

Longitudinal Community Studies in Africa: Challenges and Contributions to Health Research

The history of longitudinal community studies in Africa attests to their value for demographic and health research, policy and practice, and their resilience in the face of multiple challenges. Their potential to contribute significantly to monitoring progress towards attaining the Millennium Development Goals should be harnessed.

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Reliable and timely information is a central pillar of well-functioning health systems. In fact, much of the progress in improving human health is “due to technical progress, including advances in knowledge about diseases and about appropriate, cost-effective responses” (Jamison and others, 2006; p. 155). Developing health technology requires sound research and the precise information that is needed for gauging the efficacy of interventions. Moreover, comprehensive sociodemographic and health information is needed to guide policy deliberations. The need for such information is particularly acute in

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developing countries because policy that lacks empirical grounding can be more damaging to public welfare in such settings than is the case in relatively prosperous countries where the public enjoys multiple service options and individuals have resources for financing personal choices.

In most developed countries, the vital registration and health data that are needed to guide health policy and action are comprehensive, available and complete. However, in sub-Saharan Africa, the coverage of the vital registration and health systems is inadequate. Household surveys are the most important source of information on population health, but retrospective data fail to provide essential information on the timing of events. The causes and consequences of problems remain poorly understood; thus, policies must be formulated in an information vacuum.

Longitudinal data-collection efforts attempt to reproduce the wealth of information that is afforded by the continuous recording of events and their causes. Prospective analyses of longitudinal data permit scientists to examine the incidence of events, change over time and the causes of change, all of which are fundamental requirements of scientific inference that are very difficult with cross-sectional studies.

The critical need for longitudinal investigation justifies the cost and complexity of tracking individuals over time. Longitudinal health research falls into three general categories, all of which involve “following” a precisely defined population over an extended period of time: (a) cohort studies which follow a subgroup of individuals selected on the basis of a time-specific characteristic such as year of birth; (b) panel studies which follow a representative sample of households whose members are tracked and reinterviewed over time; and (c) longitudinal community studies which cover every household and individual living in a well-defined location.

Unlike panel and cohort studies, which are interested in subgroups of the population, longitudinal community studies focus on the community as a whole, even if the data are collected on an individual basis. Longitudinal community studies have at their core a demographic surveillance system (DSS), which records continuously and meticulously all births, deaths and migrations, the only sources of change in the community’s initial population.¹

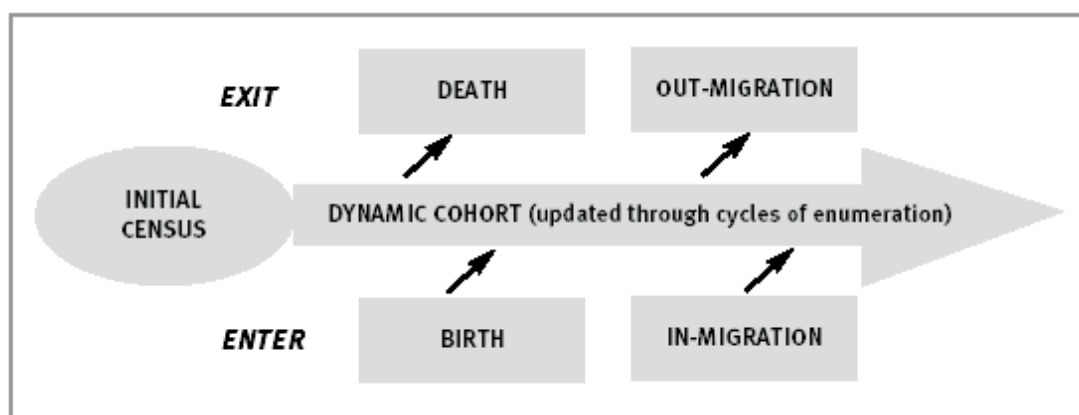
The purpose of this article is to discuss the contributions of longitudinal community studies to health research in Africa as well the challenges faced by the scientists and decision makers who rely on them to guide health policy and practice. The authors begin with an overview of the DSS concept and turn to a

discussion of the history of its use in sub-Saharan Africa, the contribution of this legacy to the science of demographic surveillance and the technical challenges that are motivating DSS methodological initiatives in Africa. Particular attention is devoted to the emergence and function of the INDEPTH Network, an international network of DSS sites involved in demographic and health research; the network is based in Accra.

State of the art of the demographic surveillance system

DSS starts with a baseline census that identifies each and every household and individual residing in a well-demarcated area. A system is then put in place to record continuously all births, deaths and migrations (of individuals and households) that occur in this area and their exact timing. The product that emerges is an “open cohort”, a longitudinal register of individuals at risk of events as demographic dynamics unfold over time (see figure 1). The typical DSS is augmented with the registration of marriages, divorces and changes in status and household relationships, additional information that is critical to achieving an understanding of the demographic dynamics that are being observed.

Figure 1. The “Open Cohort” concept



Depending on the objectives of a study, this core system is enriched by additional information collected from the same population. The most advanced studies add verbal autopsies of all deaths in order to identify underlying causes of death and to track the burden of disease.

Advanced DSS systems define the open cohort information in figure 1 at the individual level. This capability depends upon assigning a unique identification number to every individual and household that enables tracking of all elements of change so that data from all studies in the DSS area can be logically related to the individuals under observation. The fact that each study can build on the foundation

provided by previous studies permits the accumulation of scientific capabilities and serendipitous research. Well-designed cross-sectional surveys, for example, link to the figure 1 open cohort data, permitting studies that draw upon survey information as covariates of the prospective events that transpire in the time following cross-sectional data collection. Some of the more remarkable contributions of longitudinal community studies were completely unanticipated by the designers of cross-sectional studies that have been fielded in DSS sites.

In order to realize the full potential of DSS, exposure to risk must be well defined for each individual. This requires information on the timing of migration and procedures for linking out-migration records to individuals at risk and procedures for initiating the observation of in-migrants at the time of their arrival in a DSS household. This requirement complicates data management significantly but it also enables research that fulfils the requirements of demanding impact studies involving hazard models and individual-level inference. Since health research aimed at determining the effectiveness of a given drug or intervention tolerates little ambiguity in exposure to the risk of getting the target disease, there is no shortcut to recording unambiguously all entries (birth, in-migration) and exits (death, out-migration) and their timing in order to ensure the reliability of estimates of exposure, incidence and lethality. Naïve attempts to simplify data collection by dropping any of the demographic events in figure 1 lead to incomplete information on the population at risk and impaired capability to conduct individual-level analysis. By addressing this need, well-designed DSS-based population and health studies permit causal inference and formal appraisal of hypotheses on the impact of interventions. Initiating and sustaining a good DSS is challenging, however, requiring interdisciplinary cooperation of medical, computer and population scientists.

Demographic surveillance system in Africa

The history of DSS in sub-Saharan Africa attests to both the inherent importance and challenges associated with the longitudinal approach to data collection. Although the underlying concepts of surveillance were first demonstrated in China and Europe, Africa has recently been at the forefront of innovation in scientific demographic surveillance.

The idea and practice of collecting registration of vital events in defined populations was well developed during China's Ching dynasty in the sixteenth century, and systematic longitudinal registration dates back 2,000 years to China's Han dynasty, although these early efforts were limited to the coverage of adults. For the most part, archival historic records were compiled for administrative or religious functions, such as the European parish registers of the seventeenth to

nineteenth centuries (Phillips, 2003). Modern longitudinal community studies for research investigations emerged from a synthesis of public health, epidemiology and demography in the early twentieth century. The first such study on record is the pellagra study (1916-1921) designed to identify the etiology of this nutritional disorder in a number of poor and deprived villages in South Carolina, United States of America (Das Gupta and others, 1997). In referring to such studies, Omran (1974) concluded that the application of epidemiological methods and techniques to the field of population dynamics and family planning created a new field of science that he referred to as “population epidemiology”.

Methods of surveillance that combine data management, linkage and scientific inference were first developed in Africa as products of studies focusing on the epidemiology of tropical diseases. The first such study was launched by the Pholela Health Centre in 1940 to study the diseases that were prevalent in rural Natal (South Africa) and workable methods for their prevention and treatment (Ngom and others, 2001). The Pholela study is credited with having collected longitudinal DSS-type data for a population of 10,000 over a period of 15 years. Although it was closed in 1955, its methods and productivity as a research station inspired much of the innovation in community longitudinal research that followed (Ngom and others, 2001).

In 1950 another Gambian epidemiological study investigating the effects of disease in a tropical environment was launched by Sir Ian McGregor of the British Medical Research Council in the Gambia (McGregor and Smith, 1952). The Keneba study, as it is known, set up a system whereby all births and deaths occurring in three villages (Keneba, Kanton Kunda and Manduar) were continuously recorded by literate village residents. This project added the innovation of monitoring non-vital events and critically important characteristics of the study population, such as detailed information on marriage, migration and other residential changes, and anthropometric and health status for all residents.

The Keneba study established procedures for the unique identification of each individual, enabling all the data linkages that are needed to exploit fully half a century of data on this Gambian population (Sear and others, 2000, and 2001; Rayco-Solon and others, 2004; Allal and others, 2004). In contrast with the Pholela study, the Keneba study is still ongoing and is the longest lasting DSS in Africa. It is however not as well known as more recently launched initiatives. The long delay in the dissemination of demographic findings from Keneba is probably due, in part, to the small size of the study population (about 1,000 people initially) and the consequent need for decades of accumulation of person years of observation before meaningful demographic analyses could be conducted. By 1975, a quarter of a century after the launch of the Keneba study, fewer than 2,000

person/years were accumulated on children under five years of age (estimates based on data produced by Rayco-Solon and others, 2004).

In 1962, Pierre Cantrelle, a French epidemiologist, launched a study to test the feasibility of reliably recording births, deaths, migration and marriages in the Niakhar and Paos-Koto districts of the Sine Saloum region in Senegal. This was the first African study where demographic objectives seemed clearly dominant. It was part of the newly born Senegalese State's effort to develop its vital registration system. During the first phase of the study (1962-1966), a total population of more than 50,000 was monitored in different areas. After a few years of trial, the decision was made to focus the research on the Niakhar district alone, hence the name of the study (Garenne and Cantrelle, 1991). According to Cantrelle, "only two published studies [of similar type, e.g. a DSS] were available when he started: the Yangtze River Valley study in China and the Guanabara study in Brazil. The Khanna study had just finished and had not yet been published while the Keneba study and the Pakistan Growth Experiment were underway" (Garenne and Cantrelle, 1991; p. 19).

These pioneers of the DSS approach in sub-Saharan Africa contributed to the science of demographic surveillance more generally. The success of the Niakhar study was translated into commitment to develop future initiatives. In the 24 years following the launch of the Niakhar study, five DSS studies were initiated, all of which were based in the Senegambia region of West Africa (Senegal, Gambia and Guinea-Bissau), except the short-lived Machakos study in Kenya (1974-1981). The launch of the Butajira study in Ethiopia in 1987 was the precursor to a rapid expansion of geographical coverage into Eastern and Southern Africa.

Table 1 provides a list of the ongoing programmes. It shows that about half the sites are concentrated in West Africa. The other half are distributed between Eastern and Southern Africa while Central Africa is virtually empty. Despite their high costs in human, material and financial resources, African DSS sites have been highly sustainable. Of the 31 sites that were launched since 1940, only 4 have ceased to exist. Currently, 27 sites are still functional.²

Table 1. Ongoing demographic surveillance sites in Africa

Site name	Country	Start date	Age in years	Population*	Lead institutions
West Africa				907 800	
Sapone	Burkina Faso	2005	2	100 000	MOH, CNRFP
Dodowa	Ghana	2005	2	98 200	MOH, Ghana Health Services
Kintampo	Ghana	2003	4	140 000	MOH, Kintampo Health Research Centre
.../					

Table 1. (Continued)

Site name	Country	Start date	Age in years	Population*	Lead institutions
Ouagadougou	Burkina Faso	2001	6	5 500	University of Ouagadougou, UERD/ISSP
Navrongo	Ghana	1993	14	141 000	MOH, Navrongo Health Research Centre
Oubritenga	Burkina Faso	1993	14	175 000	MOH, CNRFP
Nouna	Burkina Faso	1992	15	55 000	Centre de Recherche en Sante de Nouna, U. of Heidelberg
Mlomp	Senegal	1985	22	7 600	Centre National de Recherche Scientifique, Musée de l'Homme, Ined
Farafenni	Gambia	1981	26	43 000	MRC-Gambia
Bandim	Guinea Bissau	1978	29	101 000	MOH, Danish Epidemiology Science Center
Bandafassi	Senegal	1970	37	10 500	Centre National de Recherche Scientifique, Musée de l'Homme, Ined
Niakhar	Senegal	1962	45	30 000	Institut pour la Recherche et le Developpement (IRD)
Keneba	Gambia	1950	57	1 000	MRC-Gambia
East Africa				743 000	
Iganga-Mayuge	Uganda	2005	2	62 000	Makerere University
Kilifi	Kenya	2003	4	225 000	KEMRI and Oxford University
Kisumu	Kenya	2001	6	135 000	CDC and KEMRI
Nairobi NUDSS	Kenya	2000	7	60 000	APHRC
Rufiji-Ifakara	Tanzania	1998	9	85 000	Ifakara Centre for Health Research and Development, former TEHIP
UI/Kil-Ifakara	Tanzania	1996	11	65 000	Ifakara Centre for Health Research and Development
Magu	Tanzania	1994	13	28 000	TANESA program, Mwanza
Rakai	Uganda	1989	18	42 000	Makerere, Johns Hopkins and Columbia universities
Butajira	Ethiopia	1987	20	41 000	University of Addis Ababa and University of Noumea
Southern Africa				227 000	
Karonga	Malawi	2002	5	30 000	London School of Hygiene & Tropical Medicine, Karonga Prevention Study
Hlabisa	South Africa	1999	8	85 000	ACDIS, University of Kwazulu Natal
Manhica	Mozambique	1996	11	37 000	MOH, Centre de Investigacao em Saude da Manhica
Dikgale	South Africa	1995	12	8 000	University of the North Dikgale Project
Agincourt	South Africa	1992	15	67 000	University of the Witswatersrand
Total Africa				1 877 800	

* Last population size known. Initial population size for Keneba is estimated at 1,000.

Table 2 shows a remarkable explosion of DSS sites in the early 1990s. The average number of new sites established every year increased consistently with time, from 0.1 in the 30 years following the launch of the Keneba study to 1.5 sites for the period starting in 2000. In addition, there was a marked increase in the size³ of the populations being covered by these surveys. Table 2 shows a doubling of the average size of a DSS from 1990 onward. The size of the DSS populations has varied from 1,000 in Keneba (initial size in 1950) to 225,000 in Kilifi, Kenya.

Table 2. Evolution of demographic surveillance system site characteristics over time

Period	Number of new sites	New sites per year	Added population	Average population per site
2000-2006	9	1.5	855 700	95 078
1990-1999	10	1.0	746 000	74 600
1980-1989	4	0.4	133 600	33 400
1950-1979	4	0.1	142 500	35 625

This acceleration in DSS would not have happened without an increased demand for longitudinal community health research, but it was definitely rendered possible by technological breakthroughs that reduced the complexity of data management and the creation of the INDEPTH Network in the 1990s.

The complexity of data management and analysis has long represented a major challenge to the sustenance of DSS-based research. The initiation of field stations requires heavy investments in time, money and expertise for the development of software and a foolproof data management system. The development of the household registration system (HRS) and its subsequent dissemination across the world simplified the process dramatically. The relevant software was developed in collaboration with the Population Council with financial support from the Thrasher Research Fund and the Rockefeller Foundation. It was developed with the explicit intention of strengthening the capacity of developing countries to conduct demographic surveillance (Phillips and MacLeod, 1995).

HRS, which was inspired and shaped by the Matlab DSS, incorporates rigorous design principles, performs consistency checks and computes and reports key demographic indicators. It is easily adaptable to any longitudinal household study with minimal additional programming, and modifications do not require extensive knowledge of database management.

Generating such a complex system required a team of skilled computer scientists and demographers, in addition to field capacity (provided by the Navrongo Health Research Centre) in order to respond to queries and to advise on needed changes. The development of HRS constitutes a landmark in the history of longitudinal community studies, which broke the long-lasting problem of surveillance systems: the difficulties in data management and analysis. The mechanization of the complex logic of surveillance systems contributed significantly to reducing dependence on computer specialists, thereby reducing the cost of starting and sustaining DSS.

Since its adoption of HRS in 1993, the Navrongo Health Research Centre team played a key role in the dissemination and improvement of the software concerned. Many international workshops were organized to train interested parties in the use and adaptation of the software. Many visitors from other field sites spent some time in Navrongo to develop the hands-on expertise needed to implement an HRS-based solution for their sites. The software was freely downloadable from the Internet; technical advice was also readily available for its adaptation to local conditions.

This international role of the Navrongo Health Research Centre motivated the Rockefeller Foundation's decision to provide seed funding to the Centre to lead efforts to develop a network of longitudinal community studies. The birth of the INDEPTH Network in 1998 was a landmark event in the development of these studies in Africa. Not only did it provide a larger forum for the continued dissemination of HRS, but it also contributed to developing the software's capabilities further through confrontation with competing technology utilized at other sites and the creation of an INDEPTH reference data model⁴ covering aspects that are common to all sites (Benzler, Herbst and MacLeod, 1998; Phillips and others, 2000; INDEPTH Network, 2002). The INDEPTH Network's technical working group took the technology of software design for DSS to new heights by broadening thinking beyond the dominating HRS (see for example Benzler and Clark, 2005; and Clark, 2006). Of the existing 27 sites, 9 of them were launched in the 8 years following the creation of the network!

A half century of contributions to science

Longitudinal community studies have made groundbreaking contributions to public health knowledge over the years. An ongoing effort to analyse these contribution has already identified more than 1,100 peer-reviewed publications resulting from these studies (Brosius and others, 2007). While awaiting an in-depth analysis of this mass of information in the next stages of the study, it is

worth pointing to a few contributions that would have been impossible without the rigour of the DSS approach.

One early contribution is the documentation of highly specific levels and patterns of mortality in childhood. The studies in the previously mentioned Senegambia region revealed extremely high levels of mortality, comparable to levels observed in seventeenth century Europe. A child mortality rate of about 500 per 1,000 live births (which meant that half of the newborn children did not reach their fifth birthday!) was observed in the early years of the Niakhar study. Furthermore, the age pattern of child mortality was very unusual. Mortality between exact ages 1 and 5 years was significantly higher than infant mortality, contrary to what is usually observed among populations outside of West Africa (Cantrelle, 1972). Exactly the same pattern was discovered by the Keneba study in neighbouring Gambia (McGregor, 1968, quoted by Cantrelle, 1972). Except in a few atypical years, the mortality rate between ages 1 and 5 years was consistently 50 per cent above the infant mortality rate in Niakhar from 1963 to 1990 (Delauney, 1999).

The DSS contribution to the characterization of mortality levels and patterns culminated with the development of authentic model life tables for sub-Saharan Africa (INDEPTH Network, 2004). These life tables, which condense the data collected in 19 DSS sites over 5 years, capture the diversity of the continent and reflect well the differential impact of the AIDS epidemic.

Studies of the relationships between the different components of population dynamics are impossible without detailed longitudinal data. The landmark article by Cantrelle and Leridon (1971), describing the relationships between fertility, mortality and breastfeeding, is one of the major contributions of DSS in its early phases of development in Africa.

Most of the initiatives launched since the 1990s were set up to study the impact of health interventions. This is an area where longitudinal community studies do not have much competition. The bibliometric analysis referred to previously (Brosius and others, 2007) found that 30 per cent of DSS-related publications are on health interventions. These studies provide insights into which population and health interventions work, why they work and how they work. Examples include the following: community health in Ghana (Phillips, Bawah and Biaka, 2006), integrated management of childhood illnesses in the United Republic of Tanzania (Schellenberg and others, 2004) and decentralized health financing in the United Republic of Tanzania (de Savigny and others, 2004).

Longitudinal studies also contributed to the scientific validation, through field trials of most health technologies in use today, including drugs, vaccines,

vitamins and insecticide-treated bednets (Aaby and others, 1986; Ross and others, 1995; Binka and others, 1996; Lengler and others, 1998).

Taken together, the ongoing longitudinal studies cover relatively well the diversity of situations in sub-Saharan Africa. A study of the environmental footprint of INDEPTH member sites in Africa concludes that these sites “provide a comprehensive coverage of much of the wide range of climates and environments” found across sub-Saharan Africa” and that “findings and relationships derived at DSS sites can be applied elsewhere within the same environmental class with some confidence.” (Tatem and others, 2006). The initiation of additional sites in Nigeria and in central Africa would definitely provide better coverage.

Challenges and Africa’s contribution to addressing them

Data management and processing

Without any doubt, the major challenge facing longitudinal community studies lies in the complexity of managing the large databases that such studies generate and stimulating the “production of science” by simplifying access to the data that are stored. Fortunately, as has been discussed in the preceding section, technological advances and their broad dissemination through cross-site collaboration are progressively lifting this major constraint.

The development of the INDEPTH reference data model is promoting common data management systems that will facilitate the construction of generic tools for data extraction and analysis, enabling scientists to work with complex databases just as they now work with commercial statistical packages.

Data analysis, utilization and sharing

African longitudinal community studies face one major and persistent criticism: the levels of data analysis and utilization to guide policy and practice are low. Data analysis is often limited to the minimum required to satisfy commitments to funding partners. Underanalysis is hampering the scientific community’s ability to harness fully DSS data in order to provide the evidence base needed to improve public health. This unfortunate situation is due to many factors ranging from capacity shortages to ethical challenges arising from the need to protect the privacy of contributing populations.

The members of the INDEPTH Network understand technology’s key role in addressing these challenges and is investing significant efforts in developing a platform that will further break down barriers between users of data and the mountain of DSS-generated information, stimulate cross-site comparative research

and facilitate access to the larger scientific community. These efforts on the technological front need to be backed by strategies to improve site leaders' willingness to share data.

Reducing cost without sacrificing quality

DSS will remain unattractive as long as data collection is seen as an expensive competitor to service delivery for scarce resources. Innovative ways of reducing the cost of data collection without jeopardizing data quality are urgently needed. Here, too, technology plays a key role. For example, handheld computers have become so powerful that they make it possible for the designers of computer systems to place some data management operations, such as automatic edits and consistency checks, in the hands of interviewers. By eliminating the cost and complexity of paper-based information transfer, DSS per capita operating costs can be reduced substantially.

While the use of handheld computers in DSS data collection is just beginning, one can foresee a future where very simple remote updating procedures would use mobile telephones as data entry devices or very wide area network cards as transmitters of information. These and other hardware innovations may transform DSS field operations by enabling key informants to signal DSS managers where interviewing should take place, thereby reducing significantly the number of unnecessary household visits. The experience of the Karonga DSS in Malawi suggests that innovative but less sophisticated use of the traditional key informant can go a long way in reducing costs without critically jeopardizing data quality (Jahn and others, 2007).

Research capacity

Another major challenge lies in the stringent human capacity requirement of DSS that is commensurate with the complex management and scientific tasks that are involved. Most African sites are unable to address effectively their capacity requirements. Because they are located typically in rural and remote areas, site leaders confront major difficulties in attracting and retaining local scientists. It is however clear that, because they entail long-term involvement with communities, longitudinal community studies have great potential for building both individual and institutional capacity for scientific inquiry and action. The experiences of Matlab in Bangladesh and Navrongo in Ghana provide vivid expressions of this potential and attest to the fact that, for greater effectiveness, capacity-building must be an explicit goal of the initiative.

Some principles of surveillance systems define contexts for capacity-building that other research strategies lack. The complexity of operations requires

career ladders, with entry-level interviewers, supervisors, managers and scientists at various levels of expertise. If the recruitment of talented young entry-level staff is combined with sustained career advancement strategies, longitudinal data systems can become engines for the development of scientific talent. This is particularly evident when sites are aligned with local and international university training programmes, and when degree-level training is augmented with site-based workshops and technical exchange. The fact that sites are engaged in critical policy and scientific issues can provide local scientists and support staff with opportunities for the dissemination of scientific information that other individuals lack. Exposure to international learning, combined with the challenges of operating sites, develops capacity, builds leadership and sustains African science in ways that other institutional arrangements cannot match.

Ethical challenges

Given the dire health situation in most of Africa, longitudinal community studies cannot afford the luxury of remaining purely scientific endeavours with no visible benefits for local communities, regional health administrations or national health programmes. In the absence of strategic planning about community engagement, research utilization and policy impact, there can be serious ethical tensions between science and service.

Furthermore, the need for unambiguous identification of each individual and household combined with the ubiquity of modern technology, makes it an obligation to develop ethical safeguards that ensure that the privacy and rights of respondents are fully protected.

Biomarkers may eventually replace identification numbers as the basis for data linkage, making DSS data models compatible with health information systems and providing direct links between service delivery information and DSS population registers. As these technologies are refined and applied, the potential scope for expanding the policy, administrative and research relevance of DSS data models will be enormous. Combining these benefits with ethical safeguards will represent a critical challenge for DSS planning in Africa.

Conclusions

It is fair to say that longitudinal community studies have improved our understanding of the ecology of health and disease, including the physical and social environment shaping human health in Africa. However, despite its palpable contributions to scientific knowledge, the DSS paradigm is often criticized for its complexity, cost and isolation from the policy processes. In Africa where these

studies are most needed, the shortage of technical human and financial resources has required sites to collaborate, share technology and pursue common strategies. As a consequence, African sites have been at the forefront of developing new technology for cross-site research, methods for reducing costs and general procedures for starting new DSS operations.

While this article is focused on health research, the usefulness of DSS as a research tool extends far beyond population and health. The DSS approach is valuable in all socio-economic studies requiring a measurement of change and its sources, including behavioural change, ageing and life cycle changes. Longitudinal community studies in Africa and elsewhere have the potential to contribute significantly to monitoring progress towards attainment of the Millennium Development Goals and particularly to measuring the impact of poverty reduction programmes, which are at the heart of development efforts. We hope that the INDEPTH Network will help to ripen this potential by sustaining and enhancing its efforts aimed at strengthening DSS sites throughout the world.

Endnotes

1. Three publications provide a comprehensive picture of this kind of study across the world: Das Gupta, 1997; INDEPTH Network, 2002; NRC, 2002.
2. The AMMP project in the United Republic of Tanzania was active in three areas but is counted here as one site. Its focus on adult mortality worked against the reliable recording of births.
3. Population size is important because the smaller is the size of a study population, the longer that study needs to continue in order to accumulate the number of person-years required for a reliable measurement of rare events.
4. "Data models" refer to predicted logical relationships that must be sustained despite any possible event that might be registered in a DSS database over time. For example, a pregnancy must have a woman associated with that event, she must be present as a member of the household where the event is registered and her age must fall within the reproductive years extending from menarche to menopause. Over time, women become ineligible for these events. Also, pregnancies must eventually end and other logic must prevail. All such logical specifications have a structure, order and predictability that permit software to identify errors and precisely define who is present, the days of risk associated with that presence and the events of interest that arise. Episodes of various kinds that members of a population experience are predictable with a data model, and changes in episode status are logically predictable as events unfold. The challenge in designing a DSS computer system is defining all such events, episodes and relationships. Tools that are now available to software developers permit the mechanization of computer logic once the underlying model is defined.

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