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A Systems Approach to Malaria Control:
Institutional Perspective

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Abstract

This study introduces a systems approach to malaria control from an institutional perspective. This approach allows us to characterize the system of complex linkages of health, environmental, agricultural, economic, political, and social organizations that share a common goal of improving living conditions of poor communities through reduced malaria. These linkages are expected to facilitate the generation, dissemination, and application of relevant information by the organizations in the so-called malaria control system. Implicitly assumed by the approach is the premise that the relevant information in the control of malaria is generated everywhere in the society and should therefore be made available to all relevant parties to lead to improvements in the living conditions of people through effective anti-malaria activities. The study further describes how to apply the approach, provides in light of the approach a critical assessment of an existing malaria control initiative for sub-Saharan Africa, and with an example from Ghana, indicates the advantages of the approach in the context of planning sustainable malaria control strategies.

Keywords: Systems approach, cross-sectoral organization, multi-factorial disease control strategies, agriculture-health-environment system, malaria, HIV/AIDS

1. Introduction

Conventionally, the epidemiology of malaria is the study of nature and spread of the *Plasmodium* parasite and its vectors, the various species of mosquitoes, the human host, and their interaction within a natural environment (Krier and Baker, 1980; Clyde, 1987). However, close association of malaria prevalence with poverty indicates that economic, social and political factors may also be closely associated with interaction of agents, hosts and environment – the epidemiological triad (see Gallup and Sachs, 2001; Panvisavas, 2001; Sharma, Pradhan, and Padhi, 2001; Sachs and Malaney, 2002).

There are several perspectives adopted in the study of malaria, including medical and clinical; behavioral; development and poverty; social, political and economic perspectives. From the perspective of malaria as a medical problem, medical and public health research should provide information vital for prevention, early diagnosis and treatment of the disease. Information about epidemic-prone communities, such as characteristics of the mosquitoes, the demographic features of the population, the distance to the nearest health clinic, the availability of diagnostic laboratories, and the status of diagnostic equipment, is also crucial for estimating the extent of vulnerability and planning anti-malaria activities in the affected communities. From a clinical perspective information required is about incidence, prevalence, response to preventive and curative measures and best therapeutic practices among others.

When malaria is viewed from a behavioral perspective, information with respect to social and cultural factors must be embedded in malaria control strategies. Concerns such as sleeping, working, and recreational hours and locations; religious practices; proximity of homes to breeding places; understanding of disease etiology; and acceptance and use of various prevention and control measures influence the malaria situation. Nomadic pastoral cultures also encourage the spread of the parasite through infected individuals into uninfected areas (Prothero, 1965).

Malaria from a developmental and poverty perspective has been studied extensively (see Prothero, 1965; Conley, 1975; Bruce-Chwatt, 1980; Gomes, 1993; WHO, 2000; Gallup and Sachs, 2001; Nacher et al. 2001; Sachs and Malaney, 2002). Evidence suggests that during the initial stages of economic development, malaria prevalence rates are likely to be high because a successful implementation of malaria control requires a certain minimum level of economic development and basic health services. Below this level, there occurs a negative relationship between incomes and malaria prevalence. In particular, conditions of poverty, poorly funded and underdeveloped health and educational infrastructure, malnutrition, illiteracy and ignorance all serve to create an environment that enables *Plasmodium* to thrive. Conversely, illness from malaria can lead to loss in earnings. Families affected by malaria are less likely to plant and harvest crops, and when they do they are more likely to plant less labor-intensive crops, rather than crops that generate greater revenue but require more energy. Illness from malaria can also lead to slow children's cognitive and social development, and in school age children will slow their educational progress.

It can be argued that malaria is provoked by carelessly designed development activities. Therefore, information regarding the likely adverse consequences of these activities should be integrated into the project design and implementation. Agricultural and environmental information is the key to early detection and prevention of environmental degradation that creates optimal breading places for mosquitoes and poor living conditions for people. Climate change, land cover change, urbanization, unfavorable agricultural terms of trade, etc. are some of the factors that would eventually bring environmental degradation and change agricultural land use, cropping patterns, irrigation water use, chemical application, etc. (see Wang'ombe and Mwabu, 1993; Fleming, 1994; Konradsen, et al, 1998a, 1998b).

Demographic, political, and economic pressures all widen malaria's area of influence by forcing groups to leave non-endemic areas throughout the region and to enter endemic areas without natural immunity. Long-term migrants, seasonal laborers, and nomadic populations suffer some of the gravest consequences because of their transient status (Martens and Hall, 2000). These population movements introduce malaria into areas that had previously been malaria-free. Political, social, cultural, and economic information is the key to predicting responses of epidemic-prone communities to malaria and to developing socially and culturally acceptable and economically viable control strategies.

We therefore consider malaria as a multi-factorial problem beyond the conventional triad of interaction between the agent, the host, and the environment. Its causes spread over a large domain including medical, health, ecological, agricultural, social, political, and economic factors. Therefore, activities to control malaria and reduce its impact on communities need to be planned and carried out using information from different fields of work. Earlier this century, medical approaches alone were expected to be able to control malaria. As noted by AAAS (1991), it is now increasingly recognized that a much broader, coordinated approach, range of skills, and resource base are required. In addition to epidemiology and parasitology, for example, entomology is required to investigate the occurrence and habits of the vectors; ecology, to study the impact of changing vector and host environments on the transmission; agricultural sciences, to investigate the impact of agricultural activities; anthropology, to find out the local beliefs and practices as to the perceived causes of malaria, and local methods of prevention and treatment. Economics is also needed to evaluate financial viability of alternative control strategies and estimate willingness-to-pay for malaria control activities.

This study introduces a systems approach to malaria control from an institutional perspective. This approach allows us to characterize the system of complex linkages of health, environmental, agricultural, economic, political, and social organizations that share a common goal of improving living conditions of poor communities through reduced malaria. These linkages are expected to facilitate the generation, dissemination, and application of relevant information by the organizations in the so-called malaria control system. Implicitly assumed by the approach is the premise that the relevant information in the control of malaria is generated everywhere in the society and should therefore be made available to all relevant parties to lead to improvements in the living conditions of people through effective anti-malaria activities. The study further describes how to apply the approach, provides in light of the approach a critical assessment of an existing malaria control initiative for sub-Saharan Africa, and with an example from Ghana, indicates the advantages of the approach in the context of planning sustainable malaria control strategies.

2. A Brief Review of the Literature

Insofar as it is meaningful to make a distinction between cybernetics and systems theory, we might say that systems theory has focused more on the structure of systems and their models, whereas cybernetics has focused more on how systems function, that is to say how they control their actions, how they communicate with other systems or with their own components. Since structure and function of a system cannot be understood in separation, it is clear that cybernetics and systems theory should be viewed as two facets of a single approach. Emphasizing the interactions and connectedness of the different components of a system, the systems approach applies systems concepts and principles to aid a decision-maker with problems of identifying, reconstructing, optimizing, and controlling a system, while taking into account multiple objectives, constraints, and resources. It aims to specify possible courses of action, together with their risks, costs and benefits.

The literature on the systems approach is rich, with a wide variety of theoretical and applied studies. On the theoretical account, Laszlo (1972), Bunge (1979), and Bahm (1983) study conceptual foundations and philosophy of the approach; Murota (1987) investigates structural properties of systems such as solvability and controllability. Mesarovic and Reisman (1972) and Klir (1991) study mathematical modeling and information theory, respectively. On the empirical account, the approach is applied to examine agricultural, environmental, and cross-cutting issues such as malaria. Goldsworthy and de Vries (1994) present a collection of studies adopting the systems approach as a tool to assess opportunities in the developing country agriculture. Savory (1991) and Gill (1996) elaborate on the potential of systems approach in sustainability planning in agro-ecological issues. Some recent applications include Temel (2003) proposing cross-sector collaboration against malaria and Temel, Janssen, Karimov (2003) examining agricultural innovation systems in Azerbaijan. The list can be extended at will.

3. Systems Approach to Malaria Control

3.1. Definition

A malaria control system (MCS) is defined as a group of actors (i.e., organizations, communities, individuals, etc.) that jointly and/or individually contribute to the generation, dissemination, and use of existing or improved or new information that directly and/or indirectly improves living conditions through reduced malaria.

3.2. Flow and value of information

Information that concerns all the aspects of malaria is the only element that flows in the MCS. The organizations interact with each other during the process of the generation, exchange, and use of the relevant information. The sole content of this interaction is information that directly and/or indirectly concerns malaria control. The value of the information would determine the speed and extent of information flow in the MCS. The systems approach introduced by the current study implicitly assumes that there is a benevolent decision-making body whose only goal is to improve living conditions by reduced malaria incidence, given the system constraints. This benevolent body solves a constraint maximization problem that determines a shadow price for the information.[1]

3.3. A structure for the MCS

This study draws on a mixture of concepts and principles from systems theory and cybernetics to establish and analyze the malaria control system. Following systems theory, first proposed in the 1940's by von Bertalanffy (1968) and later furthered by Ashby (1956), our framework focuses on the arrangement of and relations between a set of actors organized around the

[1] The reader is referred to the literature on public economics for further reading on price determination for public goods. Information as public goods and shadow pricing for its provision and exchange reduces the complications that one will otherwise encounter in the determination of a unit of exchange flowing in the malaria control system. One should also note that this pricing approach does not necessarily restrict the provision of information to the benevolent body; it only sets a value (or a subsidy) for which this body will be willing to support the private provision of information.

system goal. This particular organization determines the malaria control system. Following cybernetics, the framework emphasizes interactions taking place in the system by studying feedback mechanisms. How the system functions and how it interacts with its own components receives the core attention.

The following properties all together define a structure for the malaria control system.

- The system constitutes components, each of which includes actors that share a comparable objective and operate under similar resource constraints.
- The system itself is defined as a unified body with its own objective and resource constraints, independent of component-level objectives and constraints.
- Information needs are assessed of each component and the system as a whole; types of linkage mechanisms to facilitate the flow of this information between the components and key constraints hindering the effective use of these mechanisms are described.
- At least one new property, which components cannot support individually, is introduced by the system. This would imply that the system is greater than the sum of its components. For example, two forest stands may contain the same tree species, but the spatial arrangement and size structure of the individual trees will create different habitats for wildlife species. The new property emergent is the wildlife habitat.

In the context of malaria control, the systems approach provides a useful tool to assess this structure. It helps:

- To identify critical gaps in information and linkages,
- To identify key capacities for the generation of information and the development of linkage mechanisms,
- To develop guidelines for cross-sector collaborative actions,
- To plan and implement these collaborative actions, and
- To monitor and evaluate the system performance.

3.4. Concepts for characterizing the structure of the MCS

The following concepts have been adopted from graph theory (Marshall, 1971; Hudson, 1992; Gregory, 1995; Pearl, 1995; Wasserman and Faust, 1995; Freeman, 2000).

3.4.1. A linkage matrix **L**

L maps cross-component linkages in the MCS. In the context of malaria control, this matrix would include organizations that deal with host-agent-environment interactions (epidemiological triad), organizations that deal with political-economic-social factors, and organizations that deal with changes in agricultural technologies, agricultural systems, and agricultural resources. **L** consists of 9 components (or focus areas), and each one includes a set of organizations, such as disease diagnostic laboratories, medical research laboratories, hospitals, environmental monitoring laboratories, agricultural research institutions, which directly or indirectly contribute to malaria control. The dimension of the matrix **L** depends on the extent to which the problem at hand is investigated. Each set of organizations has a primary focus on one of the 9 areas though there might be overlap in their areas of focus. **L** maps all binary (or one-to-one) linkages between the components, including Host denoted by **H**, Agent by **A**, Environment by **E**, Political by **P**, Economic by **Ec**, Social by **S**, Agricultural technologies by **T**, Agricultural systems by **As**, and Resource development by **R**. The components are placed in the diagonal cells, and following clock-wise rotation, binary linkages among them are placed in the off-diagonal cells of **L**:

$$\mathbf{L} = \begin{bmatrix} [\mathbf{H}] & HA & HE & HP & HEc & HS & HT & HAs & HR \\ AH & [\mathbf{A}] & AE & AP & AEc & AS & AT & AAs & AR \\ EH & EA & [\mathbf{E}] & EP & EEc & ES & ET & EAs & ER \\ PH & PA & PE & [\mathbf{P}] & PEc & PS & PT & PAs & PR \\ EcH & EcA & EcE & EcP & [\mathbf{Ec}] & EcS & EcT & EcAs & EcR \\ SH & SA & SE & SP & SEc & [\mathbf{S}] & ST & SAs & SR \\ TH & TA & TE & TP & TEc & TS & [\mathbf{T}] & TAs & TR \\ AsH & AsA & AsE & AsP & AsEc & AsS & AsT & [\mathbf{As}] & AsR \\ RH & RA & RE & RP & REc & RS & RT & RAs & [\mathbf{R}] \end{bmatrix}.$$

L contains three types of organizational linkages.

- Type I, called within-component linkages, for example those within **H** in the 1^{st} row – 1^{st} column represent linkages among organizations such as hospitals and clinics that only deal with **H**.

- Type II, called between-component linkages, for example those between **H** and **A** denoted by HA in the 1^{st} row – 2^{nd} column represent the linkages that organizations such as hospitals and clinics dealing with **H** declare to have with those organizations such disease research and diagnostic labs dealing with **A**. Likewise, linkages such as those between **A** and **H** denoted by AH in the 2^{nd} row – 1^{st} column represent the linkages that organizations such as disease research and diagnostic labs dealing with **A** declare to have with hospitals and clinics dealing with **H**. It is important to note that the information content of the linkages represented by HA will not be the same as the content represented by AH, because organizations in different components generate and/or demand different types of information, which provide the rational for the development of linkages.

- Type III represents the linkages established between the two components through pathways of binary linkages. Consider, for instance, a pathway denoted by HEPA, which can also be written as **H**→**E**→**P**→**A**. This pathway between **H** and **A** contains a sequence of binary linkages, starting with those between **H** and **E** (namely, HE), then between **E** and **P** (EP), and finally between **P** and **A** (PA). Sequencing is important because the pathway HPEA would not necessarily lead to the same outcome as that of HEPA. In this example, HEPA and HPEA are called three-edged pathways because they both contain three groups of binary linkages. The total number of k-edged pathways in a system can be calculated by $\frac{n!}{(n-k-1)!}$, where n and k stand for the number of components in the system and the number of edges in a pathway, respectively. The number of components, n, is an integer whose upper bound is determined by the specificities of the issue or problem under investigation. Applying this formula, one can easily calculate, for example, the number of one-edged pathways in **L**: $\frac{9!}{(9-1-1)!}=72$ where $n=9$ and $k=1$.

L has a structure with three features: context of the MCS, context of the organizational linkages noted above, and nature of these linkages.

- Malaria control, for example, defines the context, which determines the domain of organizations in the nexus. Organizations that deal with Host (**H**), Agent (**A**), and Environment (**E**) in the context of malaria are placed in the 1^{st}, 2^{nd}, and 3^{rd} diagonal cells of **L**, respectively. Organizations that contribute to Political (**P**), Social (**S**), and Economic (**Ec**) factors in the context of malaria are placed in the 4^{th}, 5^{th}, and 6^{th} diagonal cells, respectively. Lastly, organizations that concern with changes in Technology (**T**), Agricultural systems (**As**), and Resource development (**R**) in the context of malaria are placed in the 7^{th}, 8^{th}, and 9^{th} diagonal cells, respectively.

- Information, which is directly and/or indirectly related to aspects of malaria, defines the context in which the organizational linkages are established.

- These linkages should be analyzed in three categories. The first includes linkages claimed by individuals interviewed; the second, linkages expected by the individuals interviewed; and the third category, linkages actually realized. Questionnaires, structured interviews, observations, archival records, and stakeholder workshops are among the tools to identify the claimed, expected, and realized linkages. For the identification of realized linkages, organizational activities should be classified by linkage mechanisms (such as meetings, correspondence, commissions, etc.), the flow of information in which these mechanisms are employed, and frequency of use of the mechanisms. The frequency may indicate the intensity and strength of the linkages. Mapping of all the linkages should allow us to identify areas where expectations are not fulfilled and areas where there is a gap between claimed and realized linkages.

The linkages of an organization with others in the MCS are assumed to be purposeful, designed to optimize the organizational goal. This goal is represented by an objective function optimized under organization-specific constraints (such as financial, physical, and human), community-specific constraints (such as natural resources, public infrastructure and services, political orientation, culture, and religion), and institutional constraints (such as rules, procedures, and social norms) that govern all the linkages within- and between the organizations in the MCS.

Hospitals and clinics, for example, represent organizations that deal with **H**. Their objective is to maximize physical wellbeing of patients; they face budgetary, human resource, and material constraints; their effectiveness is constrained by the treatment-seeking attitude of people in the community in which they operate, by health information, education, and communication skills of people in the community, by the state of public infrastructure and public service delivery systems; and all the relations between patients and health clinics are governed by formal rules and social norms. These rules and norms regulate patients' expectations of health clinics and health service staff's expectations of patients, facilitating the equilibrium of the supply of and demand for health services. Similarly, universities, research organizations, extension units, industries, trade associations, technology assessment units, and farmers, for example, represent organizations that concern **T**. Each of these organizations operates in a similar fashion to **H**-related organizations. Consider research organizations. Their objective is to improve the state of knowledge in their field, operating under organizational, political, community-related constraints. And the way they provide services is governed by regulations and formal rules at the macro level and by community norms at the micro level.

It is relatively easy to identify the linkages between organizations within a given component; however, it is difficult to find out areas where the linkages emerge between two organizations from two different components. The optimization approach adopted is especially useful in examining the linkages between organizations from different components through the analysis of constraints and events that commonly affect organizational objectives and resources.

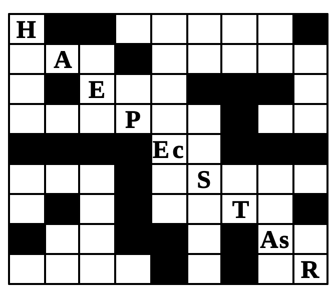
3.4.2. A coded linkage matrix $\mathbf{L_c}$

$\mathbf{L_c}$ is defined as a matrix with binary codes: 0 for absent and 1 for existing linkages. For illustrative purposes, an arbitrary matrix $\mathbf{L_c}$ is given below.

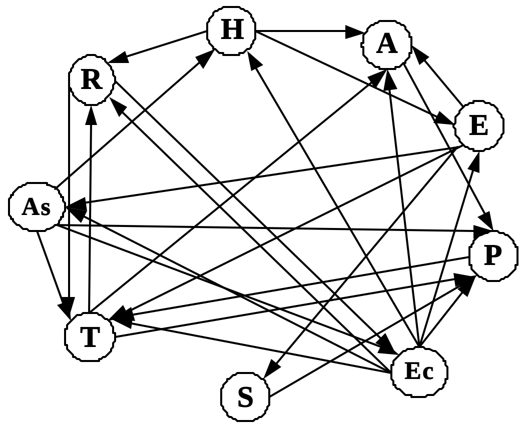
$$\mathbf{L_c} = \begin{bmatrix} [\mathbf{H}] & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & [\mathbf{A}] & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & [\mathbf{E}] & 0 & 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & [\mathbf{P}] & 0 & 0 & 1 & 0 & 0 \\ 1 & 1 & 1 & 1 & [\mathbf{Ec}] & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0 & [\mathbf{S}] & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 & [\mathbf{T}] & 0 & 1 \\ 1 & 0 & 0 & 1 & 1 & 0 & 1 & [\mathbf{As}] & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & [\mathbf{R}] \end{bmatrix}$$

H has a linkage with **A**, **E**, and **R**, implied by 1; and **P** has a linkage with **T** only. Notice that the linkage EcH exists but the HEc linkage does not, as manifested by 1 in the 5th row – 1st column and 0 in the 1st row – 5th column of $\mathbf{L_c}$, respectively. This coding convention enables us to show that linkages are directional and not necessarily symmetric, which is also explained above as Type II linkages. Below, $\mathbf{L_c}$ is shown in a different format that can be used for visual identification of patterns, where black (white) cells indicate the existing (nonexistent) linkages:

Visual Format of L_c =



A third format to represent $\mathbf{L_c}$ is to define it as a *digraph* (i.e., *directed graph*). The digraph consists of nine vertices, H, A, E, P, Ec, S, T, As, and R and assumes an implicit function that translates the linkages into real values {0, 1}. Although it is difficult to recognize patterns immediately in the following diagram, this format has its own advantages (Marshall, 1971; Wasserman and Faust, 1995).



3.4.3. The matrix $\mathbf{L_c}$

$\mathbf{L_c}$ is refined using a questionnaire or conducting a stakeholder workshop. Individuals interviewed by using the questionnaire would provide opinions on the degree and nature of linkages their organizations have developed with the rest of the organizations in the system. (Linkages mechanisms used such as meetings, printed documents, electronic tools, etc. are also explained.) Since the answers to the questions in the questionnaire would be expressed in scales, like none, weak, medium, and strong, we can assign to each scale a value, 0 for a nonexistent, 1 for a weak, 2 for a medium, and 3 for a strong linkage.[2] This procedure would yield a vector of values representing the degree of linkages between the interviewed organization and the rest of the organizations in the system. Repeating the same procedure for each organization in the MCS would result in as many vectors as organizations. Next, the components are defined as subsets of the organizations already characterized, and the vector of values assigned to the organizations in each subset is reduced to a single vector by choosing the modes of the relevant values. This reduces the dimension of the system at hand from the number of organizations to the number of components. Suppose that repeating this procedure for each component yields the refined matrix $\mathbf{L_r}$ whose values represent the degree of binary linkages claimed only. (Note that these linkages do not imply direction of influence.)

$$\mathbf{L_r} = \begin{bmatrix} [\mathbf{H}] & 1 & 2 & 0 & 0 & 0 & 0 & 0 & 2 \\ 0 & [\mathbf{A}] & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2 & [\mathbf{E}] & 0 & 0 & 3 & 1 & 2 & 0 \\ 0 & 0 & 0 & [\mathbf{P}] & 0 & 0 & 3 & 0 & 0 \\ 2 & 1 & 1 & 2 & [\mathbf{Ec}] & 0 & 1 & 3 & 2 \\ 0 & 0 & 0 & 2 & 0 & [\mathbf{S}] & 0 & 0 & 0 \\ 0 & 3 & 0 & 1 & 0 & 0 & [\mathbf{T}] & 0 & 2 \\ 1 & 0 & 0 & 2 & 3 & 0 & 2 & [\mathbf{As}] & 0 \\ 0 & 0 & 0 & 0 & 2 & 0 & 2 & 0 & [\mathbf{R}] \end{bmatrix}.$$

[2] Note that if the scale consists of such categories as "very harmful", "harmful", "neutral", "useful", and "very useful", then an appropriate set of values to be assigned to these categories would be –2, -1, 0, 1, and 2, respectively. For more reading on measurement techniques for surveys with scaled questions, the reader is referred to Miller (1956) and Tull and Hwakins (1984).

Organizations in the MCS are most likely to be different with respect to the degree of their "success" denoted by ***s*** and "importance" denoted by ***i***. The success of an organization can be measured by the degree of the realization of the organizational mandate; the importance, by the degree of the organization's contribution to the system goal. New data should be gathered to generate two parameters: one for "organizational success", another for "organizational importance". Externally conducted impact assessment reports can be used to extract information for the measurement of success, while expert knowledge that can be obtained by separate interviews with experts in the field can be used for the measurement of importance. For simplicity, we assume that all the organizations share equal weights for both success and importance.

3.4.4. *Adjusted*-$\mathbf{L_r}$

Adjusted-$\mathbf{L_r}$ transforms the component linkages into the influences. During the interview, questions are asked to determine how strongly the interviewed organization believes to influence the others in the system. Depending on the degree of claimed influence, which is scaled as none (**n**=0), weak (**w**=0.33), medium (**m**=0.66), and strong (**s**=1), $\mathbf{L_r}$ is adjusted as:

$$\mathbf{L_a} = \begin{bmatrix} [\mathbf{H}] & 1\mathbf{w} & 2\mathbf{s} & 0 & 0 & 0 & 0 & 0 & 2\mathbf{s} \\ 0 & [\mathbf{A}] & 0 & 1\mathbf{w} & 0 & 0 & 0 & 0 & 0 \\ 0 & 2\mathbf{m} & [\mathbf{E}] & 0 & 0 & 3\mathbf{n} & 1\mathbf{w} & 2\mathbf{s} & 0 \\ 0 & 0 & 0 & [\mathbf{P}] & 0 & 0 & 3\mathbf{n} & 0 & 0 \\ 2\mathbf{s} & 1\mathbf{n} & 1\mathbf{n} & 2\mathbf{w} & [\mathbf{Ec}] & 0 & 1\mathbf{s} & 3\mathbf{s} & 2\mathbf{n} \\ 0 & 0 & 0 & 2\mathbf{n} & 0 & [\mathbf{S}] & 0 & 0 & 0 \\ 0 & 3\mathbf{s} & 0 & 1\mathbf{s} & 0 & 0 & [\mathbf{T}] & 0 & 2\mathbf{n} \\ 1\mathbf{w} & 0 & 0 & 2\mathbf{w} & 3\mathbf{m} & 0 & 2\mathbf{m} & [\mathbf{As}] & 0 \\ 0 & 0 & 0 & 0 & 2\mathbf{s} & 0 & 2\mathbf{w} & 0 & [\mathbf{R}] \end{bmatrix}$$

$$\mathbf{L_a} = \begin{bmatrix} [\mathbf{H}] & 0.33 & 2 & 0 & 0 & 0 & 0 & 0 & 2 \\ 0 & [\mathbf{A}] & 0 & 0.33 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1.32 & [\mathbf{E}] & 0 & 0 & 0 & 0.33 & 2 & 0 \\ 0 & 0 & 0 & [\mathbf{P}] & 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & 0 & 0.66 & [\mathbf{Ec}] & 0 & 1 & 3 & 0 \\ 0 & 0 & 0 & 0 & 0 & [\mathbf{S}] & 0 & 0 & 0 \\ 0 & 3 & 0 & 1 & 0 & 0 & [\mathbf{T}] & 0 & 0 \\ 0.33 & 0 & 0 & 0.66 & 1.98 & 0 & 1.32 & [\mathbf{As}] & 0 \\ 0 & 0 & 0 & 0 & 2 & 0 & 0.66 & 0 & [\mathbf{R}] \end{bmatrix}.$$

3.4.5. *The source-sink structure of* $\mathbf{L_a}$

Following Hudson (1992), the source-sink structure of $\mathbf{L_a}$ is established as follows. *Source* (*So*) is defined as the origin of influence of a single component on each of the rest of the components in $\mathbf{L_a}$; and *Sink* (*Si*), as the influence of each of the rest of the components on that single component. For example, the 2nd row in $\mathbf{L_a}$ indicates that A only influences P, while the 2nd column in $\mathbf{L_a}$ indicates that H, E, and T influence A. The *So-Si* coordinates of $\mathbf{L_a}$ are (4.33, 2.33) for **H**, (0.33, 4.65) for **A**, (3.65, 2) for **E**, (0, 2.65) for **P**, (6.66, 3.98) for **Ec**, (0, 0) for **S**, (4, 3.31) for **T**, (4.29, 5) for **As**, and (2.66, 2) for **R**. In this system, **Ec** is the most dominant component with a cause of 6.66, and is followed by the component **H** with a cause of 4.33. There are two subordinate components, **A** and **P,** with an effect of 4.65 and 2.65, respectively. **T** and **R** are the most interactive components, influencing others in the system as much as others influence them. In Figure 1, the *So-Si* coordinates determine the location of the individual components, while the values in $\mathbf{L_a}$ determine the directed arrows between the components.[3] For example, the relation HE represented by 2 in the 1st row – 3rd column of $\mathbf{L_a}$ is shown with a directed arrow from H to E. This figure provides a very useful visual tool to quickly see the sources and sinks in the MCS.

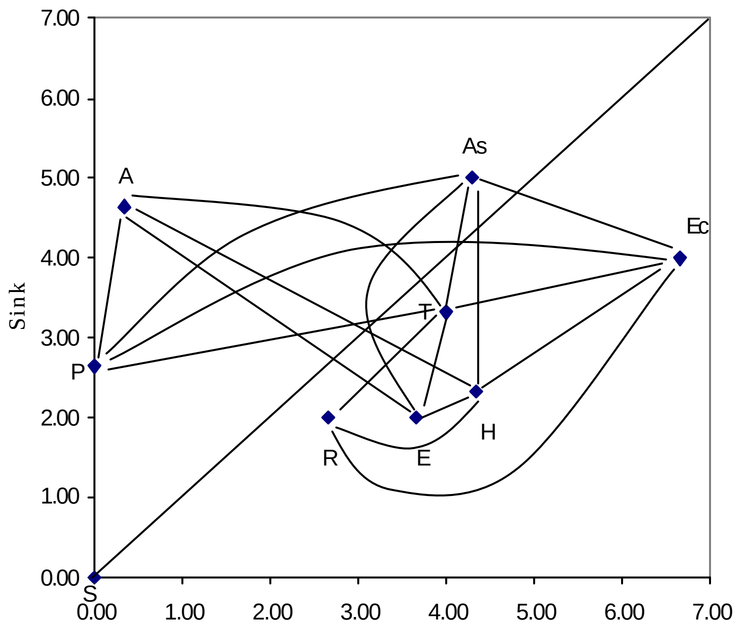


Figure 1. The source-sink structure of **La**

3.4.6. The density of $\mathbf{L_a}$

The density of $\mathbf{L_a}$, denoted by *d*, is calculated as *d=b/[n(n -1)]* with *1 ³ d ³ 0*, where *b* denotes the total number of existing binary interactions, and *n* is the number of dimensions in $\mathbf{L_a}$. Thus, $\mathbf{L_a}$ has a density of 0.36, where *b*=26 and *n*=9. A structure is said to be fully identify if *d*=1, which implies that all the components influence each other.

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[3] The authors thank Rick Davies for his suggestion as to make Figure 1 more visual and useful by mapping the binary relations in $\mathbf{L_a}$ as directed arrows.

3.4.7. A cluster

A cluster is a subset of components concentrated around a (So, Si)-coordinate. The So-Si structure is a useful tool for detecting clusters in the system. This concept, useful especially in a system with a large number of components, helps identify subsystems and examine their characteristics.

4. An Application

With an application we illustrate how to apply the systems methodology described above. Table 1 provides the data required to construct a MCS. The MCS consists of seven components placed in the first column of Table 1. The first component, Host (**H**), defines human beings as hosts to malaria mosquitoes; the second, Agent (**A**), defines Plasmodium Species as causal agents and mosquitoes as vectors that bridge the gap between malaria and human beings; the third, Environment (**E**), implies physical surrounding of human beings and mosquitoes; the fourth, Political factors (**P**), refers to national and local government policies; the fifth, Economic factors (**Ec**), refers to market transactions; the sixth, Social factors (**S**), refers to societal changes; and finally, the seventh component, Agriculture (**Ag**), refers to all the activities that relate to agricultural technologies, agricultural systems, and resource development. Each component comprises many organizations sharing an implicit or explicitly common goal of malaria control.

The second column in Table 1 indicates selected research areas associated with each component. Consider, for example, Component **A**. Among the research areas that concern this component are the effects of changing parasite and/or vector ecology, such as changes in vector density, distribution, feeding habits, and prevalence, on the demand from the health sector, on the direction of research and development activities, on people's health-seeking behavior, on crop patterns, on the use of pesticides, and on drug resistance.

In the third column of Table 1, scientific disciplines are listed that concern only with changes in the environment of the component concerned. For example, in the case of Component **A**, data, information, and knowledge on changes in parasite and/or vector ecology are expected from malariology, parasitology, immunology, microbiology, entomology, and epidemiology. In the case of Component **H**, data, information, and knowledge on changes in human health status are expected from medical science, immunology, health education, human biology, social medicine, nutrition science, medical entomology, and epidemiology. What about data, information, and knowledge that relate to effects of changes in the environment of one component, for example **A**, on the environment of another component, for example **H**? This is the area where multidisciplinary research teams should focus.

In the fourth column of Table 1, organizations are listed that concern only with changes in the environment of the component concerned. For example, research and diagnostic labs, information collection and dissemination centers, surveillance centers, and national and international research institutes and universities should take part in activities that concern with changes in the environment of **A**; and similarly, ministry of health, hospitals, clinics, research and diagnostic labs, health information collection and dissemination centers, health surveillance centers, national and international research institutes and universities, donors, medical supply delivery forms, and NGOs should take part in activities that concern with changes in the environment of **H**. What about activities that relate to effects of changes in the environment of one component, for example **A**, on the environment of another component, for example **H**? This is the area where cross-sectoral collaboration is needed.

Table 2 represents a structure for the MCS, using the same data in Table 1. Disciplines that relate to individual components are placed in the diagonal cells; and the multi-disciplinary research areas, in the off-diagonal cells of Table 2. Consider, for example, the 2nd row and the 2nd column that together represent Component **A**. Research areas placed in the 2nd row all consider the effects of changes in **A** on other components. For instance, the off-diagonal cell (2nd row-7th column) concerns agricultural implications of new strains of vectors (i.e., the effects of changing vector-plant relations on crop patterns, on the use of pesticides, and on drug resistance). Research areas placed in the 2nd column all consider the effects of changes in other components on Component **A**. For instance, the off-diagonal cell (7th row-2nd column) concerns implications for vector ecology of changing agricultural systems, resource development, and technologic changes (i.e., the effects of irrigation techniques on vector abundance). As discussed in the paragraphs above, such mapping of research areas helps us identify relevant disciplines in order to form multi-disciplinary teams. For example, studying the areas stated in the cells (2nd row – 7th column) and (7th row – 2nd column) would require teams of researcher and/or experts from two sets of disciplines. One set studies changes in **A**, including malariologists, parasitologists, immunologists, microbiologists, entomologists, and epidemiologists; another set studies changes in **Ag**, including agriculture and food Scientists, agronomists, animal scientists, and veterinary entomologists. Table 2 can further be used in the formation of cross-sectoral teams of organizations. To do so, we replace disciplines in the diagonal cells with organizations in the fourth column of Table 1 and apply the same reasoning as in the formation of multi-disciplinary teams.

With an example in Table 3, we illustrate how to apply the methodology to the MCS in order to identify key research areas, capacities required (organizational, technical, and institutional), and organizational linkages for cross-sectoral collaboration in the context of water resource development activities and malaria transmission. The flow in the MCS is information, which is directly and/or indirectly related to malaria. This flow is described, for example, by three pathways. The first pathway (policy reform), denoted by **Ag®A→H→P**, starts with changes in agriculture (**Ag**) and ends with changes in policy (**P**). Changes in agriculture introduced by investment in water resources would invite changes in vector abundance and distribution (**A**), denoted by **Ag®A**. Potential health effects of vector abundance are represented by **A→H**, and finally, information on health effects of possible increase in vector abundance flows from organizations that deal with **H** to those that deal with **P**, denoted by **H→P**. Policy organizations are expected to utilize this information in the design of policies and actions to avoid adverse health impacts of water resource development activities. This pathway is not only a sequence of events originating from agriculture and terminating at policy but also a sequence of interactions of organizations that deal with agriculture (placed in the 7th diagonal cell of Table 3), vector (placed in the 2nd diagonal cell of Table 3), human health (placed in the 1th diagonal cell of Table 3), and policy-making (placed in the 4th diagonal cell of Table 3). The pathway further determines the set of organizations to collaborate. One possible cross-sectoral collaboration would include ministry of agriculture, ministry of water resources, agricultural research organizations, agricultural extension and information units, microbiology department, research and diagnosis labs, ministry of health, medical research and diagnosis labs, hospitals, and clinics, information collection and dissemination centers, NGOs, and district administration.

Having described the policy reform pathway, **Ag®A→H→P**, and the set of possible organizations for a cross-sectoral cooperation, the next step is to identify capacities required to establish, operationalize, and maintain this pathway. These capacities include:

- *Organizational, technical, and institutional capacities to link disciplines and organizations*. In the context of the policy reform pathway, the development of such capacity requires agricultural organizations to have experts on health impacts of water resource development; it further requires health organizations to have experts on public policy implications of water-related diseases in order to enhance understanding of changes to be made in public health policy. But, such organizational capacities are not sufficient for the effective flow of information from one component to another in the pathway. They should, on the part of individuals, be supported by good communication skills, inter-disciplinary and cross-sector decision making skills, negotiation skills, etc. Lastly, the organizations in a cross-sector collaboration should also have the capacity to design and implement procedures, guidelines, rules, etc. to sustain the effective linkages created. Planning and implanting actions, monitoring and evaluating impacts of these actions are some of the areas such capacities should find wide use. (The same capacities are also relevant in the context of the two pathways described below.)

The second pathway (community participation), denoted by **Ag** ® **A**→**H**→**S**→**P**, again starts with changes in agriculture (**Ag**) and ends with changes in policy (**P**). Changes in agriculture introduced by investment in water resources would invite changes in vector abundance and distribution (**A**), denoted by **Ag** ® **A**. Potential health effects of vector abundance are represented by **A**→**H**; health information goes from human health organizations to the community concerned, denoted by **H**→**S**. Having better understanding of health implications of water resource development, the community exerts pressure on policy makers for changes in public health policy to reduce the adverse health effects of water investments, denoted by **S**→**P**. Of course, the success of this pressure strongly depends on the degree of democratization and the community participation in political processes. This pathway is a sequence of interactions of organizations that deal with agriculture (placed in the 7th diagonal cell of Table 3), vector (placed in the 2nd diagonal cell of Table 3), human health (placed in the 1th diagonal cell of Table 3), social issues (placed in the 6th diagonal cell of Table 3), and policy-making (placed in the 4th diagonal cell of Table 3). The pathway further determines the set of organizations to collaborate, with additional organizations dealing with social factors.

The third pathway (agriculture-health feedback), denoted by **Ag** ® **A**→**H**→**Ag**, starts and ends with changes in agriculture. Changes in agriculture introduced by investment in water resources bring changes in vector abundance (**A**), denoted by **Ag** ® **A**. Potential health effects of vector abundance are represented by **A**→**H**; and finally, information on the effects of malaria on the choice of production technique are passed to organizations that deal with water resource development, denoted by **H**→**Ag**. In a situation where a great deal of labor is lost due to malaria, farmers are expected to respond to it by adopting labor saving agricultural production techniques or by changing crops cultivated from those demanding labor to those saving labor. This pathway is a sequence of interactions of organizations that deal with agriculture (placed in the 7th diagonal cell of Table 3), vector (placed in the 2nd diagonal cell of Table 3), and human health (placed in the 1th diagonal cell of Table 3). The pathway also determines in a similar fashion as in the first pathway the set of organizations to collaborate.

An assessment of AAAS' cross-sectoral approach to malaria control

AAAS (1991) introduced a cross-sectoral approach and applied it to make recommendations for the prevention and control of malaria in sub-Saharan Africa. These recommendations were used in the setting of policies and of priorities for investments in malaria control. This section critically evaluates AAAS' approach, using our framework as a point of departure. Drawing on AAAS (1991), Table 4 maps the malaria problem and solution strategies and shows relevant disciplines and organizations; Table 5 presents a structure by using the information in Table 4; Table 6 points out with the gray colored cells the areas in which multi-disciplinary research is relevant; and Table 7, the areas in which cross-sectoral collaboration is relevant.

Several observations are immediate from this expression of AAAS's views in the format of our framework. First, political factors and organizations are not included in the analysis. Second, what flows through organizational linkages is not mentioned, and this jeopardizes the effective operation of a cross-sectoral team. Third, capacities to be developed for organizational linkages are not addressed. Fourth, such mechanisms as regional resources centers, networks of specialists, and training centers are proposed for the system to operate, however, mechanisms for the creating of pathways are not addressed. This should be attributed to the fact that AAAS proposes a centralized as opposed to our decentralized approach. One advantage of the decentralized approach is that creating and maintaining a database relevant to the pathway of interest are easier to manage.

5. Case Study

Malaria control requires the cooperation of organizations from different sectors. With a case study from Ghana (AAAS, 1991), the current study examines the conditions for the emergence, operation, and sustainability of a cross-sector cooperation, as well as the factors that impede effective malaria control.

The Ghana Health Committee on Water Resource Development was inaugurated in 1979 to examine health implications of proposed water development projects.[4] The purpose of the Committee was to promote and stimulate research by appropriate organizations on health effects of water development, to distribute information on such effects, and to determine resources necessary for improvement of adversely affected groups. The Committee consisted of experts and representatives from health, irrigation, finance, environmental protection, water resource development, and the Council for Scientific and Industrial Research. These individuals represented ministries and related research institutions. The Committee evaluated already-existing water development projects, reviewed plans for new ones, and made recommendations to groups responsible for implementation and monitoring of such projects. The Committee suffered from a lack of funding for these collaborative efforts, resulting in a cessation of interactions of the participating organizations for several years. Based on this experience, several recommendations were made: The collaborative body itself must be funded in order to be sustainable; high-level officials should be involved in the collaboration in order to lend credibility and authority to the effort; individuals likely to be involved in such efforts should gain exposure to interdisciplinary approaches through training courses.

The application of the proposed systems approach should start with the identification of the issue or the problem, the sources of expected health effects, and the information to be collected. The *issue* in the Ghana example is that proposed water development projects are expected to have adverse health effects in the communities concerned unless protective measures are taken before and during the project implementation. Environmental changes and

[4] A wide range of studies exists in the literature on the relationship between water resource development and malaria. For several case studies, the reader is referred to Mutuwatte, Konradsen, Renault, Sharma, Gulati, Kumara (1997), Konradsen, Stobberug, Sharma, Gulati, van der Hoek (1998a), Konradsen, Matsuno, Amerasinghe, Amerasinghe, van der Hoek (1998b), Mutero, Blank, Konradsen, van der Hoek (2000) among many others.

irrigation development following from water development projects would be the two likely *sources* of these expected health effects. This implies that the Environment and Agriculture components, which are respectively represented by the 3rd and 7th diagonal (gray colored) cells of Table 2, are the driving forces behind the health effects. On the other hand, the off-diagonal cells in the 3rd and 7th rows of Table 2 show the areas where *information* needs to be collected to provide insights into the implications on the rest of the system of environmental changes and irrigation development, respectively.

In the next stage, for the collection and analysis of information required, *multi-disciplinary teams* need to be formed. The off-diagonal cells, for example, in the 3rd row of Table 2 indicate the type of information demanded and hence predetermine the composition of the teams to be formed. For instance, the off-diagonal cell corresponding to the 3rd row and 7th column of Table 2 indicates that information should be collected to analyze the agricultural implications of environmental changes such as land salinity, soil fertility, etc. But, this can be done only when does the relevant team include scientists from environmental and agricultural sciences and do the team members acquire multidisciplinary research skills.

In the last stage, for planning and implementing actions, a cross-sector body, like the Committee, is required, which should rely in its decisions on the scientific information provided by multidisciplinary teams. The systems approach suggests that the Committee in the Ghana example should have included representatives from all of the 7 components in the malaria control system represented by Table 2. Unfortunately, the Committee suffered from the incomplete representation: it did not include anybody from policy making bodies and community associations. It failed to see the vitality of community participation for the success of the initiative. The approach further suggests that prior to performing the tasks, the Committee members should have been educated on multidisciplinary research and cross-sectoral decision making methods and their communication skills been improved in special programs. Although such capacity building activities are known to be absolutely essential for the success of such cross-sector bodies, apparently no initiative has been taken in this direction during the process of the formation of the Committee. Obviously, in the case of Ghana, the performance of the Committee has not been considered a limiting factor at all.

The approach introduced suggests that the Committee has not given thought on the development of linkages for information flow across components of the system. The composition of the members of the Committee reflects that information is flowing towards the Committee and that no mechanisms are present to send it out to the community concerned. In other words, information feedback mechanisms are not allowed by this type of centralized committees, especially in public health issues such as malaria. Without the input from communities suffering from malaria, it is not possible to develop effective interventions. Using the terminology of our approach, the critical source of influence for development of control strategies is excluded from analysis.

This case study suggests that trained manpower was needed at the ministerial level in anthropology, community medicine, economics, epidemiology, health planning, information sciences, medical entomology, public health engineering, and sociology. Program managers should be trained cross-sectorally -- through work in, for example, agriculture, health, education, water, and economics -- to prepare for cross-sectoral collaboration. Training should expose students to other perspectives, encourage exploratory ideas and provide experience working in a cross-sectoral team. Management training must be included in technical training curricula. Entomologists and malariologists need to be trained not only in research, but also in the design, management, and implementation of malaria prevention and control programs.

Presently, the successful implementation of technically sound programs may be compromised because of a lack of management training for technical staff.

6. Conclusion and Future Research

Adopting a systems approach, this study introduced a conceptual tool for studying organizational linkages in a malaria control system that counteracts a multi-factorial problem through several cross-sectoral solutions. These linkages, otherwise complex and difficult to identify, can through using the approach developed in this study be described. This description should enable improving the learning process across the web of organizations that make the control system and can give impetus to the process of change within organizations and in the MCS.

The framework proposed by this study would find a wide range of applications in at least three areas. First and foremost, it can be used to identify gaps in information as to how agricultural, health, and environmental factors interact; second, to assess alternative pathways to improved human health; and third, to form problem-oriented cross-sectoral teams for planning and implementing actions.

Future research should first focus on the identification of information gaps that have significant implications for human health. The key research questions should include:

- What factors are behind health benefits and/or health risks?
- What situations are more likely to create health benefits and/or health risks?
- What characteristics (i.e., gender, age, occupation, socio-economic status, etc.) does the most affected population have?
- What capacities are required to support the benefits and/or avoid the risks?
- How could the benefits and the risks be quantified or evaluated?
- What roles should agricultural, health, and environmental research play?

Future research should then study the features of alternative pathways in the MCS. The key research questions should include:

- Which pathways prevent or diminish the risks and/or promote the benefits?
- What institutional arrangements are required to promote and support the positive pathways and/or avoid the negative pathways?
- What are the results obtained with each of these pathways?
- What factors are critical in obtaining good results with this pathway?
- Which pathways should be promoted?

Finally, future research should focus on how to form cross-sectoral teams for planning and implementing actions implied by the best pathways. The key research questions should include:

- What organizations should be involved in the process of planning, implementation, and evaluation of the positive pathways?
- What institutional arrangements are required to promote and support this triple process?
- Which methodologies and instruments are recommended?

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Table 1. Areas for multi-disciplinary research and cross-sectoral collaboration

	Selected areas for multi-disciplinary research	Disciplines relating to	Organizations dealing with
H	Deteriorating human health conditions induces actions to reduce human-mosquito contact, to improve management of environmental determinants of malaria, to increase public awareness of adverse effects of malaria on livelihood assets, to increase investment in early malaria diagnostic & treatment clinics and in R&D for new drugs & genetic technology, to adopt agricultural production techniques and farming systems that reduce poverty;	Medical Science, Immunology, Health Education, Human Biology, Social Medicine, Nutrition Science, Medical Entomology, Epidemiology	Ministry of Health (Hospitals, Clinics, Research & Diagnostic Labs); Health Information Collection & Dissemination Centers; Health Surveillance Centers; National & International Research Institutes & Universities; Donors; Medical Supply Delivery Orgs; National & Int'l NGOs (like Red Cross);
A	Effects of changing parasite/vector ecology such as increased density, prevalence, distribution, abundance, feeding on malaria transmission, on demands from health sector, on resource allocation, on new demands for R&D, on people's health-seeking behavior; and effects of mosquito-plant relations on crop patterns, use of pesticide, and drug resistance;	Malariology, Parasitology, Immunology, Microbiology, Vector Biology, Vector Ecology, Entomology, Epidemiology	Research & Diagnostic Labs; Information Collection & Dissemination Centers; Surveillance Centers; National & International Research Institutes & Universities; Private Research Centers;
E	Effects of environmental changes such as water-land use, chemical spray, climate change on human health; loss of genetic diversity, global warming, deforestation & desalinization on vector abundance; degradation of environmental amenities on preservation regulations; declining soil fertility, raising urbanization, and poverty on social conflicts;	Ecology, Environmental Sciences, Meteriology, Natural Resources Science (oil, mining, geology, land, water, forest), Civil Engineering, Water & Sanitation Engineering, City Planning, Botany	Ministry of Environment; Community Planning, Environmental Interest Groups & NGOs; Environmental nformation Collection & Dissemination Units; Surveillance Center; Meteorology; National & International Research Institutes & Universities; Donors; Private Consultancy Firms;
P	Effects of changing public policy such as health budget share, research policy; health-safety regulations on the supply & quality of health services; private property rights (PPR) on private R&D, inventions of new drugs, conservation of environmental amenities; gender-equity considerations on poverty & economic growth; decentralized health system on the availability & access to health-services & the democratization process; pesticide regulations on agricultural production;	Political Science, Law, Public Administration, Management & Organizational Sciences,	Political Networks & NGOs; Local Administrations; Legislators; Government Bodies, Interest Groups; Political Survey Firms; Private Consultancy Firms; National & Int'l Research Inst's & Universities;
Ec	Effects of changing economic conditions such as macro investment & trade, energy production, household income, housing on availability and access to health services, employment related seasonal migration on malaria transmission, economic growth on the environmental degradation, job related migration to urban cities on national health policy, economic growth on gender equality in education and access to public services, adoption of agriculture-based economic development strategy on agricultural resource use, technology, farming systems;	Economics, Finance, Industrial Organization, Marketing, Tourism	Ministry of Economy; NGOs; Interest Groups; Marketing Orgs; National & Int'l Research Centers & Universities; Information Collection & Dissemination Centers; State Statistical Institute; Private Consultancy Firms; Donors; Ministry of Tourism; Regional & District Tourism Centers; Private Firms;
S	Effects of changing social factors such as community sleeping habits, customs, taboos, understanding of disease on demand for health services, indigenous knowledge on the prevalence of disease, increased rural population on land use, increased community participation in public health activities on the design of effective policies, schooling on economic efficiency, increasing rural population & family size on the direction of agricultural technology (labor vs capital intensive);	Human Ecology/Behavior, Education, Health Education, Communication Sciences (journalism, mass media), Psychology, Genetic Psychology, Anthropology, Sociology, Demography, Community Development, City Planning	Ministries of Social Affairs & Education; Schools, Community Training Centers; Communication Means (newspapers, radio, TV); Social Work Groups; Child & Elderly Care Orgs; Social Networks; Public Social Security Orgs; National & Int'l Research Insts & Universities; Information Collection & Dissemination Centers; State Statistical Institute; Private Consultancy Firms; Ministry of Culture;
Ag	Effects of changes in agricultural technologies, agricultural systems, & resource development on the malaria situation, the environment, public policy, macro- and micro economic situation, and social wellbeing; Examples include nutritional effects of changing crop farming, effects of irrigation techniques on vector breeding, high-yield variety invites policy changes to speed up adoption, shift from pastoral to sedentary life style increases investment in land, land colonization invites new settlements & investment in community development;	Agriculture & Food Science, Agronomy, Animal Science, Veterinary Entomology, Livestock & Crop Science	Ministry of Agriculture; Extension & Information Units; National & International Research Centers & Universities; Farmers' Orgs; Interest Groups; Technology Assessment Units; Food Quality Standards Unit; Seed & Soil Quality Units; National & Int'l Research Insts & Universities; Private Consultancy Firms;

Table 2. Areas for multi-disciplinary research to generate information (INFO)

H **Medical Sc, Immunology, Public Health, Human Biology, Social Medicine, Nutrition Sc, Medical Entomology, Epidemiology**	**INFO** on implications for parasites/vectors of changing health conditions of individuals or communities, i.e. advice on strategies to reduce human-mosquito contact; **H® A**	**INFO** on environmental implications of changing human health conditions, i.e. better management of env-tal determinants of malaria; **H® E**	INFO on public policy implications of changing human health conditions, i.e. exert pressure on political priorities by increased public awareness of malaria; **H® P**	INFO on economic implications of changing human health conditions, i.e. increased investment in early malaria diagnostic & treatment clinics; **H® Ec**	INFO on social implications of changing health status, i.e. effects on religious practices of availability of new drugs, newfound genetic know/tech on malaria; **H® S**	INFO on agricultural implications of changing human health, i.e. effects of malaria on the choice of production techniques, farming systems, & rural poverty; **H® Ag**
INFO on health implications of changing parasites /vectors, i.e. new demands from health sector due to changing malaria transmission; **H¬ A**	**A** **Malariology, Parasitology, Microbiology, Entomology, Epidemiology, Vector Biology, Immunology**	INFO on environmental implications of changing parasites/vectors, i.e. information on habitat choice of mosquitoes; **A® E**	INFO on public policy implications of new strains of vectors, i.e. changing political priorities & resource allocation to respond to malaria problem; **A® P**	INFO on economic implications of new strains of parasites/vectors, i.e. effects of new demands for R&D on sectoral resource allocation; **A® Ec**	INFO on social/cultural implications of new strains of vectors, i.e. changes in people's health-seeking behavior; **A® S**	INFO on agr implications of new strains of vectors, i.e effects of mosquito-plant relations on crop patterns, use of pesticide, drug resistance; **A® Ag**
INFO on health implications of changing environmental factors, i.e. health effects of water & land use, chemical spray, climate change; **H¬ E**	INFO on implications for vector ecology of env'tal changes, i.e. effects on vector abundance of genetic diversity, global warming, deforestation & desalinization; **A¬ E**	**E** **Ecology; Environmental Sc, Meteriology, Natural Res Sc, Civil Eng, City Plan, Botany**	INFO on public policy implications of env'tal changes, i.e. changes in environmental regulations & political agenda; **E® P**	INFO on economic implications of env'tal changes, i.e. re-allocation of resources to offset env'tal degradation; **E® Ec**	INFO on social implications of env'tal changes, i.e. links b/w declining land productivity, raising urbanization-poverty, social conflict; **E® S**	INFO on agricultural implications of env'tal changes, i.e. links b/w land salinization, poor soil fertility, low productivity; **E® Ag**
INFO on health effects of macroeconomic policies, i.e. on health budget share, research policy; health-safety regulations; **H¬ P**	INFO on implications for vector ecology of changing policies, i.e. effects of pr property rights PPR on pr R&D, availability of new drugs; **A¬ P**	INFO on environmental implications of changing policies & regulations, i.e. effects of PPR on the conservation of env'tal amenities; **E¬ P**	**P** **Political Sc, Law, Public Administration, Management & Organizational Sc**	INFO on macro-micro economic implications of changing public policy, i.e. effects of user charges on the demand for health services; **P® Ec**	INFO on social implications of changing public policy, i.e. effects of decentralization in the health sec on democratization; **P® S**	INFO on agr implications of changing public policy, i.e. effects of pesticide use regulations on agr production & on drug resistance of mosquitoes; **P® Ag**
INFO on health effects of macro investment & trade, energy production, household income, housing, etc **H¬ Ec**.	INFO on implications for vector control of changing economic conditions, i.e. effects on malaria of seasonal migration; **A¬ Ec**	INFO on environmental implications of changing economic conditions, i.e. effects of growth on the env degradation; **E¬ Ec**	INFO on public policy implications of changing economic conditions, i.e. effects on nat health policy of job related mig, **P¬ Ec**	**Ec** **Economics, Finance, Industrial Organization, Marketing, Tourism**	INFO on social implications of changing economic conditions, i.e. effects of growth on gender equality in edu **Ec® S**	INFO on agr implications of changing econ conditions, i.e. effects of agr-based econ dev on res use, tech, farm sys **Ec® Ag**
INFO on health effects of social conditions, i.e., effects of community sleeping habits, customs, taboos, understanding of malaria on demand for health services; **H¬ S**	INFO on implications for vector control of changing social conditions, i.e. effects of refugee situation, or indigenous knowledge on the prevalence of malaria; **A¬ S**	INFO on environmental implications of changing social conditions & institutions, i.e. effects of increasing rural population on land use; **E¬ S**	INFO on public policy implications of changing social conditions/institutions, i.e. effects of increased community participation in pub health activities on the design of effe policies; **P¬ S**	INFO on macro-micro economic implications of changing social conditions/institutions, i.e. schooling brings economic efficiency; **Ec¬ S**	**S** **Human Ecology, City Planning, Education, Demography, Psyc, Sociology, Anthropology, Community Dev, Communication Sc**	INFO on agricultural implications of changing social conditions/institutions, i.e. increasing rural population & family size induces labor intensive agr **S® Ag**
INFO on health effects of changing agr systems, resource dev, technologic changes, i.e. nutritional effects of changing crop farming, land use, pesticide use; **H¬ Ag**	INFO on implications for vector habitats of changing agr systems, resource dev, technologic changes, i.e. effects of irrigation techniques on mosquito abundance; **A¬ Ag**	INFO on environmental implications of changing agr systems, resource dev, technologic changes, i.e. effects of poor drainage on water quality; **E¬ Ag**	INFO on public policy implications of changing agr systems, resource dev, technologic changes, i.e. high-yield variety invites policy changes to speed up adoption **P¬ Ag**	INFO on economic implications of changing agr systems (i.e. urban agr), resource dev, tech change, i.e. shift from pastoral to sedentary life style increases investment in land; **Ec¬ Ag**	INFO on social implications of changing agr sys, res dev, tech changes, i.e. land colonization invites new settlements & investment in community dev; **S¬ Ag**	**Ag** **Agr/Food Sc; Agronomy; Animal Sc; Veterinary Entomology; Livestock & Crop Science;**

Table 3. Areas, capacities, and linkages for cross-sectoral collaboration

H MoH, Res&Diag Labs, R&D Inst, Univ, Info Coll/Diss Cen, Hospital, Clinics, Surveillance Cen, Donors; Medical Supply Orgs, NGO			INFO on components of national health policy to be reformed to respond to malaria attributable to water res development **H® P**		INFO on availability of and access to new drugs & newfound genetic knowledge & techno-logies specific to malaria in the community concerned **H® S**	INFO on the effects of malaria transmission on the choice of production technique **H® Ag**
INFO on expected malaria transmission patterns attributable to new strains of vector, drug resistance **H ¬ A**	**A** Res/Diag Labs, Info Coll/Diss Cen, Surveil-lance Cen, R&D Inst, Univ, Pr Res Cen					
		E MoE, Community Plan, Env Interest Grp, NGO, Info Coll/Diss Cen, Univ, Donors, Surveillance Cen, Meteorology, R&D Inst, Pr Consultant Firms				
			P Political Nets, NGO, Loc Adm, Gov't units, Interest Grp, Survey Firms, Univ, Pr Consultant Firm, R&D Inst			
				Ec MoEc, MoTourism, NGO, Inter est Grp, Marketing Orgs, R&D Inst, Univ, Donors, Info Coll/ Diss Cen, State Statistic Inst, Pr Constant Firms, Reg/Dist Tour ism Cen, Pr Firms		
			INFO on the community demand for the design of policies for better public health services for malaria control **P ¬ S**		**S** MoSocial Affairs, MoEdu, Schools, Community Training Cen, Communica-tion Means, Social Work Grp, Health Care Cen, Social Nets; Pub Social Sec, R&D Inst, Univ, Info Coll/Disse, State Stat Inst, Pr Consultant Firm, MoCul	
	INFO on possible changes in vector habitats because of investment in water resources **A ¬ Ag**					**Ag** MoA, Ext/Info Cen, R&D Inst, Univ, Farms' Org, Interest Grp, Technology Assessment Cen; Food/Seed Q&S, Pr Consultant Firms

Table 4. A description of AAAS's (1991) problem definition and solution strategies by using the systems approach

	Areas for multi-disciplinary research	Disciplines relating to	Organizations dealing with
H	Design programs addressing the beneficiaries' needs **(S)**; Increased attention to urban and peri-urban populations, groups with high mobility, pregnant women, & children under five **(S)**; Health education strategies should consider cultural factors;	Biology, Epidemiology, Health Education, Medical Entomology	Ministry of Health, Christian Medical Commission (NGO), Medical Research Center, National Health Research Center, Hygiene & Public Health Organizations
A	Increasing human toll induces increased demand for health services **(P1);** Patterns of malaria transmission; Multi-drug resistant parasite strains; prevalence & incidence **(P1 & P2);**	Biology, Microbiology, Immunology, Parasitology	
E	Environmental factors (P1); Environmentally sound planning & implementation of water projects **(S)**; Household & community environments create breeding places **(P2)**; Urban populations face most acute environmental problems **(S)**; Environmentally sound planning & implementation of water projects **(S)**;	Ecology, Botany, Environment, Water & Sanitation Engineering	Ministry of Environment, Ministry of Water Development, Engineering Companies
P **Ec**	Increasing decentralization of governmental decision making offers an opportunity for cross-sectoral initiatives to control malaria **(S)**; Invest in human capital **(S)**: research, training, networks of scientist; Population changes related to employment & resettlements affect malaria transmission **(S)**; Financial incentives/disincentives influence transmission of malaria **(S)**; Economic development has an inverted-U effect on malaria prevalence **(P2)**; Industrial & infrastructural projects sites create breeding places **(P2)**; Urbanization decreases the salt marshes and rain forests that have been ecologically unfriendly to some vectors;	Economics	Ministry of Economy
S	Increased community participation **(S)**: in measures like clearing breeding sites, purchasing drugs, nets, sprays; Cultural factors **(P1)**: understanding of disease etiology; acceptance & use of prevention & control measures; sleeping, working, and recreational hours & locations; religious practices; proximity of homes to breeding areas; Migration;	Anthropology; Community Development, Demography, Urban Planning	Community Development & Community-based Health Care Organizations
Ag	Agricultural development & water resource management create breeding places **(P2)**;	Agricultural Sciences	Ministry of Agriculture, Agriculture & Food Institute

P1 – problem statement 1, P2 – problem statement 2, S – strategy to counteract the problems

Table 5. A structure for information given in Table 4

H **Biology, Epidemiology, Health Education, Medical Entomology**					Design programs addressing the beneficiaries' needs **(S)**; Increased attention to urban and peri-urban populations, groups with high mobility, pregnant women, & children under five **(S)**; Health education strategies should consider cultural factors;	
Increasing human toll induces increased demand for health services **(P1);**	**A** **Biology, Microbiology, Immunology, Parasitology** [Patterns of malaria transmission; Multi-drug resistant parasite strains; prevalence & incidence (P1 & P2)];					
	Environmental factors (P1); Environmentally sound planning & implementation of water projects **(S)**; Household & community environments create breeding places **(P2)**;	**E** **Ecology, Botany, Environment, Water & Sanitation Engineering**			Urban populations face most acute environmental problems **(S)**;	Environmentally sound planning & implementation of water projects **(S)**;
			P Increasing decentralization of govt'l decision making offers an opportunity for cross-sectoral initiatives to control malaria (S);			
Invest in human capital **(S)**: research, training, networks of scientist;	Population changes related to employment & resettlements affect malaria transmission **(S)**; Financial incentives/disincentives influence transmission of malaria **(S)**; Economic dev has an inverted-U effect on malaria prevalence **(P2)**; Industrial & infrastructural projects sites create breeding places **(P2)**; Urbanization lowers the salt marshes & rain forests that are ecologically unfriendly to some vectors;			**Ec** **Economics**		
Increased community participation **(S):** in measures like clearing breeding sites, purchasing drugs, nets, sprays;	Cultural factors **(P1)**: understanding of disease etiology; acceptance & use of prevention & control measures; sleeping, working, and recreational hours & locations; religious practices; proximity of homes to breeding areas; Migration;				**S** **Anthropology; Community Development, Demography, Urban Planning**	
	Agricultural development & water resource management create breeding places **(P2)**;					**Ag** **Agricultural Sciences**

Table 6. Areas for multi-disciplinary research teams to address

H Biology, Epidemiology, Health Education, Medical Entomology						
	A Biology, Microbiology, Immunology, Parasitology					
		E Ecology, Botany, Environment, Water & Sanitation Engineering,				
			P	**Ec** Economics		
					S Anthropology; Community Development, Demography, Urban Planning	
						Ag Agricultural Sciences

Table 7. Areas for cross-sectoral collaborative efforts to address

H Min of Health, Christian Med Commis (NGO), Med Res Cen, Nat Health Res Cen, Hyg/Pub Health Org						
	A					
		E Min of Env., Min of Water Dev, Engineering Companies				
			P			
				Ec Ministry of Economy		
					S Community Development & Community-based Health Care Org	
						Ag Min of Agriculture, Agriculture & Food Institute