

HEALTH & DEMOGRAPHIC SURVEILLANCE SYSTEM PROFILE

Profile of the Navrongo Health and Demographic Surveillance System

Abraham Rexford Oduro,^{1*} George Wak,¹ Daniel Azongo,¹ Cornelius Debpuur,¹ Peter Wontuo,¹ Felix Kondayire,¹ Paul Welaga,¹ Ayaga Bawah,² Alex Nazzar,³ John Williams,¹ Abraham Hodgson³ and Fred Binka⁴

¹Navrongo Health Research Centre, Navrongo, Ghana, ²Mailman School of Public Health, Columbia University, New York, ³Ghana Health Service, Private Mail Bag, Ministries, Accra, Ghana and ⁴University of Health and Allied Sciences, Private Mail Bag, Ho, Ghana

*Corresponding author. Navrongo Health Research Centre, Post Office Box 114 Navrongo, Ghana.
E-mail: aoduro@navrongo.mimcom.org; aroduro@yahoo.com

Accepted 12 June 2012

Located in the Kassena-Nankana districts of northern Ghana, the Navrongo health and demographic surveillance system (NHDSS) was established in 1992 by the Navrongo health research centre (NHRC). The NHRC is one of three research centres of the Ghana health service. The activities and potential of the NHDSS for collaborative research are described. The NHDSS monitors health and demographic dynamics of the two Kassena-Nankana districts of northern Ghana and facilitates evaluation of the morbidity and mortality impact of health and social interventions. The total population currently under surveillance is 152 000 residing in 32 000 households. Events monitored routinely include pregnancies, births, morbidity, deaths, migration, marriages and vaccination coverage. Data updates are done every 4 months by trained fieldworkers. The NHRC also undertakes biomedical and socio-economic studies. Additional features of the NHDSS include the community key informant system where trained volunteers routinely report key events, such as births and deaths as they occur in their locality and the verbal autopsy (VA) system for determining the probable causes of deaths that occur at the community level. Data from the NHDSS are shared with funders and collaborators and partners in the INDEPTH Network. The Director of the NHDSS is the contact person for potential collaboration with the NHDSS and the use of its data.

Keywords Health surveillance, health research, research collaboration, field site

Why was the health and demographic surveillance system set up?

The Navrongo health and demographic surveillance system (NHDSS) has been designed to provide an efficient platform for evaluating health and social

interventions. The Navrongo health research centre (NHRC) operates the NHDSS that covers the Kassena-Nankana districts (KNDs) of the upper east region of northern Ghana (Figure 1). The NHRC started in 1988 when the Ministry of Health of Ghana, the University of Science and Technology, Kumasi and the London School of Hygiene and Tropical Medicine selected the KND as a site to

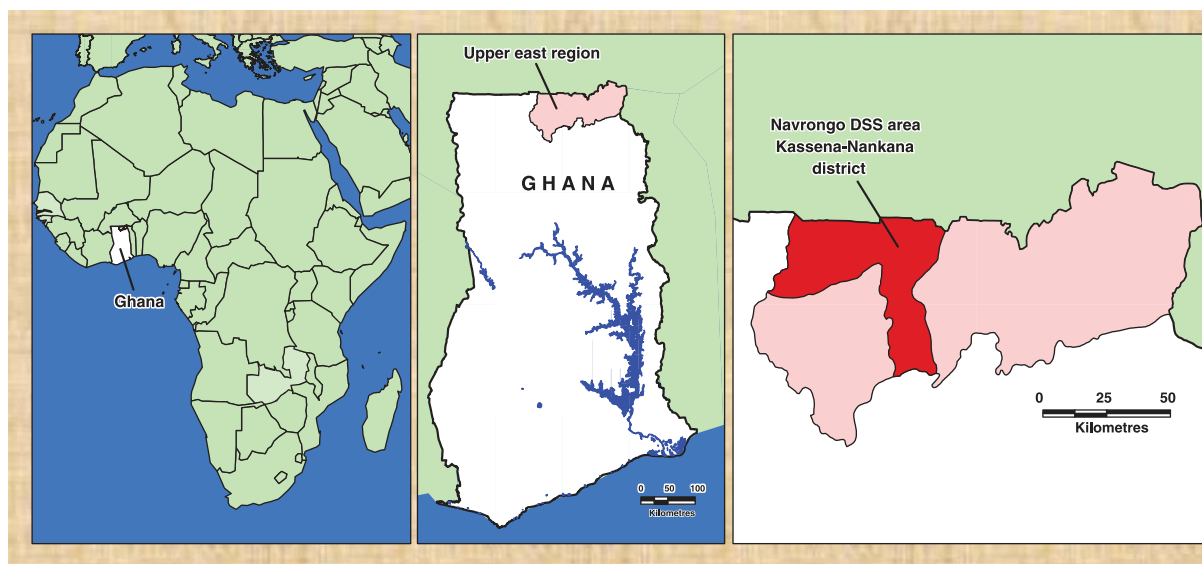


Figure 1 Location of Ghana in Africa, the upper east region in Ghana and the Navrongo HDSS area in the Kassena-Nankana districts of the upper east region

investigate the impact of repeated large doses of vitamin A supplementation on child survival (the Ghana VAST Project). The VAST project showed that providing vitamin A supplements to children reduced the number of clinic attendances and hospital admissions, and lowered all-cause mortality by 20%.^{1,2}

Following the completion of the VAST project in 1992, the Ministry of Health redesignated the Ghana VAST site as the NHRC with a broader mandate to investigate into health problems of the Sahelian ecological belt of northern Ghana, and appointed Professor Fred Binka as the Founding Director.

Although surveillance for research activities started with the Ghana VAST project that registered and followed up children <5 years of age,^{1,2} full HDSS was established in July 1993, initially to support the evaluation of the permethrin impregnated bednets study, which demonstrated that sleeping under a treated bednet was associated with ~17% reduction in all-cause morbidity and mortality in children.³

The platform has subsequently been used to determine the health and demographic impact of the Navrongo community health and family planning project.⁴⁻⁶ This project placed nurses within communities and supported them with trained locally based volunteers. By reducing the distance between patients and primary health-care services, the project led to an increase in the uptake of family planning services, reduction in fertility level and improved immunization coverage and other health outcomes.⁴⁻⁶ The community health and family planning was the first African experimental trial to establish the demographic impact of a family planning project. The findings of the project are now a national policy in Ghana and are being replicated in many other countries in

Africa. The NHDSS has since provided platforms for evaluating several interventions of national and international significance (<http://www.navrongo-hrc.org/pubs/publications.html>).

What does it cover now?

The NHDSS currently provides a framework for evaluating the morbidity and mortality impact of our research interventions and a reliable sampling frame for research projects. In addition, it monitors demographic and health changes in our study area, serves as a control system for other health indicators in Ghana and supports assessment of national public health interventions. As one of the old community-based surveillance systems in Africa, the HDSS is a training ground for new health and demographic surveillance systems across Africa and Asia. Table 1 presents variables that are collected routinely.

Presently, the platform is supporting a number of studies; prominent among them are the INDEPTH-led project that is assessing the effectiveness and safety of new anti-malarials (www.indepth-network.org), the quality of prenatal and maternal care (QUALMAT) project that aims to improve the quality of health care through addressing the existing know-do gap challenges (www.qualmat.net) and the meningitis vaccine project, which is a phase II, double-blind, randomized, controlled, dose-ranging study to evaluate the safety, immunogenicity, dose response and schedule response of a meningococcal-A conjugate vaccine administered concomitantly with EPI vaccines in healthy infants (<http://www.meningvax.org/clinical-004.php>). The

Table 1 Routine information collected by the NHDSS

Update of residency status: (member present, died, out-migrated), mother ID, father ID, sex, date of birth, birth order.

Pregnancy: estimated date of conception, antenatal clinic attendance, gestational age at booking, gestational age at IPT in pregnancy dose, tetanus injection, sleeps under insecticide-treated nets

Pregnancy outcome of existing pregnancy records, including date of delivery, number of children born, stillbirth or live-born child

Births: date and place of birth, skilled attendance at delivery, sex of child, cord care, mother's personal identity number and birth history.

Vaccination updates for children ≤ 3 years: name of vaccine, date vaccine was received, mass campaigns and Bacillus Calmette-Guérin scar, mid-upper arm circumference measurements and breastfeeding practice.

Education: currently in school, ever been to school, previous grade and current grade

Deaths: date and place of death. This is followed by VA for information on cause of death.

In-migration: name, sex and date of birth of migrant and date of in-migration. Place of origin of migrant and if previously registered with the HDSS

Out-migration: name, sex, date and place of destination, and reason for migration

New marriage: name, religion, rank, lives with husband, lives with rivals. Marital updates for existing marital records (still married, divorced, widow, died or migrated away).

Household-level information: household name, household size, ethnicity, religion, source of drinking water, toilet facilities, number of rooms used for sleeping, main material used for floor and roof, type of cooking fuel, source of lighting, ownership of land, methods of waste disposal, use of mosquito nets, access to mobile phones, number of durable household goods and animals.

Compound-level information: number of households, latitude, longitude and elevation and place of location (urban and rural).

VAs: cause of death, substance use (alcohol and smoking)

group is also involved in determining whether screening and treatment at each scheduled antenatal clinic visit, in pregnant women who sleep under a long-lasting insecticide-treated bednet, is as effective in protecting them from anaemia, low birthweight and placental infection as the existing intermittent preventive treatment (IPT) with Sulfadoxine-Pyrimethamine (www.mip-consortium.org/research_projects/prevention_africa/Seasonal_IPT_africa.htm). The NHDSS is part of the MenAfrican consortium, which is describing the epidemiology of meningococcal carriage in the African meningitis belt before the introduction of new meningococcal conjugate vaccines (www.menafrican.org/countries/ghana).

Where is the HDSS area?

The NHRC is located in the upper east region of Ghana in West Africa (Figure 1). It is one of the three field research centres of the Ghana Health Service, with a specific mandate to research into prevailing health issues in the three northern regions of Ghana. The NHDSS covers the Kassena-Nankana east and west districts of the upper east region (Figure 1). Geographically, the surveillance area lies between latitude 10.30' and 11.10' North and longitude 1.1' west and covers a total land area of ~ 1675 km². The area is characterized by Guinea Savannah vegetation with a short rainy season and a prolonged dry season from

October to March. The mean annual rainfall is ~ 1300 mm with the heaviest usually occurring in August. Mean monthly temperatures range from 22.8°C to 34.4°C.^{7,8} The local economy of the area is based on subsistence agriculture, government establishments and several tourist attractions.

Operationally, the surveillance area has been divided into five zones (North, South, East, West and Central), and they have been further divided into 247 clusters (Figure 2). Each cluster has an average of 70 compounds and a maximum of 99 compounds. Individual compounds are mapped using hand-held geographical positioning system receivers.⁹ The area has one referral district hospital, seven health centres and several primary health-care clinics in the area. In addition, there are 27 community health compounds with resident community health officers providing door-to-door health services to the people. The NHDSS area is accessible by an efficient road network and air transport with the nearest international and domestic airports being ~ 200 km away.²

Who is covered by the HDSS and how often have they been followed up?

The operations of the NHDSS cover all persons and households in the Kassena-Nankana east and west districts. This involves regular visits to the households

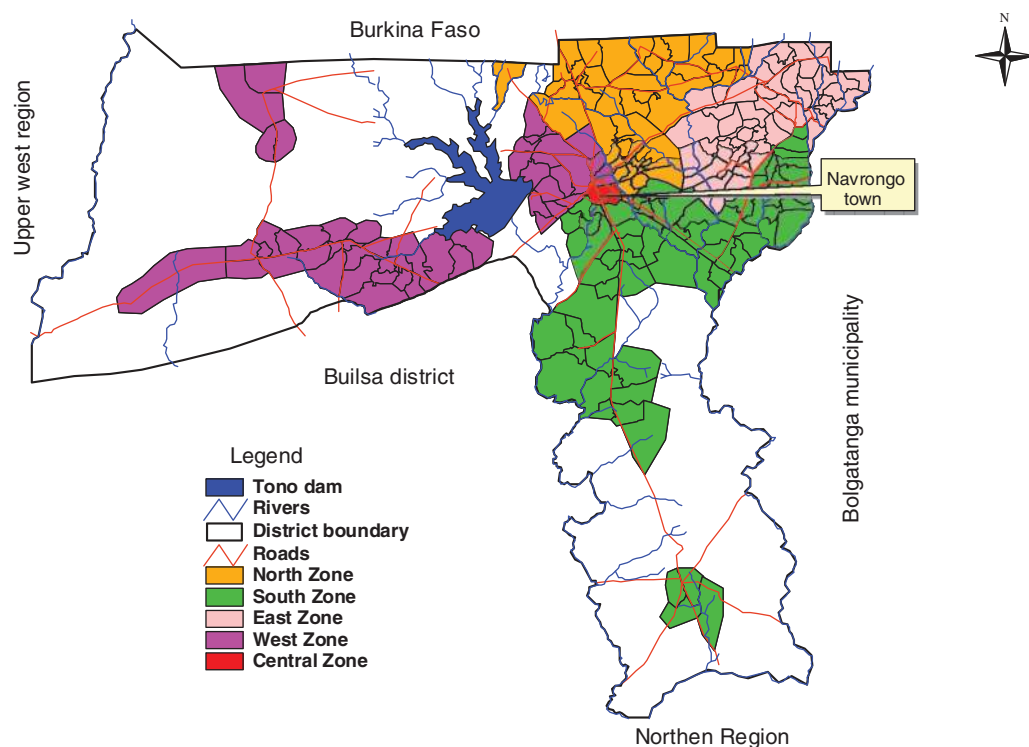


Figure 2 A map of the Kassena-Nankana district showing the district boundaries, the five zones of the NHDSS and other physical landmarks within the district



Figure 3 Trained fieldworker interviewing a household head during a census interview within the NDSS using a CRB

to update health and socio-demographic information. Trained fieldworkers visit compound every 4 months to interview heads of households (Figure 3) using a compound registration book (CRB), which contains basic information of all individuals in a household. Where a new event is recorded, the CRB is filled to provide detailed information about that particular event. The system maintains one unique identification (ID) number for each individual who is registered.

For those who migrate from one part of the surveillance area to another, they do so with the initial ID number assigned to them in their original location.

Data that are collected routinely include pregnancies, live and stillbirths, morbidity, deaths, in- and out-migrations, childhood vaccinations and verbal autopsy (VAs) on all deaths. Information collected annually includes educational status, marriage, religion and national health insurance coverage. Information on household socio-economic characteristics is updated every other year. Table 1 provides basic information on the HDSS routine data collection.

The data collection process also includes the community key informant (CKI) system where individuals are selected by their respective communities and given some training by the research team to report events, such as pregnancies, births and child deaths (deaths to children aged <12 years). The CKIs are paid a commission for each event they report after verification by a field supervisor. The CKI system complements the routine data collection machinery by recording in a timely manner, events that may occur after a fieldworker has passed a particular location during his or her routine rounds. All newborn children registered are provided with birth certificates.

Data quality in the NHDSS is assured by field supervisors who do on-site quality checks by liaising with the data processing centre to resolve queries and reconcile all migrations. Specially trained field



Figure 4 A traditional architecture within the NHDSS area of northern Ghana

supervisors conduct VAs on all deaths recorded at the household level to help ascertain the probable causes of death. The VA interviewers collect information from caregivers of deceased individuals on all that transpired from the time of illness till death occurred. This includes a disease narrative, a checklist of signs and symptoms and a structured questionnaire based on the INDEPTH network standard VA questionnaire.¹⁰ The data are usually reviewed by three physicians to determine the probable causes of death. A cause of death is assigned when there is concurrence between at least two of the physicians using the codes of the International Classification of Disease¹¹ as a guide.

As at June 2011, the HDSS covered 18 000 compounds with 33 600 households; average household and compound sizes were five and nine, respectively. Overall, 80% of the households were located in rural areas, and 31.6% were headed by females. Types of household dwellings were mixtures of traditional (Figure 4) and modern architecture. The total population size stood at 153 293 with 52% being females: 37% <15 years and 10% ≥60 years of age. A total of 3886 live births and 1531 deaths were also registered. Table 2 provides population description of the NHDSS as at June 2011.

Figure 5 shows the population pyramid of the HDSS in 1995 (above) and as at 2011 (below). Overall total fertility in the area has declined from 5.1 in 1995 to 3.8 in 2011, whereas life expectancy increased from 43 years to >60 years within the same period. During the 2011 year under review, 17 244 out-migrations (62.5% external) and 16 021 in-migrations (60.7% external) were recorded. Reasons for out-migration included looking for job (38.4%), moving out with relatives (30.8%), new residence (7%), marriage (5%) and others (18.8%). For in-migrations, these included moving in with relatives (32.2%), looking for job (17.5%), new residence (10.8%), marriage (7.4%) and others (29.2%).⁹

Table 2 Demographic characteristics of the Navrongo HDSS as at June 2011

Characteristics	Estimate
Total resident population	153 293
Male:female ratio	0.92
Population density	91.5 km ²
Population growth	8.1/1000 (0.81%)
Crude birth rate	25/1000
Crude death rate	10/1000
Crude out-migration rate	70.4/1000
Crude in-migration rate	63.5/1000
Total fertility rate	3.8
Neonatal mortality rate/1000 live births	13.4
Infant mortality rate/1000 live births	32.1
Under-5 mortality rate/1000 live births	60.8
Life expectancy at birth (males) (years)	56.4
Life expectancy at birth (females) (years)	67.0

What has been measured and how have the HDSS databases been constructed?

Different data have been measured at different time periods under the NHDSS. Longitudinal health and demographic data have been collected over the past two decades. In addition, information on non-communicable diseases involving adult, maternal and child health has been determined. Data on malaria epidemiology, including malariometric features of the area, have been extensively characterized (www.navrongo-hrc.org). Other biological measures that have been documented in the area include carriage, outbreaks and surveillance of the meningococcal meningitis (Figure 6). Respiratory infections including pneumonias, diarrhoeal diseases and rotavirus infections in children are being investigated. Studies on neglected tropical diseases, micronutrient deficiencies, and safety, immunogenicity and pharmacokinetics of drugs and vaccines are also investigated. Immunology, genomics and genetics biomarkers are studied.¹²⁻¹⁷

The NHDSS uses a relational database system called the Household Registration System (HRS2).¹⁸ The HRS2 was a collaborative venture of the NHRC, the Population Council of United States of America and the University of Southern Maine. The HRS2 is a structured system, designed and programmed

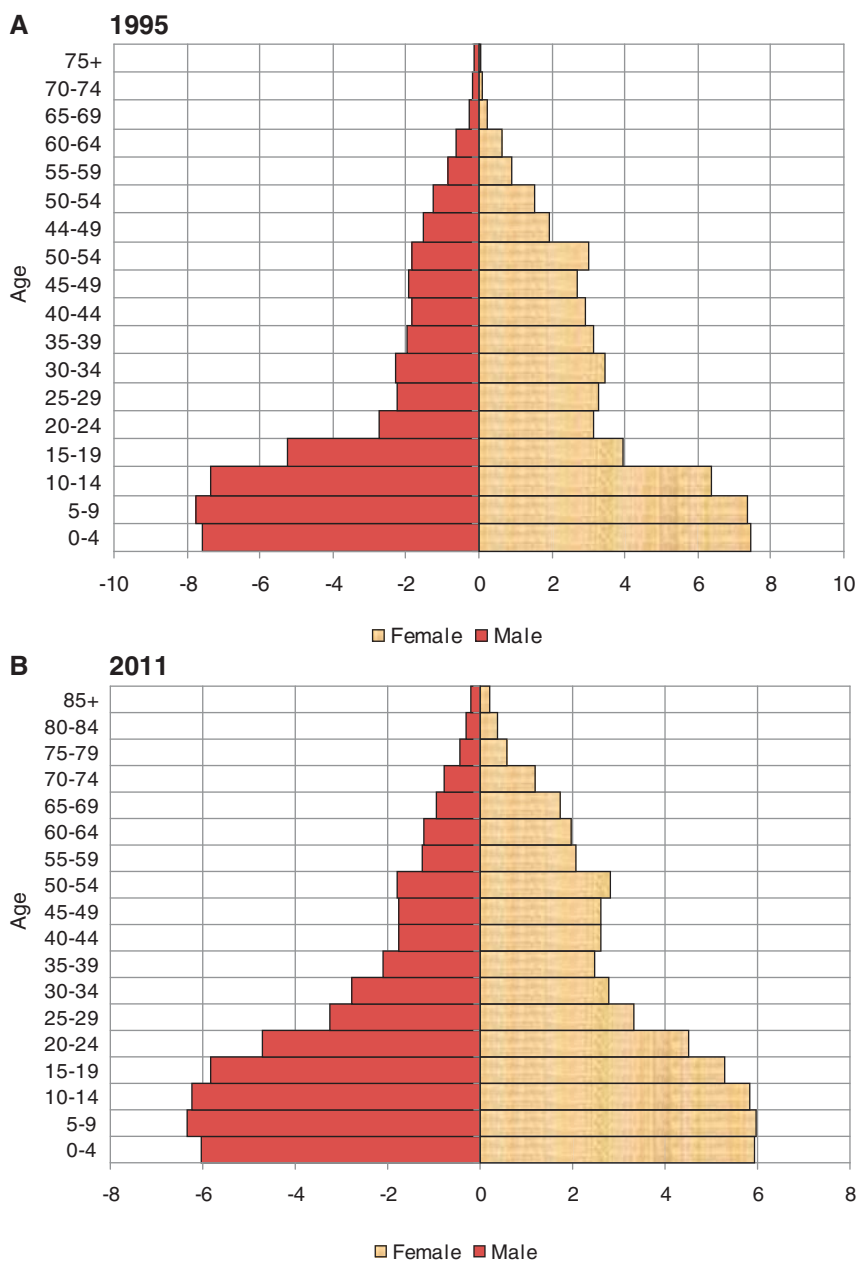


Figure 5 Two population pyramids from the Navrongo HDSS. Pyramid A is from data collected in the 1995 census and pyramid B is from the 2011 census

through the relational database package, using Visual FoxPro. It is designed to function as a template for generating computer programs that facilitate the collection, management and analysis of demographic surveillance system data. It is an 'application framework' designed purposely to facilitate the development of population-based demographic surveillance systems. It has a 'core system' that provides many of the common software requirements of field research laboratories and can be modified to tailor software of different specifications.

In addition to its core functions, the building block of the HRS2 framework allows for the construction of

additional modules for project-specific data. The HRS2, which is presently in use, has a data quality and integrity with field and row-level validation rules and table triggers to maintain consistency in the database. It has a user interface with automatic recording of errors, simplified data entry forms and a high interactive capability. The system has the flexibility to track new types of information, multiple relationships and the concept of social groups (multiple families in one location). Others are non-resident individuals, pregnancy outcome with multiple births, Windows and NT compatibility, robust object-oriented software design and great user interface.



Figure 6 Biomedical scientists working on meningococcal throat samples in the clinical bacteriology laboratory of the Navrongo Health Research Centre

Key findings and publications

Several outputs and publications have come from the NHDSS (<http://www.navrongo-hrc.org/pubs/publications.html>). Selected publications include the demonstration that vitamin A supplementation to children can reduce the number of deaths by ~20%,^{1,2} and the use of permethrin-impregnated bednets is associated with ~17% reduction in all-cause morbidity and mortality in children.³ Recently, the Navrongo experiment showed that placing nurses within communities and assisting them with trained locally based volunteers can lead to reduced fertility, increased utilization of family planning services, increased childhood immunization coverage and better health outcomes.⁴⁻⁶

Other outstanding findings include the demonstration that pre-referral rectal artesunate can prevent death and severe disability in children with severe malaria,¹⁹ a randomized, controlled trial of intermittent preventive treatment with sulfadoxine-pyrimethamine, amodiaquine or the combination in pregnant women²⁰ and a cluster randomized trial of intermittent preventive treatment for malaria in infants in areas of high seasonal transmission.²¹ Others are a randomized, double-blind, placebo-controlled trial of the efficacy of pentavalent rotavirus vaccine against severe rotavirus gastroenteritis in infants²² and a phase II, randomized study on an investigational DTPw-HBV/Hib-MenAC conjugate vaccine administered to infants in northern Ghana.²³ We recently used the HDSS to show rapid achievement of the child survival millennium development goals (MDG) in our catchment area,²⁴ the decline in maternal mortality in the Kassena-Nankana district of northern Ghana,²⁵ and the impact of immunization on the association between poverty and child survival.²⁶ Other salient studies the NHDSS have supported include testing of drugs, vaccines, clinical and other socio-epidemiological studies²⁷⁻⁴⁰ (<http://www.navrongo-hrc.org/pubs/publications.html>).

Future analysis plan

Future analyses of the demographic data will among other things investigate the long-term impact of the Navrongo experiment on fertility, child survival and mortality and examine the health and demographic transition of the study area. We shall examine the migration dynamics in the study area and the effect of changes in household structure on child survival, total mortality and fertility. We are also monitoring the attainment of some of the MDG in the surveillance areas. We plan to use the existing comprehensive malaria, meningitis and other infectious diseases data to examine recent changes in communicable diseases epidemiology in the surveillance area. Collaboration for examining and analysing these and other research activities are most welcome.

Strengths and weaknesses

The major strength of the NHDSS is the cumulative experience and capacity in health and demographic surveillance built up in the two decades that the system has existed. The regular household census updates allow continuous, household-level monitoring of all vital events and health indicators. The longitudinal nature of our HDSS allows for the determination of causal effects of many phenomena of interest and long-term impact assessment of research interventions. Individuals who were instrumental in the setting up of the HDSS ~20 years ago are still providing technical guidance for the running of the system. They also train and provide technical support to new sites which are in need of such expertise.

Among the weaknesses is the existence of data accumulation because of the limitation of all-round capacity to do different analyses, probably resulting from the lack of an *priori* hypothesis. Frequent and rigorous data collection brings with it high cost and other complexities, such as respondents' fatigue. Though the current location has been a success, there is a need for additional sites or cluster of sites in the other two regions of northern Ghana, so as to spread the surveillance success to all our catchment regions.

Data sharing and collaboration

Access to the NHDSS data is controlled and determined by the head of the NHRC. There are, however, opportunities for collaboration to analyse or re-analyse some of the existing data. Collaboration in research in our catchment areas using the HDSS platform is also very much encouraged. Persons interested in working in the NHRC should contact the Director using the address below. Data sharing is frequently done with funders, collaborators and partners in the INDEPTH-Network. Details of the contact person for potential collaboration with the HDSS in the use of data are as follows: The Director,

Navrongo Health Research Centre, Post Office Box 114, Navrongo, Ghana. E-mail: aoduro@navrongo.mimcom.org / director@navrongo.mimcom.org.

Acknowledgements

We are most grateful to the people of the Kassena-Nankana districts for the support they continue to give the NHDSS all these years. We are also thankful to the traditional and political authorities' for their continued support. We would particularly

like to acknowledge all past and present field staff, data management staff and senior managers of the NHDSS for the tremendous work done. We are very grateful to all our sponsors who have supported and continue to support the NHDSS, particularly the Rockefeller Foundation, which supported the NHDSS in its early years of operation. The information reported here do not necessary reflect the views of the Ghana Health Service and/or the Ministry of Health, Ghana.

Conflict of interest: None declared.

KEY MESSAGES

- The NHDSS has been designed to provide an efficient platform for evaluating health and social interventions.
- The NHDSS is community based and located in rural northeastern Ghana with more than two decades of cumulative longitudinal demographic data and more than 150 000 people under continuous surveillance.
- The NHDSS currently supports assessment of interventions to prevent infectious diseases, monitors demographic and epidemiological changes in the study area and serves as a control system for other health indicators in Ghana.
- We have recently shown, using the NHDSS data, a rapid achievement of the child survival MDGs, a significant decline in maternal mortality ratio and the impact of immunization on the association between poverty and child survival in our operational area.

References

- ¹ Ghana VAST Study Team. Vitamin A supplementation in northern Ghana: effects on clinic attendances, hospital admissions, and child mortality. *Lancet* 1993;**342**: 7–12.
- ² Binka FN, Morris SS, Ross DA, Arthur P, Aryeetey ME. Patterns of malaria morbidity and mortality in children in northern Ghana. *Trans R Soc Trop Med Hyg* 1994;**88**: 381–85.
- ³ Binka FN, Kubaje A, Adjuik M *et al*. Impact of permethrin impregnated bednets on child mortality in Kassena-Nankana district, Ghana: a randomized controlled trial. *Trop Med Int Health* 1996;**1**:147–54.
- ⁴ Binka FN, Nazzar A, Phillips JF. The Navrongo community health and family planning project. *Stud Fam Plann* 1995;**26**:121–39.
- ⁵ Pence BW, Nyarko P, Phillips JF, Debpuur C. The effect of community nurses and health volunteers on child mortality: the Navrongo community health and family planning project. *Scand J Public Health* 2007;**35**:599–608.
- ⁶ Debpuur C, Phillips JF, Jackson EF, Nazzar A, Ngom P, Binka FN. The impact of the Navrongo Project on contraceptive knowledge and use, reproductive preferences, and fertility. *Stud Fam Plann* 2002;**33**:141–64.
- ⁷ Binka FN, Anto FK, Oduro AR *et al*. Incidence and risk factors of paediatric rotavirus diarrhoea in northern Ghana. *Trop Med Int Health* 2003;**8**:840–46.
- ⁸ Ghanadistricts. <http://www.ghanadistricts.com/home/> (15 May 2012, date last accessed).
- ⁹ NHDSS 2011 annual report; Navrongo Health Research Centre, Navrongo. www.navrongo-hrc.org.
- ¹⁰ International Network for the Demographic Evaluation of Populations and Their Health in Developing Countries (INDEPTH). www.indepth-network.org.
- ¹¹ International Classification of Diseases (ICD). World Health Organization (WHO). www.who.int/classifications/icd/en.
- ¹² Ghansah A, Rockett KA, Clark TG *et al*. Haplotype analyses of haemoglobin C and haemoglobin S and the dynamics of the evolutionary response to malaria in Kassena-Nankana District of Ghana. *PLoS One* 2012;**7**:e34565.
- ¹³ Doodoo D, Atuguba F, Bosomprah S *et al*. Antibody levels to multiple malaria vaccine candidate antigens in relation to clinical malaria episodes in children in the Kasena-Nankana district of Northern Ghana. *Malar J* 2011;**10**:108.
- ¹⁴ Osafo-Addo AD, Koram KA, Oduro AR, Wilson M, Hodgson A, Rogers WO. HLA-DRB1*04 allele is associated with severe malaria in northern Ghana. *Am J Trop Med Hyg* 2008;**78**:251–55.
- ¹⁵ Leimkugel J, Forgor AA, Dangy JP *et al*. Genetic diversification of *Neisseria meningitidis* during waves of colonization and disease in the meningitis belt of sub-Saharan Africa. *Vaccine* 2007;**25**:A18–23.
- ¹⁶ Chandramohan D, Hodgson A, Coleman P *et al*. An evaluation of the immunogenicity and safety of a new trivalent meningococcal polysaccharide vaccine. *Vaccine* 2007;**25**: A83–91.
- ¹⁷ Malaria Genomic Epidemiology Network. A global network for investigating the genomic epidemiology of malaria. *Nature* 2008;**456**:732–37.
- ¹⁸ Phillips JF, Macleod BB, Pence B. The household registration system: computer software for the rapid

- dissemination of demographic surveillance systems. *Demogr Res* 2000;**2**:40.
- 19 Gomes MF, Faiz MA, Gyapong JO *et al*. Pre-referral rectal artesunate to prevent death and disability in severe malaria: a placebo-controlled trial. *Lancet* 2009;**373**:557–66.
 - 20 Clerk CA, Bruce J, Affipunguh PK *et al*. A randomized, controlled trial of intermittent preventive treatment with sulfadoxine-pyrimethamine, amodiaquine, or the combination in pregnant women in Ghana. *J Infect Dis* 2008;**198**:1202–11.
 - 21 Chandramohan D, Owusu-Agyei S, Carneiro I *et al*. Cluster randomised trial of intermittent preventive treatment for malaria in infants in area of high, seasonal transmission in Ghana. *BMJ* 2005;**331**:727–33.
 - 22 Armah GE, Sow SO, Breiman RF *et al*. Efficacy of pentavalent rotavirus vaccine against severe rotavirus gastroenteritis in infants in developing countries in sub-Saharan Africa: a randomised, double-blind, placebo-controlled trial. *Lancet* 2010;**376**:606–14.
 - 23 Hodgson A, Forgor AA, Chandramohan D *et al*. A phase II, randomized study on an investigational DTPw-HBV/Hib-MenAC conjugate vaccine administered to infants in Northern Ghana. *PLoS One* 2008;**3**:e2159.
 - 24 Binka FN, Bawah AA, Phillips JF, Hodgson A, Adjuik M, MacLeod B. Rapid achievement of the child survival millennium development goal: evidence from the Navrongo experiment in Northern Ghana. *Trop Med Int Health* 2007;**12**:578–83.
 - 25 Mills S, Williams JE, Wak G, Hodgson A. Maternal mortality decline in the Kassena-Nankana district of northern Ghana. *Matern Child Health J* 2008;**12**:577–85.
 - 26 Bawah AA, Phillips JF, Adjuik M, Vaughan-Smith M, Macleod B, Binka FN. The impact of immunization on the association between poverty and child survival: evidence from Kassena-Nankana District of northern Ghana. *Scand J Public Health* 2010;**38**:95–103.
 - 27 Anto F, Asoala V, Anyorigiya T *et al*. Simultaneous administration of praziquantel, ivermectin and albendazole, in a community in rural northern Ghana endemic for schistosomiasis, onchocerciasis and lymphatic filariasis. *Trop Med Int Health* 2011;**16**:1112–19.
 - 28 Oduro AR, Anyorigiya T, Anto F *et al*. A randomized, comparative study of supervised and unsupervised artesunate-amodiaquine, for the treatment of uncomplicated malaria in Ghana. *Ann Trop Med Parasitol* 2008;**102**:565–76.
 - 29 Oduro AR, Anyorigiya T, Hodgson A *et al*. A randomized comparative study of chloroquine, amodiaquine and sulphadoxine-pyrimethamine for the treatment of uncomplicated malaria in Ghana. *Trop Med Int Health* 2005;**10**:279–84.
 - 30 Oduro AR, Anyorigiya T, Adjuik M *et al*. A randomized, comparative study of two regimens of beta-artemether for the treatment of uncomplicated, Plasmodium falciparum malaria, in northern Ghana. *Ann Trop Med Parasitol* 2004;**98**:433–40.
 - 31 Hale BR, Owusu-Agyei S, Fryauff DJ *et al*. A randomized, double-blind, placebo-controlled, dose-ranging trial of tafenoquine for weekly prophylaxis against Plasmodium falciparum. *Clin Infect Dis* 2003;**36**:541–49.
 - 32 Oduro AR, Koram KA, Rogers W *et al*. Severe falciparum malaria in young children of the Kassena-Nankana district of northern Ghana. *Malar J* 2007;**6**:96.
 - 33 Binka FN, Anto FK, Oduro AR *et al*. Incidence and risk factors of paediatric rotavirus diarrhoea in northern Ghana. *Trop Med Int Health* 2003;**8**:840–46.
 - 34 Appawu M, Owusu-Agyei S, Dadzie S *et al*. Malaria transmission dynamics at a site in northern Ghana proposed for testing malaria vaccines. *Trop Med Int Health* 2004;**9**:164–70.
 - 35 Koram KA, Owusu-Agyei S, Utz G *et al*. Severe anemia in young children after high and low malaria transmission seasons in the Kassena-Nankana district of northern Ghana. *Am J Trop Med Hyg* 2000;**62**:670–74.
 - 36 Engmann C, Walega P, Aborigo RA *et al*. Stillbirths and early neonatal mortality in rural Northern Ghana. *Trop Med Int Health* 2012;**17**:272–82.
 - 37 Adjuik M, Kanyomse E, Kondayire F, Wak G, Hodgson A. Clustering of under-five mortality in the Navrongo HDSS in the Kassena-Nankana District of northern Ghana. *Glob Health Action* 2010;**3**:15–25.
 - 38 Rogers WO, Atuguba F, Oduro AR, Hodgson A, Koram KA. Clinical case definitions and malaria vaccine efficacy. *J Infect Dis* 2005;**193**:467–73.
 - 39 Akazili J, Gyapong J, McIntyre D. Who pays for health care in Ghana? *Int J Equity Health* 2011;**10**:26.
 - 40 Mills S, Williams JE, Adjuik M, Hodgson A. Use of health professionals for delivery following the availability of free obstetric care in northern Ghana. *Matern Child Health J* 2008;**12**:509–18.