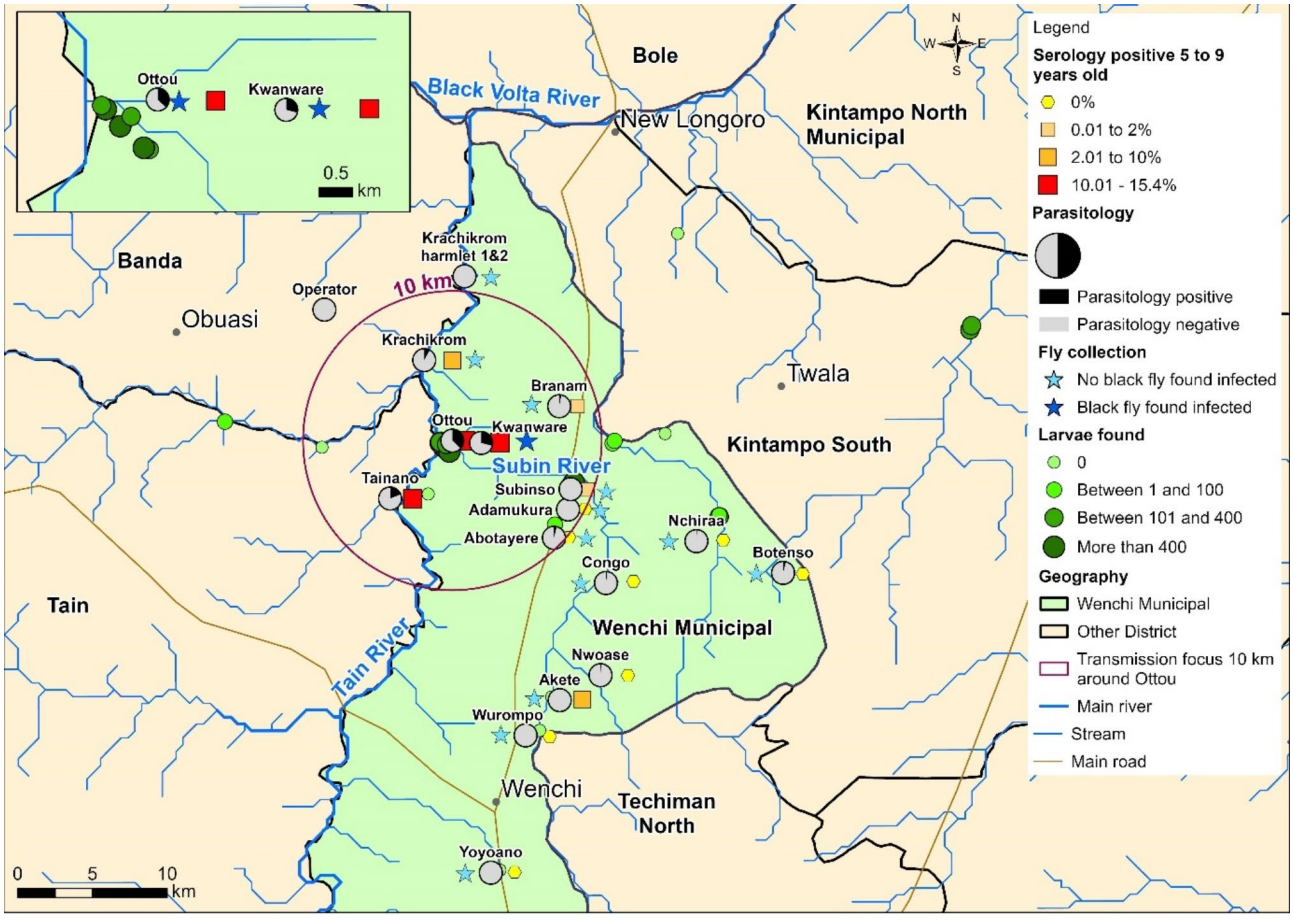

Fig. 5 Map showing the spatial distribution of blackfly breeding sites and onchocerciasis infection in blackfly and human populations. The 10 km radius delimits the infection/transmission focus around Ottou. The data sources are as follows: (i) Fly collection, parasitology and serology results, and GPS data were collected during field activities. (ii) Hydrologic data were extracted from HydroRIVERS v1.0, available at 'https://www.hydrosheds.org/.' (iii) Road data were extracted from 'https://www.naturalearthdata.com/downloads/. (iv) administrative boundaries were extracted from Ghana Statistical Services, available at 'https://data.humdata.org/dataset/cod-ab-gha'

Table 4 Human landing catch and dissection outcomes

Community/site	# Flies	# catching days	Daily biting rate	# Dissected	# of parous flies	# of infected flies	‰ of infected flies	# of infective flies	infectivity rate (‰)	MBR	MTP
Ottu	1393	7	199.0	1363	300	2	6.7	2	6.7	6169.0	9.1
Kwanware	640	4	160.0	624	169	2	11.8	1	5.9	4960.0	7.9
Abotayere	1110	7	158.6	1091	371	0	0.0	0	0.0	4915.7	0.0
Adamukura	0	5	0.0	n/a	n/a	n/a	n/a	n/a	n/a	0.0	n/a
Subinso	249	4	62.3	244	78	0	0.0	0	0.0	1929.8	0.0
Yoyoano	1	4	0.3	0	0	0	0.0	0	0.0	7.8	0.0
Nchiraa	377	8	47.1	349	121	0	0.0	0	0.0	1460.9	0.0
Botenso	191	2	95.5	184	60	0	0.0	0	0.0	2960.5	0.0
Branam	69	3	23.0	67	40	0	0.0	0	0.0	713.0	0.0
Akete	16	4	4.0	15	6	0	0.0	0	0.0	124.0	0.0
Wurompo	24	3	8.0	24	9	0	0.0	0	0.0	248.0	0.0
Congo	69	4	17.3	64	24	0	0.0	0	0.0	534.8	0.0
Krachikrom	0	5	0.0	n/a	n/a	n/a	n/a	n/a	n/a	0.0	n/a
Krachikrom_harmlet 1&2	0	5	0.0	n/a	n/a	n/a	n/a	n/a	n/a	0.0	n/a

‰ = per 1000; MBR = monthly biting rate, expressed as bites/man/month; MTP = monthly transmission potential, expressed as infective larvae/man/month; n/a = not applicable. All the collections occurred in October 2020, except for Krachikrom, where the collection occurred in February 2021. The durations of fly collection were different for Kwanware and Ottou, so they are presented here separately. The average Kwanware and Ottou is 8.5 infective larvae/man/month

Table 5 Onchocercal infection levels in humans (mf and seroprevalence) and blackflies in the surveyed communities.,

Communities	Blackflies' infectivity (October 2020)			Anti-Ov16 IgG4 antibodies Seroprevalence[1] among children aged 5–9 years (March 2021)			Microfilarial prevalence among individuals aged ≥ 20 (March 2021)		
	# parous flies	# infective	‰ infectivity rate (CI)	# tested	#+ve	% (CI)	# tested	#+ve	% (CI)
Ottou	300	2	6.7 (0.8–23.9)	12	1	8.3 (1.2–41.4)	20	8	40.0 (21.4–62.0)
Kwanware	169	1	5.9 (0.1–32.5)	15	2	13.3 (1.3–40.6)	20	6	30.0 (14.1–52.7.)
Krachikrom	0	n/a	n/a	21	4	19.0 (6.9–42.8)	67	6	9.0 (4.1–18.5)
Adamukura	n/a	n/a	n/a	33	0	0 (0–0)	59	0	0 (0–0)
Abotayere	371	0	0 (0–0)	62	0	0 (0–0)	93	4	4.3 (1.6–10.9)
Congo	24	0	0 (0–0)	44	0	0 (0–0)	55	1	1.8 (0–11.8)
Tainano	-	-	-	23	3	13.0 (4.3–33.6)	60	12	20.0 (11.7–32.0)
Botenso	60	0	0 (0–0)	93	2	2.2 (0.5–8.2)	79	4	5.0 (1.9–12.7)
Subinso	78	0	0 (0–0)	75	1	1.3 (0.2–8.9)	107	0	0 (0–0)
Yoyoano	n/a	n/a	n/a	37	0	0 (0–0)	85	0	0 (0–0)
Nchiraa	121	0	0 (0–0)	74	0	0 (0–0)	105	1	1.0 (0.1–6.4)
Branam	40	0	0 (0–0)	86	1	1.2 (0.2–7.8)	97	3	3.1 (1.0–9.2)
Akete	6	0	0 (0–0)	44	1	2.3 (0.3–14.5)	94	0	0 (0–0)
Wurompo	9	0	0 (0–0)	44	0	0 (0–0)	90	0	0 (0–0)
Nwoase	-	-	-	82	0	0 (0–0)	87	1	1.0 (0.1–7.0)
Operator	-	-	-	-	-	-	20	0	0 (0–0)

The communities were classified into three main types according to population mobility: [1]hamlet, where the population is mostly mobile; [2]main, where the population is mainly settled; and [3]mixed, equally mobile and settled. *Flies were collected in Krachikrom in February. * Krachikrom 1 & 2 combined. +v = positive for those found with microfilariae or in whom anti-(Onchocerca volvulus) Ov16 IgG4 antibodies have been detected

Blackfly human landing catch and dissection

A total of 4,226 adult female blackflies were collected from 15 communities in October 2020. The highest daily biting rates were observed in Ottou (199), Kwanware (160), and Abotereye (159). In the remaining communities, daily biting rates were less than 100 (see Fig. 5; Table 4 for details).

Among the 4,226 blackflies caught, 4,104 (97.1%) were dissected, of which 1,214 (30.0%) were parous. Among the 1,214 dissected parous flies, two each from Ottou and

Kwanware were infected with different larval stages of Onchocercal species. This corresponds to infection levels of 6.7 (per 1000) ‰ (2/300; CI: 0.8–23.9) and 11.8‰ (2/169; CI: 1.4–42.1), respectively. Three blackflies were found with L3: two in Ottou and one in Kwanware, with infectivity rates of 6.7‰ (2/300; CI: 0.8–23.9) and 5.9‰ (1/169; CI: 0.1–32.5), respectively. This results in an overall infectivity rate of 6.4‰ (3/469; CI: 1.3–18.6) for both communities, which are situated 2.5 km from each other.

The monthly transmission potentials were estimated to be 9.1 and 7.9 larvae per man per month for Ottou and Kwanware, respectively. No infection was detected in the dissected parous blackflies from the remaining communities. See Table 4 for details of the flies caught and the outcomes of dissection and Fig. 5 for a summary.

Parasitological and serology survey

The results of the parasitology and serology surveys are presented in Table 5; Fig. 5. The hamlet of Ottou had the highest mf prevalence at 40.0% (confidence interval (CI): 21.4–62.0), followed by Kwanware at 30.0% (CI: 14.1–52.7) and Tainano at 20.0% (CI: 11.7–32.0). When the data from Kwanware and Ottou were combined, as was done in 2017, the mf prevalence was 35.0% (CI: 21.6–51.3).

For the serology study, a total of 745 DBS samples were collected and analysed from children aged 5–9 years across 15 communities. The seroprevalence of anti-Ov16 IgG4 antibodies ranged from 0 to 13%, with an overall prevalence of 4.0% (confidence interval (CI): 3.0–5.4). The communities of Kwanware, Tainano, and Ottou had the highest seroprevalence rates, at 13.3% (CI: 3–40), 13.0% (CI: 4.3–33.6), and 8.3% (CI: 1.2–41.4), respectively. When considered together, as was done in 2017, the seroprevalence for Kwanware and Ottou was 11.1% (CI: 6.0-30.6). For more detail, refer to Table 5; Fig. 5.

Multiple logistic regression that included age, sex, and community category revealed that males were more likely to have mf than females were (odds ratio (OR) = 1.9; $p = 0.025$). When the types of communities were considered, individuals in the hamlet and mixed communities were more likely to have an infection than those in the main communities were (OR = 5.2, confidence interval (CI): 2.5–10.9, $p < 0.001$ for mixed communities; OR = 9.2, CI: 4.2–20.3, $p < 0.001$ for hamlet communities; see Table 6 below for details).

The community mf load (CMFL) was 0.06 mf per skin snip (ss). When each community type was considered, it was 0.03 mf/ss for the main, 0.13 mf/ss for the mixed, and 0.28 mf/ss for the hamlet. The CMFL for mixed settlements was 5.2 (2.5–10.9; $p < 0.001$) times greater than that of the main settlements. For the hamlet settlements, the CMFL was 8.7 (3.9–19.8; $p < 0.001$) times greater than that of the main settlements.

Table 6 Microfilarial (mf) prevalence and seroprevalence rates and adjusted odds ratios (ORs) by sex, age, and community type categories

Characteristics	# tested	# infected	Mf prevalence, % (CI)	Adjusted OR
All	1,138	46	4.0 (3.0–5.4)	
	Sex			
Female	682	20	2.9 (1.9–4.5)	Reference
Male	456	26	5.7 (3.9–8.2)	1.7 (0.9-3.0; $p = 0.09$)
	Age-groups			
20–29 years	224	7	3.1 (1.5–6.4)	Reference
30–39 years	236	11	4.7 (2.6–8.2)	1.5 (0.6–4.0; $p = 0.42$)
40–49 years	219	14	6.4 (3.8–10.5))	2.1 (0.8–5.3; $p = 0.13$)
≥ 50 years	459	14	3.1 (1.8–5.1)	1.2 (0.5–3.0; $p = 0.96$)
	Community type			
Main	732	11	1.5 (0.8–2.7)	Reference
Mixed	287	21	7.3 (4.8–11.0)	5.0 (2.4–10.6; $p < 0.001$)
Hamlet	119	14	11.8 (7.0–18.9)	8.8 (3.9–19.6; $p < 0.001$
Characteristics	**# tested**	**# positive**	**Seroprevalence (children aged 5–9 years)**	**Adjusted OR**
All	745	15	2.0(1.2–3.3)	
Sex				
Female	366	7	1.9 (0.9-4.0)	Reference
Male	379	8	2.1% (1.1–4.2)	1.1 (0.4–3.1; $p = 0.871$)
Age	-		-	1.0 (0.7–1.5; $p = 0.888$)
	Community type			
Main	462	6	1.30 (0.6–2.9)	Reference
Mixed	222	5	2.3 (0.9–5.3)	1.7 (0.5–5.8; $p = 0.361$)
Hamlet	61	4	6.6 (2.5–16.2)	5.3(1.5–19.5; $p = 0.011$)

CI = confidence interval; OR = odd ratio

With respect to seroprevalence, children in the hamlets were five times more likely to test positive for anti-Ov 16 antibodies than were those in the main communities were (OR = 5.3; CI: 1.5–19.5; $p = 0.011$).

The hamlets with high infection levels (in terms of blackfly infectivity level, seroprevalence, and mf level) were generally closer to the productive breeding sites (Ottou at 0.7 km, Kwanware at 2.5 km, and Tainano at 5 km) than the main communities (Branam, the closest main community, is 8.2 km from active breeding sites).

Discussion

This study confirms persistent and localized high transmission of onchocerciasis within a 10 km radius centred on the Kwanware-Ottou community after more than 27 years of the annual Mass Drug Administration of IVM [16]. This 10 km radius is similar to the 12 km radius confined onchocerciasis transmission area found in a similar investigation in the Massangam Health District in Cameroon [28]. Since the highest mf prevalence, seroprevalence level in children aged 5–9 years, and onchocercal larvae infection in parous blackflies were found in the Kwanware-Ottou community, this is considered the centre/focus of transmission. A high mf prevalence of 35.0% (CI: 21.6–51.3) was observed in Kwanware-Ottou following skin snip sampling in March 2021. A recent study by Otabil and colleagues [16] also reported considerable mf levels at 12.3% (CI: 6.6–21.8%) in November 2020 and 11.4% (CI: 4.5–26.0%) in August 2021 in Kwanware-Ottou. An anti-Ov16 IgG4 antibodies seroprevalence of 11.1% (CI: 6.0-30.6), > 100 times higher than the WHO elimination threshold of 0.1% [29], was detected in Kwanware-Ottou in children aged 5–9 years. This seroprevalence is comparable to the 11.3% reported by Otabil and colleagues [16] at all ages (median age 26). Since we tested children, our results attest to recent exposure. Similarly, blackfly infectivity rate of 6.4‰ (3/469; CI: 1.3–18.6) was detected in Kwanware-Ottou. These high levels of seroprevalence, mf prevalence, and blackfly infection unequivocally confirm the active high transmission of onchocerciasis in the Kwanware-Ottou community. Furthermore, when considered along with the preceding mf infection level, notably 26.3% in 2017 [16], the infection rate in the Kwanware-Ottou community remains persistently high.

The higher mf infection levels of 12.3% (CI: 6.6–21.8%) reported by Otabil and colleagues [16] are notably lower than ours, which is 35.0% (CI: 21.6–51.3) for the Kwanware-Ottou community, considering the narrow overlapping confidence intervals (CIs) [16]. This finding is surprising. More infections should have been detected due to (infected) human population immigration [16, 17, 30], coupled with a longer skin snip incubation time of 24 h. This discrepancy could be attributed to several factors. A critical factor is likely the age difference between the two study populations. This work targets only those ≥ 20 years versus Otabil's, which targets everyone aged 5 and over, as the prevalence increases with age [30]. Another factor is the different timing of data collection: the data were collected in November 2020, whereas our data were collected in March 2021. The mass drug administration (MDA) took place in July 2019, thus allowing more time for mf repopulation before sample collection. Additionally, a considerable proportion of the population in the Kwanware-Ottou community is mobile [17], which could have led to the presence of subgroups of people with varying epidemiological profiles during our sample collection in March 2021 and theirs in November 2020. The qualitative assessment indicates that the people infected in our study are new arrivals. This complex mix of factors is likely an explanation for the high mf prevalence reported in this study compared with that reported by Otabil and colleagues [16]. However, the reported mf prevalence of 12% in their study is still significantly high.

The confined limit of a 10 km radius from the Kwanware-Ottou community is based on declining parasitological, entomological, and serological indices. The highest seroprevalence in children aged 5–9 years was observed in Ottou (8.3%, CI: 1.2–41.4%), Kwanware (13.3%, CI: 1.3–40.6%), Tainano (13.0%, CI: 4.3–33.6%), and Krachikrom (19.0%, CI: 6.9–42.8%). These communities are located along the banks of the River Tain, within 5 km, and Kwanware and Ottou are additionally situated along the banks of the Subin River. Communities located further away presented a seroprevalence of less than 3%. For example, Branam, which is 8.2 km from Ottou, had a seroprevalence of 1.2%, whereas Subinso, which is located 9.0 km away, had a seroprevalence of 1.3%. Beyond this distance, other communities presented a seroprevalence of 0%. This observation is consistent with mf prevalence, blackfly biting rates, and infectivity levels. Specifically, the mf prevalence was 40.0% (CI: 21.4–62.0%) in Ottou, 30.0% (CI: 14.1–52.7%) in Kwanware, 20.0% (CI: 11.7–32.0%) in Tainano, and 9.0% (CI: 4.1–18.5%) in Krachikrom. In the remaining communities, the mf prevalence was 5% or lower. Infective blackflies were found only in Ottou and Kwanware, which are situated 2.5 km apart and within 5 km of the River Subin and Tain. These findings indicate that the transmission is localized within a 10 km radius from Ottou.

Although we selected communities at varying distances from Kwanware for coverage evaluation at the beginning, breeding site assessments were exhaustive up to 20 km upstream and downstream from Kwanware-Ottou, including any streams or rivers within the 20 km radius. Where larvae were found, nearby communities were identified with the help of GIS and local knowledge and

included for blackfly collection and dissection, as well as for serological and parasitological surveys. This approach reduced the likelihood of missing frontline or first-line settlements that might have high infection levels in the catchment area. In situations where communities or settlements are spontaneously set up, and with the likelihood that the main/settled community may not be aware of new settlements, as was the case in our study area, the use of satellite imagery is essential to better understand the human population at risk.

The Akete community, located in the same transmission zone (TZ) as Kwanware-Ottou, 17 km away and sharing a similar intervention history, has experienced a more significant decrease in mf prevalence over time than Kwanware-Ottou. This decrease went from 54.4% in 1980 to 0% in 2021, whereas it decreased from 48.1% in 1989 to 35.0% (CI: 21.6–51.3) in 2021 for Kwanware-Ottou, despite over 27 annual rounds of treatment with consistently high program-reported epidemiological coverage of >65% in the most recent 17 years. These efforts have not eliminated onchocerciasis in the Kwanware-Ottou focus. Even with the high baseline prevalence of 48.1%, 17 yearly rounds with epidemiological treatment coverage of >80%, as reported by the program, should have been sufficient to eliminate transmission [8, 10, 11, 31]. This suggests that the focus of Kwanware-Ottou may have unique contributing factors. Indeed, this study revealed that a high blackfly biting rate and mass drug administration (MDA) underperformance were the main contributing factors.

Although the coverage evaluation survey (CES) reported adequate coverage in the most recent MDA treatment round in 2019, this likely does not reflect reality, as indicated by key informant interviews. The interview respondents highlighted new arrivals in the communities that frequently missed treatment. This is often overlooked in the register, as those missed are not registered, thereby giving a false impression of good coverage. These MDA challenges are also encountered during CES, such that the same population is missing MDA and CES [32, 33]. Almost all individuals who reported not taking the medicine - 95% (95.6%, CI: 93.1–97.2) during the CES also mentioned that they were not offered it. Other challenges included difficulties in reaching remote mobile populations with MDA due to short distribution periods, timing issues, community drug distributor (CDD) attrition, seasonal migration, and inadequate transport support. The participants noted that the population in small remote settlements fluctuated, with a poor understanding of their movements. All these mean that maintaining consistent treatment over time, for example, for the required 12–15 years, can be daunting in remote areas where a significant portion of the population is mobile [34]. Follow-up studies should, as a first step, explore the detailed IVM treatment history, especially that of infected individuals.

High blackfly biting rates equally contribute to the high force of transmission against the backdrop of suboptimal MDA coverage and adherence in the Kwanware-Ottou focus. The biting rates of 6169 bites/man/month and 4960 bites/man/month are among the highest reported in Ghana [35]. High blackfly biting species have also been reported recently in the vicinity of Wenchi (35–36). With infectivity rates of 6.7‰ and 5.9‰, the corresponding monthly transmission potentials were high, at 9.1 and 7.9 infective/larvae/man/month for Ottou and Kwanware hamlets, respectively. The infectivity rates of 6.7‰, although detected by microscopy, which is less sensitive than polymerase chain reaction (PCR), is 13 times higher than the WHO elimination threshold of 0.05% [29]. This attests to a high force of transmission in the area.

Simulium damnusum s.s., which is highly effective in transmitting onchocerciasis, has been reported in nearby communities (35–36). Subsequent studies should assess dry and rainy conditions to obtain a complete annual breeding profile of the area and identify/confirm the species of blackflies in the area.

The limitations of this study include the inability to distinguish nonhuman onchocercal species, such as *Onchocerca ochengi*, from *Onchocerca volvulus* (*OV*) during blackfly dissection and microscopy [37]. Consequently, some larval stages found in blackflies might not be *OV*, although this is unlikely due to the spatial overlap of infections in blackflies and humans. As blackfly dissection and skin snip microscopy techniques have lesser sensitive than polymerase chain reaction (PCR) techniques, our study might have underestimated infections in both adult humans and blackflies. Additionally, the study's limited period, conducted over one season with eight or fewer collection days, restricts a comprehensive understanding of the perennial profile of onchocerciasis transmission in the area.

The kwanware-Ottou focus is holding the entire country back from progress towards the elimination of onchocerciasis. The community mf load (CMFL) of 0.28 mf/ss found in Kwanware-Ottou is four times greater than the national average of 0.07 reported 5 years earlier, in 2015 [15]. In addition, the mf prevalence and monthly transmission potential (MTP) remain unacceptably high at 35% and 8.5 infective larvae/man/month, respectively. The Kwanware-Ottou community is situated in the Tano-Ankobra onchocerciasis Operational transmission zone (OTZ), one of the seven OTZs in Ghana [15, 38]. It was initially scheduled for pre-stop and stop mass drug administration (MDA) evaluations in 2023 and 2024, respectively (proceedings of the 6th GOEC meeting in Accra, Ghana; 2021). However, the significant transmission levels observed in the Kwanware-Ottou focus,

which may not be the only localized transmission in the OTZ, indicate that the area is not yet ready for the pre-stop MDA assessment. Consequently, this assessment has been postponed to 2025 (proceedings of the WHO Ghana country-focused Global Onchocerciasis Network for Elimination (GONE) meeting in April 2024). Rapid identification of high transmission foci and addressing them within the OTZ is crucial; otherwise, Ghana will not be able to submit elimination dossiers within the desired timeline.

The localized nature of the transmission within a 10 km radius from Kwanware-Ottou suggests that a tailored intervention would be feasible and more cost-effective than continuous IVM MDA in larger transmission zones over a long period of time. Modelled results advocate this approach as a way of safely scaling down MDA and concentrating efforts on problematic areas. This principle has been demonstrated by investigations in the Galabat-Metema focus along the Sudan-Ethiopia border, where IVM MDA was increased to four times per year, effectively clearing the transmission [19]. A large population will benefit from focusing efforts in Kwanware-Ottou, as clearing this infection could mean that MDA cessation will be applied over the wider OTZ. Urgently addressing persistent transmission areas such as Kwanware-Ottou will not only quickly lead to elimination but also crucially deter resurgence and the emergence of IVM resistance [39, 40].

The recent introduction of biannual treatment in 2018 in Wenchi Health District represents a positive step toward addressing the high prevalence and MDA reach issues [40]. However, reinforcing community engagement, providing additional transport support, extending distribution time, and optimizing timing to ensure maximum availability and reach across all population subgroups are essential. Focal vector control and curative treatment strategies hold promise for rapidly reducing mf in both human and blackfly populations, thereby halting local transmission in small foci [28, 41]. Infected individuals found during impact surveys but failing to treat them represent a missed opportunity. All eligible individuals found to have mf infection should receive doxycycline treatment, as already implemented in the Americas [41].

Conclusions

This study presents a comprehensive approach to investigating a focus of high and persistent onchocerciasis transmission. This confirms ongoing transmission within a 10 km radius from the Kwanware-Ottou community in the Wenchi Health District of Ghana. The inability of the mass drug administration program to reach remote and mobile subpopulations effectively and consistently, together with high blackfly biting rates, are the main contributing factors. Addressing this through focal efforts is urgent to meet the elimination timeline in Ghana. Future studies should explore individual treatment histories in detail, conduct year-round breeding site assessments and identify/confirm the blackfly species in the area.

Abbreviations

ATS	Alternative treatment strategy
CDC	Center for Disease Control and Prevention (Atlanta)
CDD	Community Drug Distributor
CDTI	Community-Directed Treatment with ivermectin
Mf	Microfilaria(e)/microfilarial
CRFilMT	Centre for Research on Lymphatic Filariasis and Other Neglected Tropical Diseases
CSIR	Council for Scientific and Industrial Research
DBS	Dry blood spot
GHS-ERC	Ghana Health Service Ethical Review Committee
GOEC	Ghana Onchocerciasis Expert Committee
GPS	Global Positioning System
HLC	Human landing catch
IVM	Ivermectin
KII	Key informant Interview
MDA	Mass Drug Administration
Mf	Microfilaria (e)
MTP	Monthly transmission potential
OCP	Onchocerciasis Control Programme for West Africa
Ov	Onchocerca volvulus
RDT	Rapid Diagnostic Test
TCS	Treatment Coverage Survey
TZ	Transmission zone
WHO	World Health Organization

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

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Author contributions

R. N., D. A., B. M., R. D., L.S., M. O. conceived and designed the study; (A) C., E. T., R.D., I. F., (B) I. collected data; A.C., D. A., R.N., I.F., B.I., L. S., R.D. analysed and interpret results; RN, R.D., E.S., L. S, R.S. draft manuscript preparation. All authors reviewed the results and approved the final version of the manuscript.

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Data availability

The relevant data generated or analysed during this study are included in this published article [and its supplementary information files]. Additional data are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

Ethical clearances were obtained from the Andrews University Institutional Review Board (Ghana) (Clearance N°18-151) for interviews and treatment

record review and the Ghana Health Service Ethical Review Committee (Clearance N° GHS-ERC 009/07/19) for treatment coverage surveys (TCSs) and entomological, parasitological, and serological assessments. All participants underwent an informed consent process and signed written informed consent forms. In addition, for children aged 5–10 years, assent forms were signed by their parents or guardians.

Competing interests
The authors declare no competing interests.

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