Cey. J. Sci. (Bio. Sci.) 37 (1): 87-95, 2008

WATER, AGRICULTURE AND VECTOR-BORNE DISEASES

Wim van der Hoek* and Flemming Konradsen
Department of International Health, University of Copenhagen, Øster Farimagsgade 5, Building 16, P.O. Box 2099, 1014 Copenhagen K, Denmark.
Accepted 17 April 2008

ABSTRACT

This paper gives an overview of the research on vector borne diseases, especially malaria, at the International Water Management Institute. It provides a review of published research that focuses on key questions concerning how malaria is linked to agriculture. What the economic costs of the disease are and what solutions the agriculture sector can offer. Environmental management measures are site specific but have great potential in complementing the established biomedical approach to controlling malaria and other vector borne diseases. To develop and implement effective measures, partnerships between the biomedical and agricultural research communities are essential.

INTRODUCTION

The International Water Management Institute (IWMI) is a research organisation focusing on the sustainable use of water in agriculture and is committed to help alleviate rural poverty through increases in food production and income generation. Unfortunately, agricultural systems, especially irrigated ones, have long been associated with manifestations of human ill-health arising from water-related diseases (Hunter *et al.*, 1993; Jobin, 1999). The major reason is that public health and disease control programs have not been concerns of the water resources sector, which typically has focused on potential economic benefits in terms of food production and power generation. Thus, researching ways and means of protecting both human health, and the health of the natural environment, whose breakdown would eventually threaten the sustainability of agricultural systems, is a logical progression in thought for IWMI. This was translated into action via a Health and Environment Programme from September 2001. An internal document on water, health and environment research at IWMI is included in a synthesis of IWMI's overall research efforts over the period 1996-2005 (Amerasinghe, 2006). The present paper is based on this internal document and provides a review of the research done in the area of vector borne diseases. It highlights the research performed at IWMI on the linkages between agriculture and human health.

History of IWMI involvement with the water-health interface

One of the first international meetings hosted by the International Irrigation Management Institute (IIMI, the progenitor of IWMI) at its original headquarters at Digana, Sri Lanka, was a Workshop on Irrigation and Vector Borne Disease Transmission organized in 1985 under auspices of the Joint WHO/FAO/UNEP Panel of Experts on Environmental Management for Vector Control (PEEM). This workshop focused on the links between irrigation and vector-borne diseases such as malaria and Japanese encephalitis, with special emphasis on the 125,000 ha extent Accelerated Mahaweli Development Project of Sri Lanka. A paper on vector populations in areas under development in Mahaweli System C was presented by Amerasinghe (1985). It was suggested at the Workshop that the links between irrigation and human health were legitimate subjects for IIMI research. However, while recognizing the relevance of the issue, the Institute's position at the time was that it did not have the capacity to actively pursue such a course of action.

Interactions with PEEM on irrigation – human health issues continued and IIMI was designated as an official collaborating centre of PEEM in 1987. Subsequently, in August 1991, a PEEM-sponsored consultancy team to IIMI-HQ in Sri Lanka and its country offices in Pakistan and Nepal, as well as to India identified specific health-related research topics of relevance for IIMI, highlighting opportunities for incorporating health components into some of IIMI's then on-going projects (Sanmuganathan and Amerasinghe, 1991). Finally, a DANIDA-sponsored Associate Professional Officer initiated health-related research relevant to irrigation in January 1994. A DANIDA-sponsored workshop in 1997 in

*Corresponding author's email: w.vanderhoek@compaqnet.nl

association with the Danish Bilharziasis Laboratory further explored the irrigation-health research agenda of relevance to IWMI (Konradsen and van der Hoek, 1998). The success of this initiative resulted in human health being formally incorporated into the mainstream of IIMI research.

Defining IWMI potential and contribution

At the time of commencement of health and environment research at IWMI, there was limited recognition, globally and regionally, of the importance of human health and sustainable ecosystems within the irrigation and agricultural sectors, and no cross-sectoral institutions to actively promote a research agenda investigating such issues. The biomedical sector had traditionally emphasized the negative effects of large-scale irrigation development. IWMI considered health as a goal of development rather than ill health as a side effect of development. Emphasis in the research activities was therefore on opportunities for improving health and the environment through changes in irrigation water management. The following research hypothesis was formulated: “The operation of irrigation systems can be changed so as to achieve positive health impact, with minimum impact on agricultural performance”.

The Institute’s comparative advantages in this endeavour were IWMI research strengths in the agricultural engineering sciences; in policy/institutional aspects relating to agriculture and irrigation management; its links to both national and international partners in the agriculture and water sectors (especially in developing countries); a core group of health/environment specialists; and the institute’s culture of encouraging cross-sectoral research approaches.

From the outset of the research, the Health and Environment Programme has been serviced by a multidisciplinary staff, cutting across the agricultural engineering, biological, health and environmental divide. Many researchers undertook projects (and completed M.Sc. and Ph.D. Degrees) at field sites in various countries, including Sri Lanka, Pakistan, Vietnam, and Ghana. Initial focus of the research that developed from 1994 onwards was on health and environmental impacts of irrigated agriculture, especially in relation to vector-borne diseases. Later on, irrigation was more and more seen in the context of water resources management in general, and the focus of the Programme was broadened to include wastewater use for peri-urban agriculture, non-agricultural uses of irrigation water, health effects of agricultural pesticides, and wetland conservation. From 2002 most of the malaria research activities of IWMI were brought under the umbrella of the newly established Systemwide Initiative on Malaria and Agriculture (SIMA), a partnership of a range of international and national organisations hosted by IWMI with a focus on the malaria problem in Sub-Saharan Africa.

Malaria & agriculture:Contextual introduction

Malaria has been linked with agricultural development since historical times, and these associations have been extensively documented and reviewed (Bradley., 1977; Mather and That, 1984; Service, 1984 & 1989; Lacey and Lacey, 1990). Recent studies in Africa and Asia have shown that the malaria-agriculture linkages are complex and situation-specific, with greater or lesser malaria prevalence depending upon local conditions and vectors (Ijumba and Lindsay, 2001; Amerasinghe, 2003). Focus of international malaria research efforts is primarily in the areas of drugs, vaccines, diagnostic tools, and insecticide-impregnated bed nets. Unfortunately, there seems to be little recognition of the need for research to address issues relating to the agro-ecological, economic and social dimensions of the disease that are the-ground realities and continue to bedevil the long term sustainability of malaria control. There has also been a lack of research into how the non health sectors can contribute to malaria research and control. Within the massive global malaria research constellation IWMI has arguably been the leading international agricultural research centre involved in malaria research over the past decade, investigating specifically the water-agriculture-livelihoods dimensions of the disease.

Key questions and synthesis of findings

How is malaria linked to irrigated agriculture?

IWMI studies, focused primarily on three Asian countries with the same major vector species (*Anopheles culicifacies*), illustrated the complexity and situation-specific nature of the irrigation-malaria links. The studies portrayed different types of irrigation systems: a traditional small cascade-tank system that is characteristic of rural Sri Lanka (Upper Yan Oya watershed, North Central Province), a medium-scale canal system in India (Kheda District, Gujarat), and a large-scale canal system in Pakistan (Indus Basin Irrigation System [IBIS], South Punjab). In keeping with other Indian studies (Yadav *et al*,. 1989; Sharma *et al.,* 1991; Tyagi, 2004), rainfall and irrigation water releases were related to population peaks of the malaria vector in the Gujarat study (Konradsen *et al.,* 1998a). In the Sri Lankan case study, by contrast, dry climatic conditions, the scheduling of irrigation water releases between the two large irrigation tanks, and water leakage through broken tank sluices contributed to the maintenance of vector breeding pools within a natural stream that also doubled as an irrigation conveyance channel (Amerasinghe *et. al.,* 1997, 1999 & 2001; Konradsen *et al.,* 2000a). The proximity of houses and villages to the natural stream and the type of house construction were major risk factors for malaria (Konradsen *et al,*. 2003; van der Hoek *et al,*. 1998 & 2003).

In the southern Pakistani Punjab, where water-logging is an important issue, an IWMI study did not find a conclusive relationship between depth to ground water and malaria prevalence, mainly because of the poor reliability of health statistics resulting from low attendance at state clinics (Donnelly *et al.,* 1997a & b). Later entomological studies showed that mosquito vector generation in both domestic and agricultural locations in this arid area was primarily dependent on irrigation water, viz., irrigated and waterlogged fields, and communal drinking water tanks (Herrel *et al.,* 2001 & 2004). From a long term perspective, however, the irrigation development of the Punjab has been associated with a decline in malaria. The area was highly malarious and epidemic-prone historically, but prevalence is now at a low ebb and the last great epidemic dates back to 1972 (de Zulueta *et al.,* 1980). A recent retrospective analysis of the period 1970-1999 suggests that the increased abundance of rural *An. stephensi* (a poor vector) relative to *An. culicifacies* (the main vector) may be the cause of the low malaria levels at present. The shift may have been due to water-logging with related salinisation that has created an environment favourable for the more salt-tolerant *An. stephensi* (Klinkenberg *et al.,* 2004).

Geographical Information Systems (GIS) and Remote Sensing tools have been used to generate malaria risk models in Africa (MARA/ARMA, 1998; Kleinschmidt *et. al.,*. 2001). IWMI's foray into the use of such tools in malaria was inspired by the possibilities of manipulating malaria incidence and other secondary data to analyze risk factors at irrigation system or river basin scales. Two GIS-based Asian studies within well-established irrigation systems have indicated that in the long term, irrigated areas may not be significantly more malarious than adjacent non-irrigated areas. The first, in the Mahi Kadana Irrigation Scheme in Gujarat, India analyzed secondary data on to malaria incidence and water-related factors such as rainfall, rice cultivation intensity, depth to groundwater, and irrigation density (Mutuwatte *et al.,* 1997). The overall outcome was that irrigated areas had only marginally higher malaria incidence than non-irrigated areas. Depth to ground water and irrigation density did not explain the pattern of malaria transmission, while the impact of rainfall and rice intensity was inconsistent, being significant in some years and not in others. One rather obvious limitation of this study was its focus only on water-agriculture-climate related factors, to the exclusion of socio-economic factors.

The second GIS-based study, in the Uda Walawe irrigation scheme in Sri Lanka, included socioeconomic parameters in addition to meteorology, land use, irrigation and malaria control related factors. The results, again, were counter-intuitive: over a 10-year period (1991-2000), the irrigated areas had less malaria than adjacent non-irrigated slash-and-burn agriculture areas in this dry-semiarid environment (Klinkenberg *et al.,* 2003). Rainfall (which generates vector breeding habitats) was an important independent risk factor at all levels of risk, but factors such as food stamps (a proxy socioeconomic indicator), the extent of forest, and the occurrence of abandoned irrigation tanks were associated with high malaria risk in a multivariate analysis. Interestingly, the extent of paddy cultivation and livestock (cattle, buffalo) husbandry were not significantly associated with malaria risk. The overall message was that in the long term, the functional rice irrigation scheme generated less malaria than the adjacent forested slash-and-burn areas of abandoned ancient irrigation land with semi functional irrigation structures. Such a conclusion cannot automatically be applied to all irrigation systems: both in Asia and Africa some systems consistently generate more (or less) malaria than others (Amerasinghe, 2003), and one of the current research challenges in malaria epidemiology is to precisely identify the determinants.

In addition to rural malaria, Asian countries such as India, are also familiar with urban malaria transmitted by a vector that breeds successfully in overhead water tanks and other clean water collections in cities (Kumar, 1997). It is less well documented in Africa, where the disease is associated with rural communities. For example, malaria parasite prevalence has been estimated to range from 2 – 45 times higher in rural areas than in urban or periurban areas in countries such as Ghana, Gambia and Zambia (Gardiner *et al.,* 1984; Lindsay *et al.,* 1990; Watts *et al.,* 1990). None of these cited studies, however, have taken cognizance of the possible impacts of urban agriculture on malaria transmission within the cities themselves (Donnelly *et al.,* 2005). Recent IWMI research has focused on two cities (Accra and Kumasi) in Ghana where an "informal" irrigation sector cultivates mainly vegetable crops using water from streams and city drains. These studies have provided preliminary evidence of significantly higher vector densities, infective bites, and juvenile parasitaemia rates in communities close to urban agriculture sites than those without such sites (Afrane *et al.,* 2004; Klinkenberg *et al.,* 2006).

What are the direct and indirect costs of the disease?

IWMI evaluations of the socioeconomic aspects of malaria in terms of costs to the affected people, and the costs of national malaria control efforts to the Government were limited to the Upper Yan Oya watershed in Sri Lanka. Direct costs averaged 1% of net family income per episode of malaria, while families with multiple episodes spent up to 10% of income per annum. The indirect costs (loss of agricultural work days, labour substitution costs etc.) averaged 6% of family income per year (Konradsen *et al.,* 1997a & b). From the standpoint of national costs for malaria control, a comparative analysis indicated that where feasible, vector control through water management would be the cheapest option, with larviciding of breeding habitats the next cheapest. Other methods such as indoor residual spraying, treatment at hospital clinics, local level treatment centres, and mobile clinics were more expensive (Konradsen *et al.*, 1999, 2000a & b).

What solutions can the agricultural sector offer?

IWMI experiences in this area have been mixed, but nevertheless provided valuable insights into the practicalities of implementing an approach to disease control that is often advocated by the health sector but treated with great circumspection by water managers. The studies at the Upper Yan Oya watershed in Sri Lanka provide a case in point. The clear linkage between malaria, major vector population dynamics and irrigation water dynamics provided the possibility that irrigation water releases could be managed so as to minimize vector breeding. This feasibility was confirmed by detailed water balance and modelling studies (Konradsen *et al.,* 1998b; Matsuno *et al.,* 1999). However, subsequent upstream water diversions resulted in insufficient water for the proposed management regimen to be implemented. Instead, another environmental intervention was implemented: the clearing of fallen trees and overhanging vegetation that obstructed the waterway (without damaging the canopy vegetation), the removal of natural obstructions such as rocks, the flattening of the bed, and the consolidation of the embankments in order to facilitate water flow and reduce pooling. In order to reduce ecosystem damage, the intervention was limited to a key malariogenic 7 km stretch of the 20 km waterway. There has been no significant vector breeding in this channel and almost no malaria cases in the area during a 2 year post-intervention monitoring period (Boelee *et al.,* 2003). For the irrigation managers, one of the unintended benefits of the intervention was the increased speed of water conveyance, which provided them with greater flexibility in water scheduling.

Another approach to mosquito vector control involves the management of water at field crop level, especially in flooded rice fields. Originally tested in Portugal in the 1940's, this technique of intermittently wetting and drying rice fields (known as alternate wet and dry irrigation, or AWDI) purportedly resulted in heavy mortality of mosquito larvae and, at the same time, improved rice yields and reduced the amount of water used. The technique has been tested in North America, Philippines, Japan, China, and India with mixed success in relation to the three key factors of mosquito reduction, rice yield improvement, and lower water use (van der Hoek *et al.,* 2001 and Keiser *et al.,* 2002). Except in Japan and China where large-scale implementation has been possible under well-managed irrigation conditions, other studies have been done in experimental plots. Hardly any attention has been paid to AWDI in Africa. IWMI studies, therefore, focused on two areas: testing out the technique under farmer-managed conditions in south Asia (where mainly vectors of Japanese encephalitis breed in irrigated rice fields), and under experimental conditions in Africa (where major malaria vectors occur in the fields). In both studies AWDI saved water locally whilst maintaining rice yields on par with the other water management regimes tested, but there were no significant overall differences in immature mosquito abundance between AWDI and other fields (Mutero *et al.,* 2000; Krishnasamy *et al.,* 2003). The Indian study, in particular, highlighted the limitations that could be encountered in large-scale farmer-managed field implementation: the levelling of fields was inadequate for proper drainage, and the interval between wettings and dryings was too short for effective kill of stranded mosquito larvae. Rainfall was an added complication that negated the impact of periodic drying. The IWMI experiences in Kenya and India (together with some previous studies by others) indicate that many factors play a role in determining the success or failure of AWDI. Some of these factors can be influenced, such as irrigation infrastructure and irrigation management capacity, while others cannot be, such as rainfall and soil conditions. The water saving aspects, not the mosquito control is likely to be the critical factor that will make farmers and irrigation department officials adopt AWDI in water scarce areas. This is illustrated in China, where AWDI is implemented on a large scale mainly because volumetric charges for water provided an important incentive for farmers to use less water. The large scale implementation of AWDI contributed to a dramatic reduction of malaria in Sichuan Province (Qunhua *et al.*, 2004).

Mosquitoes and malaria thrive in poverty-afflicted communities that are also affected by other environmental and economic problems such as malnutrition, poor living conditions, lack of medical care, lack of access to safe drinking water, inadequate household sanitation and waste disposal, food contamination with pathogens, and occupational injury hazards. The disease requires a holistic approach to unravel the complex interactions between parasite, vector, host, society and ecosystem, and this is provided by the agro ecosystem management concept (Forget and Lebel, 2001). This takes account of the role in disease burden of factors such as age, gender, education, occupation, family size, nutritional status, location, water management practices, cropping systems, livestock production systems and the effectiveness of public health institutions, in addition to the traditional biomedical epidemiological approaches. Thus, IWMI and partners have launched a multidisciplinary, participatory, community-based research project in the Mwea irrigation scheme in Kenya to improve the health and economic well-being of irrigated riceland communities through researching agro ecosystem management practices with the potential to reduce malaria.

The Mwea villages exhibited a classic malaria ‘paddies paradox’ (Ijumba and Lindsay, 2001), with irrigated villages having 30-300 fold greater mosquito vectors but 2-6 fold less human malaria cases than non-irrigated villages. The reason appeared to be that the major vector, *An. arabiensis*, fed mainly (85-96% of meals) on cattle and other non-human hosts in irrigated villages, in contrast to much heavier human feeding rates (42-45% of meals) in the non-irrigated villages (Mutero *et al.,* 2004a). Another finding was that experimental rice field pools seeded with ammonium sulphate, a common broadcast fertilizer in paddy rice in the area, generated significantly higher populations of *An. arabiensis* than untreated pools (Mutero *et al.,* 2004b). The results suggested that in addition to strengthening malaria control interventions such as insecticide-treated bednets, other measures such as zooprophylaxis using cattle, and the use of alternative chemical fertilizers that did not promote vector population increases, could be practical options for long term malaria control in this system.

These original research activities have to be put in the context of the long history of environment-based interventions that have contributed to the prevention of malaria, especially in Asia (Konradsen *et al.,* 2004; Keiser *et al*., 2005). Some of the interventions piloted and implemented early in the last century still have relevance today but in a site-specific manner and in combination with other preventive and curative activities.

Conclusions and future research

The work on vector-borne diseases at IWMI has contributed substantially to raising the awareness of human health issues in water resources development and management among the non-biomedical oriented irrigation and agricultural sectors. This has been especially achieved through working in partnership with a large number of national and international institutions and publications on these issues in the irrigation and agriculture-oriented journals, as well as biomedical journals. Overall, human health issues are now very much on the international development agenda, and also much more prominent on the agricultural sector agenda. It is clear that to complement the traditional biomedical approaches to malaria and other vector-borne disease there is a role for control by managing water and land in a manner that will reduce the disease-generating potential of agricultural systems, thereby reaping the benefits of better health, greater crop productivity and improved livelihoods.

Among a multitude of remaining research priorities, four aspects stand out. They are: (a) the testing of holistic agro-ecological interventions for disease control based on research done in specific types of agricultural systems, and the application of the lessons learned more generically; (b) the development of modern information technology-based tools to map disease risk, analyze risk factors, and possibly provide predictive capability, to support disease control managers in their decision-making and the strategic mobilization of resources; (c) research on how the use of chemicals in agriculture affects the levels of vector abundance and resistance; and (d) the use of agricultural institutions in the promotion of health in general and specific disease-associated interventions.

Unfortunately, over the last few years IWMI's health component has gradually diminished. This followed a decision of the management to consider health as a cross-cutting issue rather than a separate programme. This has reduced the focus on the interactions between water, agriculture, and human health. However, the Consultative Group of International Agricultural Research Centers (CGIAR), of which IWMI is a member has maintained some focus on human health and the experiences and research generated by IWMI has been followed up by a number of research groups around the world.

ACKNOWLEDGEMENTS

The authors have been responsible for the health program at the Colombo headquarters of the International Water Management Institute, Flemming Konradsen from 1994 to 1997 and Wim van der Hoek from 1997 to 2001..The late Dr.. F. P. Amerasinghe is acknowledged for his involvement in the research on vector borne diseases, especially malaria, at the International Water Management Institute, from the early planning stages.

REFERENCES

Afrane, Y.A., Klinkenberg, E., Drechsel, P., Owusu-Daaku, K., Garms, R. and Kruppa, T. (2004). Does irrigated urban agriculture influence the transmission of malaria in the city of Kumasi, Ghana? *Acta Tropica* **89**: 125-134.

Amerasinghe, F.P. (1985). Current studies on vector populations in areas under development in Mahaweli System C. In: Proceedings of the workshop on irrigation and vector-borne disease transmission. Digana, International Irrigation Management Institute and Joint WHO/FAO/UNEP Panel of Experts on Environmental Management for Vector Control.

Amerasinghe, F.P., Konradsen, F., Fonseka, K.T. and Amerasinghe, P.H. (1997). Anopheline (Diptera: culicidae) breeding in a traditional tank-based village ecosystem in north central Sri Lanka. *Journal of Medical Entomology* **34**: 290-297.

Amerasinghe, P.H., Amerasinghe, F.P., Konradsen, K., Fonseka, K.T. and Wirtz, R.A. (1999). Malaria vectors in a traditional dry zone village in Sri Lanka. *American Journal of Tropical Medicine and Hygiene* **60**: 421-429.

Amerasinghe, F.P., Konradsen, K., van der Hoek, W., Amerasinghe, P.H., Gunawardena, J.P.W., Fonseka, K.T. and Jayasinghe, G. (2001). *Small Irrigation Tanks as a Source of Malaria Mosquito Vectors: A Study in North-Central Sri Lanka*. IWMI Research Report No. 57. International Water Management Institute, Colombo.

Amerasinghe, F.P. (2003). Irrigation and mosquito-borne diseases. *Journal of Parasitology* **89**: 14-22.

Amerasinghe, F.P. (2006). Water, health and environment. In: M.A. Giordano, F.R. Rijsberman and R.M. Saleth (Eds), *More Crop per Drop: Revisiting a Research Paradigm. Results and Synthesis of IWMI's Research: 1996-2005*. IWA Publishing, London, UK.

Boelee, E., Amerasinghe, P.H. and Amerasinghe, F.P. (2003). *Water Management for Malaria Control in an Area of the Huruluwewa Watershed.* Final Report, submitted to the Ministry of Health, Government of Sri Lanka. 11 pp.

Bradley, D. (1977). The health implications of irrigation schemes and man-made lakes in tropical environments. In: R. Feachem, M. Mcgarry and D. Mara (Eds), *Water, Wastes and Health in Hot Climates*. John Wiley, London, 18-29.

De Zulueta, J., Mujtaba, S.M. and Shah, I.H. (1980). Malaria control and long-term periodicity of the disease in Pakistan. *Transactions of the Royal Society of Tropical Medicine and Hygiene* **74**: 624-632.

Donnelly, M.J., Birley, M.H. and Konradsen, F. (1997a). *An Investigation of the Relationship between Depth to Groundwater and Malaria Prevalence, Punjab, Pakistan.* IIMI Working Paper No. 40. International Irrigation Management Institute, Colombo.

Donnelly, M.J., Konradsen, F. and Birley, M.H. (1997b). Malaria-treatment-seeking behaviour in the southern Punjab, Pakistan. *Annals of Tropical Medicine & Parasitology* **91**: 665-667.

Donnelly, M.J., McCall, P.J., Lengeler, C., Bates, I., D'Alessandro, U., Barnish, G., Konradsen, F., Klinkenberg, E., Townson, H., Trape, J.F., Hastings, I.M. and Mutero, C. (2005) Malaria and urbanization in sub-Saharan Africa. *Malaria Journal* **4**: 12.

Forget, G. and Lebel, J. (2001). An ecosystem approach to human health. *International Journal of Occupational and Environmental Health* **7**: 3-38.

Gardiner, C., Biggar, R.J., Collins, W.E. and Nkrumah, F.K. (1984). Malaria in urban and rural areas of southern Ghana: a survey of parasiteamia, antibodies, and antimalarial practices. *Bulletin of the World Health Organization* **62**: 607-613.

Herrel, N., Amerasinghe, F.P., Ensink, J., Mukhtar, M., van der Hoek, W. and Konradsen, F. (2001). Breeding of *Anopheles* mosquitoes in irrigated areas of South Punjab, Pakistan**.** *Medical and Veterinary Entomology* **15**: 236-248.

Herrel, N., Amerasinghe, F.P., Ensink, J., Mukhtar, M., van der Hoek, W. and Konradsen, F. (2004). Adult anopheline ecology and malaria transmission in irrigated areas of South Punjab, Pakistan. *Medical and Veterinary Entomology* **18**: 141-152.

Hunter, J.M., Rey, L., Chu, K.Y., Adekolu-John, E.O. and Mott, K.E. (1993). *Parasitic Diseases in Water Resources Development.* WHO, Geneva, Pp.152.

Ijumba, J.N. and Lindsay, W. (2001). Impact of irrigation on malaria in Africa: paddies paradox. *Medical and Veterinary Entomology* **15**: 1-11.

Jobin, W. (1999). *Dams and Disease: Ecological Design and Health Impacts of Large Dams, Canals and Irrigation Systems*. E & FN Spon (Taylor & Francis Group), Pp.580/

Keiser, J., Utzinger, J. and Singer, B.H. (2002). The potential of intermittent irrigation for increasing rice yields, lowering water consumption, reducing methane emissions, and controlling malaria in African rice fields. *Journal of the American Mosquito Control Association* **18**: 329-340.

Keiser, J., Singer, B.H. and Utzinger, J. (2005). Reducing the burden of malaria in different eco-epidemiological settings with environmental management: a systematic review. *Lancet Infectious Diseases* **5**: 695-708.

Kleinschmidt, I., Omumbo, J., Briet, O., van de Giesen, N., Sogoba, N., Mensah, K.N., Windmeijer, P., Moussa, M. and Teuscher, T. (2001). An empirical malaria distribution map for West Africa. *Tropical Medicine and International Health* **6**: 779-786.

Klinkenberg, E., van der Hoek, W., Amerasinghe, F.P., Jayasinghe, G., Muttawatte, L. and Gunawardena, D.M. (2003). *Malaria and Land Use: a Spatial and Temporal Risk Analysis in Southern Sri Lanka*, Research Report No. 68. International Water Management Institute, Colombo.

Klinkenberg, E., Konradsen, F., Herrel, N., Mukhtar, M., van der Hoek, W. and Amerasinghe, F.P. (2004). Malaria vectors in the changing environment of the southern Punjab, Pakistan. *Transactions of the Royal Society of Tropical Medicine and Hygiene* **98**: 442-449.

Klinkenberg, E., McCall, P.J., Wilson, M.D., Akoto, A.O., Amerasinghe, F.P., Bates, I., Verhoeff, F.H., Barnish, G. and Donnelly, M.J. (2006). Urban malaria and anaemia in children: a cross-sectional survey in two cities of Ghana. *Tropical Medicine and International Health* **11**: 578-588.

Konradsen, F., van der Hoek, W., Amerasinghe, P.H. and Amerasinghe, F.P. (1997a). Measuring the economic cost of malaria to households in Sri Lanka. *American Journal of Tropical Medicine and Hygiene* **56**: 656-660.

Konradsen, F., van der Hoek, W., Amerasinghe, P.H., Amerasinghe, F.P. and Fonseka, K.T. (1997b). Household responses to malaria and their costs: a study from rural Sri Lanka. *Transactions of the Royal Society of Tropical Medicine and Hygiene* **91**: 127-130.

Konradsen, F. and van der Hoek, W. [Eds.] (1998). *Health and Irrigation: Proceedings of the Copenhagen Workshop on Health and Irrigation.* Ministry of Foreign Affairs, Copenhagen, Denmark, 18-20 August 1997. International Irrigation Management Institute, Colombo. Pp.32.

Konradsen, F., Stobberup, K.A., Sharma, S.K., Gulati, O.T. and van der Hoek, W. (1998a). Irrigation water releases and *Anopheles culicifacies* abundance in Gujarat, India. *Acta Tropica* **71**: 195-197.

Konradsen, F., Matsuno, Y., Amerasinghe, F.P., Amerasinghe, P.H. and van der Hoek, W. (1998b).

Anopheles culicifacies breeding in Sri Lanka and options for control through water management. *Acta Tropica* **71**: 131-138.

Konradsen, F., Steele, P., Perera, D., van der Hoek, W., Amerasinghe, P.H. and Amerasinghe, F.P. (1999). Cost of malaria control in Sri Lanka. *Bulletin of the World Health Organization* **77**: 301-309.

Konradsen, F., Amerasinghe, F.P., van der Hoek, W. and Amerasinghe, P.H. (2000a). *Malaria in Sri Lanka: Current Knowledge on Transmission and Control*. International Water Management Institute, Colombo. Pp.. 77 .

Konradsen, F., Amerasinghe, P., Perera, D., van der Hoek, W. and Amerasinghe, F. (2000b). A village treatment center for malaria: community response in Sri Lanka. *Social Science & Medicine* **50**: 879-889.

Konradsen, F., Amerasinghe, P., van der Hoek, W., Amerasinghe, F., Perera, D. and Piyaratne, M. (2003). Strong association between house characteristics and malaria vectors in Sri Lanka. *American Journal of Tropical Medicine and Hygiene* **68**: 177-181.

Konradsen, F., van der Hoek, W., Amerasinghe, F.P., Mutero, C., Boelee, E. (2004). Engineering and malaria control: learning from the past 100 years. *Acta Tropica* **89**: 99-108.

Krishnasamy, S., Amerasinghe, F.P., Sakthivadivel, R., Ravi, G., Tewari, S.C. and van der Hoek, W. (2003). *Strategies for Conserving Water and Effecting Mosquito Vector Control in Rice Ecosystems: a Case Study from Tamil Nadu, India*. Working Paper No. 56. International Water Management Institute, Colombo.

Kumar, A. (1997). Urban malaria and its control in India. *Journal of Parasitic Diseases* **21**: 83-88.

Lacey L.A. and Lacey, C.M. (1990). The medical importance of riceland mosquitoes and their control using alternatives to chemical insecticides. *Journal of the American Mosquito Control Association* **6**: 1-93.

Lindsay, S.W., Campbell, H., Adiamah, J.H., Greenwood, A.M., Bagali, J.E. and Greenwood, B.M. (1990). Malaria in a peri-urban area of The Gambia. *Annals of Tropical and Medical Parasitology* **84**: 553-562.

MARA/ARMA (1998). *Towards an Atlas of Malaria Risk in Africa*. First Technical Report of the MARA/ARMA Collaboration. MARA/ARMA initiative, Durban, South Africa (available at www.arma.org.za)

Mather, T.H. and That, T.T. (1984). *Environmental Management for Vector Control in Rice Fields*. FAO Irrigation and Drainage Paper No. 41. FAO, Rome, 152 pp.

Matsuno, Y., Konradsen, F., Tasumi, M., van der Hoek, W., Amerasinghe, F.P. and Amerasinghe, P.H. (1999). Control of malaria mosquito breeding through irrigation water management. *International Journal of Water Resources Development* **15**: 93-105.

Mutero, C.M., Blank, H., Konradsen, F. and van der Hoek, W. (2000). Water management for controlling the breeding of *Anopheles* mosquitoes in rice irrigation schemes in Kenya. *Acta Tropica* **76**: 253-263.

Mutero, C.M., Kabutha, C., Kimani, V., Kabuage, L., Gitau, G., Ssennyonga, J., Githure, J., Muthami, L., Kaida, A., Musyoka, L., Kiarie, E. and Oganda, M. (2004a). A transdisciplinary perspective on the links between malaria and agroecosystems in Kenya. *Acta Tropica* **89**: 171-186.

Mutero, C.M., Ng'ang'a, P.N., Wekoyela, P., Githure, J. and Konradsen, F. (2004b). Ammonium sulphate fertiliser increases larval populations of *Anopheles arabiensis* and culicine mosquitoes in rice fields. *Acta Tropica* **89**: 187-192.

Mutuwatte, L.P., Konradsen, F., Renault, D., Sharma, S.K., Gulati, O.T. and Kumara, W.A.U. (1997). *Water-Related Environmental Factors and Malaria Transmission in Mahi Kadana, Gujarat, India*. IIMI Working Paper No. 41. International Irrigation Management Institute, Colombo.

Qunhua, L., Xin, K., Changzhi, C., Shengzheng, F., Yan, L., Rongzhi, H., Zhihua, Z., Gibson, G. and Wenmin, K. (2004). New irrigation methods sustain malaria control in Sichuan Province, China. *Acta Tropica* **89**:241-247.

Sanmuganathan, K. and Amerasinghe, F.P. (1991). *Research Needs to Promote Control of Vector-borne Diseases in Irrigation Systems trough Environmental Management*. WHO, PEEM, Geneva.

Service, M.W. (1984). Problems of vector-borne diseases and irrigation projects. *Insect Science and its Applications* **5**: 227-231.

Service, M.W. (1989). Rice, a challenge to health. *Parasitology Today* **5**: 162-165.

Sharma, R.C., Gautam, A.S., Bhatt, R.M., Gupta, D.K. and Sharma, V.P. (1991). The Kheda malaria project: the case for environmental control. *Health Policy Planning* **6**: 262-270.

Tyagi, B.K. (2004). A review of the emergence of *Plasmodium falciparum*-dominated malaria in irrigated areas of the Thar Desert, India. *Acta Tropica* **89**: 227-239.

van der Hoek, W., Konradsen, F., Dijkstra, D.S., Amerasinghe, P.H. and Amerasinghe, F.P. (1998). Risk factors for malaria: a microepidemiological study in a village in Sri Lanka. *Transactions of the Royal Society of Tropical Medicine and Hygiene* **92**: 265-269.

van der Hoek, W., Sakthivadivel, R., Renshaw, M., Silver, J.B., Birley, M.H. and Konradsen, F. (2001). *Alternate Wet / Dry Irrigation in Rice Cultivation: a Practical Way to Save Water and Control Malaria and Japanese Encephalitis?* Research Report No. 47. International Water Management Institute, Colombo.

van der Hoek, W., Konradsen, F., Amerasinghe, P.H., Perera, D., Piyaratne, M.K. and Amerasinghe, F.P. (2003). Towards a risk map of malaria for Sri Lanka: the importance of house location relative to vector breeding sites. *International Journal of Epidemiology* **32**: 280-285.

Watts, T.E., Wray, J.R., Ng'andu, N.H. and Draper, C.C. (1990). Malaria in an urban and a rural area of Zambia. *Transactions of the Royal Society of Tropical Medicine and Hygiene* **84**: 196-200.

Yadav, R.S., Sharma, R.C., Bhatt, R.M. and Sharma, V.P. (1989). Studies on the anopheline fauna of Kheda district and species specific breeding habiats. *Indian Journal of Malariology* **26**:65-74.