Water level regulation and control of schistosomiasis transmission: a case study in Oyan Reservoir, Ogun State, Nigeria

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The effect of different water discharge patterns from the artificial Oyan Reservoir in Ogun State, Nigeria, on water level fluctuations and on schistosomiasis transmission was investigated between August 1990 and March 1993 to determine the impact of water level regulation on schistosomiasis transmission and control. The results show that transmission was greatly influenced by the pattern of water discharge during the hot dry season (January–April). A high discharge during this period of no rainfall, high temperatures, and intense sunshine stimulated rapid water level fluctuations and lake draw-down, which led to significant reductions in all indices of schistosomiasis transmission, i.e. snail density, snail infection rates, human water contact patterns, and incidence of infection. Although these results support continuous water discharges from the reservoir during the hot dry season, this may run counter to current water management policies. Further investigation is therefore required to harmonize the potential benefits in this type of discharge pattern with the objectives of efficient water management in artificial reservoirs.

Introduction

The association between schistosomiasis transmission and water resources development projects such as reservoirs, irrigation schemes, etc. is well established (*1–6*). Earlier attempts to develop suitable engineering methods to control transmission were hampered by many factors, including the misconception that schistosomiasis is an unavoidable accompaniment of water development projects (*7*) and a shift in emphasis from control of transmission to morbidity control (*8*). This shift was due to important advances that simplified the diagnosis of schistosomiasis (*9*, *10*), and to availability of safe and effective oral drugs for population-based chemotherapy (*11*, *12*). However, the inevitability of reinfection has meant that mass drug treatment can only temporarily reduce the prevalence to a level that corresponds to the site-specific environmental risk factors (*13–15*). This failure of chemotherapy intervention to sustain the benefits of disease control has revived interest in transmission control, but within the context of an integrated control approach (*16*).

Water level fluctuation has long been recognized as an effective control method against snails and snail eggs, and against mosquito larvae (*17–19*). Widescale application was, however, constrained by limited understanding of the basic relationship between such control and water release patterns, and the effect of this interplay on reservoir draw-down, human water contact patterns, and schistosomiasis transmission during different seasons of the year.

To obtain information that could enhance our understanding of the foregoing, and hence facilitate transmission control by water level fluctuation, we examined the effect of water release patterns on water level fluctuation and disease transmission in a typical man-made reservoir. The investigation was carried out in Oyan Reservoir, a medium-size artificial lake in south-west Nigeria, over a period of 34 months (August 1990 to May 1993). As this reservoir is typical of many other small and medium-size reservoirs in the schistosomiasis endemic areas of Africa, our results and follow-up studies will have a bearing on many cases concerning recommended water management regimens.

Materials and methods

Study area and reservoir

The Oyan Reservoir is located at lat. 7°14′N, long. 3°13′E near Abeokuta, the capital city of Ogun State, Nigeria (see *20* for a detailed description of

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the area). The reservoir was established in 1984 with, lying adjacent, two resettlement communities named Abule-titun and Ibaro. An outbreak of urinary schistosomiasis occurred in the two communities within 4 years of the reservoir being established, probably as a result of the impoundment (*20*).

The dam has an embankment crest length of 1044 m, a height of 30.4 m, four spillway gates (each 15 m wide and 7 m high), and three outlet valves (each 1.8 m in diameter). The reservoir has a surface area of 40 km^2, a gross storage capacity of 270 million m^3, and a dead storage capacity of 16 million m^3.

The reservoir is used for breeding fish, sprinkler irrigation, and water supply to downstream end-user Water Boards in Abeokuta and Lagos metropolitan cities. Water discharge is by a regulated opening of the gates and valves. The gates and valves are usually operated at 8.00 a.m. when the percentage opening for each day is set and the water level is read off an automated gauge. Water discharge during each opening period was read off an operating chart provided by the construction engineers.

Transmission studies

The transmission of urinary schistosomiasis was assessed by the presence, number, and the rate of *Schistosoma* infection of *Bulinus globosus*, the local snail intermediate host; by the human water contact pattern; and by the incidence and intensity of infection among schoolchildren in the two communities. The detailed methods used to carry out these investigations are described below.

Snail density. The relative density of *B. globosus* was determined every month in each of six human water contact sites using a standard technique involving 30 passes of Hairston drag scoop, supplemented by a manual search for 30 person-minutes. The number of snails per month was the total collected in all sites during each month's survey. The snails were examined for patent *Schistosoma* infection using the shedding method (*21*).

Human water contact pattern. People's activities in the six human water contact sites were studied once every 3 months between 7 a.m. and 7 p.m. from February 1991 to November 1992. Information was collected on all persons entering and/or leaving the water (sex, age, activity, time of entering and leaving the water, and the parts of the body exposed). Each exposure type was assigned an activity coefficient for estimating the relative index of exposure (RIE), i.e. the product of activity coefficient and duration of contact (*22*).

Human infection pattern. Urine samples were collected from 118 schoolchildren (5–14-year-olds) in Abule-titun and Ibaro primary schools in April/May 1991. The samples were examined for *S. haematobium* eggs using the sedimentation-by-gravity concentration method (*23, 24*). A total of 77 children who were found to be uninfected by this method were re-examined in April/May 1992 to determine the incidence[a] and intensity (eggs/10 ml urine) of any new infection during the 1991–92 transmission season. All the children found infected in the first and second examinations were treated immediately after the second examination and re-examined 4 weeks later in order to identify those children who had stopped excreting eggs. Those children who became negative by treatment were followed as cohort A, while those who had remained uninfected since 1991 were followed separately as cohort B. Members of the two groups were re-examined in April/May 1993 to assess the incidence and intensity of new infection during the 1992–93 transmission season.

The geometric mean intensity of infection was calculated after transforming egg counts to $\log(x + 1)$ to include zero counts and to normalize the variance. Differences in incidence were examined using χ^2 tests, while Student's *t*-test was used to compare intensities of infection during the two transmission seasons.

Results

Water discharge and their ecological consequences

The pattern of water discharge in Oyan Reservoir since impoundment in 1984 was highly seasonal and regular every year (Fig. 1). Usually, the reservoir gates are closed from the onset of the dry season in November to the onset of the rainy season in April. During this period, only a limited discharge is allowed through the outlet valves. As rainfall increases, the gates are gradually opened, from 2% to 30%. Correspondingly, the quantity of water discharged increases gradually, reaching a maximum at peak rainfall (either in July or September). With the onset of the dry season, the gates are again gradually closed, reducing the discharge to a minimum in the hot dry season (January to March).

[a] Incidence was calculated as $i = 100\ (p/n)$, where n = number of children not infected in the first examination, and p = number infected in the second examination.

Fig. 1. **Monthly variations in the water level, in the number of discharge days per month, and in the quantity of water discharged each month from Oyan Reservoir, from January 1984 to March 1993.**

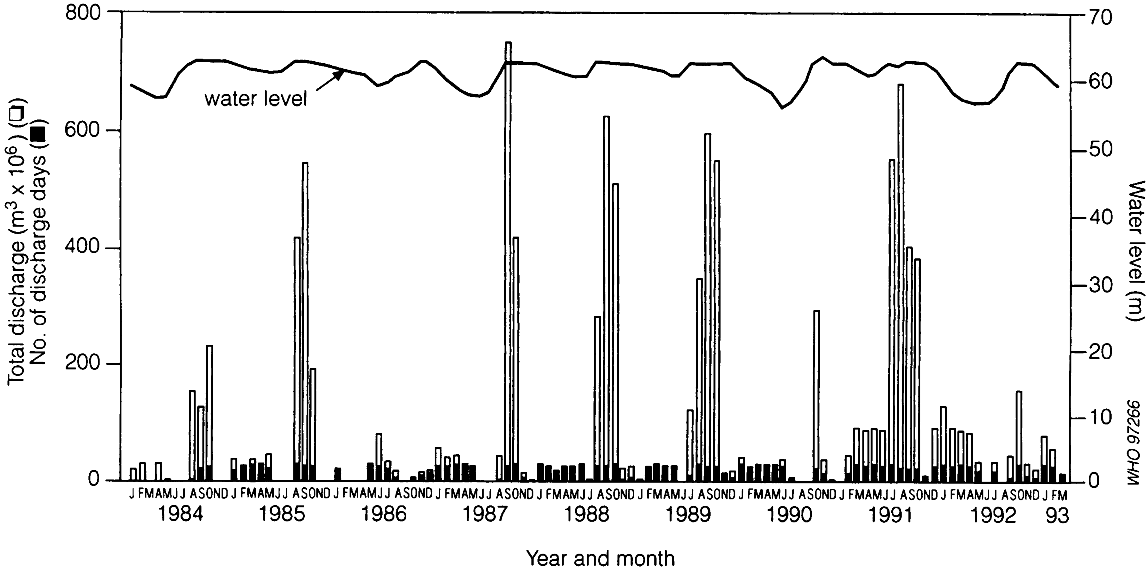

Table 1: **Data on water level fluctuations and meteorological factors in Oyan Reservoir from August 1990 to November 1992**

Year and month	Rainfall (mm)	Temperature (°C)	No. of days gates open	Water level (m elevation)	Maximum draw-down (m)	Rate of draw-down/ water rise (m/day)
1990:						
Aug.	30	36.3	0	58.4	0	0
Sept.	184.6	36.0	0	59.8	0	0
Oct.	105.8	35.6	26	62.9	0	0
Nov.	0	36.0	16	62.9	0	0
Dec.	115.5	36.3	2	62.8	3	0.10
1991:						
Jan.	0	36.2	0	62.8	8.6	0.18
Feb.	33.0	35.9	15	62.6	21.1	0.45
Mar.	45.7	37.4	31	62.0	37.3	0.52
Apr.	165.1	38.8	30	61.3	43.7	0.21
May	92.6	38.1	31	60.8	47.1	0.11
Jun.	118.8	37.7	30	61.8	36.6	–0.35
Jul.	189.4	38.9	31	62.8	12.9	–0.76
Aug.	68.9	38.7	27	62.3	1.0	–0.38
Sep.	189.7	38.6	25	62.8	0	–0.03
Oct.	148.4	38.2	26	62.8	0	0
Nov.	0	37.8	10	62.6	8.9	0.30
Dec.	0	37.6	29	62.2	25.9	0.55
1992:						
Jan.	0	39.0	31	60.9	47.0	0.68
Feb.	0	42.1	29	58.8	84.4	1.34
Mar.	12.3	41.0	31	57.8	112.4	0.90
Apr.	93.3	39.2	30	57.3	115.6	0.10
May	105.2	36.5	21	56.8	94.1	–0.69
Jun.	165.3	34.5	0	56.8	51.0	–1.44
Jul.	169.5	32.9	13	57.2	8.4	–1.37
Aug.	29.3	31.1	0	58.6	0.6	–0.25
Sep.	259.4	33.3	8	61.1	0	0
Oct.	138.5	35.8	31	62.8	0	0
Nov.	10.2	37.2	11	62.4	0	0

This pattern was altered in 1992 when, unlike the preceding years, the gates were opened every day from December 1991 to April 1992. This gave rise to a high discharge pattern throughout the hot dry season when water was usually conserved. Table 1 shows that this high discharge may have been prompted by a drought which occurred between December 1991 and April 1992, when no single episode of rainfall was recorded and the temperature was exceptionally high. As a result, the mean monthly lake level in the hot dry season of 1992 was more than 3 m lower than its 1991 level and the water level fluctuated at 1.03 m/month (3.4 cm/day), which was twice its fluctuation rate in 1991. These occurrences had important ecological consequences: the horizontal shoreline at the water contact sites receded by 134 cm/day compared with 52 cm/day in 1991, snail density was 351 in the hot dry season of 1991 compared with 173 for the same period of 1992, and no infected snails were found in 1992 compared with a rate of 8% in 1991. The rapid lake draw-down and consequent fast receding shoreline also caused the water contact sites to shift regularly, thereby altering the depth and topography of the contact sites. Consequently, the frequency of human water contact decreased from 206 in the hot dry season of 1991 to 173 over the same period of 1992; other decreases were in the mean duration from 14.4 minutes/contact in 1991 to 9.6 minutes/contact in 1992 and in the relative index of exposure from 1463.3 in 1991 to only 723.9 in 1992 (Table 2).

Incidence and intensity patterns

The annual incidence of new *S. haematobium* infections among schoolchildren in the two schools investigated is summarized in Table 3. Incidence among untreated children decreased from 66.2% during the 1991–92 transmission season to 10.0% in the 1992–93 season. Among 79 treated children the incidence by the end of the 1992–93 season was only 39.2%. Compared with the 1991–92 season, the level of reduction achieved in the 1992–93 season among the treated and untreated children was significant.

The geometric mean intensity of infection decreased from 25.5 eggs/10 ml urine in 1991–92 to 1.3/10 ml and 6.3 eggs/10 ml urine among the untreated and treated children, respectively. These changes were highly significant ($P < 0.01$). Individual intensities were also heavier during the 1991–92 season, with more than 80% and 25% of the infected children, respectively, excreting over 50 eggs/10 ml and 500 eggs/10 ml urine compared with 66% and 3% in the 1992–93 transmission season.

Table 2: **Seasonal variation in the indices of water contact and in the number and infection pattern of *B. globosus* at the water contact sites in Oyan Reservoir in 1991 and 1992**

Season	No. of contacts	Total duration (min)	Relative index of exposure	*B. globosus* No. collected	No. infected	% infection
1991:						
Hot dry (Jan.–Mar.)	206	2974	1463.3	351	28	8.0
Early rain (Apr.–Jun.)	229	2412	939.3	288	10	3.5
Rain (Jul.–Sept.)	131	1036	439.8	833	17	2.0
Early dry (Oct.–Dec.)	155	1390	480.4	682	NE[a]	NE[a]
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	
1992:						
Hot dry (Jan.–Mar.)	173	1653	723.9	124	0	0
Early rain (Apr.–Jun.)	142	1543	444.2	146	1	0.7
Rain (Jul.–Sept.)	121	913	241.6	671	21	3.1
Early dry (Oct.–Dec.)	83	817	252.6	402	15	3.7
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	
Total	1240	12738	4985.1	3497	92	2.8

[a] NE: not examined.

Table 3: **Incidence and intensity of *S. haematobium* infection among schoolchildren examined in Abule-titun and Ibaro primary schools during the 1991–92 and 1992–93 transmission seasons**[a]

Subjects	1991–92	1992–93		
	Untreated (*a*)	Untreated (*b*)	Treated (*c*)	Total (*d* = *b* + *c*)
No. negative	77	20	79	99
No. positive	51	2	31	33
Incidence (%)	66.2	10.0	39.2	33.3
Intensity (eggs/10 ml urine):				
Geometric mean	25.5; *0–1672*[b]	1.3; *0–64*	6.6; *0–1584*	4.6; *0–1584*
No. infected with:				
<50 eggs/10 ml urine	6 (19.4)[c]	1 (50)	10 (32.3)	11 (33)
>50 eggs/10 ml urine	25 (80.6)	1 (50)	21 (67.7)	22 (66)
<500 eggs/10 ml urine	23 (74.2)	2 (100)	30 (96.8)	32 (97)
>500 eggs/10 ml urine	8 (25.8)	0 (0)	1 (3.2)	1 (3)

[a] Results of statistical comparison of 1991–92 and 1992–93 infection patterns:

Incidence	*Geometric mean intensity*
a × *b*: χ^2 test = 16.15, $P < 0.001$	*a* × *b*: *t* test = 4.99, $P < 0.001$
a × *c*: χ^2 test = 6.99, $P < 0.01$	*a* × *c*: *t* test = 2.96, $P < 0.01$
a × *d*: χ^2 test = 11.96, $P < 0.001$	*a* × *d*: *t* test = 3.81, $P < 0.001$

[b] Figures in italics are the range.

[c] Figures in parentheses are percentages.

Discussion

The consequences of the unusual water discharge pattern in 1992 were not at all expected. The emergency measure was taken by those responsible for the Oyan Dam Project to offset the effects of the drought on the downstream-receiving water boards. The dramatic health and ecological impact of this action was therefore unplanned and totally unexpected.

As shown in our results, the reservoir draw-down was more highly pronounced than hitherto and produced significant declines in all indices of schistosomiasis transmission — snail abundance, snail infection rates, and human water contact patterns. Subsequently, the incidence and intensity of new infections among schoolchildren declined significantly, suggesting that a fall in transmission potential may have occurred between the 1991–92 and 1992–93 seasons. The exceptional drought conditions, which led the reservoir management to change the conventional water release pattern, thus provided a rare opportunity to compare the health impacts of two opposing water release patterns. The usual policy of conserving water during the dry periods poses greater risks to human health, while the unconventional recommendation to allow continuous releases of water at such periods appears to protect human health. However, the latter policy is associated with a high rate of water loss, which goes against efficient water management in reservoirs.

These findings point to a conflict between the need for water conservation and health protection in reservoir management. Resolution of this conflict requires further studies to shift the balance towards minimal water loss and maximum health benefits. These studies demand both engineering and biological inputs and, as emphasized by Ackers & Smith (*25*), call for multidisciplinary collaboration in disease research.

One option for collaborative research is the development of decision-making criteria for water-release patterns. In this regard, the levels of transmission associated with a spectrum of releases will be determined and used to formulate health mitigating and operationally sound water release guidelines. The other option is to reduce the marsh potential, i.e. the ability of the draw-down area to retain water, at identified transmission sites. This will involve application of various environmental management measures such as modifying the shoreline to enhance the effects of reservoir draw-down, subdividing the reservoirs in compartments so that water can be pumped from one part to the other, causing water-level fluctuation with minimal overall water loss, and/or constructing multiple dams downstream to conserve water releases upstream (see *7*, *19* and *26* for further information on environmental management techniques). Although the multiple dam option has been used to great benefit in the Nile delta region (*27*, *28*), detailed studies are still required to understand the cost-effectiveness of the various possibilities.

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Résumé

Régularisation du niveau de l'eau et lutte contre la transmission de la schistosomiase: le cas du réservoir d'Oyan, Etat d'Ogun, Nigéria

L'effet des différences de débit du réservoir artificiel d'Oyan, Etat d'Ogun, Nigéria, sur les fluctuations du niveau de l'eau et la transmission de la schistosomiase a été étudié entre août 1990 et mars 1993. L'étude avait pour objectif de déterminer l'impact de la régularisation du niveau de l'eau sur la transmission de la schistosomiase et la lutte contre cette maladie. Les résultats montrent que la transmission est fortement influencée par le débit du réservoir pendant la saison chaude et sèche (janvier à avril). Pendant cette période où les précipitations sont absentes, la température élevée et l'ensoleillement intense, les déversements d'eau à débit élevé provoquent une fluctuation rapide du niveau de l'eau et une vidange du lac, avec comme conséquence une diminution sensible de tous les indices de transmission de la schistosomiase, à savoir la densité de gastéropodes, le taux d'infection des gastéropodes, les modalités des contacts homme-eau et l'incidence de l'infection humaine. Bien que ces résultats plaident pour un déversement continu pendant la saison chaude, cette pratique irait à l'encontre des politiques actuelles en matière de gestion des resources en eau. Il est donc nécessaire de poursuivre ces travaux afin de parvenir à un équilibre entre les bénéfices potentiels de ce mode d'exploitation des réservoirs et les objectifs d'une gestion efficace des ressources en eau.

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