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Human ecology and behaviour in malaria control in tropical Africa

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Since about 250 BC, human modification of African environments has created increasingly favourable breeding conditions for Anopheles gambiae. *Subsequent adaptations to the increased malaria risk are briefly described and reference is made to Macdonald's mathematical model for the disease. Since values for the variables in that model are high in tropical Africa, there is little possibility that simple, inexpensive, self-help primary health care initiatives can control malaria in the region. However, in combination with more substantial public health initiatives, simple primary health care activities might be done by communities to (1) prevent mosquitos from feeding on people, (2) prevent or reduce mosquito breeding, (3) destroy adult mosquitos, and (4) eliminate malaria parasites from human hosts. Lay methods of protection and self-care are examined and some topics for further research are indicated. Culturally appropriate health education methods are also suggested.*

ECOLOGY AND ADAPTATION

Archaeological evidence suggests that about 2000 years ago human populations in the wet, forested areas of tropical Africa were very sparse, consisting of tiny bands of hunters and gatherers. At about 250 BC, iron appeared in the Nok sites of Nigeria. People made iron axes that were far more effective in cutting the forest than their stone tools had been. They made iron hoes, and cultivated cut-and-burned areas of forest with new wetland crops just entering Africa by sea trade from south Asia. The population of Bantu-speaking people who had been living in the Benue and Cross River valleys between Nigeria and Cameroon expanded remarkably throughout tropical Africa. Cleared forest and low-growing food crops also led to a remarkable expansion in the breeding sites for *Anopheles gambiae*. In settled agricultural villages, sited conveniently near water sources, human beings became the most easily accessible large animal for mosquitos to feed upon.

In savanna areas, animals were domesticated, fire was used to clear land for grazing, and people with their animals clustered around water. People, cattle, and mosquitos are all water dependent, especially in savanna environments. In both savanna and cleared forest, people who clustered near water became dense enough populations to be adequate reservoirs for *Plasmodium falciparum* parasites and facilitated transmission of the disease. Previously, malaria may have had very little effect on sparse, widely dispersed groups of hunters and gatherers (*1*). Possibly, the parasites and the human hosts were not yet well adapted to each other. In a well-adapted symbiosis, parasites do not kill a significant proportion of their hosts (*2, 3*). Since children with the genetic advantage of the sickling trait are more likely to reach sexual maturity and reproduce, we might view the sickling trait as a *genetic* adaptation to what were originally *cultural* innovations: the use of iron for tool-making, domestication of plants and animals, and settled agriculture. We might also conclude that "development" activities, and concomitant "man-made malaria" have been with us for a very long time.

From this brief summary of 2000 years of malaria, two conclusions may be drawn. First, we sometimes modify our environment to gain nutritional or convenience benefits to the detriment of our disease status; and second, we then adapt to the new disease risk. Adaptations are of three kinds: genotypical, phenotypical, and cultural. Genetic adaptations come about through differences in the reproductive success of individuals, bringing slow change to a human population. Within the short life-span of individuals, people adapt on a purely biological level by acquiring immunity, and they adapt culturally through behaviour choices. The widespread adoption of chloroquine in marked preference to traditional herbal cures for malaria is an example of the latter type of adaptation.

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Although genetic adaptations are very slow compared with cultural adaptations, the sickling trait may have been selected relatively rapidly since malaria is a disease that tends to kill children who have not yet reproduced. (Diseases such as cancer, diabetes, and heart disease affecting older people are not very important in relation to natural selection because the sufferers have usually already reproduced by the time the disease develops.) Nevertheless, as we do not now have the leisurely time scale, nor the ethical mandate, to attempt a human genetic solution to malaria control, it is necessary to concentrate attention on strategies that rely on behavioural adaptation.

HUMAN HOST VERSUS PARASITE AND VECTOR

Having established that the human host is not a passive factor in malaria ecology, we might consider Macdonald's ecological model of the disease (*4*). This requires that numerical values be given to factors relating to the human population, the parasites, and the vectors. The following questions must be asked: What are the parasite rates in the human population (especially in non-immune children), recovery rates from infection, and the immune status of the population? What is the relative virulence of the parasites and is there a tendency to relapse in humans? Do the mosquitos have suitable breeding conditions (water, temperature, humidity), how long do they live, how effective are they as vectors (biting rate and preference for human blood), and are people readily available as donors and recipients of parasites? Alas, in much of tropical Africa the answers to these questions are highly favourable to the spread of malaria. Most *Anopheles* vectors in Africa prefer to bite humans and they have long life, the temperature and humidity conditions are high for long periods of time, and so forth. The number of secondary infections resulting from a single primary case is very high among non-immune persons. With so much excess transmission, most simple self-help strategies for malaria control, within a low-budget primary health care context, are not going to have much effect on the disease.

In holoendemic or hyperendemic areas with vast excess transmission, effective attacks on the vector will require motor transport, expensive chemicals, and relatively sophisticated training, supervision, and supply systems. Most spraying and larviciding programmes require resources beyond the financial capabilities of rural communities, no matter how committed they are to self-help in health and development.

For effective attacks on the parasite, two options are possible: prophylaxis programmes that aim to suppress the disease or chemotherapy programmes that aim to limit mortality. Analysis of the programme in which chloroquine was distributed to about 100 000 children in North Mara, United Republic of Tanzania, between 1977 and 1981 suggests that large-scale prophylaxis programmes, even when they are very well designed, supervised, and include a degree of community participation, cannot be managed with the precision necessary to suppress the disease. Nor will children necessarily comply with a regular regimen of pill-taking over long periods of time, especially when they perceive side-effects (*5*). Even if small-scale scientific studies suggest that prophylaxis reduces morbidity and mortality better than treatment, it may not be possible to carry out that strategy successfully on a large scale in Africa because of management, financial, and compliance problems.

Let us now consider the other option — mortality-reducing therapy. The cost of chloroquine has been calculated by assuming that children below the age of 12 years will comprise about 25% of the population and will have, on average, 3 attacks of fever per year. Adults will have, on average, one such attack. In a population of a million people chloroquine therapy would then require 4.5 million tablets (150 mg base) costing about US$15 per 1000 tablets, which is US$67 500, or about $0.07 per person per year. But health budgets in some African countries provide no more than $0.05 per person for all drugs. Added to the price of the drug is also the cost of transport, health worker training, salaries, and other expenses. A rough estimate is that the true cost of a mortality-reducing chemotherapy strategy is about $1.00 per person per year. The alternative strategy of providing morbidity-reducing chemoprophylaxis for children and pregnant women is estimated to cost at least $2.00 per protected person per year (*6*). The treatment option is thus cheaper, easier to manage, and also allows children to acquire immunity to malaria in environments of intense transmission.

Although ideally chloroquine is readily available through the primary health care system, only an estimated 20% of the African population has access to medical services (*6*). Beyond access is the question of supply. Even in relatively affluent African countries health workers in the rural periphery commonly go for weeks or months without chloroquine supplies. Health centre utilization rates understandably drop off. Village women, especially in the wet season when their farming tasks are very demanding, will not waste time to go to health services that have no drugs. Where households have enough cash they then resort to the private sector. Governments might consider, as a high priority, short training courses in diagnosis and correct prescribing for the shopkeepers and traders who are the effective providers of antimalarial drugs in much of tropical Africa. This is particularly important in areas where there is clear evidence of widespread resistance of plasmodia to drugs that are still being imported and sold in shops.

SELF-HELP STRATEGIES AND RESEARCH PRIORITIES

Inexpensive self-help strategies for malaria control can be a valuable supplement to more expensive measures in hyperendemic areas, and may be effective on their own in highlands, dry areas, and other parts of Africa where the basic case-reproduction rate is usually low. Some of these measures are recommended by medical experts and are being carried out through government primary health care services. Other measures are lay practices, many of which were followed by people long before the introduction of sprays and drugs. They are usually based upon technologies accessible to every household. They now need to be investigated systematically through field research in order to build up an accurate picture of their efficacy and enable malariologists to offer encouragement and suggest refinements. These primary health care self-help strategies are discussed under four headings: preventing mosquitos from feeding on human beings, reducing mosquito breeding, destroying adult mosquitos, and eliminating malaria parasites from human hosts.

Preventing mosquitos from feeding on humans

In savanna and other areas where zoophilic *Anopheles* predominate, animals are usually impounded for the night near the house entrance, providing an accessible blood meal. In some areas, small animals, such as goats, are taken into the house at night and kept near the sleeping platform, offering an alternative blood meal for any mosquitos that might have entered the house. However, if the number of animals suddenly decreases from disease, war, or other causes, the human population becomes especially at risk (*2*, p. 138).

In much of rural Africa tight-fitting wooden shutters and doors are closed against mosquitos as the afternoon sun sets. In Kenya, I have seen wads of sisal fibres inserted between the top of the wall and the roof, functioning as a screen that lets air through but keeps mosquitos out. In precolonial times, the Fulani slept under fine-mesh mats (Last, personal communication, 1983), and throughout Africa even very poor rural people have been observed to use bed nets if they can get them. Health education might include optimal use and repair of nets, and community-based primary health care activities might include soaking even tattered bed nets in an inexpensive commercial repellent, such as diethyl toluamide.

Table 1. Effectiveness of citronella as a repellent[a]

	Aedes aegypti	*Anopheles quadrimaculatus*	*Aedes taeniorhynchus*
No. of tests	31 laboratory tests	8 laboratory tests	15 field tests
Duration of protection (min)	39–157	7–41	27–89

[a] After Boyd (*9*), p. 1177.

Table 2. Tests of effectiveness of cloths in preventing bites of *Anopheles albimanus* (40 females)

Test	Results
15 minutes in feeding pot on open-weave cloth	0 fed
15 minutes in feeding pot on close-weave cloth	0 fed
15 minutes in feeding pot direct to skin	36 fully fed
	4 not fed

The cost of impregnating one jacket, bed net, or sheet was 5 Tanzanian shillings (about US$0.56) in 1976. It will be effective for a few weeks, after which soaking must be repeated (*8*).

There might be a potential in Africa for growing the tropical grass from which citronella is made and applying simple technologies to render it into a repellent for garments or bed clothes, or to make it into a body oil. As Table 1 shows, however, it would have to be re-applied at rather frequent intervals (*9*).

In the best of circumstances, children who are still being breast-fed sleep under bed netting with their mother. Less fortunate children are at least sheltered by their mother's body, which is available to the mosquitos as the most accessible blood meal. At between 12 and 24 months of age, children are weaned and often put to sleep on a floor mat, very much at risk. Along the swampy coast of Sierra Leone, people—especially children—completely envelope themselves in thick cloth made from locally spun and woven cotton. Dr C.F. Curtis of the London School of Hygiene and Tropical Medicine tested a typical cloth of this type and found it too thick for mosquitos to penetrate, and therefore effective as a means of protection from bites (Table 2).[a]

In areas where nights are cool, as in northern Nigeria for example, people also sleep well wrapped against the cold and against mosquitos. Research might establish the thickness necessary to deter common local vectors, and health education might

[a] CURTIS, C. F. & MARCHAND, R. P. *Impregnation of cotton material with insect repellent.* Unpublished document, 1982.

include advice on effective thickness or on how to impregnate cloths with repellent.

Repellents can also be put on the body. The Dinka people of rural southern Sudan mix cow-dung ash and cow's urine, rubbing it on the exposed body in the evening. In much of Africa, men wear gowns that cover their ankles and women wear long skirts. Children, however, are usually relatively unprotected.

Other practices to repel mosquitos might be subjected to field studies and their efficacy measured. Elderly Kenyans have commented that "when we were children and slept in our grandmother's house we had no blankets and she made a smoky fire for us". Or, "Cow-dung fire drives away insects, even snakes. Sometimes a cow-dung fire is made to clear the house before guests arrive." Is cow-dung smoke a more effective mosquito repellent than wood smoke? Does eucalyptus wood make a more repelling smoke than other wood, and are eucalyptus leaves also effective? This would be useful to know, especially in areas where the tree is being introduced for firewood, or as a water-avid tree in swamp-drying projects. Is the grass from which citronella is made effective when it is put on an indoor fire? However, perhaps effective malaria vectors have already adapted to these human foils: *Anopheles gambiae*, for example, bites in the early hours of the morning after smoky fires have burned themselves out.

It would also be useful to know if soot on walls and ceilings from dung or other fires discourages endophilic mosquitos from resting in the house. Luo and other African people plaster the interior house walls with cow dung. Does fresh dung repel mosquitos? Is there anything in the chemical or physical composition of ash (or cow-dung ash) that discourages mosquitos? Red army ants can be deflected by a line of ashes where a stick or other obstacle will not deter them. What is the efficacy of leaves, hung from the ceiling in parts of Africa, in repelling mosquitos?

Pyrethrum, the oldest effective repellent and insecticide known, grows readily in hilly areas of Africa. It has high immediate toxicity to insects, is harmless to humans, and there is no evidence that mosquitos have become resistant to it. Field research might measure any benefit from putting it on smoky indoor fires. WHO might also assist in the development of simple household technologies for making pyrethrum into mosquito coils, joss sticks, and repellent applied to walls, bed nets, sheets, clothing, or the body. Using the type of wooden or stone mortar common throughout Africa, the flowers might be crushed with kerosene, or with a locally produced organic solvent. Alcoholic spirits distilled from palm wine or other drinks are widely available as a solvent in rural Africa. Pyrethrum would require more frequent application than commercial repellents, but where people cannot afford commercial preparations, the use of pyrethrum in a primary health care context might be a sensible strategy.

The recommendation that villages be sited a kilometre or more from water bodies is not reasonable advice unless the government can, at the same time, provide piped water or wells within the village. The relative costs of mosquito control, or a water system, should be calculated before advice is given and decisions taken. Similarly, some people may already site their villages on hill tops rather than in wet valleys, but there are real costs to be calculated in energy expended and farming time lost as people carry loads back and forth between their fertile valley farms and their hillside homes.

Reducing mosquito breeding

If "species sanitation" (i.e., to selectively control the breeding of species known to be vectors) is part of a primary health care initiative, then field studies by scientists are needed to guide activities in specific chiefdoms or districts. If people carry out useful activities that reduce mosquitos and malaria, they will be encouraged to take on other public health projects. But if they give their labour to drain a swamp — for example, where there never was a possibility of adequately reducing the basic case-reproduction rate by their considerable expenditure of effort — they will become cynical about all such health initiatives.

Similarly, people should not be asked to work against their essential economic interests. If pits left from road building now make convenient cattle-watering ponds, the villagers might be asked to introduce larvivorous fish, rather than to destroy the ponds. People cannot be asked to spread oils or poisons on ponds if that will make them dangerous or unpalatable to animals and people who drink there. They cannot be asked to drain swamps where paddy rice and other food can be produced in the rich organic mud.

Ideally, reservoirs and irrigation canals will be designed with smooth banks, provision for weed clearance, and gates to alter the water levels, either leaving mosquito larvae stranded on the banks or flushing them away. Fields and canals might be periodically dried out in a pattern appropriate to the crops being grown. Community education and community collaboration in these methods is essential. In some small farming areas, however, community resources in money, materials, and spare labour may not be sufficient for building malaria control dams and sluices. Other kinds of self-help activities might do more to promote general health and wellbeing than these specific malaria control strategies, and the people's own priorities must be ascertained.

Field research on biological control of mosquitos might be given high priority. The International Centre of Insect Physiology and Ecology in Kenya started some interesting work on an indigenous fungus that attacks *Anopheles* larvae, but this had to stop when funding priorities shifted. Field trials on larvivorous fish should go ahead with all possible speed, especially with "annual" fish such as *Nothobranchius* or *Cynolebias* species, whose eggs remain viable in mud during the season when ponds go dry. The mud can also be used to "seed" other ponds with fish. Some larvivorous fish can survive in the very muddy water of cattle ponds and in the warm shallow water of rice paddy. Scientists may need to work out a compromise between high-yield rice species requiring so much of fertilizer and insecticide that the fish may die, and indigenous hardy strains of rice that give lower yields but can grow in paddy relatively uncontaminated with fish-killing chemicals. In parts of Africa where fish are eaten—even very small fish cooked in a sauce—people may willingly participate in fish stocking.

Larvivorous fish alone cannot control malaria, but coupled with other strategies they may have a cumulative effect. *Anopheles gambiae* breeding sites are often too numerous and temporary to stock. Fish are only effective if they are present in large numbers, and they are less effective where there is much weed and floating debris. However, carp (*Cyprinus carpio*), species of *Tilapia*, and other fish species eat aquatic plants, floating algae, and other vegetable shelter for *Anopheles* larvae.

Spraying for larval control may be beyond the capacity of most primary health care programmes because it requires considerable skill, good judgement on the part of the sprayers, and equipment and transport. Slow-release insecticide granules are much easier to apply, but will still require workers with a good knowledge about local environments and mosquito breeding habits. House-spraying with residual insecticides demands less technical expertise, but requires workers with relatively more tact and good judgement in dealing with people.

Destroying adult mosquitos

In spraying programmes, people sometimes complain of the smell, the spray staining their walls, and the inconvenience of moving food and furniture. When chickens and cats die as a result of spraying, their loss is a "cost" to the family. People also begin to suspect that spraying causes their children to be sick as well (*10*). Initially, people appreciate a reduction in the nuisance of not only mosquitos but also cockroaches and bedbugs. But as the latter become spray-resistant, their reappearance somewhat dampens people's enthusiasm for the spraying programme. Spraymen, too, may in time begin to be perceived as a nuisance. When spraymen are not well supervised they are sometimes thought to be promiscuous with local women. In some cases, bad feelings have arisen from selection procedures for hiring spraymen, and situations may even arise where teams are made up of educated townspeople with a history of exploiting the rural population. In a study from Suriname, local chiefs were neither consulted nor informed before spraymen arrived. This was interpreted as a political snub, and the chiefs did little to encourage their people to cooperate. No links were made with local health care workers or with influential traditional practitioners either (*11*). Converting vertical malaria campaigns to horizontal primary health care programmes may help to overcome these problems, but may engender other problems in low levels of funding and diffuse organization.

Several investigations into the failure of spraying programmes suggest the need for:

— coordinating spraying activities with the local primary health care staff and with village health committees, if they exist;
— using local workers, chosen by the community, whenever possible;
— supervising the spraymen and dismissing those who steal or are unsatisfactory in other ways;
— coordinating the spraying schedules with the normal daily and seasonal household routine to minimize disruption;
— instructing the spraymen in basic health education and encouraging them to be health educators as well as technical workers;
— linking preventive spraying with curative malaria treatment through primary health care, so as to help people gain confidence that the disease can be controlled.

Eliminating malaria parasites from human hosts

Where migration occurs, a sharp rise in the incidence of malaria can often be predicted and drugs might be provided either by employers or through primary health care services to:

— people in highland or dry areas who, out of economic necessity, seek work in the wet lowland plantations;
— urban people who have lost their immunity and are forced by inflation and unemployment to return to their rural home area;
— refugees who flee to, or are settled in, a wet climate;
— settled populations whose environment has been altered by irrigation, forest clearing, borrow-pits, and other by-products of development so that they are more at risk.

People's confidence in, and desire for, antimalarial drugs has been documented throughout the world (*5*, *10*). In most of Africa, health workers lack the equipment and skill needed for microscopic examination of blood smears and rely to a great extent on the patients' self-diagnosis. Anecdotal literature suggests that self-diagnosis for malaria is usually accurate, but controlled tests might be conducted to measure the reliability of self-diagnosis. Most treatment is self-treatment as well. Either people buy their own tablets or, when a health worker gives a course of tablets, people often take them only until they feel better. The excess tablets remain within the family to treat the next fever, without the inconvenience of going to the health services. Correct advice for self-treatment should be part of all primary health care health education programmes.

Several African universities are now doing scientific research on traditional medicines used for malaria. Most reduce the fever but do not kill the *Plasmodium* parasites. Field research on the plants being used, followed by analysis of them, can lead to good advice on safe herbal remedies that make people feel better, and sound advice on combinations of antimalarial tablets and fever-reducing home remedies. Cinchona trees grow in rural Kenya, the United Republic of Tanzania, and perhaps other parts of Africa as well. The bark is knocked off and local people use it for making home remedies for malaria. Scientists might consider giving clear guidance on how best to render this bark — with home technologies — into a medicine and how much to take. Guidance is also needed on whether there is scope for *Artemisia annua*, used in China, to be planted and used as a home remedy in Africa. Good advice on home preparations of these medicines might be a useful way to reduce the costs of chemotherapy.

More research needs to be done on the side-effects of chloroquine (*5*, *12*), with particular reference to the following questions:

1. Is chloroquine best taken with a meal or immediately after a meal? (In North Mara, children were given chloroquine first thing in the morning.)
2. Is itching caused by an allergic reaction to chloroquine or to impurities in the tablet?
3. Is there an effective cheap drug that might be given with chloroquine to those who react to it with itching? (Mothers in the Mara region reported that neither aspirin nor native analgesics mitigated the itching.)

COMMUNITY HEALTH EDUCATION

To have an impact, community health education should be based on local traditions and local culture. For example, in rural West Africa an argument in the local courts is often clinched by the quotation of a proverb that encapsulates centuries of accumulated wisdom. Victory lasts for only a moment, however, until the quick-witted opponent quotes another proverb that confirms exactly the opposite point of view. Nature also is a balance of opposites. Since *Anopheles gambiae* breeds in sunlit water, we discourage it by planting shade trees by ponds and canals. This victory against *Anopheles* lasts only until *A. funestus*, also an efficient vector, arrives and thrives in the shaded water! Thus, experience, folk tales and proverbs mirror the profound truths of nature.

The practical point to be stressed is that the most abstract scientific concepts in malaria control are easy for illiterate villagers to grasp if they are presented using analogies that link the concept with African folk ideas rather than European folk ideas. Field research of this kind should be a very high priority. Furthermore, as Brieger (*13*) has cogently argued, a lack of understanding is not the main reason why people do not accept new kinds of health behaviour. The principal reason is that the behaviour being advocated is inconvenient, uncomfortable, expensive, produces unwanted side-effects, or does not give visible results.

CONCLUSION

All the above-mentioned initiatives in a primary health care programme need to be tested and their effectiveness measured. No one simple self-help measure will control malaria, but a combination of measures may reduce the basic case-reproduction rate in some areas to a sufficient degree to allow people to perceive that their children are less at risk. This kind of observation would then encourage them to maintain control activities over a sustained period of time.

RÉSUMÉ

L'ÉCOLOGIE HUMAINE ET LE COMPORTEMENT DANS LA LUTTE ANTIPALUDIQUE EN AFRIQUE TROPICALE

Depuis environ 250 avant Jésus-Christ, les habitants de l'Afrique tropicale se sont livrés à des activités agricoles et autres qui, en modifiant l'environnement, ont grandement accru les conditions propices à la multiplication d'*Anopheles gambiae*. Les gens, les animaux domestiques et les moustiques se regroupent, étant tributaires des mêmes sources d'eau. L'adaptation de l'homme à 2000 ans d'un paludisme qu'il a contribué à développer revêt un caractère à la fois génétique et comportemental. Toutefois, seules présentent un intérêt pratique les stratégies de lutte antipaludique qui reposent sur une adaptation du comportement.

En attribuant une valeur numérique à des facteurs relatifs à la population humaine, aux vecteurs et aux parasites, l'auteur montre que l'excès de transmission en Afrique tropicale est tel que les initiatives d'auto-assistance simples et peu coûteuses ne réussiront pas à maîtriser la maladie. Toutefois, si elles sont entreprises de concert avec des programmes plus vastes de pulvérisation et de chimiothérapie, les initiatives communautaires simples peuvent se révéler efficaces, surtout quand elles reposent sur des méthodes traditionnelles de prévention et de traitement du paludisme.

Les initiatives fondées sur une action communautaire sont examinées sous quatre rubriques : empêcher les moustiques de se nourrir de sang humain; réduire la multiplication des moustiques; détruire les moustiques adultes; tuer les parasites du paludisme chez l'hôte humain. Parmi les questions examinées figurent le logement, les dispositions concernant le couchage, la combustion de matières fumigènes, la fabrication locale d'autre insectifuges y compris le pyrèthre, l'utilisation de poissons larvivores, la maîtrise de l'eau, la protection des migrants et des réfugiés, la coopération de la population pour les pulvérisations dans les habitations et les enquêtes de surveillance, l'autodiagnostic et l'autothérapie, et la préparation des antipaludiques au niveau local.

Il est suggéré d'effectuer des recherches sur les effets secondaires de la chloroquine qui empêchent certaines personnes de s'en servir. Il est également suggéré d'évaluer nombre des méthodes de prévention et de traitement évoquées plus haut afin que les services de soins de santé primaires puissent présenter des recommandations sûres et claires aux villageois. Enfin, l'auteur suggère quelques techniques appropriées en matière d'éducation pour la santé qui s'inspirent du folklore africain largement diffusé au niveau local par le truchement des proverbes et des contes.

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