THE IMPACT OF THE VACCINE SUPPLY CHAIN ON THE SOCIOECONOMIC STATUS OF REGIONS IN NIGER

by

Brigid E. Cakouros

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This thesis was presented

by

Brigid E. Cakouros

It was defended on

April 19, 2012

and approved by

Thesis Advisor:
Jessica G. Burke, PhD
Assistant Professor
Department of Behavioral and Community Health Sciences
Graduate School of Public Health
University of Pittsburgh

Committee Member:
Steven J. Albert, PhD
Professor and Department Chair
Department of Behavioral and Community Health Sciences
Graduate School of Public Health
University of Pittsburgh

Committee Member:
Bruce Y. Lee, MD, MBA
Associate Professor
Departments of Medicine, Epidemiology and Biomedical Informatics
School of Medicine and Graduate School of Public Health
University of Pittsburgh

Jessica G. Burke, PhD

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Brigid E. Cakouros, MPH

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The link between low socioeconomic status and limited access to vaccines has been established in both developed and developing nations. Access to vaccines can be hindered in two ways: the population not utilizing available services, and immunization locations not offering enough vaccine to supply the demand. In the ecological framework of an immunization program, this point is critical to understand in order to assess the current national immunization program.

This study aimed to understand if the way the vaccine supply chain (i.e., the ordered system in which vaccines travel from the manufacturer to the clinics) is currently designed could be reflecting socioeconomic conditions of Nigeriens through three main measures: vaccine availability, socioeconomic status, and vaccine coverage. Consistently ranked one of the poorest nations in the world with a high burden of disease, it is vital to understand if the immunization program in Niger is functioning to its best ability to ensure resources are being adequately utilized. Vaccine availability determined the ratio of available vaccine to the demand of the population to be vaccinated. Socioeconomic status was determined by a multi-faceted measure that encompassed the state of poverty in Niger. Vaccine coverage represented the percentage of the vaccine-eligible population that actually was vaccinated.

Results indicate that most regions have vaccine availability much higher than the vaccine coverage; therefore, the supply chain is not hindering access to the vaccines by not supplying

adequate amounts of vaccines. For those that presented coverage higher than availability, evidence demonstrates that private health providers are most likely influencing the pattern and accessibility of immunization sessions. Regions did not experience lower vaccine availability based on socioeconomic status; in fact, although coverage rates were indeed lower in regions of lower socioeconomic status, these regions had the highest availability. This study demonstrates the public health significance of understanding an immunization program from all levels of supply and demand within a country in order to make the best use of the resources available.

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PREFACE

I would like to thank Dr. Burke, Dr. Albert and Dr. Lee all for their support during my time as a Master's candidate at the University of Pittsburgh. Dr. Burke helped to initially light my spark of interest in the field of public health dynamics modeling, and Dr. Albert and Dr. Lee both gave me opportunities to explore and apply such research methods. Working with the Vaccine Modeling Initiative gave invaluable exposure to the field of global health, and between the engineering, computer science, and public health teams, I have learned much beyond the classroom. I am grateful to have been in a graduate program filled with talented and dedicated colleagues, and I would consider myself lucky to work with such professionals throughout my career. Finally, many thanks to my parents and siblings for being there to listen throughout this process.

1.0 INTRODUCTION

Immunization is considered one of the most cost effective ways to save lives and prevent disease[1]. The Expanded Program on Immunization (EPI), developed by the World Health Organization in 1974, was designed to provide access to life-saving vaccines for all children worldwide. Vaccines today remain at the frontline of the battle against communicable disease in many low income countries and offer the more financially sound alternative of preventing, rather than treating, disease. Concerns such as diarrheal disease, pneumonia, and meningitis finally have answers in the form of vaccines, and some of these answers are even fully funded to lower the economic burden of introduction. Although these advancements in vaccinology are important healthcare milestones, there remains one aspect that is critical to the successful application of these advancements: access to vaccines. It is estimated that one third of the world's population does not have regular access to vaccines[2].

Access can adopt numerous definitions and be measured in multiple ways. In the most basic sense, access refers to a person's capability to obtain and properly utilize health services[2]. In regards to vaccines, access encompasses the ability to receive necessary immunizations in a timely manner. Although there are many factors affecting vaccine access, there are two basic yet critical steps that must occur in order to vaccinate the population. First, vaccines need to be available at clinics to supply the demand. National vaccine supply chains operate to deliver vaccines from the manufacturers down to the clinic levels, predicting the necessary shipment size needed to reach the clinic level based on the size of the population a clinic serves. Second, the population needs to arrive to the clinic to get vaccinated. The link between low socioeconomic status and vaccination uptake has been established[3, 4]. Areas of lower socioeconomic status tend to have lower rates of health seeking behaviors. In the context of a developing nation that is assumed to be uniformly poor, health disparities still exist among regions of varying poverty status[5]. Niger is such a country. Niger is ranked as one of the poorest countries in the world, and a majority of Niger lives in extreme poverty. However, understanding regional differences in poverty in relation to vaccine availability could help better focus efforts to immunize more of the population.

The aim of this study is to better understand the relationship between the vaccine availability (as measured by the available vaccines offered at clinics to meet the population demand) with vaccine coverage (as measured by the percentage of the population vaccinated) at the regional level in Niger. Is the way the vaccine supply chain currently structured potentially exacerbating regions of lower economic status, therefore further impacting health disparities by affecting vaccine coverage? This study will help stakeholders understand the relationship between availability and coverage in Niger, and can offer evidence to support potential changes to the vaccine supply system that will maximize the opportunity to vaccinate.

2.0 LITERATURE REVIEW

2.1 VACCINE PREVENTABLE DISEASE

The first step to understanding a vaccination program is to understand the burden of vaccine preventable disease (VPD.) It is estimated that 17% of deaths of children under five years old is attributable to disease that could have been prevented by vaccination[6]. Such diseases include diphtheria, measles, tetanus, rotavirus, and yellow fever, to name a few. Some diseases, such as maternal tetanus, polio, and measles, have specific goals of eradication.

The burden of such disease is different per country. Vaccine uptake plays a large part, but there are other factors impacting control of these diseases. Geography, seasonal patterns, overcrowding, migration, and potential genetic differences play an important role in determining disease control. Some diseases are spread through respiratory infection, others through blood contact. Some are transmitted from human contact and others are vector-born. Control of each of these diseases in each country should adopt plans that encompass numerous factors. For example, hepatitis B control varies between Southeast Asia and sub-Saharan Africa. In Southeast Asia, it is usually transmitted vertically, or from an infected mother to her child during pregnancy or delivery. However, in sub-Saharan Africa, hepatitis B is usually transmitted horizontally, or by a means other than mother-to-child or sexual contact. Often, this can be spread from child to child when one child is unknowingly infected[7].

Sub-Saharan Africa accounts for a high percentage of the burden of disease attributable to VPD. 58% of pertussis deaths, 41% of tetanus deaths, 59% of measles deaths, and 80% of yellow fever deaths occur in this region of the world[8]. Estimating such numbers can be difficult, as countries all have different methods of disease reporting and surveillance; however, the pattern of high rates of these diseases remains consistent across the region. S trong immunization programs have the ability to help control such disease. Smallpox eradication is one of the strongest testaments to the need of strong immunization programs supplemented by substantial campaigns that catch "missed opportunities," those patients that miss vaccination opportunities offered by a clinic. Other efforts, such as measles and polio, are modeled after the success of smallpox eradication campaigns[9]. However, the strongest force against VPD lies in the success of a national immunization schedule guided by ways to control and prevent outbreaks.

2.2 THE EXPANDED PROGRAM ON IMMUNIZATION

The Expanded Program on Immunization (EPI) was established in 1974 by the World Health Organization with the goal of providing all children access to life saving vaccines to prevent and control vaccine preventable diseases. It was modeled after the success of smallpox eradication campaigns[9]. The EPI originally targeted diphtheria, tetanus, pertussis, measles, polio and tuberculosis. Other vaccines have since been added, including hepatitis B and Haemophilus influenza type b (Hib.) Although the EPI varies by country, the eight vaccines listed above are the basic requirements of most national policies. In addition, some countries have region specific vaccines, such as yellow fever and Japanese encephalitis.

Over the years, advancements in research have combined many of these vaccines, such as the commonly used trivalent DTP (protecting against diphtheria, tetanus, and pertussis in a 3 dose vaccine.) The coverage rate for three doses of DTP is also the most common measure of a vaccine program across the globe. The EPI supports each country to developing its own vaccination delivery system according to the ongoing health conditions of that country[9]. The core EPI vaccines should all be administered in the first year of life. While this can be expensive, UNICEF has been critical in the negotiation of acquiring vaccines at lower prices.

The Global Immunization and Vision Strategy (GIVS) is a framework developed by the World Health Organization and UNICEF in order to help countries outline stronger immunization plans. This ten year strategy has four main goals: to immunize more people, to introduce new vaccines, to integrate immunization into other health interventions, and to help countries be able to manage vaccine programs independently. In addition, GIVS can help develop regional vaccine programs within countries in order to better supply specific areas that need attention[10].

Aside from creating vaccination schedules, the intent of the EPI is also to supply cold chain equipment (refrigerators, freezers, cold rooms, vaccine carriers, etc.) in order to ensure the safety of vaccines traveling through the system. In developing countries this was a challenge. Issues such as fickle power sources, unreliable road conditions, and limited storage capacity existed in nearly every setting in every country. However, WHO and UNICEF developed ways to finance the purchase and allocation of such equipment[9]. Just as UNICEF's purchasing power helped to obtain vaccines at reasonable prices, this was true with equipment.

As the EPI continues to adapt to new technologies, emerging diseases, and shifting health trends, it is important to be able to make educated decisions affecting the supply chain in order to control health outbreaks and epidemics. Vaccine supply chains include all of the people, equipment, and activities that must harmoniously work together in order to deliver vaccines from the producer to the patient[11]. People involved include everyone from the Ministry of Health to the health worker delivering vaccines; equipment encompasses cold rooms and hand-held vaccine carriers; activities include both delivering vaccines to locations and administering doses to patients. Temperature control is a critical step to ensuring proper vaccine delivery. Originally, the cold chain was created to keep vaccines between the recommended temperature of 2-8˚C. However, recent studies show that exposure to freezing temperatures along the supply chain is becoming just as much a problem as heat[12, 13].

Predicting adjustments to the supply chain that would be needed in situations such as vaccine introduction, vial size change, additional space needed, and changes in supply routes, among others, is challenging. Fortunately, modeling public health dynamics through equation-based and computational models has produced better means of analyzing such changes. Utilizing a computational model to evaluate changes to the vaccine supply chain can help capture more of the counterintuitive effects that take place or would otherwise be unaccounted for with a single equation-based model. Such models are country specific and usually constructed with real data from the ground, so outputs are quite reliable. Computational models of the supply chain can evaluate existing supply chain functions and strengthen the EPI, evaluate the impacts of adjustments to the supply chain before implementation, and create evidence for policy interventions regarding necessary supply chain refinement[14]. These computer models of the vaccine supply chain, built specifically to simulate real-life complexities, grant policy makers the ability to determine the best way to supply an immunization program.

2.3 THE SOCIAL ECOLOGICAL FRAMEWORK

Vaccine coverage rates reflect a multitude of factors that influence why a person would chose to be vaccinated. From the government deeming what vaccines are included in the national immunization plan and the clinic managers determining what days they will be open to parents accepting the vaccine, it is important to understand how each level affects the overall vaccine coverage in order to determine where to best intervene to increase vaccine uptake.

The social ecological model encompasses influences from numerous levels within a systems theory approach. All levels affect one another either directly it on a cyclical patter. The theoretical model states that behavior is influenced at five different levels: intrapersonal, interpersonal, institutional, community, and public policy[15]. Characteristics at the intrapersonal level include (but are not limited to) knowledge, skills, self-image, personal history; at the interpersonal level include relationships with family, friends, and coworkers; at the institutional level include organizations and structures such as type of employment and neighborhood surroundings; at the community level include places such as community centers and churches, and how they work in a network; at the policy level include the regulatory policies and laws in place to protect the health of the population. The four core principles of the ecological perspective state that there are multiple influences on health behavior, that these influences occur across all levels, the model is most effective when designed for a specific behavior with relevant potential influences identified at each level, and that interventions crossing multiple levels are the most effective[15].

There are limited resources linking the social ecological model to an entire immunization program. Research tends to focus on individual levels; however, studies rarely capture the interaction between multiple levels within the model[16]. Models, such as the Mosley and Chen framework for child survival, focus on the attributes of the caregiver, household and community [17]. While these influences are of major importance to immunization uptake, it offers a limited view of the social ecological framework.

One study in Nigeria outlined the factors influencing acceptance and uptake of the Bacille Calmette-Guérin (BCG) vaccine in regards to an ecological model[3]. B CG is the vaccine given at birth to protect an infant against tuberculosis infection. Nigeria's average BCG coverage rate is 18.1%, while the regional coverage rates range from 6.2% to 29.6%. Researchers applied the five levels of influence in regards to vaccination in Nigeria as:

- Intrapersonal: individual child characteristics (gender, place of birth, family order)
- Interpersonal: parental and household factors (education, immunization acceptance, prenatal care)
- Institutional: community characteristics (neighborhood dynamics and social norms)
- Community: service delivery factors (location of health clinics and availability)
- The immunization policy environment of Nigeria (national program goals)

The goal of this study was to understand what influenced a child to be immunized and utilized data from in-country surveys. As an infant does not make the decision, the strongest influences were in regard to maternal knowledge about immunization, paternal approval, and social influence. Vaccine supply and location of residence were strong indicators as well, emphasizing the need to intervene in immunization programs at multiple levels for the best results[3]. Other studies emphasize the importance of demographic influences on vaccine uptake, likewise using data from survey[5, 18, 19]. A study in particular out of Tanzania challenged the notion of "homogenous socioeconomic status" in rural, low-income African villages. Findings detailed that care-seeking behavior is still varied among this level, and successful interventions need to take multiple measures of poverty and well-being into account[20].

2.4 "AFRICANIZATION" OF THE DEMAND FOR HEALTH

Health economist Michael Grossman changed the notion that health was only determined by inputs related directly to medical care. His research emphasizes that "good health" is actually a demand of consumers and is determined by a consumer's specific demand is determined by economic, social, and environmental constructs[21]. While a poverty level can be set at one dollar a day or by a single national standard, it is difficult to capture the true demand for health on such a superficial level. More recent research applies his method of calculating this demand to the health status in Sub-Saharan Africa[22]. Researchers used the same model, utilizing the ration of health expenditure to GDP and food availability per capita to determine the economic construct, literacy rates and alcohol consumption to determine the social construct, and urbanization rates and carbon dioxide emissions per capita to determine the environment construct.

Health inequalities can be seen all over the world in both high-income and low-income countries. However, research shows they are very different per level of income. For example, the inequalities that exist in many Sub-Saharan African (SSA) nations are magnified by different social and economic differences than of those in the western world. With the creation of the Commission on the Social Determinants of Health (CSDH), established by the WHO, an international interest on identifying the social determinants of health had been spurred. Much of the focus of these studies still emphasize these determinants within the realm of the western world, not taking into account the differences from an sub-Saharan African perspective. In 2011, researchers out of the University of Cape Town highlighted the need for the "Africanization" of the social determinants of health in order for there to be progress in the overall health of African nations[23]. Health has to be determined within the realm of the individual country, if not broken down further into national regional disparities. While low socio-economic status (SES) is a determinant of health, it is simply not enough to use this as a reason for poor health in sub-Saharan Africa when roughly 50% of the population lives below the poverty line [24].

Dr. Peter Ndumbe has done vast research on the subject of immunization programs in Africa. Currently Dean of the Faculty of Medicine and Biomedical Sciences at the University of Yaoundé in Cameroon, he is also a member of the Task Force on Immunization in the African Region of the World Health Organization. Due to his years of expertise in the field, Dr. Ndumbe is regarded as an expert in regards to immunization practices in Africa. According to Dr. Ndumbe, there are four main reasons as to why vaccines do not reach the populations in Africa that need them most:

- Management: training of personnel, supervision of the program, scheduling of vaccine administration
- Finance: lack of financial resources, purchasing power of citizens
- Logistics: weak supply chain, lack of storage, shipment delays
- Social mobilization: community involvement, buy-in, acceptance

Across all four reasons exists barriers that need to be overcome in order to achieve better access[4]. These constructs parallel with much of the McLeroy, et al, proposal of social ecological model of health promotion[25]. By understanding immunization barriers at all levels in the system as opposed to separating the upper levels (policy makers) from the societal levels of community and the individual allows researchers to gain a better overall perspective on ways to fix problems and implement successful interventions. Far too often the physical cold chain supply and the supply of vaccines into the community are treated as separate issues; they should both be considered simultaneously when planning an immunization intervention.

2.5 NIGER

2.5.1 Country Overview

Niger is a landlocked nation in west Africa, surrounded by Nigeria and Benin to the south, Burkina Faso and Mali to the west, Algeria and Libya to the north, and Chad to the east. 80% of the country is covered by the unforgiving Sahara Desert, leaving only a small portion of the land suitable for farming and livestock. This remaining 20% mostly falls within the Sahel region of Africa, a region marked by environmental damage and a struggling economy. There is a very narrow strip of land just below the Sahel called the Sudanian vegetation zone, which offers the most suitable farming land in the country. Farming in Niger is mostly subsistence farming, which is frequently disrupted by droughts and famine. In addition, the soil quality is poor and overgrazed, and when rainfall does occur, it usually floods the region[26]. Pastoralist communities also suffer from the effects of droughts and sub sequential cyclical flooding[27]. Numerous famines since the 1970s have deemed international attention, the most recent being in 2010. During this time, it was estimated that 12 million of the 15.2 million population faced severe food shortages[28].

Niger has few areas of natural resources being mined. Uranium, gold and coal are the main three natural resource exports. Niger is one of the world's leading uranium producers, and uranium mining has existed in Niger for over 40 years operated by private firms[29]. The first national gold mine was opened in 2004 in southwest Niger and is expected to bring in sustainable revenue for the country, as the government has a 20% share in this mine. Potential oil fields are being researched in western Niger. However, these areas can do little to make up for the unforgiving landscape of Niger, where most people are farmers.

Niger has the highest birth rate (50.06/1,000) and the second highest infant mortality rate (109.98/1,000) in the world[30]. With a population of just over 15 million (2010 estimates) and a population growth rate of 3.63%, Niger represents a country with a critical need to immediately address maternal and child health. Culturally, Niger is a pronatalist nation, with many couples continuously desiring more children[28]. The number of children born per Nigerien is 7.52; a survey conducted in 2006 of married women and men reported that they wanted an average of 8.8 and 12.6 children, respectively.

Consistently one of the poorest nations in the world, the per capita income of Niger is $370 USD with 59.5% of the population living below the estimated national poverty line[30, 31]. This is higher than the average of sub-Saharan Africa, which is about 50%. In addition, roughly $20 USD is the average expenditure per household on healthcare services[32]. Poverty is highest in the rural areas along the southern border where a majority of the population lives. Education is poor and struggling. Primary school enrollment is 63%, and adult literacy rates are among the lowest in the world at 29%[31].

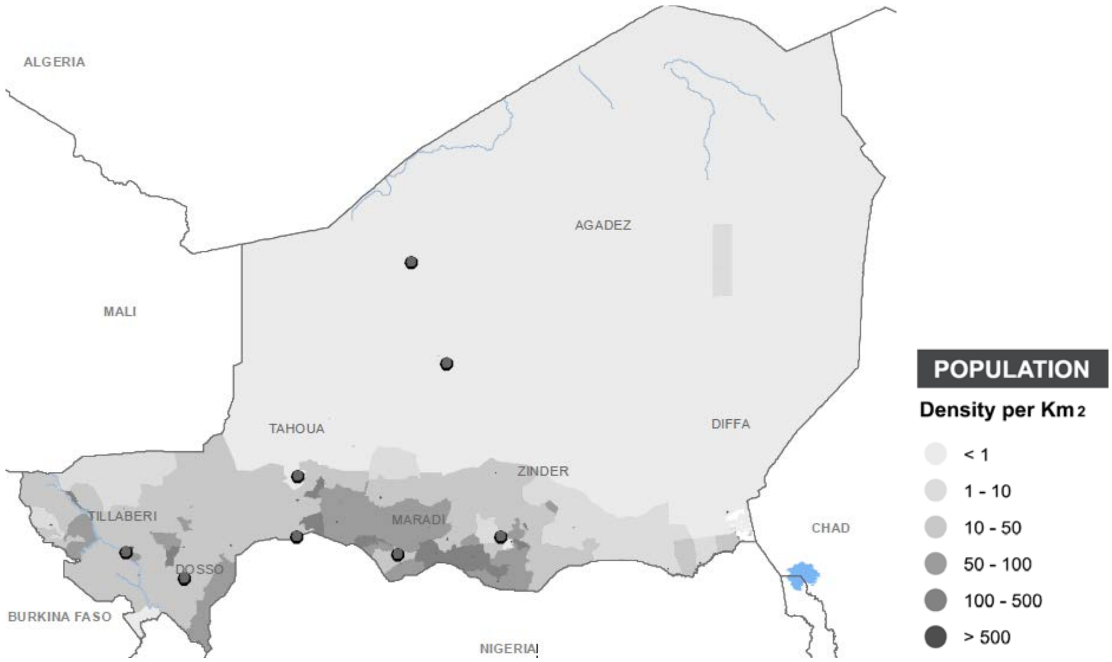
2.5.2 Regional Overview

Niger is composed of eight regions: Agadez, Niamey, Diffa, Dosso, Tahoua, Tillabéri, Maradi, and Zinder. Diffa and Agadez are the most remote of the regions. Niamey has the densest population and is the capital of the country. Maradi and Zinder have a spread of dense and rural districts, and Tillabéri, Tahoua, and Dosso have similar patterns with a smaller population (Figure 1 and Table 1).

Table 1. Population per Region Stratified by Males and Females

	Agadez	**Diffa**	**Dosso**	**Maradi**	**Tillabéri**	**Tahoua**	**Zinder**	**Niamey**
Male	*245,881*	*242,672*	*997,187*	*1,492,324*	*1,258,651*	*1,316,673*	*1,430,284*	*610,893*
Female	*241,432*	*230,891*	*1,019,503*	*1,528,845*	*1,241,803*	*1,341,426*	*1,394,184*	*611,173*
Total	*487,313*	*473,563*	*2,016,690*	*3,021,169*	*2,500,454*	*2,658,099*	*2,824,468*	*1,222,066*

Data obtained from the 2006 Demographic and Health Survey in Niger



From: www.infrastructureafrica.com; April 2012

Figure 1. Density of Population of Niger by Region

The population of Niger was estimated to be just over 15 million in 2010. When comparing Table 1 with Figure 1 at the beginning of this section, the population density varies greatly per region. The most populated regions are along the southern border of the country, while the least populated region is the largest (Agadez) in the north.

The majority of the population falls below the Sahel in the Sudanian vegetation zone. However, as discussed previously, this area of land is prone to drought and famine. It is important to note that these regions are still considered rural, although denser. Figure 2 outlines the spread of poverty in Niger.

Per region, the percent of people living below the national poverty line stratifies as follows according to Niger's National Institute of Statistics: Agadez (16%), Diffa (18%), Niamey (28%), Zinder (54%), Tahoua (58%), Dosso (67%), Tillabéri (72%), Maradi (73%)[33]. Although the numbers do not quite match the percentages of the map, the pattern is still the same. The most remote regions of Agadez and Diffa are characterized as "wealthier" while Tillabéri and Maradi rank as two of the "poorest." It is difficult to tell from Figure 2 Niamey's true poverty incidence; it is the capital but is located in the poorest section of the country.

From: www.infrastructureafrica.com; April 2012

Figure 2. Poverty Distribution in Niger

Niger's workforce is divided mainly into three sectors: agriculture, excavation (mining), and service. Figure 3 from Infrastructure Africa highlights the locations of the agriculture and mining activities in Niger. Agadez is home to a massive uranium excavation project. Diffa has been sited as a location with potential to have oil, and the southwest region of the country has been known to have large deposits of gold. In conjunction with the Sudanian vegetation region, most of the farming lies along the southern border of the country. However, as noted earlier, this region has a precarious envorinment that is known for severe famines.

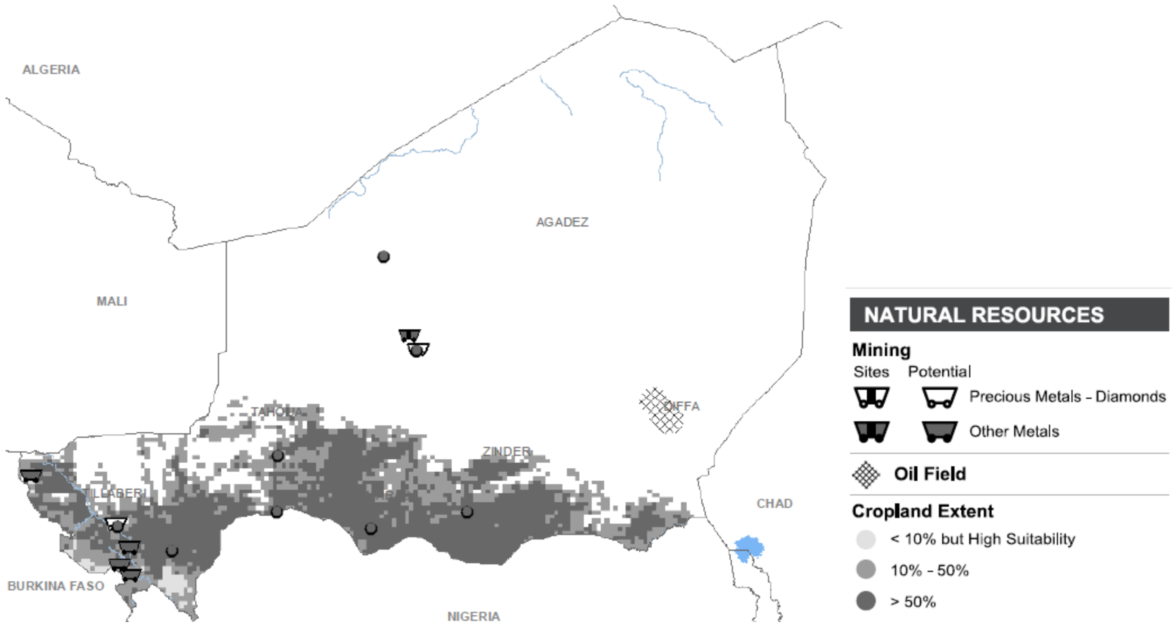


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Figure 3. Natural Resources in Niger

By looking at the numerous variations of Niger at the regional level, it is evident that poverty ranges across all regions. Therefore, by treating poverty as a uniform state when designing interventions such as immunization campaigns would not be the best solution to increasing vaccination coverage.

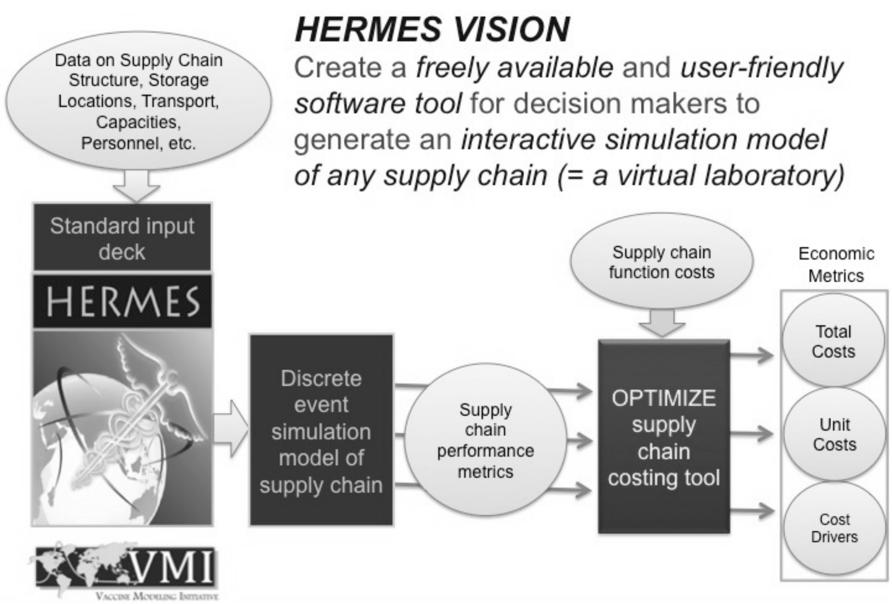
3.0 METHODS

This study will analyze measures of vaccine availability, vaccine coverage, and incidence of poverty in Niger at the regional level. It will specifically study the yellow fever vaccine. This vaccine was chosen for several reasons. First, it is a single dose vaccine, meaning a child is considered to have completed the recommended yellow fever uptake after one dose; it is more straightforward to compare the vaccine availability with vaccine coverage without factoring in multiple dose schedules and missed opportunities. Other single dose vaccines include Bacille Calmette-Guérin (BCG) and measles. BCG is a vaccine that is administered at birth, and therefore would be highly correlated with access to the option to give birth in a health facility. While this reflects socio-demographics, it also weakens the ability to analyze other health seeking behaviors. The measles vaccine is often supplemented by campaigns, and therefore it would be expected to have coverage not fully reflecting the availability of the vaccine through the national EPI. Therefore, of the single dose vaccines administered, the yellow fever vaccine represents a vaccine that is representative of the need to actively seek out vaccination (as opposed to being located by campaigns) and is not confounded with access to birthing facilities.

Three data sources are analyzed in order to examine the relation between socioeconomic status and vaccine availability. The first is a computational model developed by the University of Pittsburgh that will determine the vaccine availability of the yellow fever vaccine in Niger. The second is a health survey administered in Niger to determine the vaccine coverage rates of the yellow fever vaccine. The final data source is a measure of poverty composed of measures of education, health and living standards that allow a more in depth analysis of the socioeconomic status in a seemingly uniformly low-income country.

3.1 VACCINE AVAILABILITY

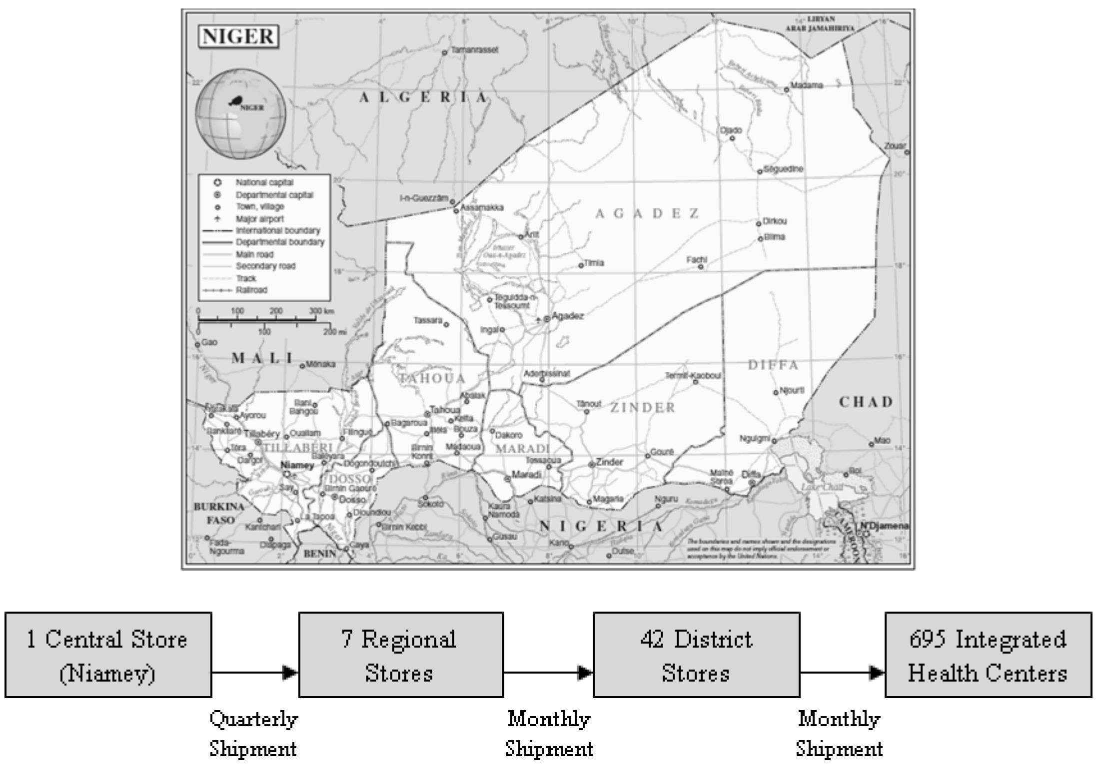
The Highly Extensible Resource for Modeling Supply Chains (HERMES) is a discrete event simulation model developed by the Vaccine Modeling Initiative at the University of Pittsburgh. HERMES includes information regarding vaccine vial size, storage capacity, transportation capacity and routes, and the number and location of all clinics in the country of Niger (Figure 4.)



From: https://www.vaccinemodeling.org/index.php/hermes-vision-secret; April 2012

Figure 4. How HERMES Works

HERMES is populated with data from the 2008 Niger Cold Chain Inventory and was further detailed with data from a team visit in 2009. Examples of subjects previously explored include vaccine vial size, vaccine introduction, and vaccine ordering policy [34-39]. The model in Niger represents the flow of vaccines from the central storage facility in Niamey throughout the country, eventually reaching integrated health centers (immunization clinics) and therefore being administered to the population. One run of the model represents one year. The size of orders is determined by demand at the clinic locations. Figure 5 illustrates how the supply chain works in Niger.



Map from: www.un.org/depts/Cartographic/map/profile/niger.pdf; March 2012

Figure 5. Niger's Vaccine Cold Chain

Each day, virtual patients arrive to the clinics and vaccines are administered based on census data gathered in Niger. The ability of patients to be vaccinated at the clinic level is measured by vaccine availability. Vaccine availability is the proportion of patients arriving to the clinic to be vaccinated for whom vaccine is available. It is represented by the following equation:

Vaccine Availaibility = *Number of vaccine doses available at the clinic / number of patients arriving at the clinic to be vaccinated*

In addition to studying vaccine availability, this study will analyze what impacts vaccine availability overall, such as:

- Cold storage utilization: the proportion of used space in all refrigerators, freezers, and cold rooms thoughout the supply chain to the amount of available space, represent by:
- Frequency of shipments: the number of trips taken from higher levels in the supply chain to lower levels in the supply chain to restock vaccine over the total possible number of trips that could be taken between levels per year

The vaccine availability reported for the yellow fever vaccine is the result of the average of ten runs.

3.1.1 Baseline Data from HERMES

Figure 6 represents the vaccine availability across the different regions in Niger. Tillabéri had the highest availability at 85%, while Agadez offered the lowest vaccine availability at 21%. Maradi, Tahoua and Zinder had relatively similar availabilities, all falling between 84% and 85%. Diffa, Dosso, and Niamey represented another tier of availabilities, with Diffa and Dosso having an availability of 53% and Niamey having an availability of 57%. The average availability across the country would most likely not be an accurate representation of what is actually offered from the perspective of the regional level.

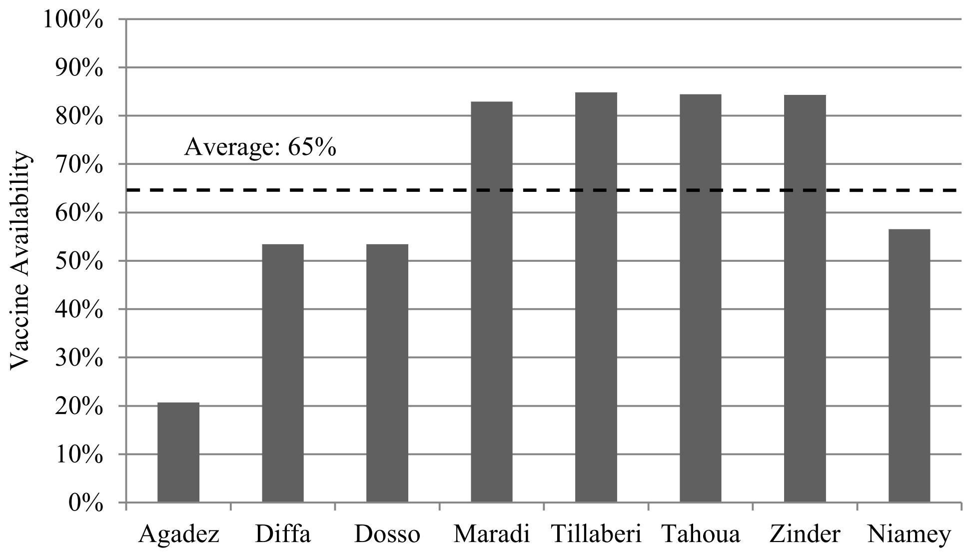


Figure 6. Yellow Fever Vaccine Availability

With such varying numbers, understanding the interaction of additional measures helps to Other relevant outputs impacting vaccine availability include storage capacity and shipping frequency. Table 2 represents the number of storage locations, the space offered totaled across all locations within the level, and the average utilization at each location.

Table 2. Number of Vaccine Storage Locations per Region in Niger

Regions	Number of Regional Stores	Total Store Space (L)	Average Storage Utilization	Number of District Stores	Total Store Space (L)	Average Storage Utilization	Number of Integrated Health Centers (IHCs)	Total Store Space (L)	Average Storage Utilization
Agadez	1	110	100%	4	1,367	23%	44	2,010	16%
Diffa	1	301	100%	3	771	41%	35	1,298	37%
Dosso	1	822	100%	5	1,015	68%	86	3,357	38%
Maradi	1	12,355[b]	21%	7	1,166	78%	84	3,812	35%
Tillabéri	0[a]	N/A	N/A	6	1,137	73%	120	4,319	40%
Tahoua	1	16,169[b]	14%	8	1,178	77%	110	3,822	42%
Zinder	1	12,277[b]	19%	6	1,745	63%	117	4,445	44%
Niamey	1	369	47%	3	632	59%	48	1,916	40%

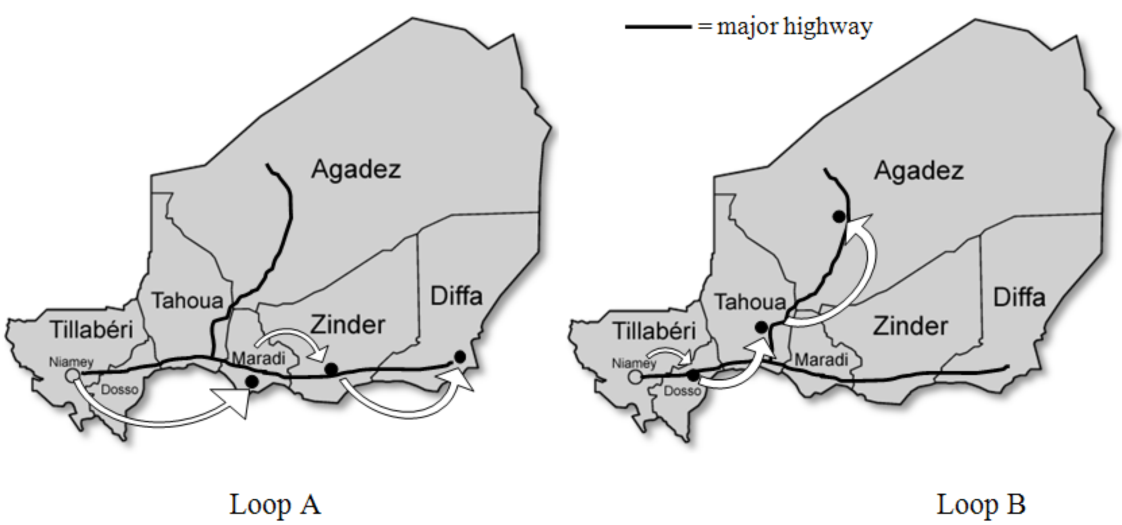
[a] Regional level removed from supply chain; central store serves District Stores directly
[b] location has a cold room

The amount of storage space at each level within the regions is a large factor in the vaccine availability by the end of the supply chain. In Agadez, for example, storage at the regional level is utilized to the maximum capacity, creating a bottleneck as soon as the vaccines enter the region. 110 L of total storage space is equal to a single refrigerator. The analysis of transport utilization will further explain how detrimental this lack of space is to the overall availability. The final level within Agadez (Integrated Health Centers) only utilizes an average of 16% of available storage space; the available space totals to almost 20 times the available space at the regional level.

The ability for certain locations to have a cold room for storage at the regional stores can be viewed as both a benefit and a waste of space. The vaccine availability for the regions with the cold rooms is much greater than the supply ratios of those without, which shows a connection between space and availability. However, the utilization rates of the storage at the regional level is quite low (14-21%), indicating a lot of empty space. While Niamey does not seem to be utilizing a lot of storage space and therefore should have higher vaccine availability, this is explained in shipping frequency.

Tillabéri does not have a storage facility at the regional level. Therefore, the central store delivers directly to the six district stores, eliminating the potential bottleneck that could occur. In addition, Tillabéri has a very large amount of storage space at both the district level and the IHC level.

Niger's vaccine transportation system from the central store to the district stores works in two ways in this model (Figure 7.) There are two shipping loops that run from the central store to three regional stores. Each loop has one cold truck stocked to deliver vaccines to all three locations and follows one of the two main highways in Niger. Loop A delivers to Maradi, Zinder and Diffa, while Loop B delivers to Dosso, Tahoua and Agadez. The loops use cold trucks to carry the vaccines, and the cold trucks do not have a utilization rate higher than 50% on either route.



Map outline from: http://www.worldatlas.com/webimage/countrys/africa/outline/neout.htm; March 2012

Figure 7. Vaccine Shipping Loops in Niger

The remaining two regions (Niamey and Tillabéri) operate in a different manner. The central store is located in Niamey, so HERMES allows Niamey regional store could be stocked very frequently, as is practiced in Niger. The means of transportation is a 4x4 truck. Tillabéri does not have a regional store; therefore, vaccine is collected by districts directly from the district stores.

Aside from Tillabéri and Niamey, each Regional level store can have vaccine delivered from Central store every three months as long as there is vaccine available at the central store to be moved (Table 3.) The Niamey regional store is able to restock once a month. Regional stores can deliver vaccine to the district stores once a month as long as there is vaccine available at the regional level. (Tillabéri districts can have vaccine delivered from central once a month as well.) This leg of the vaccine transportation system uses 4x4 trucks. IHC's can collect from district stores once a week as long as there is vaccine available. This leg uses motorbikes with vaccine carriers attached in order to reach all IHCs, including the remote ones.

Table 3. Frequency of Shipments Between Levels per Year

	Agadez	Diffa	Dosso	Maradi	Tillabéri	Tahoua	Zinder	Niamey
Central to Region	4	4	4	4	N/A	4	4	12
Region to District	4	9	5	12	12	12	12	8
District to IHCs	4	11	10	22	17	17	18	11

Every region used the maximum amount of shipments from central as possible. The region to district shipments is where there are differences in the average amount of trips per year. Those locations with more storage at the regional level (Maradi, Tahoua, Zinder) all are still about to ship as many times as possible per year on average since there is more room to store. Regions that lack a lot of cold storage at the regional level (for example, Agadez) have fewer shipments, for there is no vaccine to transport throughout the system once the regional level runs out. Therefore, more shipments in HERMES lead to higher vaccine availability.

3.2 VACCINE COVERAGE

The Demographic and Health Survey (DHS) is an in-country survey conducted by Monitoring and Evaluation to Assess and Use Results Demographic and Health Survey (MEASURE DHS), a project funded by USAID and implemented by ICF International[40]. The survey is designed to give a broad view of the demographic structure of the country, aiming to create monitoring and evaluate indicators of population, health, and nutrition. The survey is typically administered every five years in order to give researchers the ability to study trends.

The last completed survey in Niger was in 2006. 7,660 households completed the survey, with inputs from 9,223 women and 3,549 men. The ages ranged from 15-59. The topics covered include household structure, immunization uptake for children, and employment, to name a few. The time frame for the 2006 DHS was from January through May. There is currently a survey being conducted now and the DHS 2012 will be released next year.

Data utilized for this study will be in regards to the yellow fever vaccination uptake. The reported coverage rates reflect mothers being questioned in regards to what vaccines their children had received. This was determined by both evidence of vaccination cards and the mothers memory regarding immunization sessions. Overall, majority of the questions regarding immunization were answered by word of mouth as opposed to consulting immunization cards.

3.2.1 Data Extracted from the DHS

The DHS reports vaccination coverage rate of all EPI vaccines singularly (Table 4.) It also produces the rates for a fully immunized child (FIC), which is generally much lower than individual uptake.

Table 4. Vaccine Coverage per Region in Niger

	BCG	DTP 3	Measles	OPV 4	Yellow Fever	*Fully Immunized Child*
Agadez	82%	62%	69%	62%	59%	*50%*
Diffa	73%	40%	55%	50%	39%	*24%*
Dosso	71%	47%	58%	63%	44%	*27%*
Maradi	59%	31%	41%	54%	34%	*21%*
Tillabéri	65%	46%	54%	66%	46%	*35%*
Tahoua	71%	47%	50%	60%	36%	*23%*
Zinder	41%	22%	26%	33%	17%	*13%*
Niamey	94%	55%	78%	64%	66%	*36%*

3.3 THE MULTIDIMENSIONAL POVERTY INDEX

The socioeconomic status of Niger at the regional level was derived from the findings of the Multidimensional Poverty Index (MPI.) Developed by the Oxford Poverty and Human Development Initiative and the United Nations Development Program in 2010, the MPI adopts a deeper definition of poverty[41]. T he MPI captures a broader picture of poverty than the traditional income-based methods, for it factors in education, health, and standard of living to determine the level of poverty.

Across these three categories, there are ten indicators:

- Education: years of schooling, school attendance
- Health: child mortality, nutrition
- Standard of Living: cooking fuel, sanitation, water, electricity, floor, asset ownership

If an individual is lacks at least one third of the indicators, they are identified as poor. The indicators are calculated from in-country surveys, such as the Demographic and Health survey. The Niger MPI specifically utilized the 2006 DHS, the same survey this study uses to determine vaccine coverage rates. In comparison with the percentage living below the National Poverty Line in Niger (59.5%), the MPI offers a more holistic approach to understanding the depth of poverty in a country. The benefits of using this measure in this setting is that in a country such as Niger, where a majority of the country is classified as living in economic poverty, the MPI offers additional insight into the influences to poverty. The three categories factored into calculating the MPI are all associated with health behavior; therefore, it would be relevant to study a measure of poverty with direct relation to vaccination uptake.

3.3.1 Data Extracted from the MPI

According to the MPI, the head count ratio of poverty in Niger is 92.4% on average and varies by region, as seen in Table 5:

Table 5. Multidimensional Poverty at the Regional Level in Niger

Region	Percentage of Population	Multidimensional Poverty Index (MPI = H x A)	Incidence of Poverty (H)	Average Intensity Across the Poor (A)
Agadez	2.5%	0.47	77.4%	60.4%
Diffa	2.7%	0.61	93.8%	65.0%
Dosso	13.7%	0.659	96.1%	68.5%
Maradi	20.4%	0.676	96.3%	70.2%
Tillabéri	14.2%	0.698	97.1%	71.8%
Tahoua	19.0%	0.676	95.7%	70.7%
Zinder	20.2%	0.678	95.2%	71.2%
Niamey	7.2%	0.275	52.8%	52.1%

For this study, the Incidence of poverty will be utilized to determine the poverty at each regional level in Niger. The incidence represents the "head count" of those within the region that categorize as poor according to the standards set by the MPI.

4.0 RESULTS

The data shows patterns of interest between all three indicators. As the incidence of poverty increases across regions, vaccine availability increases as well. This general pattern indicates that the way the supply chain is currently operating might not be furthering socioeconomic disparities among regions. Figure 8 offers an overview of the relation of all three indicators, while subsequent sections analyze the relation of each indicator with one another.

Figure 8. Incidence of Poverty, Vaccine Availability, and Vaccine Coverage

4.1 VACCINE AVAILABILITY AND SOCIOECONOMIC STATUS

When the vaccine availability, as determined by HERMES, was compared with the incidence of poverty, as determined by the MPI, the results were quite interesting. An overall trend, as shown in Figure 9, is that the regions with higher levels of poverty also have a higher proportion of vaccine availability. Agadez, a region with only 21% vaccine availability at the clinic level, is a region with a below average poverty incidence in Niger (poverty incidence of 77%.) However, Zinder, the region with the highest proportion of vaccine availability, is also one of the poorest regions in the country.

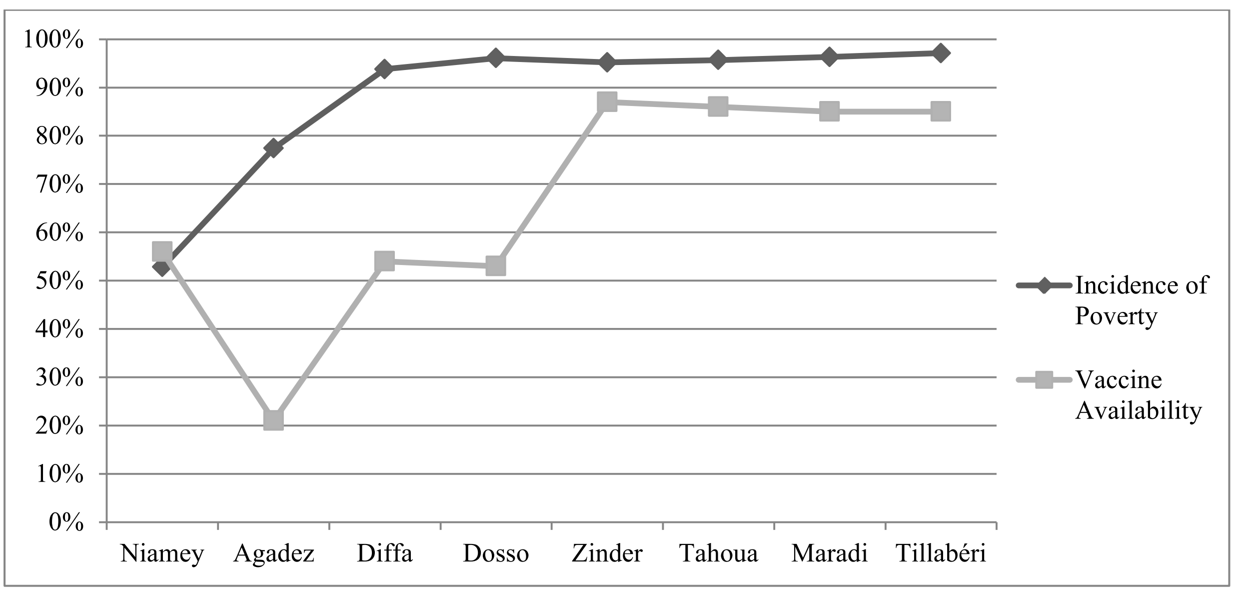


Figure 9. Incidence of Poverty and Yellow Fever Vaccine Availability

4.2 VACCINE AVAILABILITY AND VACCINE COVERAGE

When comparing vaccine availability, as determined by HERMES, with the vaccine coverage rates for yellow fever, as determined by the DHS conducted in Niger, the results show varying pattern (Figure 10.) While Agadez has a very low vaccine availability (21%) the coverage rate is much higher (59%.) In addition, the regions with the highest availability rate also have the lowest coverage rates (Zinder, Tahoua, Tillabéri.) In two instances, the vaccine coverage rate is actually higher than the vaccine availability rate, potentially showing that people are being vaccinated at other locations. The vaccine is technically getting to the clinics for immunizations to be administered, but this shows that there is disconnect between the vaccine arriving at the population arriving.

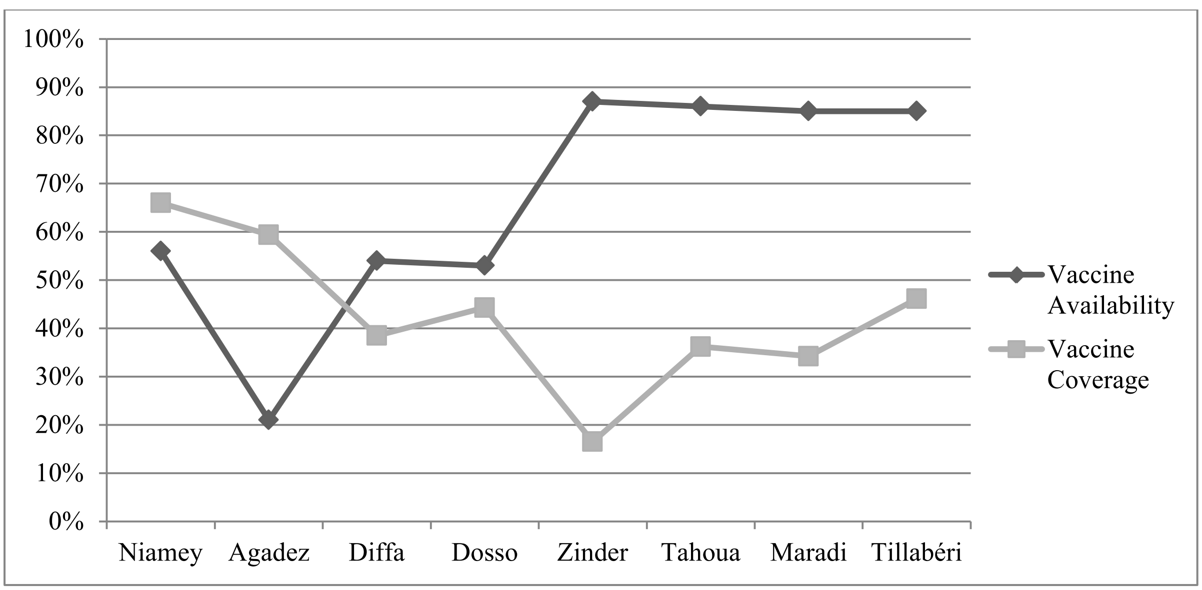


Figure 10. Yellow Fever Vaccine Availability and Vaccine Coverage

4.3 VACCINE COVERAGE AND SOCIOECONOMIC STATUS

As the incidence of poverty increases across the regions in the country, the yellow fever vaccine coverage rates initially decreases. It is interesting to note that after coverage rates initially drop as expected, they become higher for some reason in regions with virtually the same incidence of poverty. Zinder represents the region with the lowest vaccine coverage rates (17%) and one of the highest rates of poverty, and yet regions with the same level of poverty (Tahoua, Dosso, Maradi, Tillabéri) show higher rates of coverage. Figure 11 outlines this trend.

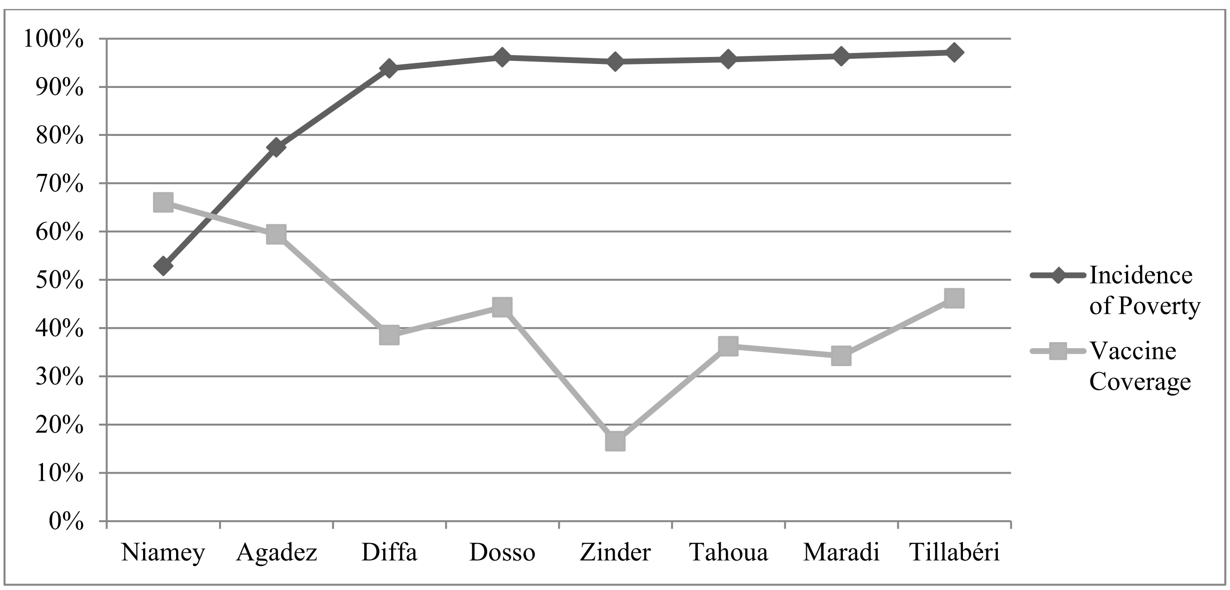


Figure 11. Incidence of Poverty and Yellow Fever Vaccine Coverage

5.0 DISCUSSION

Analysis of the indicators of vaccine availability, vaccine coverage, and the incidence of poverty outline interesting trends worth discussing further. Overall, it appears that vaccine availability is not hindering the vaccine coverage, for in the majority of the regions vaccine availability remains higher than vaccine coverage. There are two regions for which the vaccine coverage is higher than availability, and further research could better explain the initial thought process behind why this occurs.

5.1 HIGHER AVAILABILITY THAN COVERAGE

Higher availability than coverage would be somewhat expected scenario in a low-income country such as Niger. Essentially, this means that the government is getting the vaccine to the clinics, and the problem lies in getting the patients to the clinics. This occurred in Maradi, Tillabéri, Tahoua, Zinder, Dosso and Diffa. There are two tiers of vaccine availability outlined between these six regions. M aradi, Tillabéri, Tahoua and Zinder represent areas of high availability, mostly due to having more cold space available and more frequent trips to restock vaccines. However, these are also four of the poorest regions of Niger. In all of these regions, over 90% of the population in all of these regions lives in poverty. As discussed earlier, the demand for health is quite different at this level. Preventative medicine is not generally a priority in an area suffering from malnutrition and famine. From the perspective of the supply chain, however, it is working to get the vaccine where it is needed. Outreach campaigns for the yellow fever vaccine would most likely be beneficial in Niger, as yellow fever is a major factor of the burden of vaccine preventable diseases.

Dosso and Diffa have somewhat lower vaccine availability than the other four regions; however, they are still among the poorest regions in the country. Perhaps these two regions would be a point to study additional ways the supply chain could be impacting the coverage rates. There is less than a 15% difference between coverage and vaccine availability. Data such as this would be helpful if planning an awareness campaign with the intention to produce social mobilization to have more people seek vaccines; could the potential new demand overpower the current supply system? As yellow fever is not traditionally a vaccine used in outreach campaigns, it would still be administered from a clinic and would need the proper supply. However, for the most part this data is showing that in each region, there is a higher availability than coverage, and the supply chain is not hindering the availability of vaccines to regions of lower socioeconomic status.

5.2 HIGHER COVERAGE THAN AVAILABILITY

Agadez and Niamey both showed higher vaccine coverage than availability. The main question is how are these regions getting higher coverage than vaccines available? An option is to look at the pattern of outreach campaigns. Numerous outside organizations run supplementary immunization programs in sub-Saharan Africa. Unfortunately, not all of these programs keep track of the population vaccinated. In addition, the DHS survey takes information from both government issued vaccination cards and the memory of the mother. Therefore, a mother could be reporting an undocumented immunization campaign. However, as stated before, yellow fever is not typically a vaccine that is used in such activities, although recent reports indicate that it would be both safe to administer with and beneficial to include in a measles campaign[42].

Both of these regions are wealthier in comparison to all other regions. Agadez has a poverty incidence of 77% and Niamey has one of 53%. In the context of Niger, all other regions have incidences of poverty over 90%. Another pattern to note is the location of mining activities within the country. Uranium mines are located in Agadez. The AREVA group, a French-owned company, has been operating uranium mines in Agadez for close to 50 years now[43]. There are two mines currently operating with construction of a third to begin this year. AREVA also owns and operate two hospitals in the region with the intent to provide free healthcare to employees, their families and the surrounding community. This is a probable site of immunizations that are taking place that would be unaccounted for by the government. AREVA has been known to provide funding to hospitals throughout Niger, most recently the Niamey National Hospital.

Private companies, such as AREVA, have long been a controversial topic in developing nations. In recent years, groups such as the Global Business Corporation have worked to turn multi-national corporations into disease-fighting superpowers. These companies now aim to make investments into the healthcare of the community they employ in order to create a more sustainable relationship[44]. However, it is difficult for countries in dire economic problems to turn away any kind of help. The problem is that a lot of these companies operate under unhealthy conditions. In the past decade, AREVA specifically has been the target of Greenpeace for unsafe conditions, radioactive waste, and not investing enough in the community[45].

AREVA has since worked to clean the radioactive hotspots and invest in the community through schools and hospitals, but the company is still under scrutiny on mining practices. Regulations and pay scales are quite different between countries, hence why local manpower is convenient for international businesses.

Mines are also in close proximity to Niamey, although not as isolated to just that region as the uranium mines are to Agadez. Much of the gold mining activities in Niger take place just outside of Niamey, technically in Tillabéri. The region of Niamey is inside of the region of Tillabéri, located along the Niger River where the mines are located. Information on the gold mining activities is limited; however SEMAFO, Inc owns and operates the gold mines outside of Niamey. The SEMAFO website has a section outlining corporate responsibility to the community, including financing hospitals and doctors for the mining operations[46]. Specific examples showing corporate responsibility to Niger are not directly outlined.

Niamey has recently seen an enormous increase in the size of the population over the past few years, most likely due to the increase of mining in the area. Residents of Niamey could be migrants vaccinated in other countries and therefore not utilizing the services offered by the EPI. Again, practices of tracking vaccination are very different among countries.

5.3 LIMITATIONS

Although models are robust representations of actual events, they simply cannot capture every single detail that could impact the supply chain. It should be understood that these representations should be used to guide the decision making process and not be the sole source of evidence. Further, the parameters of the country change every year. New surveys will be administered and various determinants can change, hence why it is important to utilize as much up-to-date data as possible.

5.4 IMPLICATIONS FOR PRACTICE

Knowing what regions are producing high vaccine availability is vital to understanding the best method for running the supply chain. If it is a matter of space, transport routes or frequency of shipments, these are adjustments that can be made to maximize the benefits of the supply system. While each region differs, a general framework to apply would be that there is a need for cold space much like Zinder, Tahoua and Maradi currently have. For example, giving Dosso additional cold space might help to increase vaccine coverage over time. In addition, it highlights areas of low vaccine coverage despite high vaccine availability. This might be emphasizing wasted resources by the government.

This type of study also sheds light on other sources of vaccination services. In Agadez and Niamey, people are receiving vaccines elsewhere. Although this study is limited in telling the government where these people are being vaccinated, it dictates that there is some kind of difference between regions that cause people to be vaccinated even when the services is limited. Agadez, a region with extremely low availability and fairly high coverage in comparison to other regions, is a perfect example of people seeking healthcare beyond the national vaccine system.

Finally, utilizing a social ecological framework stresses the importance of stakeholders understanding how all of these factors are entwined with one another. The need for immunization programs to be designed with this theory in mind creates natural checkpoints to examine, such as if the availability is really meeting the demand.

5.5 FURTHER RESEARCH

The results of this study are not finite. Rather, numerous additional research opportunities could be complementary to these findings. To begin with, further analysis at the district level (the one directly below the regional level) would yield more detailed results. Patterns would emerge that are distinct to each region as a whole. A dditional stratification by other demographic characteristics at this level, such as ethnic background, could help decipher cultural acceptance of vaccines in relation to the available supply.

Further research into the private facilities, such as those owned by the mining industry, is necessary to understand this effect across the country. Right now, it is only determined that this could be impacting the coverage rates in one region. However, as mining is further pursued across the country in both Diffa and Dosso, it would be of assistance for the Ministry of Health to have an idea as to how mining impacts healthcare.

Finally, an analysis of the various outreach campaigns that are in the country would help to understand why coverage would be higher than availability. Again, it would be very beneficial for the government and stakeholders in the vaccine supply chain to know additional venues of vaccination. Therefore, efforts in Niger would be better organized. In a low income country, utilizing every vaccine resource from the government clinics to the foreign-run outreach campaigns help to create a stronger immunization program. In addition, a single method of tracking vaccination efforts by different campaigns would help to understand the reach of such efforts.

6.0 CONCLUSION

The purpose of this study was to determine if discrepancies in the supply chain reflect regions of lower socioeconomic status in Niger. If so, what could be potential causes of such discrepancies? Findings showed that the areas of highest vaccine supply availability had some of the lowest rates of vaccine coverage. This would reflect a problem of getting the patients to the vaccine; the supply chain is functioning in respect to getting vaccine to the clinics for immunization sessions. In addition, these areas also had a large amount of cold space at the regional level, which is associated with higher vaccine availability. This helps highlight points of intervention to the government in an ecological perspective, for adequate vaccine availability does not mean high vaccine coverage.

Another interesting pattern was areas that had higher vaccine coverage than vaccine availability, meaning patients were potentially being vaccinated outside of the clinics set up by the government. This could be reflective of two patterns of immunization: outreach campaigns from outside organizations are offering immunization services to the people of Niger, or else hospitals and clinics funded and run by outside governments are offering immunization services. Both of these options are very feasible, as Niger is a poverty-stricken country that receives a lot of humanitarian aid. In addition, mining is a huge industry in the region that is owned and operated by foreign companies. In response to harsh criticism on not giving enough back to the community, mining companies often offer free health services from private facilities. In this sense, the government might be missing vaccination sessions to quantify.

Such a study offers assistance to key stakeholders planning immunization services in Niger. By understanding areas of high coverage and low coverage, factors that influence this, and ways to get vaccines to communities that need it most, the system can be strengthened to reach as many Nigeriens as possible. This study is significant in understanding the outcomes of the two parts of the vaccine supply chain in Niger (vaccine availability at the clinic and vaccine uptake by the population) and can help guide those in the field of public health to intervene in the system at places that will yield the most impact per region.

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