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Application opportunities of geographic information systems analysis to support achievement of the UNAIDS 90-90-90 targets in South Africa

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In an effort to achieve control of the HIV epidemic, 90-90-90 targets have been proposed whereby 90% of the HIV-infected population should know their status, 90% of those diagnosed should be receiving antiretroviral therapy, and 90% of those on treatment should be virologically suppressed. In this article we present approaches for using relatively simple geographic information systems (GIS) analyses of routinely available data to support HIV programme management towards achieving the 90-90-90 targets, with a focus on South Africa (SA) and other high-prevalence settings in low- and middle-income countries. We present programme-level GIS applications to map aggregated health data and individual-level applications to track distinct patients. We illustrate these applications using data from City of Johannesburg Region D, demonstrating that GIS has great potential to guide HIV programme operations and assist in achieving the 90-90-90 targets in SA.

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Geographic information systems (GIS) analysis refers to the capture, management, evaluation and visualisation of geographically referenced data, although the term can generally be applied to any investigation that incorporates a location variable.[1] This can range from simple maps that provide information about point locations, for example facilities, to complex spatial statistical analyses.[2] GIS is an important tool to advance public health, as many aspects of health and illness have a geographical or spatial component.[2] GIS applications may include mapping of disease distribution, assessing patterns of health interventions such as immunisations, investigating spatial and temporal trends, mapping variations in risk factors and forecasting epidemics.[2]

One of the major health challenges facing South Africa (SA) and other low- and middle-income countries (LMICs), particularly in sub-Saharan Africa, is the HIV epidemic. In an effort to achieve epidemic control, the Joint United Nations Programme on HIV/AIDS (UNAIDS) has proposed ambitious 90-90-90 targets to be achieved by 2020, whereby 90% of people infected with HIV will have received a diagnosis, 90% of those diagnosed will be receiving sustained antiretroviral therapy (ART), and 90% of those on treatment will be virally suppressed.[3] GIS analyses, often involving complex spatial statistics, have been used to investigate various aspects of the HIV epidemic in a number of countries including SA, for example to examine the distribution of HIV infection, including hot-spots or clusters of high or low prevalence;[4-17] to assess the spatial distribution of factors contributing to HIV infection;[4,14,18] to describe the spatial distribution of the HIV care continuum (HIV testing, uptake of ART, viral suppression) and the factors that affect provision of this care, including location of services;[19-27] to investigate HIV infection, prevention services and location/density of key populations, including injection drug users, men who have sex with men and sex workers;[28-33] to guide or map prevention efforts such as male circumcision or condom distribution;[34,35] to understand patterns of HIV knowledge;[36] and to examine distribution of funding for HIV services.[37] Although some of these applications can inform efforts towards achieving the 90-90-90 objectives, to our knowledge no systematic approach has been presented to define the role of GIS in achieving these targets. Furthermore, GIS analyses may be of limited use in LMICs if complex analyses are performed that require highly skilled personnel or if the analyses primarily draw on research data, with no link to routine, programme data that can be used to inform programme implementation.

In this article we present approaches for using relatively simple GIS analyses of routinely available data to support HIV programme management towards achieving the 90-90-90 targets, with a focus on SA and other high-prevalence settings in LMICs. Using data from City of Johannesburg (CoJ) Region D, we present applications at a programme level to map aggregated health data and at an individual level to track distinct patients, both of which can guide efforts towards achieving the 90-90-90 targets.

The first 90: Diagnosis of 90% of people infected with HIV

GIS can be used to guide progress towards the first 90 by mapping population groups that require improved access to HIV testing services (HTS). For example, since a high number of HIV-infected males in SA remain undiagnosed, with low HTS uptake also recorded among men in other LMICs,[38,39] visualising male population density by ward would be useful to identify specific areas with high concentrations of men. These areas, identified as wards 27, 30 and 45 in CoJ Region D (Fig. 1, A), could then be targeted for testing, for example, mobilising community health workers (CHWs) or mobile testing units to perform community-based testing after hours or over weekends when men, most of whom would be at work during routine clinic hours, would more likely be available for testing. Uptake of HIV testing has been shown to be particularly low among adolescent and young males aged 12 - 24 years,[40,41] and a similar map showing population density of this target group can be generated to further focus testing in areas where this specific age group is more likely to be found (Fig. 1, B). A further use of GIS to guide progress towards the first 90 is mapping of high-risk populations to direct testing for higher yield. Explanatory variables associated with HIV prevalence, many of which have been mapped in SA and LMICs,[4,12,14,18] can be simply visualised with pie charts to identify locations with populations at high risk of contracting HIV (Fig. 2).[14] This may include populations with low socioeconomic status, multiple sexual partners or high rates of intergenerational sex.[14] HTS resources could then be directed to these areas for potentially high-yield testing. Interestingly, in CoJ Region D, ward 40 appears to be a target area based on socioeconomic status (Fig. 2) as well as population density of adolescent and young males (Fig. 1, B), suggesting that focused efforts to provide HTS to this area may well assist in supporting progress toward the first 90 target. In addition, more complex GIS techniques have been used in several African settings to identify clusters or hotspots where HIV prevalence is significantly higher than in surrounding areas,[8,13,15] which may also direct testing for higher yield by identifying locations where there are likely to be higher numbers of individuals living with HIV.

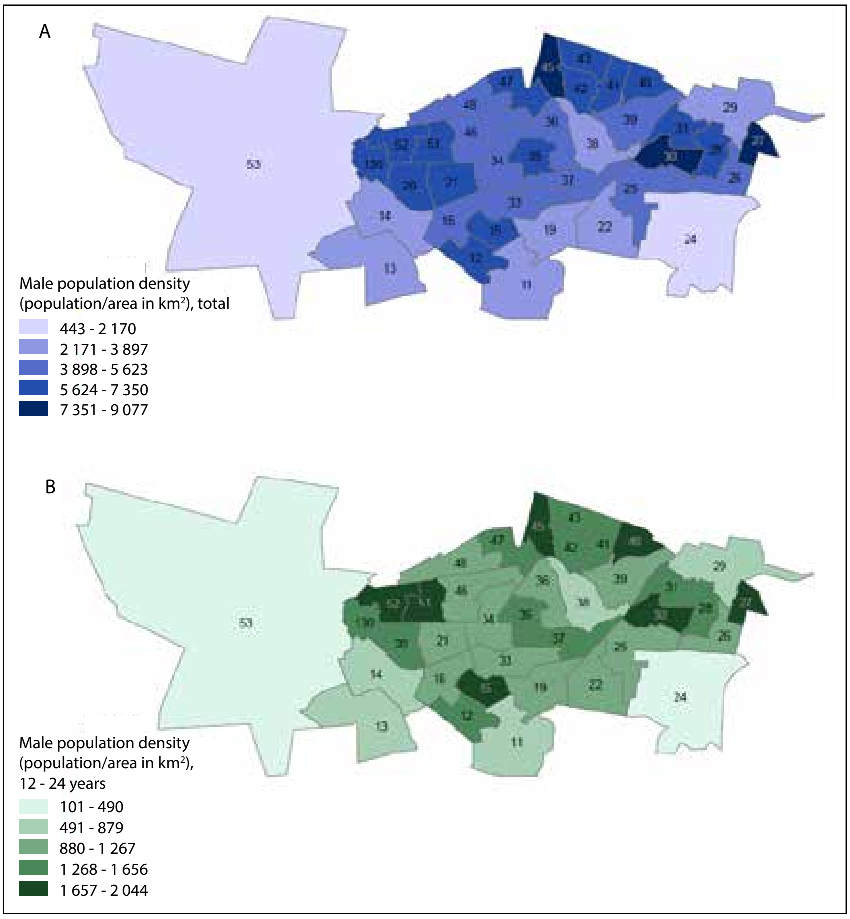

Fig. 1. Identifying the male target population for HIV testing in City of Johannesburg Region D. Population density (population/area in km^2) by ward for (A) the total male population and (B) male adolescents and youth aged 12 - 24 years (Census 2011 data[43]) (the numbers on the figure are the ward numbers). Wards 27, 30 and 45 have a high density of total males and male youth. Four additional wards (15, 40, 51 and 52) also have a high density of younger males and can be targeted for HIV testing services to reach this target group.

The application of GIS in the context of the first 90 would be largely at a programme level. Applications using individual-level data, for example plotting individuals who have undergone HIV testing, would only be of value with specific populations in small geographical areas and would therefore be of limited use in the context of the first 90, which focuses on higher-level population screening.

The second 90: 90% of people with diagnosed HIV infection on ART

Achieving the second 90% target by 2020 is likely to be a challenge in SA,[42] and closing the treatment gap will require implementation of well-considered and innovative strategies. A compelling example of how GIS can guide this process is presented in Fig. 3, where GIS analysis of routine data is used to identify geographical areas with large gaps in ART coverage. The first step in this process is to estimate the HIV-infected population by age and gender. This is performed by multiplying population data, available from Statistics South Africa,[43] by HIV prevalence data, which are publicly available from data sources such as the Thembisa model[44] or, in the case of other LMICs, from antenatal surveillance or demographic and health surveys. The number of HIV-infected individuals receiving ART by age and gender, obtained from routine monitoring and evaluation (M&E) data, can then be subtracted from the estimated HIV-infected population to calculate the programme gap, namely the number of HIV-infected individuals who are not receiving ART. By triangulating population and M&E data in this way, the specific age and gender group with the greatest programme gap can be identified. Population and ART data for the target group in individual wards can then be overlaid and mapped to visualise ward-level profiles (Fig. 3, B). These maps can be used to identify where the highest numbers of individuals who are missing from the ART programme are likely to be located, which in the case of CoJ Region D is wards 16, 33 and 37 for the male target group aged 30 - 39 years. Programme planners can thus strategically focus efforts to improve ART coverage in areas with the greatest need, including initiating community-based awareness campaigns and expanding clinic-based services into the community through mobile clinics and alternative ART distribution points. Spatial patterns of ART coverage can be monitored over time by updating ART data in the heat maps on an ongoing basis, thereby tracking progress of interventions.

In view of the recommendation for universal test and treat,[45] it is important to assess the proportion of the total HIV-infected population who are not receiving ART. This programme gap % can be calculated by dividing the programme gap by the estimated HIV-infected population.

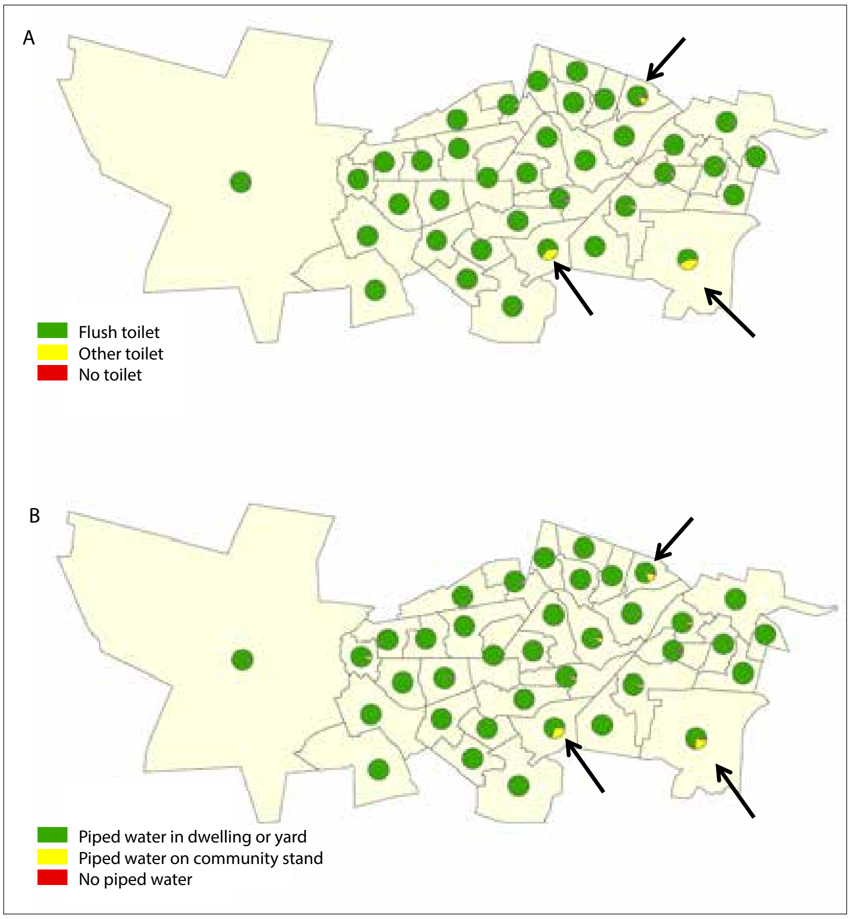

Fig. 2. Identifying potentially high-yield areas for HIV testing in City of Johannesburg Region D. Household access to (A) toilet facilities and (B) piped water by ward (Census 2011 data[43]). Wards 19, 24 and 40 (indicated by black arrows) have a lower proportion of households with flush toilets and in-dwelling or in-yard piped water and may be of lower socioeconomic status. Since low socioeconomic status is associated with an increased prevalence of HIV,[14] HIV testing services can be directed to these areas for potentially high-yield testing.

When overlaid with a heat map of the HIV-infected population, conclusions can be drawn regarding programme achievements in high-burden areas (Fig. 4). For example, in CoJ Region D, ward 11 has a large HIV-infected population among males aged 30 - 39 years with a very small programme gap %, indicating that only a small proportion of the HIV-infected population is missing from the ART programme. This suggests that the programme has been well managed and supported in this area. In contrast, other wards with large numbers of HIV-infected individuals have a large programme gap %, suggesting that these high-burden areas may benefit from further support. This GIS approach, which entails overlaying variables such as population estimates and programme performance, enables a nuanced approach to understanding performance of the ART programme in different areas.

GIS can further assist in supporting progress to the second 90% target by generating maps of population groups at high risk of attrition prior to ART initiation, such as males, adolescents and young adults.[46] Interventions targeting these groups for ART initiation, such as community-based adherence clubs or services over the weekend or after work and school hours, can then be planned in areas with high proportions of these populations where there is a large gap in ART initiation. In addition, geographical barriers to uptake of treatment that may contribute to poor ART coverage can be identified using GIS by visualising service utilisation together with geographical variables such as location of roads, villages and healthcare facilities. Identifying geographical barriers to uptake of services allows deployment of innovative alternatives, for example motorbikes in remote areas[47] or boats in island communities.[48]

In addition to programme-level applications, individual-level GIS analyses can also assist in guiding progress towards the second 90. Residences of individuals who test HIV-positive but are lost to treatment initiation can be mapped so that CHWs can perform home visits to link these individuals to care (sample map presented in Fig. 5; locations have been modified to protect patient confidentiality). This would not only be of clinical value for the individual patients, but would also serve to streamline CHW work and would inform programme planning by identifying areas with high numbers of individuals who are lost to initiation where community-dispensing points may be of benefit. In addition, maps can be used to identify HIV-infected individuals who live furthest from HIV clinics so that CHWs can proactively perform home visits to these high-risk individuals, as the odds of timeous ART access decrease with increasing distance from an HIV clinic, particularly for clinics located further from transportation hubs.[19,23] The distance between patient locations and HIV clinics can be calculated using Google Earth, precluding the need for advanced computer skills or expensive software,[23] and this approach would therefore be relatively easy to implement in LMICs.

The third 90: 90% of people on ART virally suppressed

The third 90 refers to viral suppression rates in individuals receiving ART. However, in line with a 'cascade approach' to treatment targets, this objective should encompass wider efforts to improve long-term retention in care, with sustained HIV treatment, ongoing viral load monitoring and interventions to promote treatment adherence.[3] Both retention in care and viral suppression rates can be calculated from routine M&E data and the spatial distributions visualised with heat maps (as in Fig. 3, B) to identify areas that require targeted interventions. Using GIS one can visualise whether geographical areas of poor retention overlap with areas of poor viral suppression, which interestingly has not been found to be the case, suggesting that different factors may be responsible for poor outcomes at different steps of the HIV care cascade.[21] GIS can also be used to visualise performance of individual healthcare facilities. In CoJ Region D, there are a number of facilities, located in the outer wards of the region, with viral suppression rates <90% (Fig. 6). Targeting poor viral suppression rates in these areas may involve campaigns for viral load testing and addressing factors underlying poor ART adherence – for example, running public information campaigns addressing beliefs in divine healing, preference for traditional medicine and doubts regarding the benefits and safety of ART, while providing clinical training to address poor patient-provider relationships.[49-51] It is also important for programme planning to identify areas with *high* rates of viral suppression, as individuals in these areas can be treated in the community to ease the burden on healthcare facilities. In addition to monitoring patterns of retention in care and viral suppression, GIS can be used to identify geographical barriers that may affect ART adherence, including infrastructure barriers such as inadequate transport.[52] Poor access to healthcare facilities as a result of transport challenges highlights areas for community-based interventions such as adherence clubs, alternative ART distribution points and deployment of mobile clinics.

Individual-level GIS analyses are highly beneficial in the context of the third 90. Mapping households of individuals with poor adherence or those who have defaulted from ART care would enable CHWs to perform home visits to provide intensified adherence counselling and linkage back to care (Fig. 5). Using these maps, clusters of defaulters can then be identified. Where clusters are located near healthcare facilities, possible problems with facility services should be investigated and addressed. In addition, households with high-risk individuals can be mapped for pre-emptive home visits by CHWs. High-risk individuals for poor viral suppression include those who are economically deprived,[26] while individuals living further from HIV clinics are at risk of poor adherence, as clinic distance is associated with missed clinic visits[27] and transportation costs compromise access to care.[53] CHWs can also use area maps to talk to individuals about where best to locate alternative points for ART distribution that may facilitate improved adherence.

Considerations for implementing GIS in routine settings

As illustrated above for CoJ Region D and summarised in Table 1, GIS has many practical applications in support of programme operations working towards achieving the 90-90-90 targets. When implementing this technology in routine settings, it is firstly important to consider the choice of GIS software. Open-source, web-based GIS systems can reduce obstacles to end-user access and display a high degree of learnability,[54] with web-based software that does not require specialised GIS skill having demonstrated potential for public health applications in LMICs.[55] Affordability has

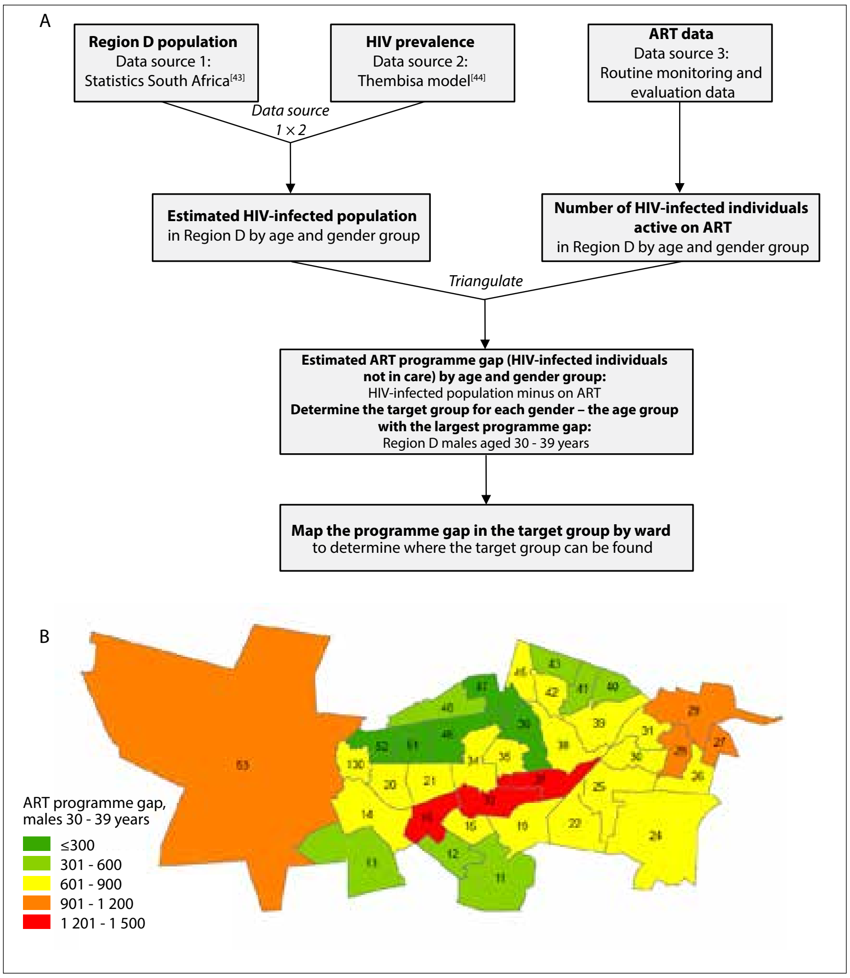

Fig. 3. Identifying wards with the highest gap in ART coverage in City of Johannesburg Region D. (A) Approach to calculating the ART programme gap in the HIV-infected population by ward. (B) Visual output of the ART programme gap by ward for the male target group aged 30 - 39 years clearly highlights that wards 16, 33 and 37 (in red) have the greatest gap in service coverage (the numbers on the figure are the ward numbers). (ART = antiretroviral therapy.)

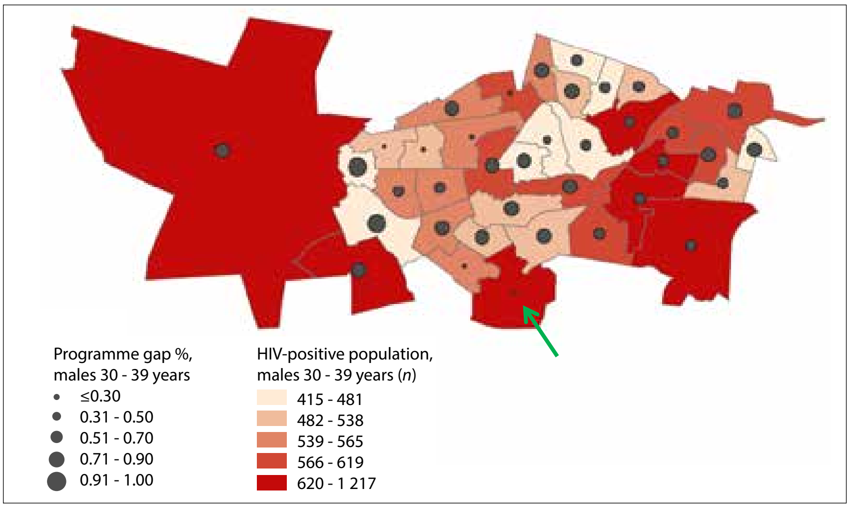

Fig. 4. Programme gap % (proportion of the HIV-infected population not in care) and the HIV-infected population by ward among males aged 30 - 39 years in City of Johannesburg Region D. Ward 11 (indicated by a green arrow) has a large HIV-infected population with a very small programme gap %, suggesting that the HIV programme has been well managed and supported in this high-burden area. In contrast, other wards in dark red with large numbers of HIV-infected individuals have a large programme gap % and may benefit from further support.

Table 1. Summary of potential applications of GIS to support achievement of the 90-90-90 targets

	Programme-level support applications	Individual-level support applications
First 90: diagnosis of 90% of people infected with HIV	• **Map population density of target groups that require improved access to HTS** to identify areas with a high density of these individuals for focussed HTS • **Map high-risk populations and/or risk factors associated with HIV infection** to identify potentially high-yield areas for delivery of focused HTS • **Map clusters or hotspots of HIV prevalence** to identify areas where there are likely to be higher numbers of HIV-infected individuals who can be identified through HTS	• **Limited use** – can map individuals who have undergone HIV testing to assess patterns of HTS uptake, but only in small geographical areas for specific populations
Second 90: 90% of people with diagnosed HIV-infection on ART	• **Visualise the spatial pattern of ART uptake** to identify areas with the greatest gap in care for targeted interventions. Overlay data from the ART programme with population data to provide a nuanced approach to understanding performance of the ART programme in high-burden areas • **Monitor spatial patterns of ART coverage over time** to assess progress of programme implementation and impact of interventions • **Generate maps of population groups at high risk of attrition prior to ART initiation** so that interventions can be planned in areas with a high proportion of these populations • **Visualise geographical barriers to ART coverage** that may contribute to poor treatment uptake, such as inadequate roads and long distances to clinics	• **Track patients who test HIV-positive but do not link to care** – map residences of these individuals to facilitate home visits by CHWs • **Streamline CHW work** by grouping visits to individuals who live in the same area • **Inform programme planning** by identifying areas with high numbers of individuals lost to initiation where community-based dispensing points may be of benefit • **Plan proactive household visits by CHWs** to HIV-infected individuals who live furthest from clinics to increase the likelihood of these high-risk individuals linking to care
Third 90: 90% of people on ART virally suppressed	• **Visualise the spatial distribution of retention in ART care and viral suppression** to identify areas with poor retention and/or suppression rates that require targeted interventions, such as viral load testing campaigns or addressing factors underlying poor ART adherence • **Identify areas with high rates of viral suppression** where patients can be treated in the community to ease the burden on healthcare facilities • **Visualise facility-level viral suppression rates** and assess whether facilities with poor performance cluster in certain areas • **Identify geographical barriers** that may affect ART adherence, including infrastructure barriers	• **Track patients who have defaulted from ART care or those with poor adherence** – map residences of these individuals so that CHWs can perform home visits to provide intensified adherence counselling and re-linkage to ART care • **Identify ART facilities with potential service problems** by identifying facilities around which there are clusters of individuals who have defaulted from care • **Plan pre-emptive home visits by CHWs to high-risk individuals** who are likely to have compromised ART adherence or viral suppression • **Plan locations for alternative ART distribution points** by using area maps to talk to individuals about where best to locate these services, thus facilitating improved adherence

GIS = geographic information systems; HTS = HIV testing service; ART = antiretroviral therapy; CHW = community health worker.

become less problematic over time, with the availability of free or inexpensive GIS software and easy mapping of point locations with inexpensive global positioning systems and/or mobile phones.[56,57] Secondly, the poor quality of routine M&E data, lack of unique patient identifiers and deficit of GIS data in some LMICs must be considered, in particular the availability of patient addresses for individual-level GIS applications. It is important to bear in mind that the definition of a patient address is multifaceted, as locations of work, sleep and family residence may vary, and that there may be no street names in rural settings for reporting patient addresses. Thirdly, it is essential to ensure confidentiality of individual-level patient data, particularly when using free web-based software.[34,58] Finally, stakeholders may prove challenging if there is a lack of understanding regarding what GIS can deliver and how to interpret the outputs. Obtaining buy-in from stakeholders may also be difficult where there are concerns regarding transition from paper-based systems, misuse of information or political interference.[54,58] It is important to address buy-in from the start and to provide adequate training for capacity development of local staff to ensure sustainable systems.[56]

Conclusions

GIS has great potential to assist in achieving the 90-90-90 targets in SA and other LMICs and is currently being under-utilised for this purpose. This article demonstrates opportunities for using easily accessible resources to generate GIS visualisations and underlines the important benefits GIS can have in guiding HIV programme operations, the principles of which can be applied to any infectious disease. GIS can be incorporated into routine programme planning by visualising the spatial distribution of programme implementation gaps and impact of interventions. Individual-level analyses are of clinical value for

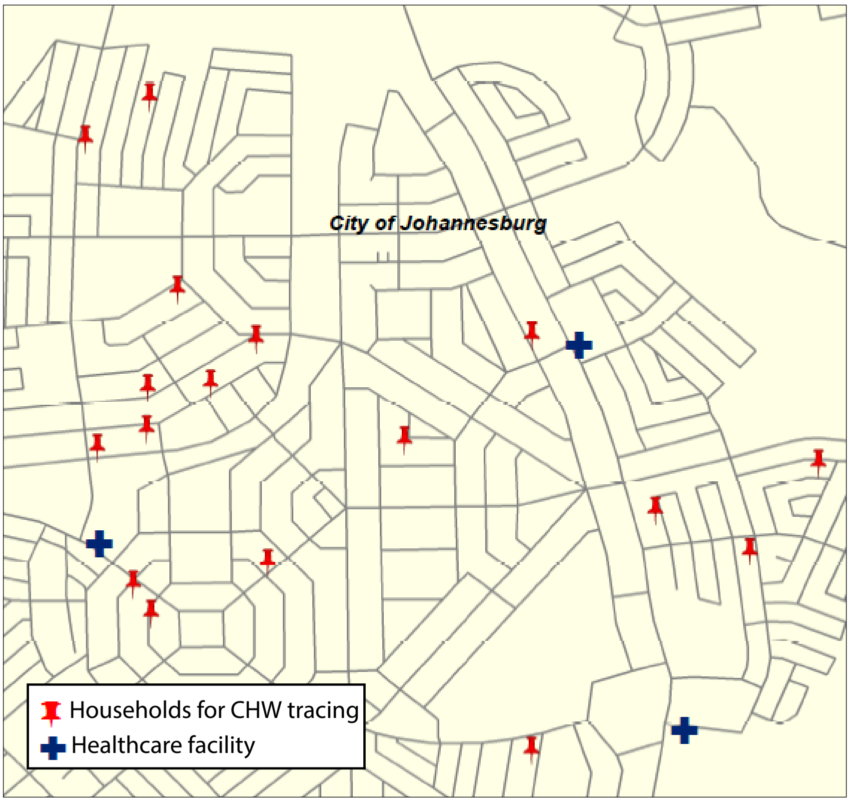

Fig. 5. Residences of HIV-infected individuals living in City of Johannesburg Region D who require home visits by CHWs (locations have been modified to protect patient confidentiality). Residences of HIV-infected individuals who are lost to treatment initiation or lost to follow-up from care can be georeferenced to generate maps that CHWs can use to perform home visits. (CHW = community health worker.)

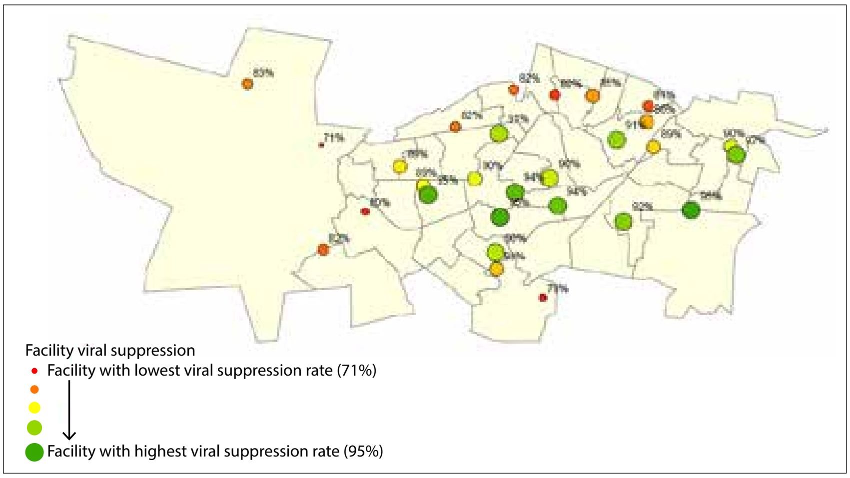

Fig. 6. Viral suppression rates at primary healthcare facilities in City of Johannesburg Region D. Facilities in red and orange with lower viral suppression rates, located around the outside of the region, should receive targeted interventions to improve progress towards the third 90% target.

patients and can also guide programme-level decisions. Interactive, dynamic systems using inexpensive GIS software may therefore prove a valuable tool to support control of the HIV epidemic in SA.

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Conflicts of interest. None.

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