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# Geospatial Planning and the Resulting Economic Impact of Human Papillomavirus Vaccine Introduction in Mozambique

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## Abstract

**Background—**Research has shown that the distance to the nearest immunization location can ultimately prevent someone from getting immunized. With the introduction of human papillomavirus (HPV) vaccine throughout the world, a major question is whether the target populations can readily access immunization.

**Methods—**In anticipation of HPV vaccine introduction in Mozambique, a country with a 2015 population of 25,727,911, our team developed Strategic Integrated Geo-temporal Mapping Application) to determine the potential economic impact of HPV immunization. We quantified how many people in the target population are reachable by the 1377 existing immunization locations, how many cannot access these locations, and the potential costs and disease burden averted by immunization.

**Results—**If the entire 2015 cohort of 10-year-old girls goes without HPV immunization, approximately 125 (111–139) new cases of HPV 16,18-related cervical cancer are expected in the future. If each health center covers a catchment area with a 5-km radius (ie, if people travel up to 5 km to obtain vaccines), then 40% of the target population could be reached to prevent 50 (44–55) cases, 178 (159–198) disability-adjusted life years, and US $202,854 (US $140,758–323,693) in health care costs and lost productivity. At higher catchment area radii, additional increases in catchment area radius raise population coverage with diminishing returns.

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**Conclusions—**Much of the population in Mozambique is unable to reach any existing immunization location, thereby reducing the potential impact of HPV vaccine. The geospatial information system analysis can assist in planning vaccine introduction strategies to maximize access and help the population reap the maximum benefits from an immunization program.

With the introduction of human papillomavirus (HPV) vaccine throughout the world, a major question is whether the target populations in each country can readily access immunization locations. As of September 2016, 67 countries had introduced the HPV vaccine fully into their national immunization schedules,[1] with more low-income and middle-income countries projected to introduce it by the end of the decade.[2] However, 3-dose coverage for the vaccine has ranged from 17% to 92%, with low coverage present even in high-income countries and often dependent on the delivery strategy for vaccination.[3,4] Immunization uptake depends on several factors including travel distance to health centers. As research has shown, distance to the nearest immunization location can ultimately prevent someone from getting immunized.[5] The World Health Organization defines “health services access” as the proportion of a population living within 5 km of a health center,[6] suggesting that people living more than 5 km away from immunization locations may not be able to access the vaccinations they need. In many health systems, the locations of such centers are not strategically placed to optimize access for the population. Decision makers may prioritize political considerations above optimal access.[7] Facilitating the maximum benefits of current and future routine immunization schedules requires addressing the issue of vaccine access.

In anticipation of HPV vaccine introduction in Mozambique, where cervical cancer is the most common cancer in women,[8] our team developed Strategic Integrated Geo-temporal Mapping Application (SIGMA) to determine the potential economic impact of immunization against HPV 16 and 18 using bivalent vaccine. We quantified how many people in the relevant target population are reachable by existing immunization locations in Mozambique, how many are not likely to access these locations, and the potential costs and disease burden averted by immunization.

## MATERIALS AND METHODS

### SIGMA Model of Mozambique HPV Immunization

We developed SIGMA for Immunization, a geospatial information system (GIS), to quantify how many people in the HPV target population are reachable by existing immunization locations in Mozambique and how many cannot access these locations. A previous publication describes our SIGMA platform in greater detail.[9] The SIGMA model of Mozambique mapped population density data from the Global Rural-Urban Mapping Project,[10] which contains the estimated density of the Mozambique population living in each square km for 2000, projected to the 2015 population of 25,727,911[11] assuming a uniform growth rate. The total population was scaled to the population of 10-year-old girls, the target population for HPV immunization in Mozambique Ministry of Health pilot activities who comprise approximately 2.1% of the total population in Mozambique.[12]

Using geospatial coordinate data from the Mozambique Ministry of Health, the SIGMA model plotted all 1377 health centers that serve as routine immunization locations for the World Health Organization Expanded Program on Immunization in Mozambique. Each immunization location has a corresponding catchment area which represents the surrounding geographic area the location can serve. The catchment area radius can be thought of as the maximum distance some people would need to travel to access vaccines. SIGMA overlaid the catchment areas for all immunization locations onto the geospatially explicit population data for 10-year-old girls to determine the number of people in the target population that the existing health centers can reach. Due to uncertainty around the actual reach of each health center, sensitivity analyses systematically tested a range of catchment area radii. To assess how feasible it may be for the entire population to reach health centers, experiments also determined the area the health centers would need to cover to immunize at least 99% of the target population.

## Disease Burden and Costs

For each catchment area radius scenario tested, we calculated the number of people in the target population who lived within any health center's catchment area. We then computed the estimated number of HPV 16,18-related cervical cancer cases that could be prevented by vaccines in a cohort of 10-year-old girls (Formula 1) and quantified the disability-adjusted life years (DALYs), health care costs, and societal costs (due to lost productivity) averted.

$$\text{Vaccine- prevented cases} = \text{target population within catchment area} \times \text{vaccine efficacy} \times \text{disease risk}.$$

We identified several studies on the economics of HPV in Sub-Saharan Africa[13–15] and chose to base our estimates on work by Goldie and colleagues[16] as it provided aggregated cost estimates for Mozambique that were inclusive of all medical care costs incurred by the disease, adjusted for the proportions of people experiencing different levels of severity of the disease (stage I–IV). Because these costs were originally reported for 2005, we used World Bank gross domestic product deflator estimates for Mozambique between 2005 and 2015 to inflate the costs to 2015.[17] We report costs in 2015 USD. Estimates of DALYs averted from HPV immunization also came from Goldie and colleagues and use a discount rate ($r$) of 0.03 with no age weighting.[16] HPV vaccine efficacy is assumed to be 100% against HPV types 16 and 18,[16] with unprotected individuals developing HPV 16,18-related cervical cancer at a rate of 23 (16–30) per 100,000 at-risk individuals.[8,18] Each case of HPV-related cervical cancer incurs US $1,792 (US $896–US $3584) in health care costs in 2015 US dollars,[16] US $2296 in productivity losses (based on a US $639 GNI per capita[19]), and 3.6 DALYs.[16] The health care cost per case represents the average costs for screening and treatment of HPV-related cervical cancer (stages I–IV). Appendix A, http://links.lww.com/OLQ/A151 contains further details about these inputs and their sources.

# RESULTS

## Impact of HPV Vaccine Introduction in Mozambique

If the entire 2015 population of 10-year-old girls goes without HPV immunization, approximately 125 (range, 111–139) new cases of HPV-related cervical cancer are expected over the lifetime of this cohort. These cases translate to 449 (399–499) DALYs and US $224,002 (US $99,533–497,005) in health care costs, and US $286,983 (US $255,034–318,372) in lost productivity. Figure 1 summarizes the impact of HPV immunization under various catchment area radii.

If each health center covers a catchment radius of 3 km, administering HPV vaccine to a cohort of 10-year-old girls could prevent 19 (17–21) new cases, 68 (60–75) DALYs, $33,901 (US $15,064–75,218) in health care costs, and $43,433 ($38,598–$48,183) in productivity losses. This catchment area size would cover only 15% of the target population. A catchment area radius of 5 km would cover 40% of the target population and could prevent 50 (44–55) cases of HPV-related cervical cancer annually, thereby averting 178 (159–198) DALYs, US $88,926 (US $39,513–197,304) in health care costs, and $113,928 (US $101,245–126,389) in productivity losses in the cohort.

If each health center can instead cover a catchment area with a radius of 7 km, then 49% of the population would be reachable. This scenario could prevent 61 (54–68) cases in the cohort and avert 220 (196–244) DALYs, US $109,846 (US $48,809–243,720) in health care costs, and US $140,730 (US $125,063–156,122). A catchment area radius of 15 km would cover 82% of the target population and could prevent 102 (92–113) cases in the cohort and avert 367 (326–407) DALYs, US $182,744 (US $81,200–405,464) in health care costs, and US $234,125 (US $208,060–259,732) in lost productivity.

## Potential Impact of Widespread HPV Immunization in Mozambique

At higher catchment radii, each additional increase in catchment area radius raises population coverage with diminishing returns. A 20-km radius would reach 91% of the target population to potentially prevent 114 (102–127) cases, 411 (365–456) DALYs, US $204,847 (US $91,021–454,504) in health care costs, and US $262,442 (US $233,224–291,146) in productivity losses in the cohort. A 30-km radius is required to reach 98% of the population, and a 35 km would cover 99% of the population. In the 2015 cohort, 99% coverage could prevent 124 (110–137) cases, 445 (395–494) DALYs, US $221,756 (US $98,535–492,021) in health care costs, and US $284,105 (US $252,476–315,179) in lost productivity. Figure 2 displays SIGMA visualizations of a sample of catchment area radius scenarios, showing where some less densely populated areas are not reachable even at high catchment area radii.

# DISCUSSION

Our study suggests that depending on how far girls are willing and able to travel to receive HPV vaccination, a substantial proportion of the target population may not have ready geographic access to immunization. Although “willingness to travel” may vary, existing studies imply that 35 km would be well beyond the travel distance limits of most people in

Mozambique, where distance to health centers is a major cause of low immunization coverage.[20] Given the proposed HPV immunization schedule in Mozambique,[12] each member of the target population would be required to make three visits to an immunization location to receive all recommended doses of the vaccine. After piloting HPV immunization in select districts beginning in 2013,[21] training for immunization program staff to scale up HPV immunization commenced in 2014.[22] For these activities to achieve the greatest potential impact, geospatial access should be an important part of planning for the introduction.

Geospatial applications can be invaluable tools for planning and evaluating immunization activities by allowing health workers to decide the most effective locations for health facilities, generate more accurate maps of catchment areas, and plan more efficient vaccination routes. The GIS data can provide additional insight into trends in disease burden (dot density maps) and vaccine coverage by location (thematic maps).[23] Immunization workers in resource-limited settings often use hand-drawn maps, which rely on local knowledge and usually do not reflect the spatial relationship between major landmarks.[24] Additionally, this kind of mapping is not conducive to locating households in high-density, urban areas given overcrowding and the lack of a formal grid structure in many areas. Another complication arising from a reliance on hand-drawn maps is that the boundaries on these maps often do not match between districts, potentially omitting households on the border from vaccination activity plans. Despite the ability of geospatial data to address these issues, implementation in low-income countries with poor immunization coverages remains limited. The costs associated with adopting proprietary geospatial applications and training health workers to have the requisite knowledge and skills needed to effectively use them may be contributing to delayed introduction in resource-constrained settings.[23] Accessible, user-friendly tools are needed to help decision makers perform geospatial analyses to improve their systems. Such tools should be flexible enough to work with different degrees of data availability. For example, our analysis mapped catchment areas based on straight-line distances, but additional data would allow SIGMA to take into account regional differences in geography and available transportation methods.

As one of the most common sexually transmitted infections in the world, HPV is responsible for many—largely preventable—diseases, including anogenital warts and cancers of the cervix, vagina, vulva, penis, anus, and oropharynx, which often place a substantial burden on health systems. The HPV vaccine has been highly effective at reducing the prevalence of oncogenic HPV serotypes contributing to these cancers in many populations, even in the presence of below target-level immunization coverage.[25] The population-level impact of female HPV vaccination, based on available country-level incidence and prevalence, has been estimated to have reduced HPV 16 and 18 infections by 68%.[26] However, these significant reductions were only achieved in settings with at least 50% coverage, underscoring the importance of increasing access to HPV immunization. While this study did not take into account the effects of herd immunity, future modeling may incorporate this aspect to further explore the impact of achieving various coverage levels in a population. Trends in HPV vaccination and coverage have supported both the vaccine's effectiveness and its cost-effectiveness, with studies demonstrating high cost-effectiveness in a majority of countries worldwide when compared with gross domestic product per capita and when compared with existing cervical cancer screening programs.[27,28]

Data have shown that HPV coverage rates have fallen short of targets after introduction in some countries. A number of factors that this study did not take into account, but could be included in future analyses, may be impeding uptake such as the high cost of the vaccine in settings without public vaccination support.[3,29] Although less access to health care is certainly a determinant of low coverage, the low level of information on HPV in the public sphere has been linked to increased cervical cancer incidence, a consequence of high-risk HPV infection. (Appendix B, http://links.lww.com/OLQA/152).[30, 31s, 32s] Parents often make the decision to vaccinate based on information from their health providers, with a strong provider recommendation being the key determinant of the choice to immunize.[29, 33s, 34s] Negative attitudes and beliefs, as well as trust in the efficacy of the vaccine, also influence this decision.[29, 35s, 36s] Finally, the delivery infrastructure for HPV as an adolescent vaccine is often dependent on the setting, with health facility-based or school-based mechanisms differing in their cost and effectiveness.[4, 37s, 38s] Without further investigating the population to be targeted, vaccination programs face difficulties in identifying and covering those eligible for immunization. Therefore, it is important that geospatial access is not an additional obstacle. Further modeling to evaluate strategies to increase access to immunization, such as new health facilities and outreach activities, can help identify impactful and cost effective ways to improve immunization coverage.

## CONCLUSIONS

Each year, Mozambique experiences new cases of cervical cancer that could have been prevented by HPV immunization. Introducing HPV vaccine in Mozambique could avert significant disease burden and costs. However, much of the target population is not able to reach any existing immunization location, thereby reducing the potential impact of this vaccine if geospatial access to immunization does not improve, particularly in rural areas. GIS analysis can assist in planning vaccine introduction strategies to maximize geospatial access and help the population reap the maximum benefits from an immunization program.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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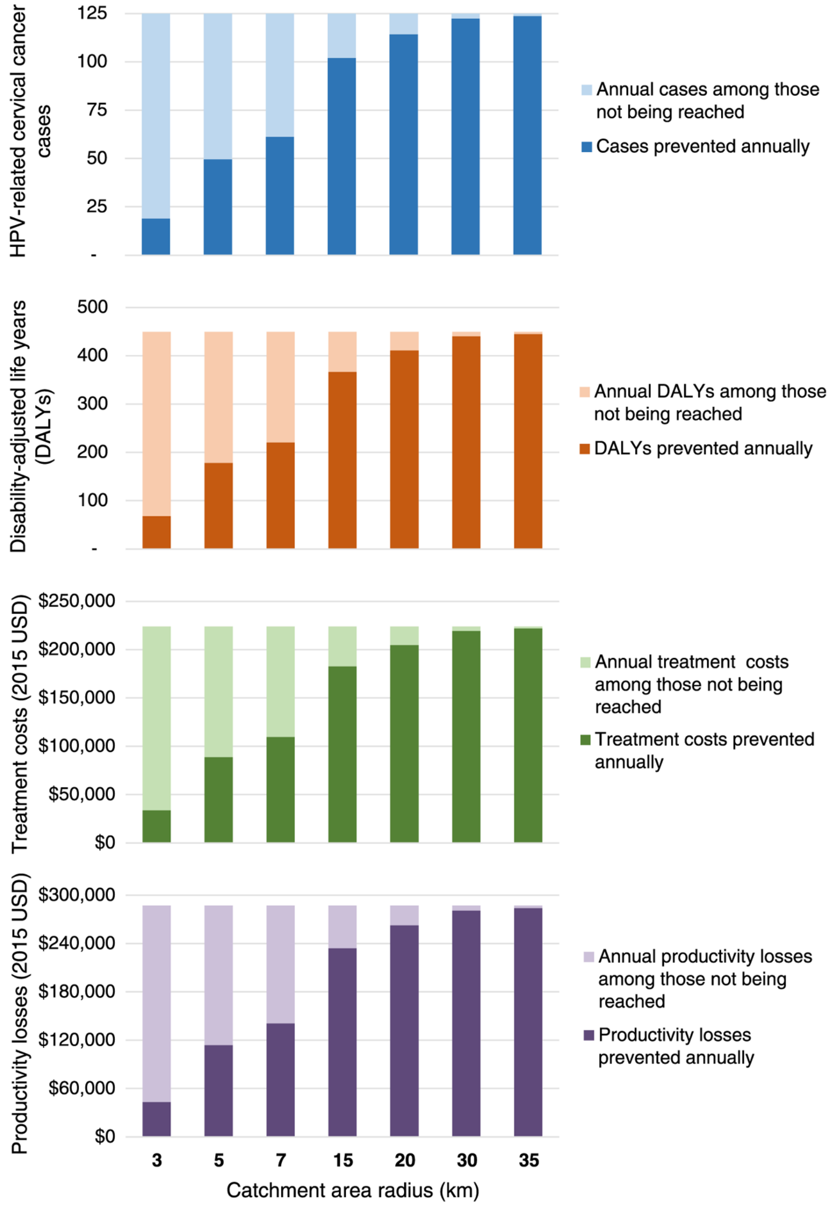


**Figure 1.**

Potential disease and economic impact of HPV immunization.

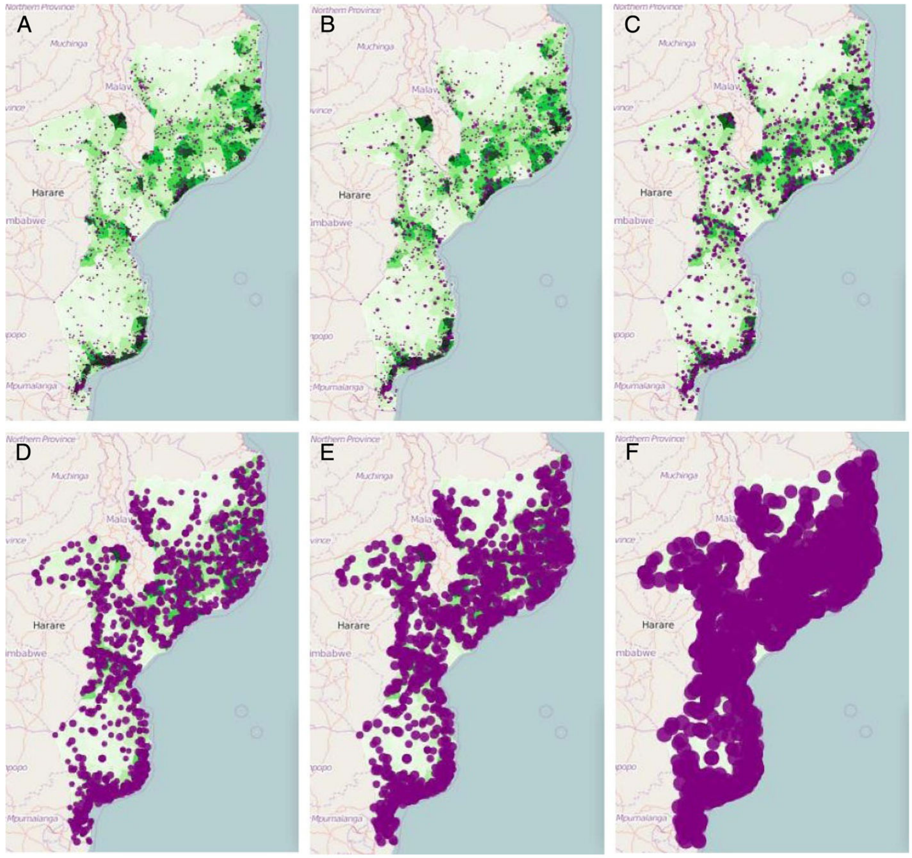


**Figure 2.**

SIGMA visualizations of immunization location catchments with progressively larger HPV catchment area radii. Purple circles represent each HPV immunization location and its catchment area. The underlying green shading represents the HPV target population density, with darker green representing greater density. Any green areas not covered by a purple circle are thus not currently reachable by an HPV immunization location. Each figure represents a different HPV immunization location catchment area radius: (A) 3 km, (B) 5 km, (C) 7 km, (D) 15 km, (E) 20 km, and (F) 35 km.