Using a geographical information system to plan a malaria control programme in South Africa

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Introduction Sustainable control of malaria in sub-Saharan Africa is jeopardized by dwindling public health resources resulting from competing health priorities that include an overwhelming acquired immunodeficiency syndrome (AIDS) epidemic. In Mpumalanga province, South Africa, rational planning has historically been hampered by a case surveillance system for malaria that only provided estimates of risk at the magisterial district level (a subdivision of a province).

Methods To better map control programme activities to their geographical location, the malaria notification system was overhauled and a geographical information system implemented. The introduction of a simplified notification form used only for malaria and a carefully monitored notification system provided the good quality data necessary to support an effective geographical information system.

Results The geographical information system displays data on malaria cases at a village or town level and has proved valuable in stratifying malaria risk within those magisterial districts at highest risk, Barberton and Nkomazi. The conspicuous west- to-east gradient, in which the risk rises sharply towards the Mozambican border (relative risk = 4.12, 95% confidence interval = 3.88–4.46 when the malaria risk within 5 km of the border was compared with the remaining areas in these two districts), allowed development of a targeted approach to control.

Discussion The geographical information system for malaria was enormously valuable in enabling malaria risk at town and village level to be shown. Matching malaria control measures to specific strata of endemic malaria has provided the opportunity for more efficient malaria control in Mpumalanga province.

Keywords: malaria, epidemiology; information systems; disease notification, methods; geography; maps; databases, factual; South Africa.

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Introduction

The Lowveld region of Mpumalanga province in South Africa is an area of low altitude in the north-east of the country; it is bounded by Mozambique in the east and the Drakensburg mountains in the west. The majority of the approximately 850 000 inhabitants reside in 48 villages and towns, which have populations ranging from 397 to 288 908. Malaria is transmitted seasonally, and *Plasmodium falciparum* is responsible for more than 90% of malaria infections.

A control programme has existed in the malarial areas of South Africa, including Mpumalanga province, for the past five decades, and indoor spraying with a residual insecticide to kill resting anopheline mosquitoes has been the cornerstone of control. The success of this resource-intensive intervention is evidenced by a reduction of more than 80% in the South African malaria endemic area, which has been accompanied by impressive development in tourism and agriculture (*1*).

South Africa is divided into nine provinces, which are each subdivided into magisterial districts. Each magisterial district covers an average area of approximately 1800 km². Malaria became a notifiable disease in South Africa in 1958; the notification system collects and reports data on cases of malaria at the level of the magisterial district. Over the past decade there has been little modification in the area covered by

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spraying largely because the information from magisterial districts does not permit fine tuning of control activities. The entire region of the Barberton and Nkomazi magisterial districts in Mpumalanga, for example, is classified as a high-risk malaria area for purposes of control and travel advisories, although local residents are aware that the malaria risk is heterogeneous within these districts (Fig. 1) (*2*).

External factors have had an impact on malaria control in Mpumalanga. The burgeoning AIDS epidemic in Mpumalanga (more than 27% of first-time antenatal clients seen in 1998 were infected with human immunodeficiency virus) resulted in the large-scale redistribution of public health funding with a consequently drastic reduction in the insecticide budget for malaria vector control.

In an effort to develop a surveillance system that would allow for efficient allocation of resources, the Mpumalanga Malaria Control Programme embarked on a process of restructuring the notification system. This included introducing a geographical information system. This system comprises personnel, hardware, software, and procedures designed to support the capture, management, manipulation, analysis, modelling, and display of case data organized by geographical area. The success of the neighbouring KwaZulu-Natal province in defining the risk to local tourism using a geographical information system to relate malaria cases to specific patriarchal homesteads has fuelled an interest in using such a system to target control activities in Mpumalanga (*1*). This paper briefly describes key revisions made to the malaria information system, including the implementation of a geographical information system, and provides an example of how a geographical information system can contribute to the planning of malaria control programmes.

Methodology

The usefulness of a geographical information system for planning and managing control programmes depends on the availability of accurate and timely raw data on malaria cases. In 1997 a comprehensive review revealed that the notification system for malaria had deficiencies similar to those in the systems for other notifiable medical conditions in South Africa (*3*). The resulting repository of incomplete, inaccurate, and tardy data was not systematically analysed nor was feedback given to health professionals who had notified the health department. Thus, a simplified malaria-specific notification form was developed, piloted, and subsequently used by the control programme throughout the malarial Lowveld region of Mpumalanga during 1997. In addition to basic demographic and diagnostic information, the form captures patients' travel and migration history during the three months before they became ill to allow determination of the most probable geographical source of infection. Clinic and hospital staff received intensive training on the correct way to complete the form when it was introduced, and retraining is conducted at facilities submitting incomplete or incorrect forms. Notification forms are collected weekly from all facilities by programme staff and by the laboratory courier service during routine collection of specimens. Doctors in the private sector fax notifications directly to the Mpumalanga Malaria Information Officer.

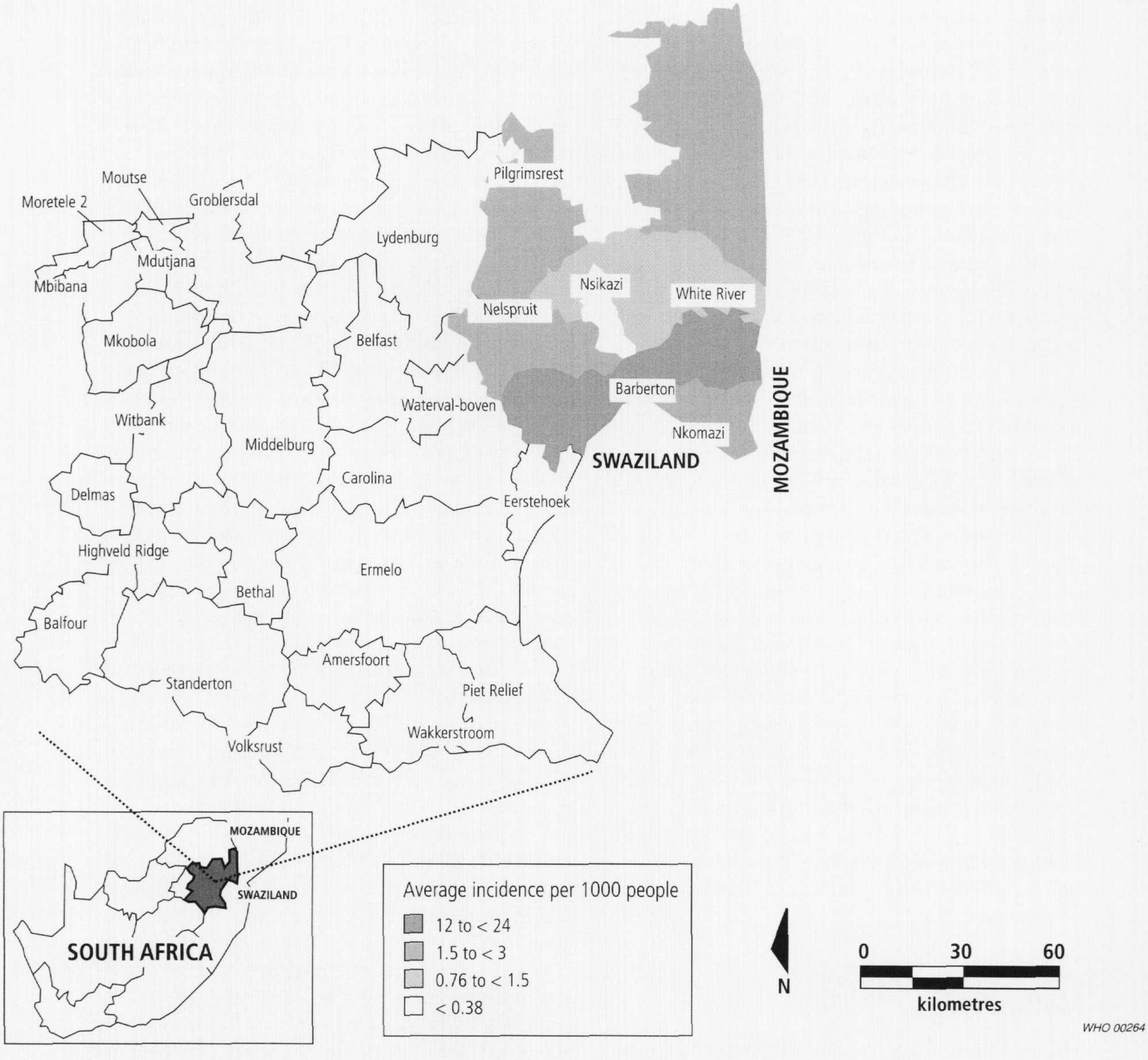
A database was designed by the Malaria Information Officer in collaboration with the database manager from the National Malaria Research Programme of the Medical Research Council using Microsoft Access for Windows 95. This allowed data on malaria cases and geographical area, including the exact position of villages and towns, to be captured by computer. This capture of both spatial data and attribute data makes it possible to display and examine both types of data simultaneously.

Data input screens were designed to facilitate easy and accurate data entry. These use drop-down lists of permissible data values, and, when possible, data are derived automatically from values previously entered. Data are also validated and edited as they are entered. A set of standard queries and reports, developed in accordance with management's requirements, was also included in the system to allow for easy analysis and to provide timely feedback to local health staff.

MapInfo software (version 4, MapInfo Corporation, New York, USA) run on a pentium 100-MHz processor with 32 megabytes of random access memory, a hard drive with 1-gigabyte capacity, and a standard colour printer are used. Commercially available digital map data sets of the entire Lowveld region at various scales were acquired from a private cartography company. Orthographs, three-dimensional displays of geographical areas, prepared during 1998 at a scale of 1:10 000 provided baseline spatial data and were overlaid with aerial photographs to generate a 1:5000 scale map of the area. Bentley and Intergraph software products (Symmetry Systems Inc., New York, USA) and Global Positioning System (Optron Precise Positioning Solutions, Johannesburg, South Africa) control points accurate to less than a metre were used to correct the images for inclusion in the geographical information system. Geomedia software (Symmetry Systems Inc., New York, USA) was used to convert the digital map data to MapInfo format, and maps were produced with delineated magisterial districts, towns, villages, and other administrative boundaries including sectors. Sectors are unique boundaries used by malaria spray programmes to plan the activities of control teams.

Local programme managers scrutinize the data capture forms twice each week for inaccuracies before the data are captured by a dedicated clerk. The Malaria Information Officer monitors the system weekly to ensure prompt and accurate capture. Weekly and monthly reports are generated and distributed via email and fax to managers of malaria control programmes, provincial health managers, the

Fig. 1. **Malaria incidence rates, Mpumalanga Province, South Africa, 1987–96**



national Malaria Control Programme, and local government officials. Additional spatial data are added to the database as it becomes available.

Retrospective case data have also been incorporated into the new database. All historical data relating to individual cases of malaria were scrutinized, checked for accuracy and entered into the system. This allowed for calculation of mean malaria incidence in all towns and villages in the Barberton and Nkomazi magisterial districts for malaria seasons from 1995 to 1999. This time frame was chosen because a rapid immunochromatographic card test was introduced in clinics and hospitals in 1995 making definitive diagnosis for treatment and notification possible (*4*). Cases imported from neighbouring countries were excluded from the numerator as they did not reflect local transmission or incidence, and no reliable estimate of migrant casual labour is available for the denominator. Because the results of a recent government census were not available, data gathered during a household census conducted by field personnel throughout the high-risk area during 1998 were used for the denominator (*5*).

Incidence was linked to localities (villages and towns), and a thematic map was constructed to display malaria risk. Five class intervals were used, ranging from <8 to 128 malaria infections per 1000 inhabitants at risk.

Results

The ongoing evaluation of routine indicators of the information system attests to the quality of the modified notification system. Between January and April 1999 inclusive, 100% of the 7071 notification forms completed at health facilities in the high-risk area were entered into the database within 7 days. The quality of notifications had also improved. Although 13% (920/7071) of notifications had minor deficiencies in completion, 99.3% (7022/7071) had complete data on the three critical items necessary for follow-up of the control programme: name, address, and diagnosis. Repeated examination of all entries identified only one duplicate entry.

Fig. 2 displays the mean incidence of malaria for local residents in all villages and towns in the two magisterial districts with the highest risk of malaria in Mpumalanga province. Marked heterogeneity of risk is apparent: the annual incidence ranges from 0.1 to 20 per 1000 residents in individual settlements (Booman et al., unpublished data.). A clear west-to-east gradient of malaria risk exists: individuals living within 5 km of the Mozambican border have a fourfold greater risk of malaria when compared with other inhabitants of these magisterial districts (relative risk = 4.12, 95% confidence interval = 3.88–4.46).

Additionally, maps of sector boundaries are being used for weekly monitoring of spraying by individual teams spraying insecticide.

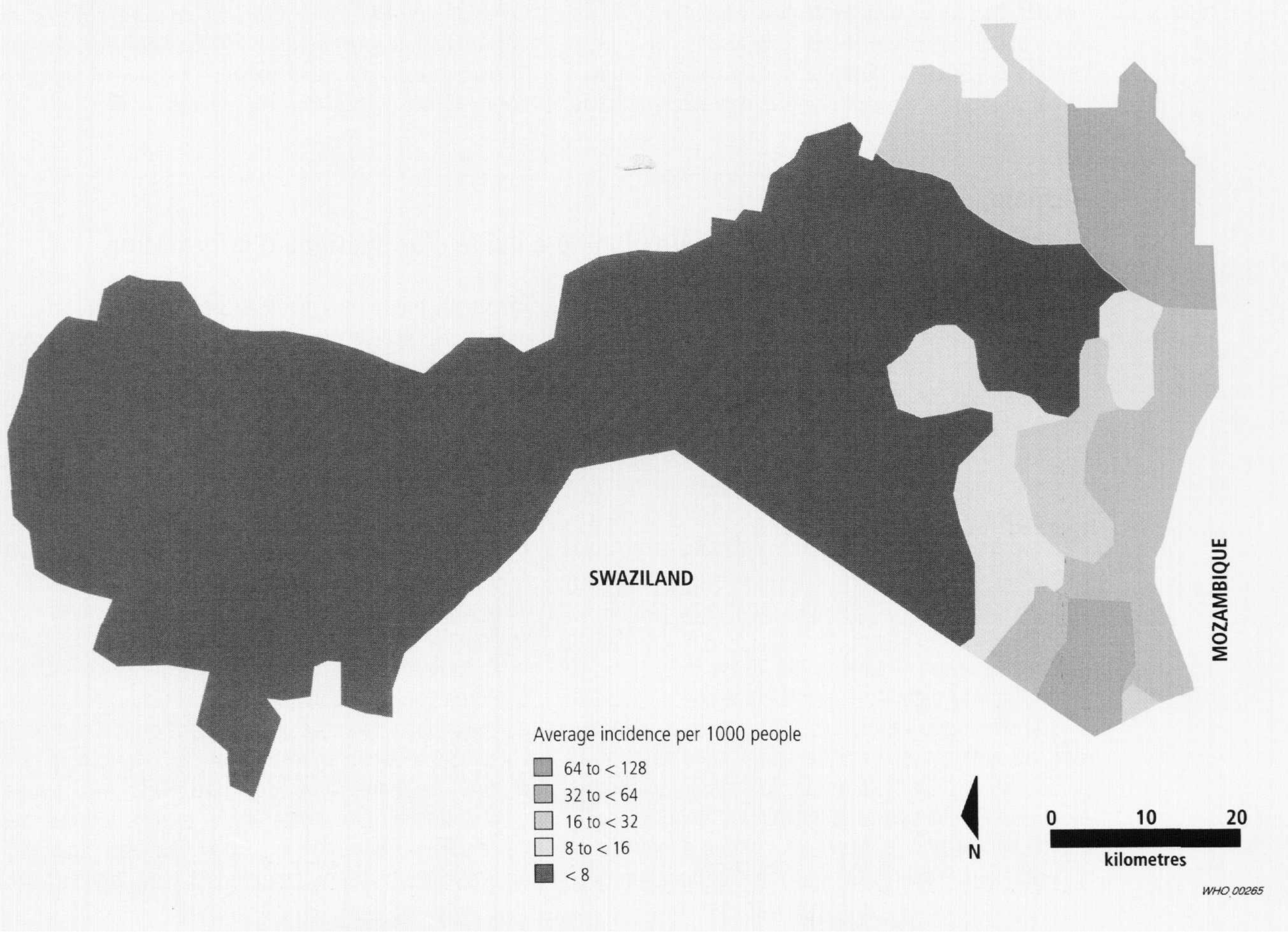
Discussion

The geographical information system for malaria was enormously valuable in enabling malaria risk at town and village level to be displayed; it unmasked a profound heterogeneity in risk that had previously been concealed within the summary data on incidence in magisterial districts. The marked stratification of malaria risk, even within two magisterial districts in Mpumalanga, confirms other findings of the highly focal nature of malaria (*6–8*). In this case, the finding allowed district managers and Mpumalanga Malaria Control Programme managers to better use the limited resources available for purchasing insecticide by limiting routine spraying of all buildings to settlements with a mean annual incidence exceeding 8 malaria cases per 1000 local inhabitants.

Proposed plans to map malaria rates to the sub-village level are clearly justified; studies have identified wide differences within individual villages that are related to identifiable environmental features which may be amenable to focal control strategies, for example the use of a larvicide (*9, 10*).

Information system enthusiasts should be cautioned that having a geographical information system is not synonymous with having an effective surveillance system. The value of any surveillance system for infectious disease is measured by its ability to provide timely, accurate "data for action" to people responsible for effective prevention and control activities, and by its ability to provide ongoing feedback to the primary gatherers of information

Fig. 2. **Average case incidence, Barberton and Nkomazi Districts, Mpumalanga Province, South Africa, 1995–99**



(*11, 12*). In this case, this is accomplished by providing weekly feedback to local managers of malaria control programmes and through a monthly bulletin sent to all health facilities in the high-risk area. The importance of dedicated staff, which at a minimum should include a well-trained geographical information system data manager and a support person for data capture, cannot be overemphasized.

Traditional statistics on malaria morbidity have been facility based and have proved inadequate for monitoring control programmes (*13*). Vector-borne diseases demonstrate decided geographic heterogeneity and therefore special tools are required for their representation and analysis. A geographical information system and other landscape ecology tools provide an excellent framework for designing malaria surveillance systems owing to their inherent ability to manage spatial information (*14, 15*). The ability of geographical information systems to display complex data in an intuitively understandable way is being harnessed to establish a continental database in Africa of the spatial distribution of malaria (*16*).

Not only have these information systems proved valuable in mapping malaria, they have also been used to elucidate the factors influencing malaria transmission (*17*). Additionally, these systems have allowed new hypotheses to be generated about the etiology of severe malaria (*18–21*); they have allowed exploration of the relation between clinical outcomes of infection and the intensity of parasite exposure (*22*); they have assisted in the interpretation of the results of intervention studies by taking account of the variability of confounding factors, including meteorological variables (*23*); and they have identified areas vulnerable to malaria outbreaks (*24*). A geographical information system is also being used to model the potential effect of climate change on areas where there is "anophelism without malaria" and for predicting epidemics (*25, 26*).

In South Africa, the geographical information system has been used in health care to provide an inventory of health facilities (*27*), predict the impact of the desegregation of hospital services on bed occupancy rates (*28*), and to estimate catchment populations for determining the optimal location of new clinics (*29*). Epidemiological investigations using this system have included assessments of the impact of agricultural development on malaria and descriptions of the macro-epidemiology and micro-epidemiology of malaria in KwaZulu-Natal (*30*). In addition a geographical information system has been used to design a study of impregnated bednets by providing blocks of paired households that have similar long-term epidemiological patterns of malaria incidence (*30*).

Although using geographical information system guidance for malaria control activities has been advocated (*31–33*), there are few published examples of this particular application. In Mpumalanga, the focused spraying programme resulting from this use of a geographical information system demands careful monitoring of coverage and a surveillance system capable of providing early warning of focal outbreaks. The geographical information system is ideally suited to both these roles.

Matching malaria control measures to specific strata of endemic malaria, which were determined using a surveillance system integrated with a geographical information system, has provided the opportunity for more efficient malaria control in Mpumalanga province. Further benefits should accrue as case mapping to sub-village level permits more dynamic focal control initiatives. ■

Résumé

Programme de lutte antipaludique planifié à l'aide d'un système d'information géographique en Afrique du Sud

La maîtrise durable du paludisme en Afrique subsaharienne est mise en péril par la baisse des ressources de la santé publique résultant des diverses priorités sanitaires qui entrent en compétition, parmi lesquelles l'épidémie massive de syndrome d'immunodéficience acquise (SIDA). En Afrique du Sud, dans la province de Mpumalanga, la planification rationnelle a de tout temps été gênée par un système de surveillance des cas de paludisme qui ne donne que des estimations du risque au niveau du district (une subdivision de la province). Pour remédier à cette situation et mieux adapter les activités du programme de lutte à leur localisation géographique, on a entièrement révisé le système de notification du paludisme et mis en œuvre un système d'information géographique. L'introduction d'un formulaire de notification simplifié uniquement réservé au paludisme et d'un système de notification soigneusement surveillé a permis d'obtenir les données de la qualité voulue pour appuyer un système d'information géographique efficace. Ce système d'information géographique fournit des données sur les cas de paludisme survenus à l'échelon du village ou de la ville et s'est avéré précieux pour stratifier le risque de paludisme dans les districts à plus haut risque que sont Barberton et Nkomazi. Ce système a permis d'obtenir 100 % de notifications et l'enregistrement des données de l'ensemble des unités de notification en une semaine. Il s'en est dégagé un gradient remarquable d'ouest en est, dans lequel le risque augmente brutalement vers la frontière du Mozambique (risque relatif = 4,12, intervalle de confiance à 95 % = 3,88-4,46 lorsqu'on compare le risque de paludisme dans les 5 km jouxtant la frontière avec le reste de ces deux districts). Le système d'information géographique s'est avéré utile pour utiliser au mieux les ressources limitées dont on dispose pour l'achat d'insecticide, en restreignant les pulvérisations de routine de l'ensemble des bâtiments aux zones d'habitation où l'incidence annuelle moyenne des cas de paludisme dépasse 8 pour 1000 habitants. En outre, on utilise des cartes où figurent les limites des secteurs

pour la surveillance hebdomadaire de la couverture des pulvérisations effectuées par les différentes équipes appliquant un insecticide rémanent. Les tenants du système d'information doivent être informés que le fait de disposer d'un système d'information géographique ne veut pas dire qu'on a un système de surveillance efficace. L'efficacité d'un tel système pour les maladies infectieuses se mesure par sa capacité à fournir en temps utile des données exactes permettant aux responsables de prendre des mesures de prévention et de lutte efficaces, et par sa capacité à fournir des informations en retour à ceux qui, initialement, ont rassemblé les données. Dans le cas qui nous occupe, cela s'opère en transmettant chaque semaine des informations en retour aux responsables locaux du programme de lutte contre le paludisme et en adressant un bulletin mensuel à tous les établissements de santé de la région à haut risque. On n'insistera jamais assez sur l'importance d'avoir affaire à un personnel spécialisé qui, au minimum, sera composé d'un gestionnaire des données du système d'information géographique et d'une personne chargée de la saisie des données. Si l'on a préconisé l'utilisation du système d'information géographique pour orienter les activités de lutte antipaludique, il existe peu d'exemples publiés de ce type d'application. A Mpumalanga, le programme de pulvérisation ciblé qui en est résulté exige une surveillance attentive de la couverture et un système de surveillance capable d'attirer l'attention précocement sur des flambées localisées. Le système d'information géographique est parfaitement en mesure d'assumer ces deux rôles. Le fait d'adapter les mesures de lutte à des strates spécifiques du paludisme endémique, déterminées au moyen d'un système de surveillance intégré à un système d'information géographique, a permis de lutter plus efficacement contre le paludisme dans la province de Mpumalanga. Un bénéfice supplémentaire pourrait s'y ajouter du fait que le recensement des cas au niveau des foyers permet des initiatives de lutte localisées plus dynamiques.

Resumen

Utilización de un sistema de información geográfica para planificar un programa de lucha contra el paludismo en Sudáfrica

La lucha sostenible contra el paludismo en el África subsahariana se ve amenazada por la progresiva reducción de los recursos de salud pública que resulta de la pugna entre las distintas prioridades sanitarias, una de las cuales es la devastadora epidemia de síndrome de inmunodeficiencia adquirida (SIDA). En la provincia de Mpumalanga, Sudáfrica, la planificación racional se ha visto dificultada tradicionalmente por un sistema de vigilancia de los casos de paludismo que únicamente facilitaba estimaciones del riesgo a nivel de distritos (subdivisiones intraprovinciales). Para corregir este problema a fin de planificar las actividades del programa de control con una mayor discriminación geográfica, se revisó el sistema de notificación de los casos de paludismo y se aplicó un sistema de información geográfica. La introducción de un formulario de notificación simplificado exclusivo para el paludismo y de un sistema de notificación estrechamente vigilado permitieron obtener los datos cualitativos necesarios para apoyar un sistema de información geográfica eficaz. El sistema de información geográfica ofrece datos sobre los casos de paludismo de cada pueblo o ciudad y ha demostrado su utilidad para estratificar el riesgo de contraer el paludismo en los distritos judiciales de más riesgo, Barberton y Nkomazi. El sistema logró registrar en el plazo de una semana el 100% de las notificaciones enviadas por las unidades informantes. Se observó un claro gradiente de Oeste a Este, que muestra que el riesgo se dispara hacia la frontera mozambiqueña (riesgo relativo = 4,12, IC95% = 3,88-4,46, cuando se comparan el riesgo de contraer paludismo a menos de 5 km de la frontera, y el riesgo en las otras zonas de esos distritos). Ha quedado demostrada la utilidad del sistema de información geográfica en lo que respecta a aprovechar mejor los escasos recursos disponibles para la compra de insecticida, al quedar limitado el rociamiento sistemático de todos los edificios a los asentamientos humanos en los que la incidencia anual media sobrepasa los 8 casos de paludismo por 1000 habitantes. Además, se están utilizando mapas de los límites del sector para controlar semanalmente la cobertura de las operaciones de rociamiento llevadas a cabo por equipos que aplican insecticida de acción residual. Habría que advertir no obstante a los entusiastas del sistema de información que disponer de un sistema de información geográfica no equivale a disponer de un sistema de vigilancia eficaz. La utilidad de un sistema de vigilancia de las enfermedades infecciosas depende de su capacidad para facilitar oportunamente datos precisos, que permitan tomar medidas, a los responsables de adoptar actividades de prevención y control eficaces, así como de su capacidad para facilitar retroinformación permanentemente a quienes reúnen la información de partida. En este caso, ello se consigue remitiendo información semanal a los gestores locales del programa de lucha contra el paludismo, y un boletín mensual a todos los centros de salud de las zonas de alto riesgo. Nunca se insistirá lo suficiente en la necesidad de disponer de personal dedicado, que debe comprender por lo menos un gestor de datos del sistema de información geográfica debidamente capacitado y un auxiliar para el registro de datos. Si bien se ha preconizado el uso de un sistema de información geográfica para orientar las actividades de la lucha contra el paludismo, son pocos los ejemplos publicados sobre esta aplicación concreta. En Mpumalanga, el programa de rociamiento selectivo resultante de ese tipo de sistema exige un estrecho seguimiento de la cobertura y un sistema de vigilancia capaz de detectar prontamente los brotes focales. El sistema de información geográfica es ideal para esas dos funciones. La focalización de la lucha antipalúdica en estratos concretos de paludismo

endémico, determinados mediante un sistema de vigilancia integrado con un sistema de información geográfica, ha brindado la oportunidad de combatir más eficientemente el paludismo en la provincia de Mpumalanga. Cabe prever que se lograrán nuevos progresos cuando la cartografía de los casos de zonas concretas de las aldeas permita aplicar iniciativas de control focal más dinámicas.

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