Studying the Dynamics of Visceral Leishmaniasis Epidemic in India
A System Dynamic Approach for Policy Development

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Abstract

Visceral leishmaniasis, also called Kala-azar is a vector-borne infectious disease caused by the parasite Leishmania donovani. The transmission of the parasite to human beings occurs via the bite of adult female sand flies (phlebotomous) previously infected by biting and sucking blood of an infectious human being. Some of the Kala-azar patients developed a complicated condition called Post-Kala-azar Dermal Leishmaniasis (PKDL) after treatment which is also a source of infectious to sand flies. By using a system dynamics approach. A model has been developed to study the Kala-azar epidemic in India. The model in this paper describes the transmission dynamics between vectors and human beings host; it provides a deeper understanding to the transmission of Kala-azar disease as being a cyclical process. In achieving the underlying goal of removing this disease, two policies are suggested, implemented and tested; the results give us reason to believe that by implementing the two policies proposed, we will prevent (or reduce significantly) the future spread of the Kala-azar and PKDL. And thus will stop suffer from the needless illness and death which will improve the HDI.

The key words: India, Kala-azar, Leishmaniasis, model, PKDL, sand fly, system dynamics

1. Introduction

1.1. Leishmaniasis

Leishmaniasis is a vector-borne disease, caused by parasites called *Leishmania* genus. The name refers to Leishman whom was first to recognize the disease mechanism in 1903. There are more than 20 species of *Leishmania.*

The disease is spread by sand flies of the genus *Phlebotomus (Old World*) and *Lutzomyia* genus (New World) who is the vector for the spread of the disease. The disease can infect human beings, dogs and rodents. The parasites are transmitted through the bite of infected adult female sand flies when they feed on blood to develop and lay eggs. They usually bite at night and at dusk.

In fact the world health organization (WHO) report is claimed that, ‘’Leishmaniasis threatens about 350 million men; women and children in 88 countries who are at risk from Leishmaniasis worldwide about 12 million people are already infected. Most of the affected populations are in the tropics and subtropics, with an estimated global prevalence of 12 million cases and an annual incidence of 1.5–2 million cases’’(WHO 2011a).

Leishmaniasis is actually a class of diseases with significant clinical and epidemiological diversity; the species of *Leishmania* can cause various clinical conditions and take on a cutaneous form, a mucocutaneous form or a visceral form (WHO 2011a). The cutaneous form is the most common one affecting the skin, cutaneous cases are caused by about twenty different species of parasites (Wikipedia 2011a), and there are approximately 10,000,000 new cases of cutaneous infection annually worldwide.

The mucocutaneous form is a condition of the cutaneous form.

The Visceral leishmaniasis is the most severe form of the disease. Visceral Leishmaniasis is also called Kala-azar, a Hindi term meaning “black fever”. The parasite attacks internal organs such as the liver, spleen, and bone marrow. Without prompt appropriate treatment the disease is deadly. There are various species of *Leishmania* parasite are recognized to cause the visceral form of Leishmaniasis, yet it is mainly caused by *Leishmania donovan I* (Africa, Asia, Europe). The predominant species are the *L. donovani* parasite and the *L. infantum* parasite in Africa, Asia, and Europe and in the South America species is *L. chagasi (Strauss-Ayali and Baneth 2000; Wikipedia 2011b).*

Visceral leishmaniasis is one of the major public health problems and is endemic in 65 countries, with a total of 200 million people at risk, especially in poor rural and suburban areas. But recently it has adapted to the urban environment as well. 90% of the cases occur in Bangladesh, India, Nepal, Sudan and Brazil. It is officially estimated that about 500,000 cases and 59,000 deaths occur every year due to visceral leishmaniasis (WHO 2011b). Approximately 50% of the global burden for visceral leishmaniasis (VL) is carried by India alone.

The world health organization (WHO) classified Leishmaniasis as one of most neglected tropical diseases and VL is classified as the second-largest parasitic killer in the world after Malaria according to published disease burden. Moreover Leishmaniasis disease is classified as a poverty-related disease. Based on the fact that Leishmaniasis usually affects the poor human beings and is associated with the poverty , illiteracy, displacement, unhygienic and poor housing as well as environmental changes, where all these factor available to sand flies good condition to breed in and easy access to human beings, because the people in the poverty class will not able to afford the simple protection from Sand flies like using net or even window screen will not able to afford for poor (WHO 2011c) .

Sand fly is the only known vector that can transmit the *leishmania* parasite (WHO 2011a). Usually domestic animals (such as dogs and rodents) are playing the role of reservoir hosts. Sometimes human beings contribute reservoirs for the disease. In India, Bangladesh and also central Kenya human beings is the only know reservoir for the disease and the disease is therefore called anthroponotic. But in countries like Brazil, the dog is the main reservoir host of the disease, therefore called Zoonotic. There is evidence that rodents play the role of reservoir in some areas like Sudan, Ethiopia, Somalia and Kenya. And it has been found that other animals such as foxes, jackals and wolves may also be infected. But, there is no information whether they can play the role of primary reservoir or not (NewsToday 2011).

The Kala-azar disease is characterized by an incubation period highly variable that varies significantly from person o person. Generally, it varies from 1 - 4 months, but in reality the range is from 10 days to 2 years. In India, the incubation period range from 4 month to a year which indicates why the progress is slowly. The extrinsic incubation period is 4-25 days (WHO 2011a), which is the time required for the vector (female phlebotomine sand fly *Phlebotomus argentipes*) to become infective after an infective blood meal.

The Visceral Leishmaniasis disease can be cured with treatment of an average duration of 30 days. After taking treatment human beings develop permanent immunity, but the drugs is very expensive and need to be take in hospital (WHO 1990).

Treatment of Visceral Leishmaniasis is often one of the greatest challenges facing Visceral Leishmaniasis spread, because some patients have developed resistance to treatment, a complicated Post-kala-azar dermal leishmaniasis (PKDL), disease may occur after on average four month to 2 years.

Post-kala-azar dermal leishmaniasis occurs especially in India up 20% of Kala-azar patient after treatment develop PKDL, complicated conditions and source of infectious to sand flies.

There are many intervention that have been suggested to prevent and protect against the spread of the disease some of them work on controlling the reservoir of infection i.e. humans beings such as: early diagnosis, increasing the public awareness of the disease and its treatment , using vaccination to susceptible human beings, but there is no effective vaccination available for Kala-azar yet against human, using of mosquito net for decreasing the spread of the disease, or by using house spraying against sand flies or control the reservoir i.e. dog by: killing infected dogs, vaccination the susceptible dogs, using collar. The choice of intervention is different from country to country because it is rely on the type of reservoir host for Visceral Leishmaniasis, if it is anthroponotic like in India the control program campaign has been work on control sand flies by using DDT.

A number of campaign programs have been developed to reduce the incidence of visceral leishmaniasis and they are still being developed. The prevalence of the disease burden is increasing worldwide and the World Health Organization (WHO) is responsible of providing technical support to countries and monitoring and assessing health trends. WHO is concerned about the Kala-azar outbreak in South-East Asia Region (India, Nepal and Bangladesh) where it has been threaten thousands of people for many years. Despite all the efforts made by the health Ministers of three Member States of WHO’s South-East Asia Region, India, Nepal and Bangladesh, to eliminate Visceral Leishmaniasis (Kala-azar) from their countries by 2005, India has missed the National Health Policy target to eliminate Kala-azar, so the health ministry's of India has a new target is to eliminate or reduce the number of Kala-azar cases to 1 per 10,000 population by 2015. There is, therefore, a need to understand the dynamics of the disease to find more viable, effective and affordable strategies the support the health ministry's of India in their

effort to eliminate or reduce the number of Kala-azar cases .We use system dynamic approach to investigate the transmission of the visceral leishmaniasis disease in India, by way of modeling and simulation. The dynamics of the transmission of the disease involves two populations that contribute to the transmission of the disease; human beings constituting the host population, and Sand flies constituting the vector population, we seek to answer following research question, related to the case of India:

- What is the structural origin of the rates of change in Infected Human and Sand flies Population?
- How will the number of infected Human develop in the future?
- What is the most effective method to control the spread of Kala-azar?
- How would a policy to increase the awareness of human to use net, to identify disease symptoms and to use indoor spray work.

Based on these research questions, we develop a model that represents the life cycle of the sand fly, epidemiological states for each population (the vector population of sand flies and the host population of human beings), to study the complexity of the transmission mechanisms of the disease. The transmission mechanism of visceral leishmaniasis or Kala-azar in India is fully described in the section below.

1.2 Kala–azar Transmission Dynamics

The visceral leishmaniasis has a transmission cycle that is based upon the dynamic interaction between the vector population and the population of human beings. This cycle of transmission is initialized by a bite from a sand fly sucking blood from a host infected with the parasite causing Kala-azar. In our case the host is an infected human being. Over a period of 4 to 25 days the parasites develop inside the female sand fly, causing the disease to diffuse across that vector. Later, if the infected sand fly survives the extrinsic incubation period, it will be able to transmit to the decease to a susceptible human being via a bite. As an infectious sand fly has previously fed on an infected host, it inoculates the susceptible human being, currently bitten, with the parasites from its saliva, and the transmission cycle is completed when the susceptible human being has turned infectious after a period of incubation time and is ready to pass on the decease

to another female vector (WHO 2011a). If the infected human being does not receive treatment within two years of becoming infectious, the infected human being will most probably die. When infected human beings are treated for Kala-azar they recover after a period of one month and develop permanent immunity from the decease. Unfortunately, a fraction of the recovered human beings may develop post Kala-azar after a period of 4 month to five years. These post Kala-azar patients also constitute a source of Kala-azar infection that spreads via the sand fly vector to susceptible human beings. This constitutes a reinforcement of the original transmission cycle.

The human beings infected with PKDL may also be treated. In that case, they need two months to recover (India 2011).

The sand fly usually searches for the blood in the evening. When the female of sand fly has accumulated a sufficient amount of blood, it lays its eggs. Over 50 to 60 percent of the eggs are female. After an opposition time of 22 days, the eggs hatch and remain larvae during the maturation until adulthood. Then the adult female sand fly starts searching for blood to develop its egg.

Sand flies breed in forest areas, in. caves, or in the burrows, i.e. in environments where the conditions, such as temperature, humidity etc., favor their development.

1. Literature Review

Since the Kala-azar disease is a vectors-transmitted disease, the literature reviewed in this study is drawn from a selection of related and relevant research studying the vector-transmitted disease.

In general, there has been a long history of epidemiology research that deals with the vector disease. Plenty of these studies of the dynamics of vector-borne diseases used mathematical models.

Ross (1911) and Macdonald (1957) were the first to begin working with one of the vector-borne neglected diseases of Malaria epidemiology. Ross has recognized the dynamics and the nonlinearities govern the vector infection disease. The mathematical model of malaria that was provided by Macdonald (1957) is a simple set of equations that describes changes in the proportion of infected human and infected vectors. Macdonald also provided simplified mathematical formulation to describe the dynamics of the transmission malaria called "Vectorial Capacity".

(Rogers, Onstad et al. 1988) reviewed the development of the vector- transmitted disease to human being models and their application.

Almost all of studies of visceral leishmaniasis epidemiology were qualitative and descriptive. The only study of the dynamics of visceral leishmaniasis (Kala-azar) using mathematical model appears to be that of (Dye and Wolpert 1988) who introduced, for the first time, a mathematical model to study the dynamics of Kala-azar by describing the mechanisms of disease progression across the population of human beings. The model was used to replicate the historical number of cases between 1875 and 1950 in Assam, India. They developed the mathematical model from existing models of malaria transmission dynamics.

Recently (Mubayi, Castillo-Chavez et al. 2010) introduced a mathematical model of Anthroponotic Visceral Leishmaniasis (AVL) or Kala-azar transmission to estimate the proportion of reported cases as well as estimates the reproduction numbers of Kala-azar's at the district-level in India.

Other studies of the dynamics of Leishmaniasis have focused on either ZVL (zoonotic VL) or cutaneous e.g. *(*DYE, 1996*)*, (Kerr, Grant et al. 1997), (Burattini, Coutinho et al. 1998), (Palatnik-de-Sousa, Batista-de-Melo et al. 2004), (Bacaër and Guernaoui 2006), (Chaves and Hernandez 2004), and (Ibrahim, 2010).

The development of dynamics models of vector born diseases that applied the system dynamics modeling approach (Fillmore 1963) and Hannon and Ruth 1979) are reviewed below:

(Fillmore1963) developed a simulation model to demonstrate that a yellow fever epidemic can be modeled using system dynamics, and that the resulting simulation conducted provode us with a deeper understanding of the nature of the such an epidemic.
(Hannon and Ruth, 1979) developed various generic dynamic modeling of diseases and pests that briefly explain how the method may be applied to model an epidemic disease.

The model of which is applied in this study, is a reformulation and has the same idea as the ones of (Macdonald 1 957; Fillmore and 1963; Hannon and Ruth 1979) model.

There appears to be no previous system dynamics study of Kala-azar disease. In the next section we discuss why we believe this is a good method for such a study of Kala-azar.

2. Research Methodology

System Dynamics method was chosen as it allows us to represent long-term dynamics, based upon on the accumulation processes (delays), the feedback loops and the non-linearities that characterize the structure of complex, dynamic systems, and because this method may well help us explain the system's development over time (Sterman 2000), - in our case to obtain proper understanding of the Indian Kala-azar epidemic.

The complexity of Kala-azar arises from the interaction (feedback) between the vector population (the adult female sand fly) and population of human being over time. The synthesis of factors influencing the Kala-azar transmission rate constitutes a non-linear relationship. The fact that the adult female sand fly must bite twice to facilitate transmission of the parasites (once to take up parasites, and once to inject into human beings) the time required for sand flies to develop from eggs and to mature, and the incubation time required to develop Kala-azar in a sand fly and person are examples of the delays involved in the feedback between the vector and the host that explain the Kala-azar in process.

Although the SD method deals with a system using an integrated approach, the examination of the individual subsystems is essential for this integration to be successful. Through this examination, interactive relationships among the subsystems and the resulting feedbacks loops across a number of system components may be identified. In this study, a simulation model has been used to facilitate the understanding of the dynamics of transmission of Kala-azar outbreak in India. In this model we provide the authorities of India, the Ministry of Health, with the predicted consequences of the development under number scenarios, estimate the propensity to grow to epidemic proportions and select optimal choices for intervention strategies and policies. The model is further expanded with causal links to allow for Post-kala-azar to impact the infection rate through variables that link the number of infected human with PKDL by increasing the density of infected human beings and thus increase the number of infected sand flies, - in turn feeding back infection of human beings.

3. The Dynamic Problem

In the country of India (located in the south-East Asia Region) the Kala-azar disease continues to cause considerable suffering and needless deaths. The first recognized epidemic occurred in 1824 in Jessore (now in Bangladesh).

In India, it is estimated that about 165 million people are at risk of developing the disease. The estimated reported number of cases is around 20,000 and the number of deaths about 200 per year. The disease is now being reported in 52 districts in India; 31 districts in the Bihar state, 11 districts in the Uttar Pradesh state, 6 districts in the West Bengal state, and 4 in the Jharkhand state. It is epidemic in 48 districts, especially in Bihar where more than 90% of the cases reported annually are found (WHO 2010e).

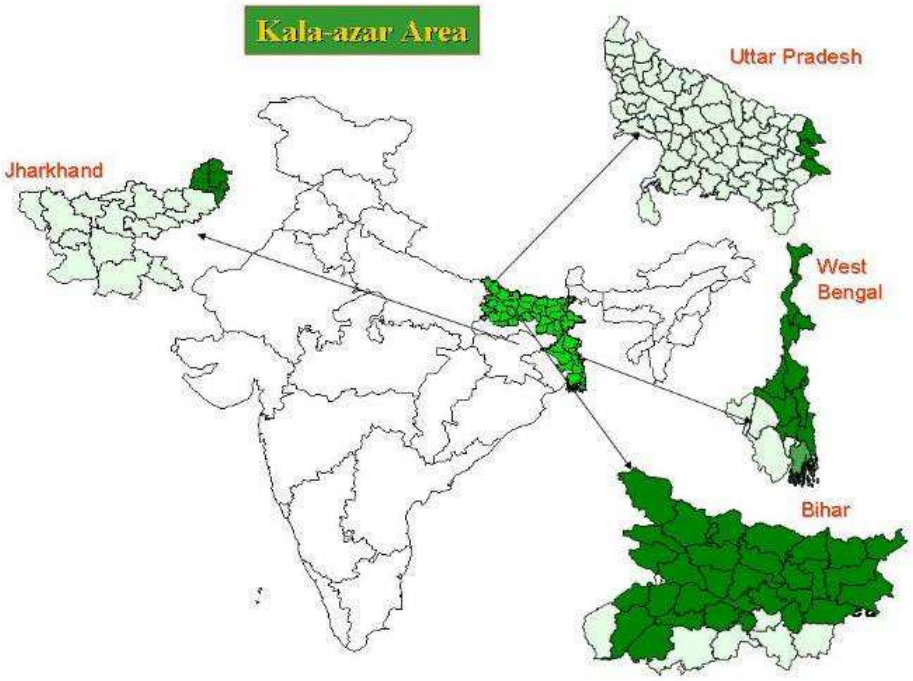


Figure 4.1: The Kala-azar endemic districts of India

Source: http://209.61.208.233/LinkFiles/Kala_azar_kala-status2008Webpagefeb2009.pdf

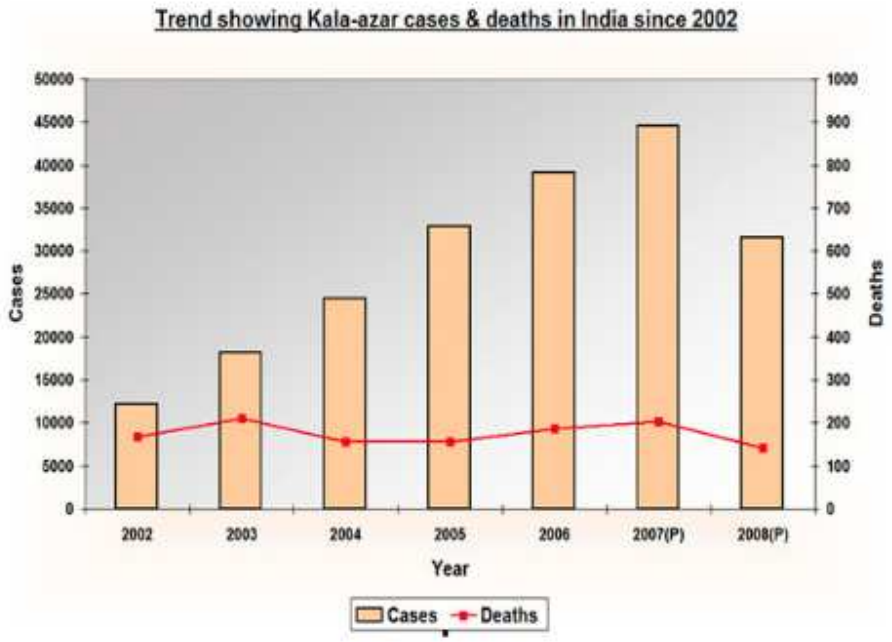


Figure 4.2: The Kala-azar Cases, from 2002 to 2008 in India (India 2011)

Source: http://nvbdcp.gov.in/kala-azar.html

The number of reported cases has been increasing since 2002 up until 2007. Thereafter, the number of reported cases dropped in 2008, while the number of death has been relatively stable over the years.

5. Dynamics Hypothesis

In this section, I develop (formulate) a dynamic hypothesis to explain the behavior of the Kala-azar disease graphed in figure 2. My dynamic hypothesis is based on the assumption that there is a positive feedback mechanism that causes the prevalence of Kala-azar or PKDL among human beings so as to produce new cases (incidences) of Kala-azar among human beings from the original ones.

This mechanism involves the population of adult female sand flies. The prevalence of Kala-azar or PKDL among human beings causes a transfer of the Kala-azar to the adult female sand flies population (incidences) that accumulate in the prevalence of Kala-azar in that population. Moreover, the prevalence of Kala-azar in the adult female sand flies population causes a transfer of the Kala-azar back to create new cases (incidence) of Kala-azar among human beings. They accumulate in the prevalence of PKDL among human beings and, subsequently, give rise also to PKDL among human beings.

The dynamic hypothesis is presented in the form of a causal loop diagram of the general model structure that can explain how the infection occurs. As mentioned earlier, the Kala-azar is a disease that is caused by a parasite (*L. infantum*), transmitted to human beings via a bite of an infected adult female sand fly. The model, therefore, focuses on studying the population of female sand flies and the transmission of the Kala-azar disease to the human population by sand fly bites.

In order to clarify the hypothesis, Casual Loop Diagrams (CLD) is utilized to explain the dynamics of the disease. A CLD is description of the important structural components forming loops that is causing of Kala-azar epidemic. The full system dynamics (stock and flow) model includes additional loops that have been deemed to have less of an impact on the systems behavior.

Human beings contract the disease from infected adult sand flies. And susceptible sand flies contract it from infected human beings. Thus the main driving feedback loop in this system is positive and portrayed in figure 3.1:

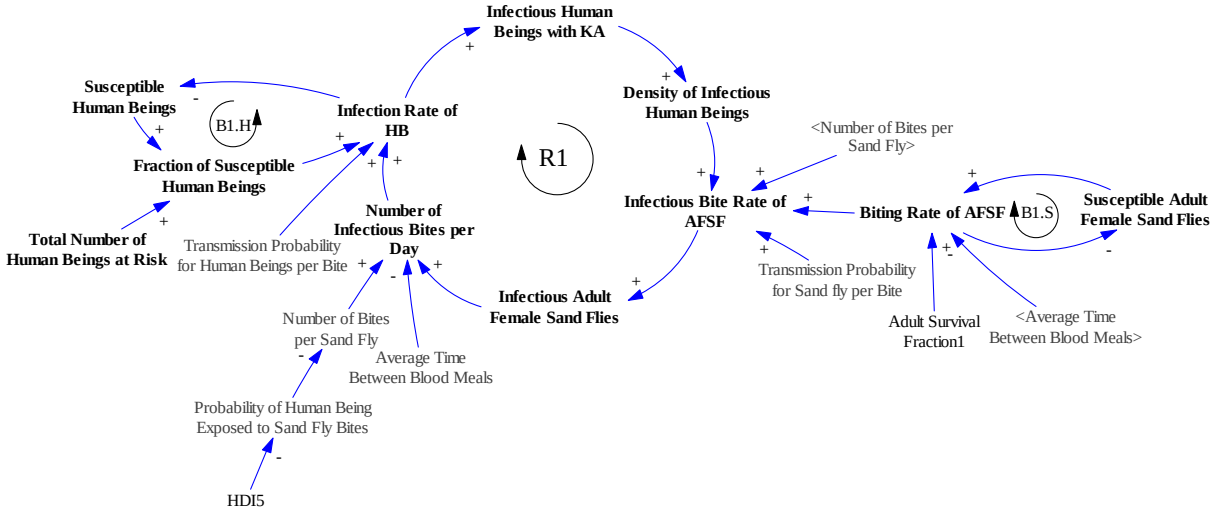


Figure 5.1: The simplified causal loop diagram of Kala-azar

We will now describe the mechanisms behind this interaction between the human beings and the sand fly population. The recruitment of human beings to the infected population originates from its interaction with the infectious portion of the sand fly population, - the females that have become infected when retrieving blood from an infections human being:

The infection rate of human beings (Infection Rate of HB) (see figure 5.1) is determined by the reservoir of susceptible human beings (Fraction of Susceptible Human Beings), the number of infectious bites each person is exposed to (Number of Infectious Bites Per Day) and the probability of becoming infected by such a bite (Transmission Probability for Human Beings per Bite). The second of these factors originates from the sand fly population, and is conditioned by human behavior:

The number of infectious bites each person is exposed to (Number of Infectious Bites per Day) is determined by the number of infected (adult female) sand flies that have laid eggs (are through

their incubation period) (Infectious Adult Female Sand Flies), the number of bites per sand fly experienced by human beings (Number of Bites per Sand Fly) and the average time between blood meals for female sand fly (Average Time Between Blood Meals).

While as the average time between blood meals for female sand fly is considered a biological constant, the total number of bites experienced per sand fly experienced by human beings is conditioned by the probability of a human being exposed to such bites (Probability of Human Being Exposed to Sand Fly Bites) which, again, is, determined by the level of life condition (Human Development Index) among those human beings (the higher the HID, the lower the probability to exposed to a sand flies bite).

The number of infected (adult female) sand flies who have laid eggs (Infectious Adult Female Sand Flies) originates from the sand fly sector that will be explained in detail, below.
Adult female sand flies suck a blood meal via bite (Biting Rate of AFSF) after the average time between blood meals. The recruitment of adult female sand flies to the infected population results from its interaction with the infectious portion of the human population (Density of Infectious Human Beings).

The rate at which adult female sand flies suck blood is determined by the number of susceptible adult female sand flies (Susceptible Adult Female Sand Flies), the proportion of adult female sand flies that survive (Adult Survival Fraction1) and the average time between blood meals (Average Time Between Blood Meals).

The infection rate of adult female sand flies (Infectious Bite Rate of AFSF) (see figure 5.1) is determined by the rate at which adult female sand flies bite (Biting Rate of AFSF), the number of the total number of bites per sand fly experienced by human beings (Number of Bites per Sand Fly), the probability that a susceptible female sand flies bites (sucks blood) from an infected human being and the probability of becoming infected by such a bite (Transmission Probability for Sand Fly per Bite). The third of this factor that originate from the human beings population and is conditioned by sand fly behavior.

The probability that a susceptible female adult sand fly bites (sucking blood from) infected human is determined by the density of infected human beings (Density of Infectious Human Beings) (where the number of the number of bites per sand fly experienced by human beings and the average time between each sand fly bites as described above).

The CLD in figure 5.2 is an expansion of figure 5.1 with a structure for the causal links representing the impact of PKDL.

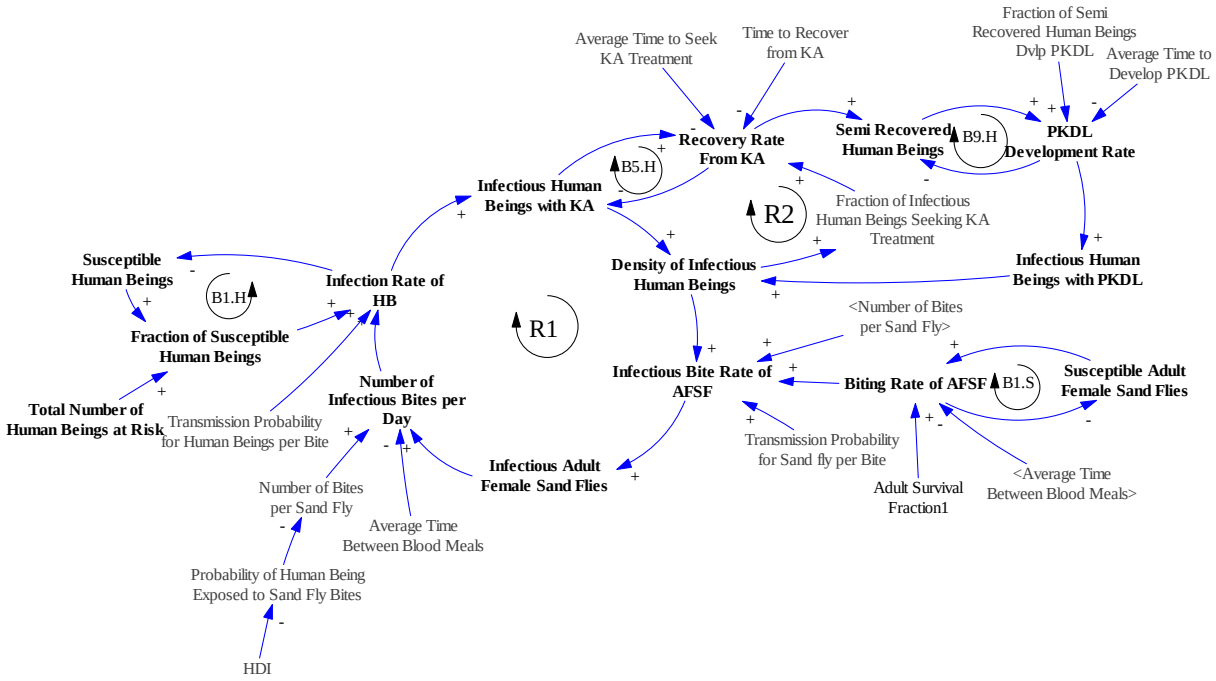


Figure 5.2: The general causal loop diagram of Kala-azar and PKDL

Subsequently, after the human beings has contracted the disease, some of them seek treatment for Kala-azar (Fraction of Infectious Human Beings Seeking KA Treatment) after an average time to seek treatment (Average Time to Seek KA Treatment) and, after a period of time to recover from Kala-azar (Time to Recover from KA) (a constant), people move on to the recovered portion of the human beings population. Of course an increase in the average time to seek treatment (Average Time to Seek KA Treatment) lowers the recovery rate of human beings from Kala-azar. And a decrease in the fraction of infectious human seeking Kala-azar treatment (Fraction of Infectious Human Beings Seeking KA Treatment) lowers the recovery from Kala-

azar rate of human beings (Recovery Rate From KA). The rate of recovery from Kala-azar (Recovery Rate from KA) increases the number of human beings recovered (Semi Recovered Human Beings).

Once human beings have recovered, there is a probability (Fraction of Semi Recovered Human Beings Dvlp PKDL) for people to develop PKDL after an average time to develop PKDL (Average Time to Develop PKDL). The recruitment of human beings to those infected with PKDL (PKDL Development Rate) increases the number of infected people with PKDL (Infectious Human Beings with PKDL). As human beings infected with PKDL constitute an infected blood source for an adult female sand fly, then the more people infected with PKDL, the higher is the 'Density of Infectious Human Beings'.

We can summarize the positive feedback loops R1, R2 as follows: The more people that are infectious with Kala-azar and PKDL, the higher density of infectious human beings. The higher this density, the higher is the infection rate of adult female sand flies. Moreover, the higher infection rate of adult female sand flies leads to a larger number of infected adult female sand flies. This causes in turn, an increase in the number of infectious bites per day and, thus, in an increase in the number of infectious bites per day. Theses bites leads to higher infection rate of human beings and to more people being infected.

6. The Model

The model has been developed to represent the dynamics of the Kala-azar disease. The structure of this disease is represented by using coupled nonlinear differential equations to produce its epidemiological dynamics in the populations of human beings and sand flies. The human beings contribute in the role of the host and the reservoir for the disease at the same time, while the sand flies play the role of the vector for the disease. We have developed this model to investigate the mechanisms behind the spread of a disease to assess the effectiveness of an education program aimed at reducing the spread of the Kala-azar disease.

6.1 The Model Assumptions

The Kala-azar model captures the basic processes of the Kala-azar disease. The Kala-azar model in this paper is based upon some overall assumptions regarding the two populations:

The life cycle of sand fly has been simplified into three stages (Egg, Young, and Adult).

In the mode, we consider only the development of female sand flies, since only they bite human beings to obtain meals of blood, and we assume that half of the egg production result in females.

Moreover, we assume that the population of sand flies is initially in equilibrium and consider the development of sand fly under the temperature of 25^0 C (resulting in a constant fertility).

Moreover, we assume that the human population sector is constant; there are no births and/or immigration adding to the human beings population. This assumption can easily be relaxed in this model.

We assume, also, that only the fraction of the Indian population that is relatively poor is effectively susceptible to Kala-azar infections due to poor housing and clothing, to illiteracy that causes them to protect themselves poorly and not seek health care services when ill, and to low income that causes them not to be able to take advantage of treatment when offered.

The population of human beings is assumed to be homogenous: Each individual in the community is assumed to interact with sand flies through the same (average) number of bites (there are no groups that remain isolated from the sand flies or whose behavior is different from others).

6.2 The Model Structure

The model structure of Kala-azar epidemic contains two sectors, the human sector and the sand fly sector. Below we will describe each of these sectors. The Kala-azar model sectors were based on the relevant scientific knowledge of the Kala-azar disease.

6.2.1 The Human Beings Sector

In the sector representing human beings, we model the mechanism behind the transmission of Kala-azar into the population of human beings in India and the diffusion of the disease throughout that population to represent how human beings constitute a reservoir and a host for the disease. The population of human beings is subdivided into different categories in accordance with the epidemiological stages of the disease. These categories include susceptible human beings, latent human beings, human beings infectious with Kala-azar, human beings semi recovered (who may, potentially, develop PKDL), human beings infectious with PKDL (Post-kala-azar Dermal Leishmaniasis), and fully recovered human beings.

We represent the progress of the disease in humans through different stages, as shown in figure 6.1. The stock of ‘Susceptible Human Beings’ consists of people who are susceptible to the disease; the stock of ‘Latent Human Beings’ consists of people living with the parasite who are not yet infectious, while the stock of ‘Infectious Human Beings with KA’ consists of people who have acquired Kala-azar and are infections.

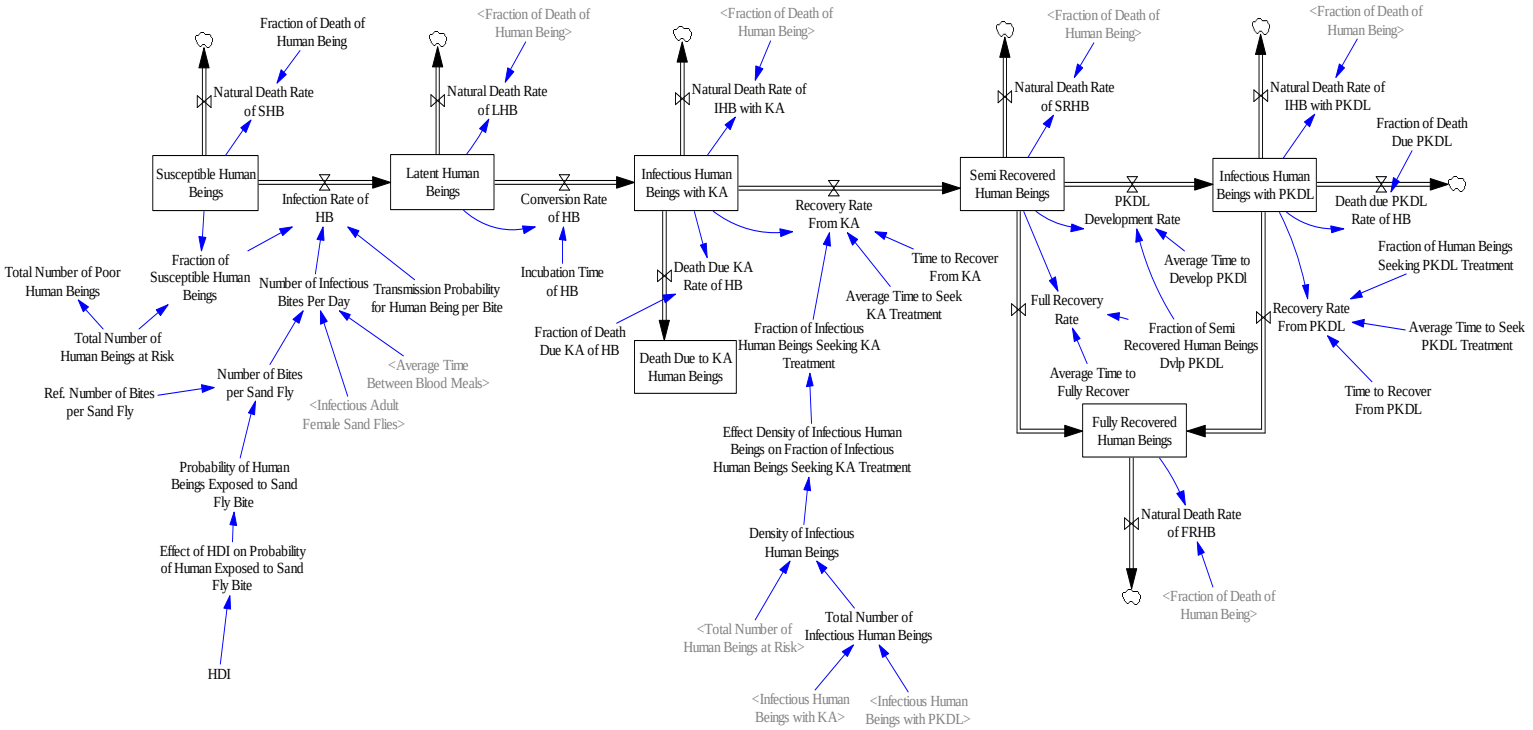


Figure 6.1: The stock and flow diagram structure for human beings sector

The stock of' Death Due to KA Human Beings' accumulates those who have died due to Kala-azar, the stock of 'Semi Recovered Human Beings' is made up of people who have recovered from Kala-azar, while as the stock of 'Infectious Human Beings with PKDL' consists of people who have developed PKDL, and the stock of 'Fully Recovered Human Beings' accumulates those who have recovered and have safely passed the latency time associated with PKDL and thus have gained permanent immunity.

To formulate the equations that describe the progress of human beings through the different stages of Kala-azar in figure 6.1, we assume that the individuals at the outset belong to the susceptible human beings (Susceptible Human Beings) stock. If a susceptible individual is bitten by an infected adult female sand fly, that individual is infected and moves from the susceptible to latent category.

The number of latent human beings (Latent Human Beings) is increased by the infection rate of human beings (Infection Rate of Human Beings) while the number of susceptible human beings (Susceptible Human Beings), is decreased by the same rate.

We have assumed that there is constant fraction of natural deaths that occurs every day among human beings (Fraction of Death of Human Beings) throughout all sub-populations (categories) of human beings

The rate of natural deaths from susceptible human beings (Natural Death Rate of SHB) that decreases the stock of susceptible human beings (Susceptible Human Beings) is represented by the following equation:

Natural Death of SHB = Susceptible Human Beings* Fraction of Death of Human Beings

People in the community receive bites from sand flies at a certain rate (1/ Average Time Between Blood Meals). Some of these bites are infectious bites that originate from infected adult female sand fly who have laid egg. The female of sand fly in this category bites human being for the second time during her life (Strauss-Ayali and Baneth 2000).

Thus infected adult female sand flies (see the sand fly sector) generate an average number of infectious bites per day (Number of Infectious Bites per Day).

Number of Infectious Bites per Day = Number of Bites per Sand Fly*

Infectious Adult Female Sand Flies/

Average Time Between Blood Meals

The number of infectious bites per day (Number of Infectious Bites per Day) is determined by the average time between blood meals enjoyed by each female sand fly (Average Time Between Blood Meals), the number of bites generated per sand fly (Number of Bites per Sand Fly) is measured bite per sand fly and the number of infected adult female sand flies (Infectious Adult Female Sand Flies) as we mentioned in section 5. We assume that the human beings populating susceptible to Kala-azar predominantly belong to the poor fraction of the population at risk in India. They are, in general, exposed to a certain number of bites from each sand flies (Number of Bites per Sand Fly). However, due to the fact that the satisfactory life condition typically enable people to protect themselves from the bites of sand flies, the Human Development Index (HDI) is considered to have an effect on the probability of human beings being exposed to sand fly bites, i.e. an increase in HDI decreases the probability of human beings being exposed to sand fly bites. We have assumed that the probability of human beings exposed to sand flies (Probability of Human Exposed to Sand Fly Bite) has effect on (Number of Bites per Sand Fly).

Thus the number of infectious bites per day (Number of Infectious Bites per Day) resulting in infection among susceptible human beings (given the probability that a person becomes infected after infectious bite), is measured in person per bite (Transmission Probability for Human Being per Bite). The infection rate of human beings (Infection Rate of HB) is, therefore, the total number of infectious bites per day (Number of Infectious Bites per Day) multiplied by the fraction of susceptible human beings (Fraction of Susceptible Human Beings), multiplied by the probability that a bite from infectious sand fly results in the infection of a human being (Transmission Probability for Human Being per Bite).

Infection Rate of HB= Number of Infectious Bites per Day*Fraction of Susceptible Human Beings*

Transmission Probability for Human Being per Bite

The total number of latent human beings in the population is a stock (see figure 6.1). The flow, characterized by the infection rate of human beings (Infection Rate of HB) moves people from the susceptible human being to the population of latent human beings.

The stock of latent human beings (Latent Human Beings) is drained by two flows: On the one hand, there is the conversion of human being to full-blown Kala-azar (governed by Conversion Rate of HB) and, on the other hand, there are the deaths, characterized by the natural death rate of human beings (Natural Death of LHB). Each of these two flows forms a balancing feedback loop.

The stock of latent human beings (Latent Human Beings) is the source of the rate of conversion of human beings (Conversion Rate of HB). This conversion moves people from latent human beings to category of human beings infectious with Kala-azar (Infectious Human Beings with KA) after a period of incubation of human beings (Incubation Time of HB), - assumed to be constant. This conversation process is assumed to constitute a fist-order negative feedback process:

Conversion Rate of HB = Infectious Human Beings with KA/

Incubation Time of HB

People who are latent (Latent Human Beings) flow out at rate of natural death (Natural Death Rate of LHB) which is dependent on the fraction of death per day (Fraction of Death of Human Beings) as represented in the following equation:

Natural Death Rate of LHB= Latent Human Beings* Fraction of Death of Human Beings

The rate of conversation of human beings (Conversion Rate of HB) accumulates in the number of infectious human beings with Kala-azar. The stock of infectious human beings with Kala-azar (Infectious Human Beings with KA) is depleted by three flows; - the recovery of infectious human beings carrying Kala-azar governed by the rate (Recovery Rate From KA), the deaths of such people due to Kala-azar governed by the rate (Death Due KA Rate of HB), and the natural deaths (from other causes) governed by the rate (Natural Death Rate of IHB with KA), determined by the natural mortality of human beings affected. The rate of each of these flows

depends on the stock of infectious human beings (Infectious Human Beings with KA) and are, therefore, each governed by a balancing feedback loop.

The rate of recovery of infectious human beings carrying Kala-azar (Recovery Rate From KA) is determined by the reservoir of infectious human beings seeking Kala-azar treatment (Fraction of Infectious Human Beings Seeking KA Treatment), the average time to seek Kala-azar treatment (Average Time to Seek KA Treatment), and the period to recover from Kala-azar (Time to Recover from KA).

The 'Time to Recover from KA' is considered a biological constant, and the average time to seek Kala-azar treatment (Average Time to Seek KA Treatment) is assumed to be a constant. Moreover, the fraction of infectious human beings seeking Kala-azar treatment (Fraction of Infectious Human Beings Seeking KA Treatment) is assumed to be influenced by the prevalence of infection in human beings (Density of Infectious Human Beings) i.e. an increase in fraction of infected human beings increases the fraction of infectious human beings seeking KA treatment. This recovery activity is assumed to follow a first-order negative feedback as represented by following equation:

Recovery Rate From KA =

Infectious Human Beings with KA* Fraction of Infectious Human Beings Seeking KA Treatment/ (Average Time to Seek KA Treatment + Time to Recover from KL)

Here the fraction of infectious human beings (Density of Infectious Human Beings) is calculated as follows: The total number of infectious human beings (Total Number of Infectious Human Beings) over the total number of population at risk in India (Total Number of Human Beings at Risk). The total number of infectious human beings (Total Number of Infectious Human Beings) is dependent on two variables; - the number of infectious human beings with Kala-azar (Infectious Human Beings with KA) and the number of infectious human beings with PKDL (Infectious Human Beings with PKDL). These two variables have a positive effect on the 'Density of Infectious Human Beings' where the total number of population at risk in India (Total Number of Population at Risk) has negative effect; it is assumed to be constant during the simulation.

The rate of death due Kala-azar of human beings (Death Due KA Rate of HB) is formulated as in the following equation:

Death Due KA Rate of HB = Infectious Human Beings with KA *

Fraction of Death Due KA

where the ‘Fraction of Death Due KA’ is assumed to be constant.

The rate of death due Kala-azar of human beings (Death Due KA Rate of HB) accumulates in the stock of ‘Death Due to KA Human Beings’

The rate of natural deaths (from other causes) of human beings infectious with Kala-azar (Natural Death Rate of IHB with KA) is formulated as:

Natural Death Rate of IHB with KA =Infectious Human Beings with KA *

Fraction of Death of Human Beings

The balancing feedback loop B5.H (from recovery) regulates the stock of infectious human beings with Kala-azar (Infectious Human Beings with KA).

The rate of recovery, ‘Recovery Rate From KA’ moves a fraction of infectious human beings who seek Kala-azar treatment to semi recovered human beings (Semi Recovered Human Beings) after an average time to seek Kala-azar treatment (Average Time to Seek KA Treatment) plus the period of time to recover from Kala-azar while under treatment (Time to Recover From KA). The stock of ‘Semi Recovered Human Beings’ is reduced by three different flows; the one leading to the development of PKDL (governed by the rate ‘PKDL Development Rate‘), the one leading to full recovery (governed by the rate ‘Full Recovery Rate ‘), and the one leading to natural deaths (from other causes) (at the rate ‘Natural Death of SRHB‘). The rates of each of these flows depend on the stock of ‘Semi Recovered Human Beings’ and, therefore, all form balancing feedback loops.

The rate of development of PKDL originating from the infectious human beings carrying Kala-azar (PKDL Development Rate) is determined by the reservoir of human beings recovered from

Kala-azar that may still develop PKDL (Fraction of Semi Recovered Human Beings Dvlp PKDL) and the average time to develop PKDL (Average Time to Develop PKDL).

The 'Fraction of Semi Recovered Human Beings Dvlp PKDL' is assumed to be constant and so is the 'Average Time to Develop PKDL'. Therefore the rate of develop of PKDL (PKDL Development Rate) is represented by the following equation:

PKDL Development Rate = Semi Recovered Human Beings*
Fraction of Semi Recovered Human Beings Dvlp PKDL /
Average Time to Develop PKDL

The rate of the flow of full recovery (Full Recovery Rate) is represented by the following equation:

Full Recovery Rate = (1 - Fraction of Semi Recovered Human Beings Dvlp PKDL)*
Semi Recovered Human Beings / Average Time to Full Recover

Where the 'Fraction of Semi Recovered Human Beings Dvlp PKDL' and 'Semi Recovered Human Beings' are both described above. The average time to fully recover (Average Time to Full Recover) is constant.

The rate of the flow of human beings recovered from Kala-azar subsequently developing PKDL (Develop PKDL Rate) contributes to the stock of infectious human being with PKDL (Infectious Human Beings with PKDL). The stock of 'Infectious Human Beings with PKDL' is depleted by three flows; the recovery of infectious human beings carrying PKDL governed by the rate 'Recovery Rate From PKDL'), deaths due PKDL of human beings (governed by the rate 'Death Due PKDL Rate of HB') and natural death (governed by the rate 'Natural Death Rate of IHB with PKDL').

The rate of recovery of infectious human beings carrying PKDL (Recovery Rate From PKDL) is dependent on the following three factor; the 'Fraction of Human Beings Seeking PKDL Treatment', the 'Average Time to seek PKDL Treatment), and the period of PKDL treatment (Time to Recover From PKDL), as represented by the following equation:

Recovery Rate From PKDL= Infectious Human Beings with PKDL*

Fraction of Human Beings Seeking PKDL Treatment/

(Average Time to seek PKDL Treatment+

Time to Recover from PKDL)

The rate of deaths due to PKDL (Death Due PKDL Rate of Human Beings) is dependent on the fraction of deaths due PKDL as characterized in the following equation:

Death Due PKDL Rate of Human Beings= Infectious Human Beings with PKDL*

Fraction of Death Due PKDL

Where the fraction of death due PKDL (Fraction of Death Due PKDL) is assumed to be constant.

And the rate of natural deaths of infectious human being with PKDL (Natural Death Rate of IHB with PKDL) is characterized as in the following equation:

Natural Death Rate of IHB with PKDL =

Infectious Human Beings with PKDL * Fraction of Death of Human Beings

The two flows, full recovery of infectious human beings carrying Kala-azar (governed by the 'Full Recovery Rate'), and recovery of infectious human beings carrying PKDL (governed by the rate Recovery Rate From PKDL), accumulate in the stock of 'Fully Recovered Human Beings'. The number of fully recovered human beings (Fully Recovered Human Beings) is drained by the natural death (Natural Death Rate of FRHB) as represented by the following equation:

Natural Death Rate of FRHB = Fully Recovered Human Beings * Fraction of Death of Human Beings

Figure 6.2 represents the casual loop diagram for the human beings sector and also disaggregates the model of human beings population.

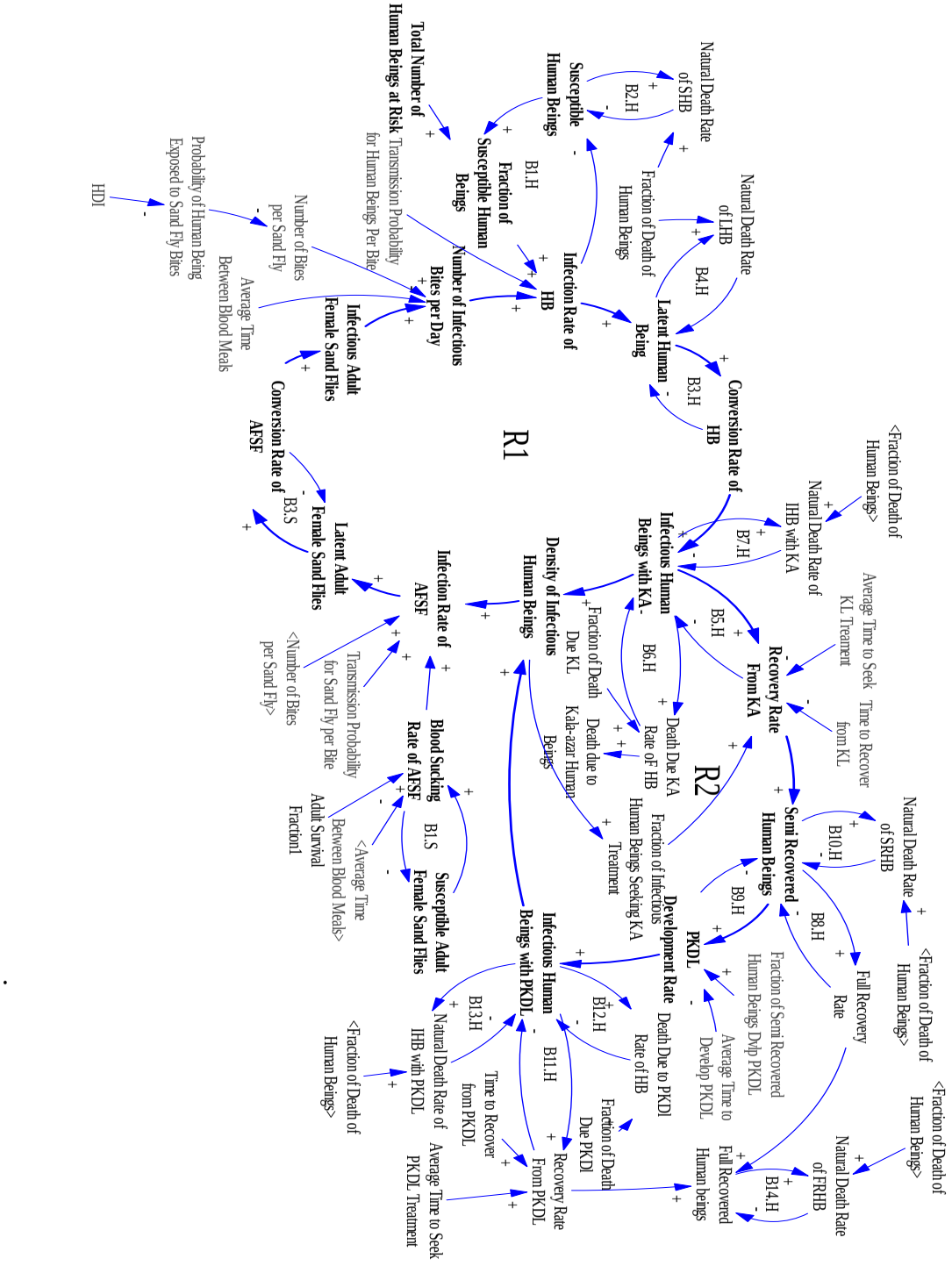


Figure 6.2: The causal loop diagram for the human beings sector

6.2.2 The Sand Flies Sector

In the sand fly sector, we model the mechanism behind the transmission of Kala-azar into the population of sand flies and the diffusion of the disease throughout that population so as to represent how sand flies constitute a vector for the disease. To structure the sand fly sector in the model, we introduce the life cycle of the female sand fly simplified into three stages, egg, young and adult. And since the female of adult sand fly can only transmit the disease to human beings. We categorize the life span of the female sand flies in the adult stage which is about 12 days according to the epidemiological stages of the disease. To describe the transmission of the disease to the adult female sand flies, we consider the process of blood meal, egg laying, and the development of the immature sand fly. Because these processes explain how the interaction between adult female sand flies and human being takes place, we utilize these processes to build the underlying structure of sand fly sector.

We represent the sand flies population by using an aging chain that captures the age structure of female sand flies population. In Figure 6.3 the female sand flies are classified into the following stocks female eggs (Female Eggs), young female sand flies (Young Female Sand Flies), susceptible adult female sand flies (Susceptible Adult Female Sand Flies), uninfected adult female sand flies (Uninfected Adult Female Sand Flies), latent adult female sand flies (Latent Adult Female Sand Flies), non- infectious adult female flies who have laid eggs (Non-infectious Adult Female Sand Flies), and infectious adult female flies who have laid eggs (Infectious Adult Female Sand Flies).

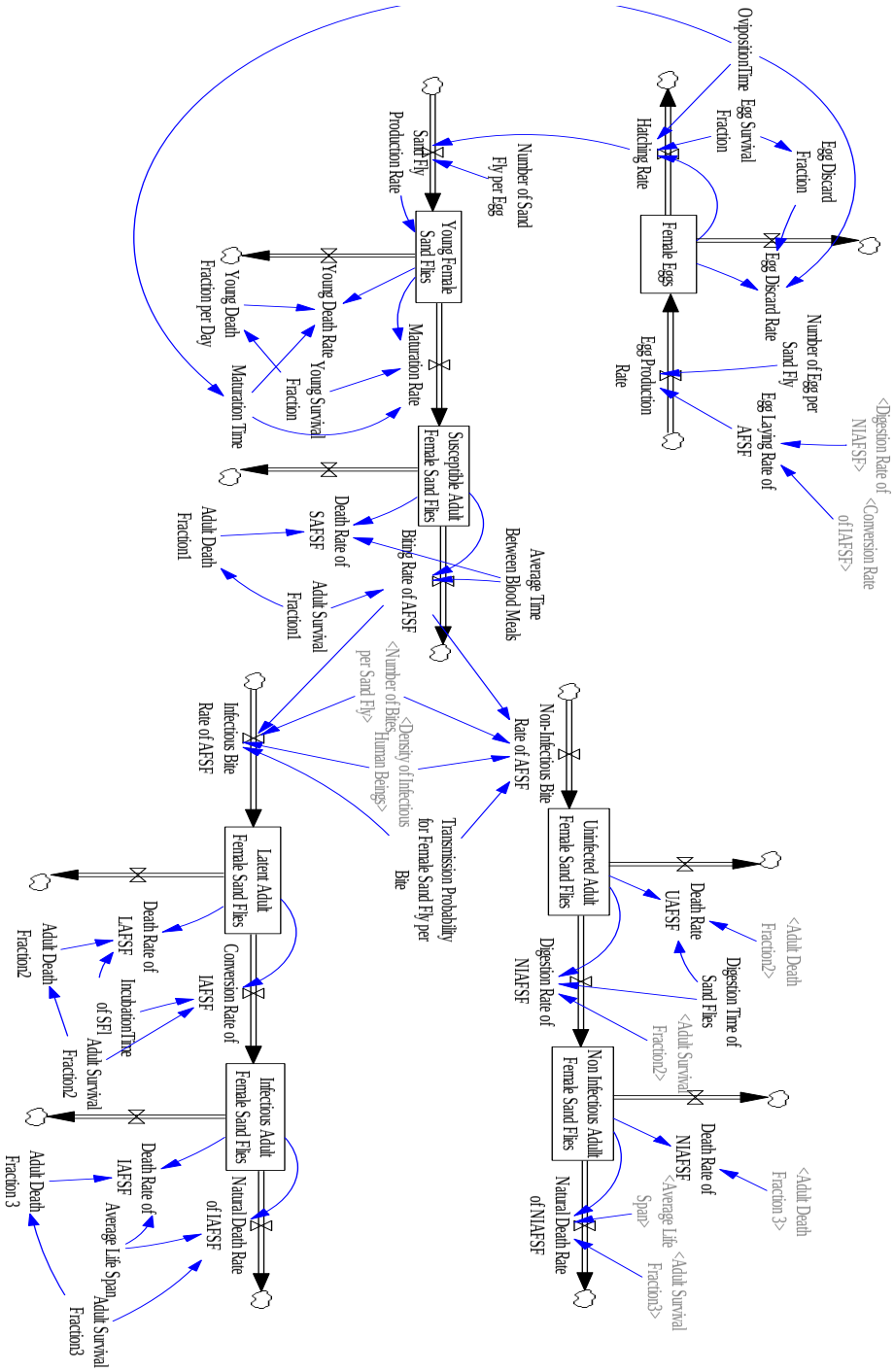


Figure 6.3: The stock and flow diagram structure for female sand flies sector

To formulate the equations that describe the development of sand flies through the various stages of its life cycle, we start from the egg stage, i.e. the total number of female eggs (Female Eggs) accumulating the flow of eggs produced (at the 'Egg Production Rate'). The equation for 'Egg Production Rate' will be discussed later in this section.

The number of female eggs (Female Eggs) is drained by two flows, governed by, respectively, the egg hatching rate (Hatching Rate) and egg discard rate (Egg Discard Rate). Each of these two flows forms a balancing feedback loop. The hatching of the female eggs, takes place after a period of oviposition (Oviposition Time) as represented by the following equation:

Hatching Rate = Female Eggs* Egg Survival Fraction/ Oviposition Time

The rate of hatching (Hatching Rate) is dependent on the proportion of egg surviving (Egg Survival Fraction). Here it is assumed that the probability of eggs surviving (Egg Survival Fraction) is constant.
On the other hand, the rate of egg discarded (Egg Discard Rate) is represented by the following equation:

Egg Discard Rate = Female Eggs* Egg Discard Fraction/ Oviposition Time

where Egg Discard Fraction = 1-Egg Survival Fraction.

Sand Fly Reproduction, From Young to Adult Sand Fly

Through the rate of produce sand fly flow (Sand Fly Production Rate) the female eggs enters, the young, female stage as describe by the followings equation:

Sand Fly Production Rate = Hatching Rate * Number of Sand Fly per Egg

Where the 'Number of Sand Fly per Egg' refers to the converter, i.e. the number of sand flies produced by one egg (= 1), measured in sand fly per egg.

The flow of produce sand fly (governed by the 'Sand Fly Production Rate ') accumulates in the stock of female young sand flies (Young Female Sand Flies). The population of young female sand flies (Young Female Sand Flies) is drained by two flows, governed by, respectively, the 'Maturation Rate' and 'Young Death Rate'. Each of these flows form a balancing feedback loop.

By way of the flow of maturation (governed by the 'Maturation Rate') the young female sand flies (Young Female Sand flies), after a period of time (Maturation Time), enters their adult stage (see figure 6.3), as described by the following equation:

Maturation Rate =Young Female Sand Flies* Young Survival Fraction/ Maturation Time

The proportion (a constant) of young female sand flies surviving (Young Survival Fraction) is one of the factors that determine the maturation process.

The proportion of young female sand flies death (Young Female Sand Flies) flow out at rate of death for young female sand flies (Young Death Rate). This flow is represented by the following equation:

Young Death Rate =Young Female Sand flies* Young Death Fraction/ Maturation Time

where Young Death Fraction per Day = (1-Young Survival Fraction).

We represent the total number of female sand flies in the adult stage by a stock of susceptible adult female sand flies (Susceptible Adult Female Sand Flies). When a female sand fly reaches an adult stage, the adult female sand fly starts seeking for a blood source to bite (in India the source is solely human beings) to develop her eggs. Therefore, once a female sand fly reaches its adult stage that means she becomes susceptible and, possibly infected / infections. Having reached the adult stage a female sand fly enjoys a blood meal every 2 to 3 days[1]. Therefore, it is assumed that the susceptible adult female sand flies bite human beings to suck blood meal at a certain rate (Biting Rate of AFSF) after an average time (Average Time Between Blood Meals) [2] which is measured in day.

The biting rate 'Biting Rate of AFSF' is determined by the number of susceptible adult female sand fly (Susceptible Adult Female Sand Flies), the proportion of adult female sand fly surviving at this stage (Adult Survival Fraction1) and the average time between blood meals for female

[1] Based on the information that mosquitoes take a blood meal every 2-3 days.

sand fly (Average Time Between Blood Meals). Therefore, the rate of biting of adult female sand fly (Biting Rate of AFSF) is described by the following equation:

Biting Rate of AFSF = Susceptible Adult Female Sand Flies *
Adult Survival Fraction1/
Average Time Between Blood Meals

Moreover, there is proportion of susceptible adult female sand flies that die (Adult Death Fraction1)[2] and flowing out at a rate of death of susceptible adult female sand flies (Death Rate of SAFS) as represented by the following equation:

Death Rate of SAFS= Susceptible Adult Female Sand Flies * Adult Death Fraction1/
Average Time Between Blood Meals

where Adult Death Fraction1 = (1- Adult Survival Fraction1).

Susceptible adult female sand flies may bite infectious or non-infectious human. Therefore, the rate at which adult female sand flies bite to suck blood of is split into: the infectious bite of adult female sand flies (Infectious Bite Rate of AFSF) and the non- infectious bite of adult female sand flies (Non- Infectious Bite Rate of AFSF) through bites. Thus the rate of infectious bite of adult female sand flies (Infectious Bite Rate of AFSF) is determined by the rate of biting of adult female sand flies (Biting Rate of AFSF), the number of bites per sand fly experienced by human beings (Number of Bites per Sand Fly), the probability of a sand fly biting an infected human beings (Density of Infectious Human Beings) and the probability that a sand fly will become infected after bite infected person (Transmission Probability for Sand Fly per Bite). Therefore, the rate of infection of adult female sand flies (Infectious Bite Rate of AFSF) may be portrayed as follows:

[2] We assume, the adult female sand flied have three different variables that represent the adult survive fraction between the first two days, the survive fraction of adult female sand fly (Adult Survival Fraction1) is 0.9, after the second day it will have 0.85 (Adult Survival Fraction2) for the adult female sand fly to live for another 6 days (Incubation time or Digestion Time), and after the 8th day the adult female sand fly will have 0.8 surviving fraction (Adult Survival Fraction3)

Infectious Bite Rate of AFSF = Biting Rate of AFSF * Number of Bites per Sand Fly *
Density of Infectious Human Beings * Transmission Probability for Sand Fly per Bite

The rate at which adult female sand flies (Non- Infectious Bite Rate of AFSF) draw blood, yet do not get infected, is represented by the following equation:

Non- Infectious Bite Rate of AFSF = Biting Rate of AFSF * Number of Bites per Sand Fly*
(1- Density of Infectious Human Beings) *
Transmission Probability for Sand Fly per Bite

In figure 6.3, the rate of the flow of adult sand flies biting without contracting the disease (Non-Infectious Bite Rate of AFSF) accumulates in the stock of uninfected adult female sand flies (Uninfected Adult Female Sand Flies), a stock that is depleted by two processes: the digestion of the uninfected blood by the female sand flies (Digestion Rate of UAFSF) and deaths of sand flies in this category (Death Rate of UAFSF), each of these activities form negative feedback loops.

The adult female sand flies who survive in the category of uninfected adult female sand flies (Uninfected Adult Female Sand Flies) need about 6 days to digest their meals in preparation for laying eggs (Digestion Time of SF). It is assumed that the average time to digest a meal is equal to the average (constant) time of incubation of the sand fly. Thus,

Digestion Rate of UAFSF = Uninfected Adult Female Sand Flies *
Adult Survival Fraction2/ Digestion Time of SF

The rate at which blood meals are digested by uninfected adult female sand flies (Digestion Rate of UAFSF) is determined by the number of uninfected adult female sand flies (Uninfected Adult Female Sand Flies) and the proportion of adult female that survive (Adult Survival Fraction2). The proportion of adult female sand flies surviving (Adult Survival Fraction2) is assumed to be constant. And the rate of deaths by of uninfected adult female sand fly (Death Rate of UAFSF) is represented by the following equation:

Death Rate of UAFSF = Uninfected Adult Female Sand Flies *

Adult Death Fraction2 / Digestion Time of SF

The proportion of adult female sand flies death (Adult Death Fraction2) is equivalent to (1- Fraction Adult Survive2).

The flow at which uninfected adult female sand flies digest a blood meal (governed by the 'Digestion Rate of UAFSF'), these flies accumulate in the stock of non-infectious adult female sand flies (Non-Infectious Adult Female Sand Flies). This stock is depleted by two flows; the deaths of non-infectious adult female sand flies (Death Rate of NIAFSF), and the natural death of non-infectious adult female sand flies (Natural Death Rate of NIAFSF). Each of these two flows depends on the stock of non-infectious adult female sand flies (Non-Infectious Adult Female Sand Flies) and, therefore, constitutes a balancing feedback loop.

The flow of natural deaths among non-infectious adult female sand flies (governed by the 'Natural Death Rate of NIAFSF') is determined by the proportion of adult female sand flies that survive (Adult Survival Fraction3) and the average life span (Average Life Span) for the remaining non-infectious adult female sand flies:

Natural Death Rate of NIAFSF = Non-Infectious Adult Female Sand flies *

Adult Survival Fraction3/ Average Life Span

The 'Adult Survival Fraction3' is assumed to be constant.

The 'Death Rate of NIAFSF' relies on the proportion of adult female sand flies death (Adult Death Fraction3), and the death rate of non-infectious adult female sand flies category is formulated as shown in the equation below.

Death Rate of NIAFSF = Non-Infectious Adult Female Sand flies*

Adult Death Fraction3 /

Average Life Span

where the portion of adult female sand fly death 'Adult Death Fraction3' is equal to (1- Adult Survival Fraction3).

The flow of infected adult female sand flies (governed by the 'Infectious Bite Rate of AFSF'), accumulates in the stock of latent adult female sand flies (Latent Adult Female Sand Flies), - a stock that is drained by two flows; the conversation of adult female sand flies (at the rate Conversation Rate of AFSF), and the death rate of latent adult female sand flies (Death Rate of LAFSF). Each of these two flows form a balancing feedback loop (see figure 6.4). The proportion of adult female sand flies that survive (Fraction Adult Survive 2) enter the infected adult female sand flies stock (Infectious Adult Female Sand Flies) at the rate of conversion of adult female sand flies (Conversation Rate of AFSF) after the period of incubation time of sand fly (Incubation Time of SF), assumed to be of 6 days. A proportion (Adult Death Fraction2) of adult female sand flies in the latent category die over the period of incubation time and flow out at rate of the death of latent adult female sand flies (Death Rate of LAFSF) . These two flow rates are represented in the following way:

Conversation Rate of AFSF = Latent Adult Female Sand Flies * Fraction Adult Survive 2/
Incubation Time of SF

Death Rate of LAFSF = Latent Adult Female Sand Flies * Adult Death Fraction2
/ Incubation Time of SF

where the proportion of adult survival 'Adult Survival Fraction2', and the proportion of adult death 'Adult Death Fraction2' are described above.

As the rate of conversations of adult female sand flies (Conversion Rate of AFSF) accumulates in the infectious adult female sand flies. The number of adult female sand flies in the stock (Infectious Adult Female Sand flies) is decreased by the death and the natural death of adult female sand flies. The rate of natural mortality flow of infectious adult female sand flies (Natural Death Rate of IAFSF) is formulated as follows:

Natural Death Rate of IAFSF= Infectious Adult Female Sand Flies*
Adult Survival Fraction3/ Average Life Span[3]

The rate of death of infectious adult female sand flies (Death Rate of IAFSF) is formulated as following:

[3] Average life span is the average remaining time span for the adult female sand fly

Death Rate of IAFSF = Infectious Adult Female Sand Flies* Adult Death Fraction3/ Average Life Span,

where the proportion of adult survival ‘Adult Survival Fraction3’ and the proportion of adult death ‘Adult Death Fraction3’ are described above.

We assume that the adult female sand flies in the stock of non-infectious female sand flies who have laid eggs (Non-Infectious Adult Female Sand Flies) and in the stock of infectious adult female sand flies who have laid eggs (Infectious Adult Female Sand flies), both of these can bite human beings for the second time in their life (this assumption used by (Strauss-Ayali and Baneth 2000)). Here the focus will be on the bite of the adult female sand flies in the infectious adult female sand flies stock only because these bite transmit the disease for human beings and we are not interested in the bite of non infectious female sand flies stock anymore because even if they become infected they do not have the chance to live and transmit the disease.

Egg Reproduction from Adult Sand Flies

In this section, we describe the egg laying process for the female adult sand flies. It is assumed that after the average time of digestion or incubation of sand fly, the adult female sand flies lay their eggs at a certain rate (Egg Laying Rate of AFSF). The ‘Egg Laying Rate of AFSF’ is defined as follows:

Egg Laying Rate of AFSF = Conversation Rate of AFSF + Digestion Rate of AFSF.

The egg laying rate of adult female sand flies (Egg Laying Rate of AFSF) produce a number of eggs per sand (Number of Egg per Sand fly). Therefore, the rate of egg production (Egg Production Rate) is:

Egg Production Rate = Laying Egg Rate of AFSF * Number of Egg per Sand Fly

As we mention earlier the ‘Egg Production Rate’ accumulates in the stock of ‘Female Eggs’ by this we complete describe the life cycle of sand fly development (See Figure 6.4) it illustrates the casual loop diagram of sand fly sector.

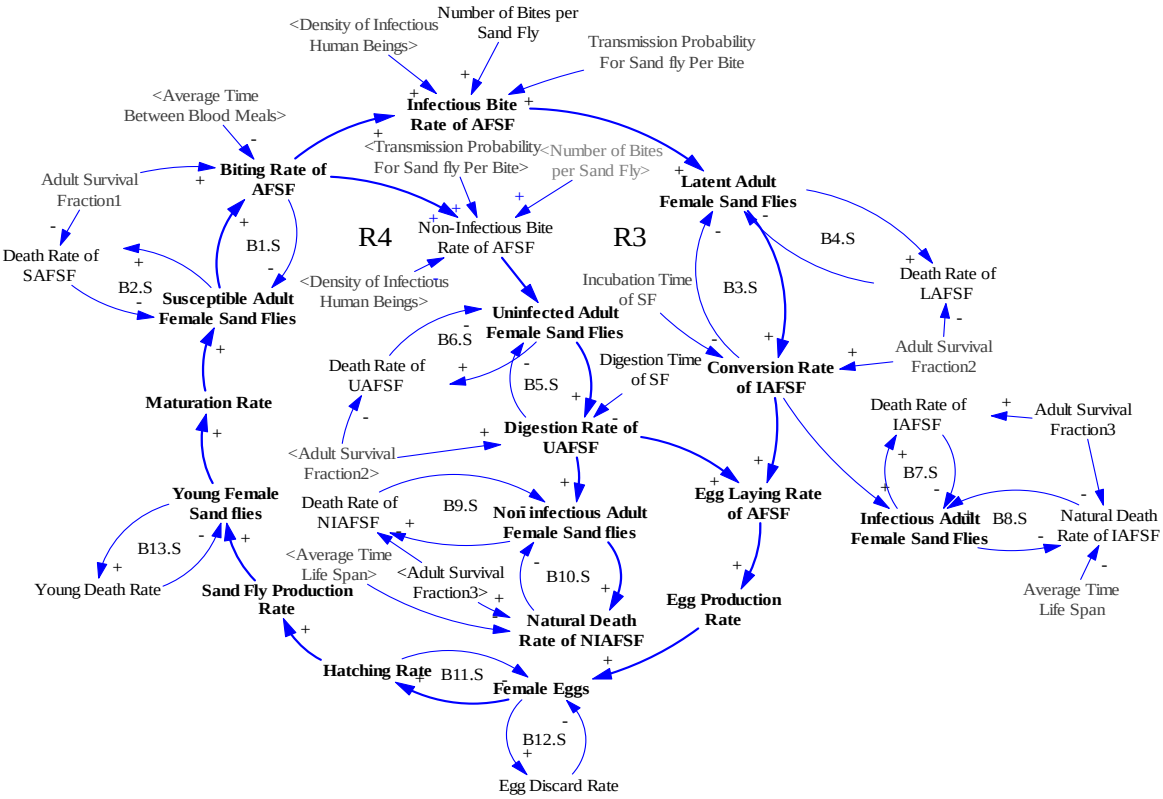


Figure 6.4: The casual loop diagram for sand fly sector

We conclude that the Kala-azar model developed shows the spread of the disease among human beings, through the bite of adult female sand fly, is a cyclic effect. The interaction of these two populations creates the positive feedback loops (R1, R2, R3 and R4). The two positive feedback loops (R1, R2) in the human beings sector summarize the hypothesis of the study and the two positive feedback loops R3 and R4 in the sand flies sector summarize the core of the interaction which constitute the life cycle of sand fly development . There is nonlinearity in the system because of the human population and the population of sand fly multiplied together in the above mentioned equations (Infection Rate of Human Beings).

6.3 Time Horizon

The time horizon for our simulation is start from day 365 to 8385 which is crossed year 2002 up to 2025, from day 365 to 1825 (2002 to 2007) to observed the historical behavior of our reference and from 2920 up to 8385 (2011 to 2025) to observed the effect of the policies to achieve the government of India goal of reduce the cases of Kala-azar.

7. Model Analysis

In this section, we will analyze the behavior of three key variables: (1) Infection Rate of Human Beings, (2) Infectious Human Beings with KA, (3) and Infectious Human Beings with PKDL.

In India where there are about 1.65 million people are at risk to be infected by KA, but only the poor fraction of the population is considered to investigate the spread of the infection. It is well known that within this population there is more exposure to sand fly bite that transmits Kala-azar. Therefore, this fraction that constitutes the poor population reflects clearly the main factor responsible for the spread of the disease. Consequently, the model would produce more reliable behavior.

The Kala-azar model is initiated by setting the initial number of human beings infected with Kala-azar (Infectious Human Beings with KA) to 12140 persons. After this initialization, the Kala-azar infected human beings population is growing rapidly until day 2190 (year 2007) whereupon it starts declining to 14819 in day 4465 (year 2012). Moreover, it is projected to reverse into grow from day 4745 (year 2014) until day 8385 (year 2025). Figure 7.1 shows the history and the simulation result (Basic Run) of the number of people infected with Kala-azar.

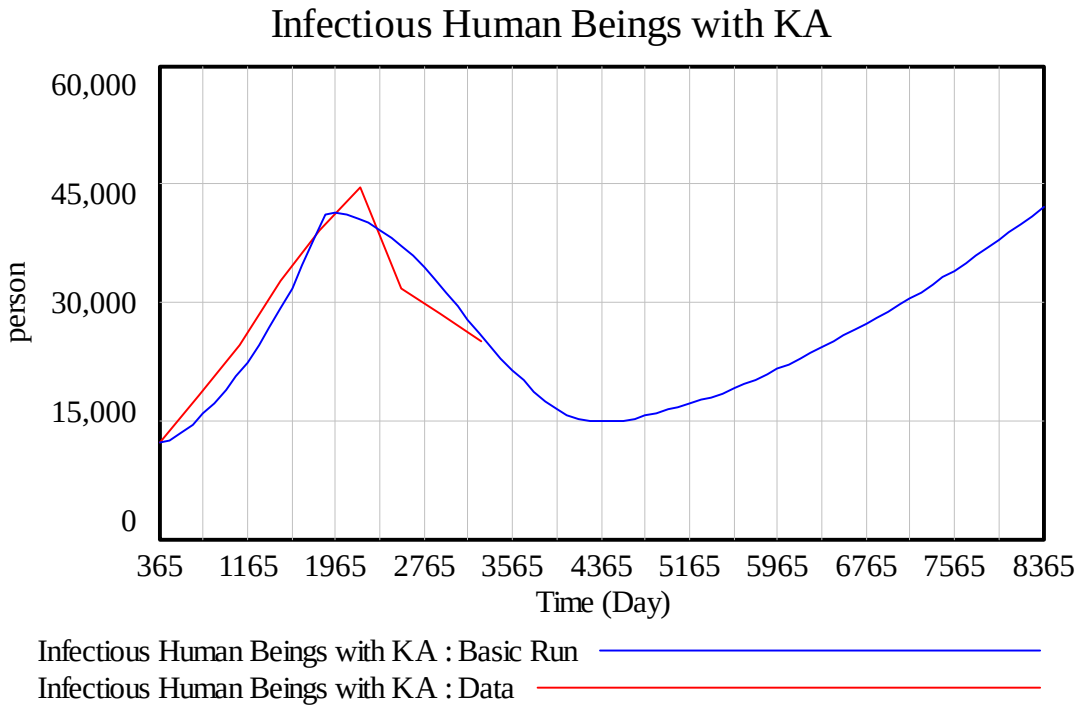


Figure 7.1: The infectious human beings with Kala-azar population

The behavior displayed in figure 7.1 is a result of the net change of the stock of infectious human beings (the conversation rate of human beings – (the sum of the out flows from infectious human beings). Figure 7.2 shows the number of infected human beings with Kala-azar increases when the conversion rate exceeds the sum of the out flows (the net change of the stock of Kala-azar is positive), while it decreases when the sum of these outflows exceeds the rate of conversion of human beings (the net change of the stock of Kala-azar is negative). The out flows are the recovery rates from Kala-azar (Recovery Rate From KA), the death rate due to Kala-azar (Death Due KA Rate of HB) and the natural death of infectious human beings with Kala-azar (Natural Death Rate of IHB with KA). Later, we will analyze the behavior of infection rate of human beings and the recovery rate from Kala-azar in more details.

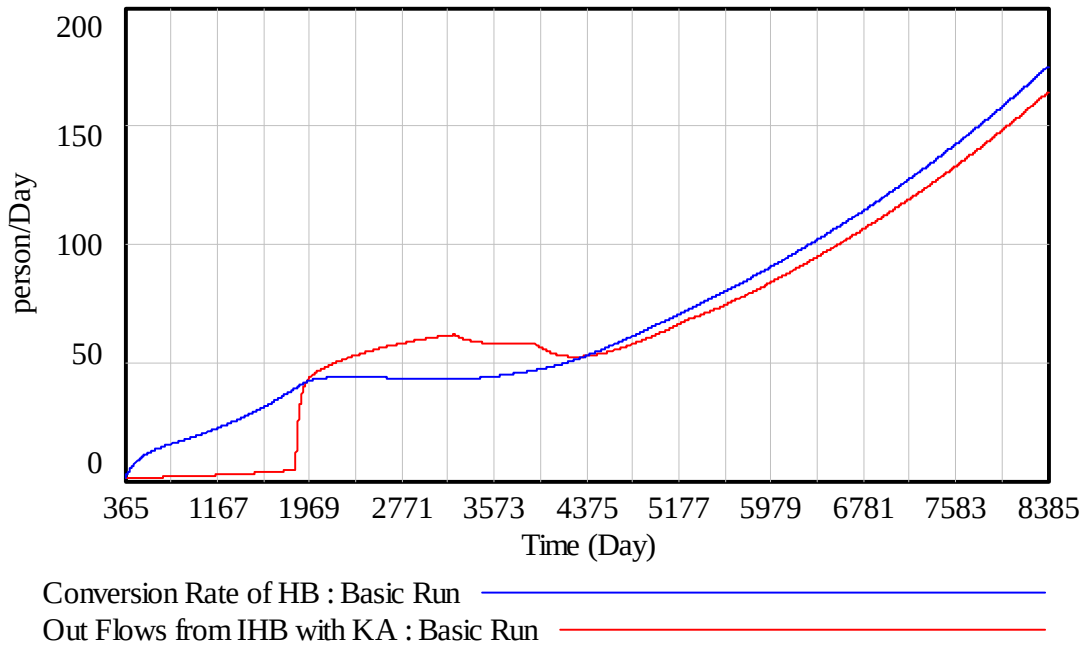


Figure 7.2: Comparison between the infection rate of HB and the out flows from IHB with Kala-azar

The number of infected human beings with Kala-azar has appositive effect on the rate of recovery of human beings (outflow), death due to Kala-azar (outflow), natural death of infectious

human beings (outflow). The recovery rate of human beings from Kala-azar moves human beings to the population of semi recovered human beings from Kala-azar (see figure 7.3) and the rate of death due to Kala-azar accumulates in the population of dead from Kala-azar (see figure 7.4).

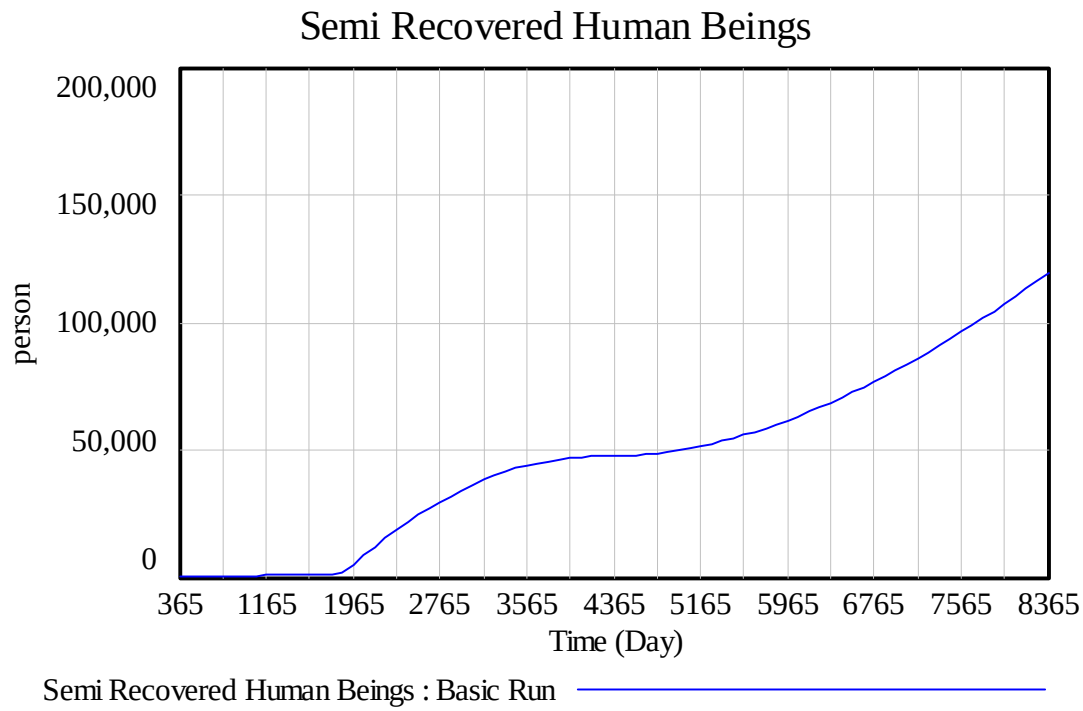


Figure 7.3: The semi recovered human beings population

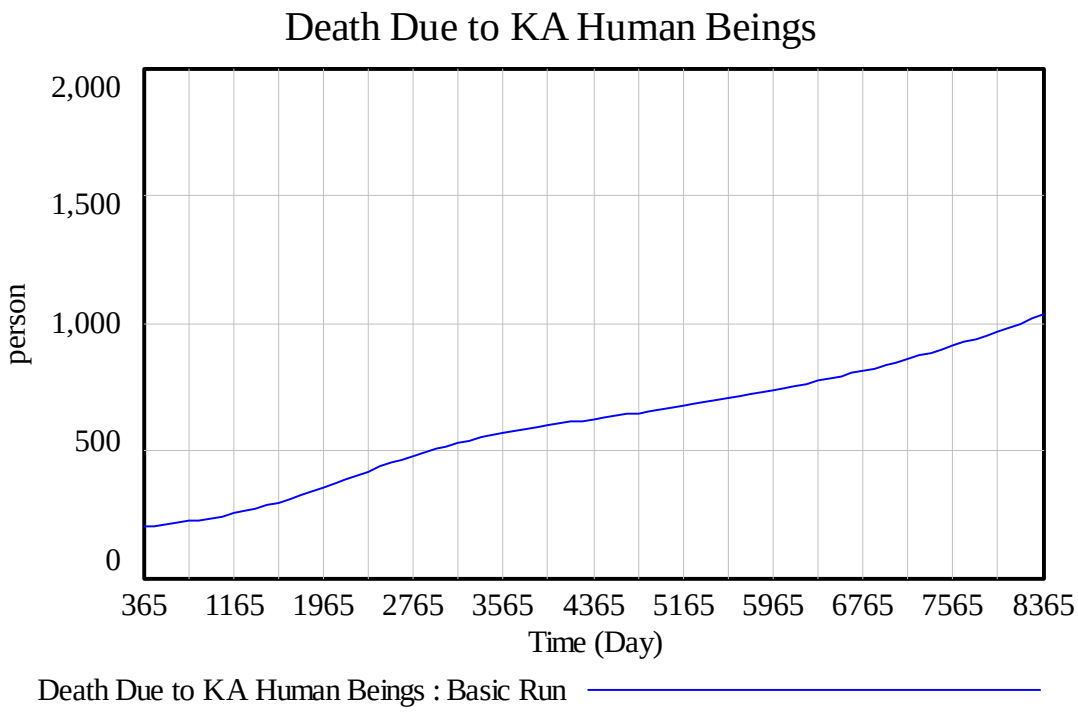


Figure 7.4: The death due to Kala-azar among human beings population

The behavior displayed in figure 7.3 is a result of the net change of the stock of semi recovered human beings (the recovery rate of human beings from Kala-azar- the sum of the out flows from this stock). The out flows from the stock of semi recovered human beings are the PKDL development rate (PKDL Development Rate), the fully recovered from Kala-azar (Full Recovery Rate) and the natural death of semi recovered human beings (Natural Death Rate of SRHB).

Figure 7.5 explains that the number of semi recovered human beings increases as long as the recovery rate of human beings from Kala-azar exceeds the sum of the out flows from this stock (the net change of the stock of semi recovered human beings is positive).

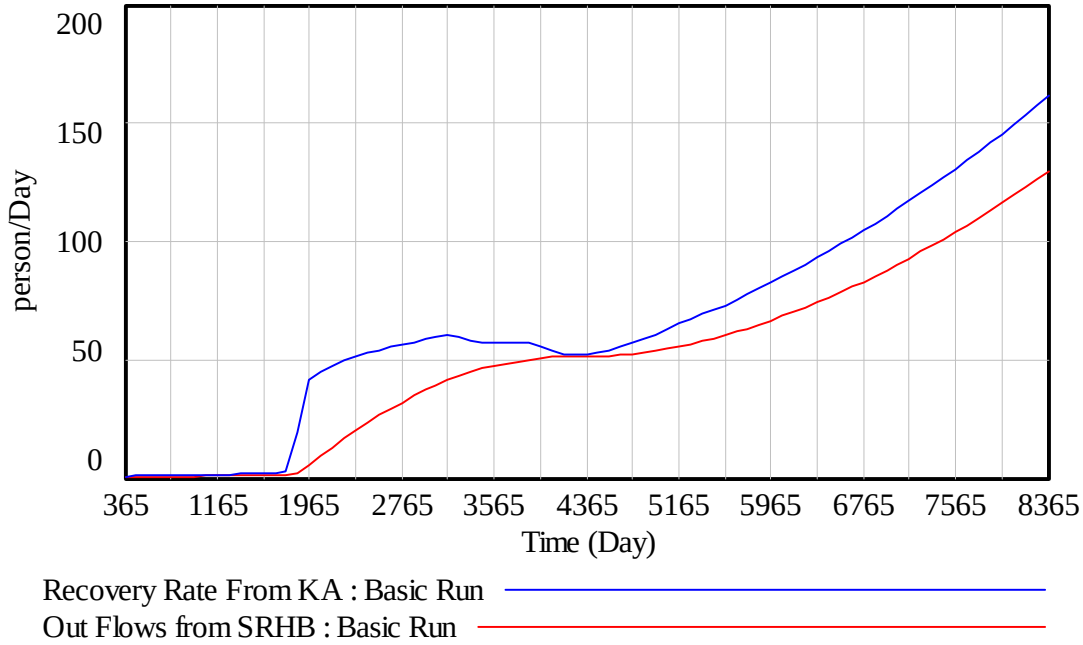


Figure 7.5: Comparison between the recovery rate of HB from KA and the out flows from SRHB

The recovered human beings from Kala-azar (Semi Recovered Human Beings) move out by the rate of full recovery (Full Recovery Rate), the PKDL development rate (PKDL Development Rate), and the rate of natural death of semi recovered human beings (Natural Death Rate of SRHB). The PKDL development rate (PKDL Development Rate) accumulates in the infected human beings with PKDL population (see figure 7.6).

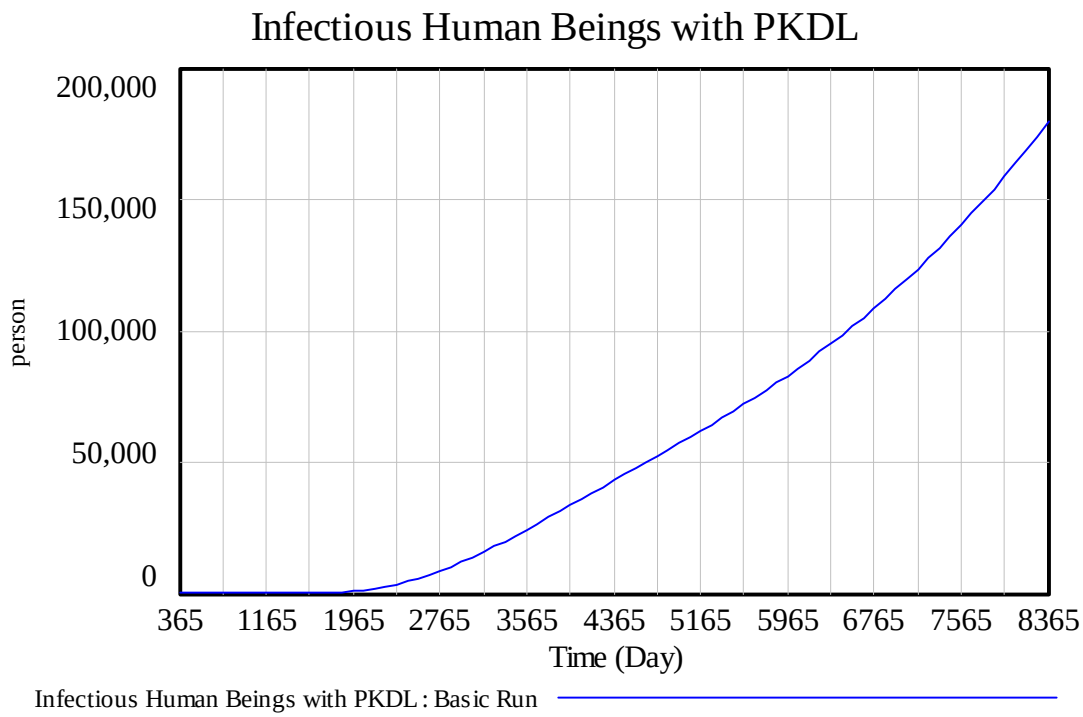


Figure 7.6: The infectious human beings with PKDL population

The behavior of infectious human beings with PKDL in figure 7.6 is an outcome of the net change of the stock of infectious human beings (the PKDL development - the sum of the out flows from this stock). The out flows from infectious human beings with PKDL are the recovery rate from PKDL (Recovery Rate From PKDL), the death rate from PKDL (Death due PKDL Rate of HB) and the natural death of infectious human beings with PKDL (Natural Death Rate of IHB with PKDL). Figure 7.7 shows the 'PKDL development rate' exceeds the out flows from infectious human beings with PKDL, therefore, the infectious human beings with PKDL increases.

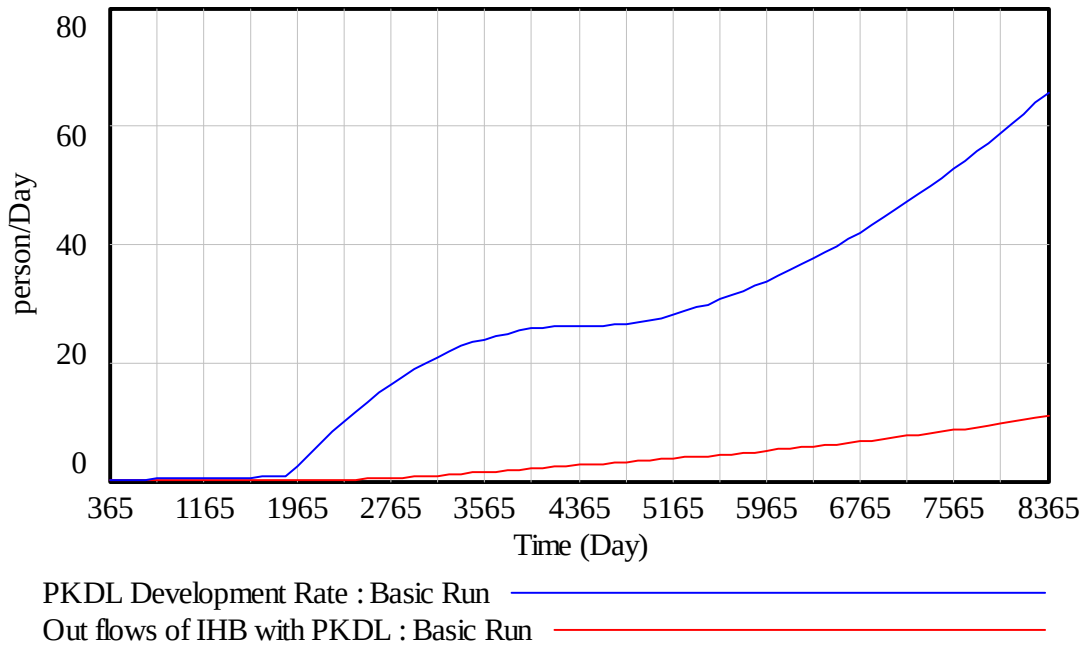


Figure 7.7: Comparison between the PKDL development rate and the outflow from latent human beings population

The infection human beings with Kala-azar and with PKDL accumulate in the total number of infectious human beings. The total number of infectious human beings has appositive effect on the prevalence of infection human beings (Density of Infectious Human Beings). Figure 7.8 shows the prevalence of infection in human beings (Density of Infectious Human Beings) increases when the total number of infectious human beings increases and it is constant when the total number of infection human beings is stable.

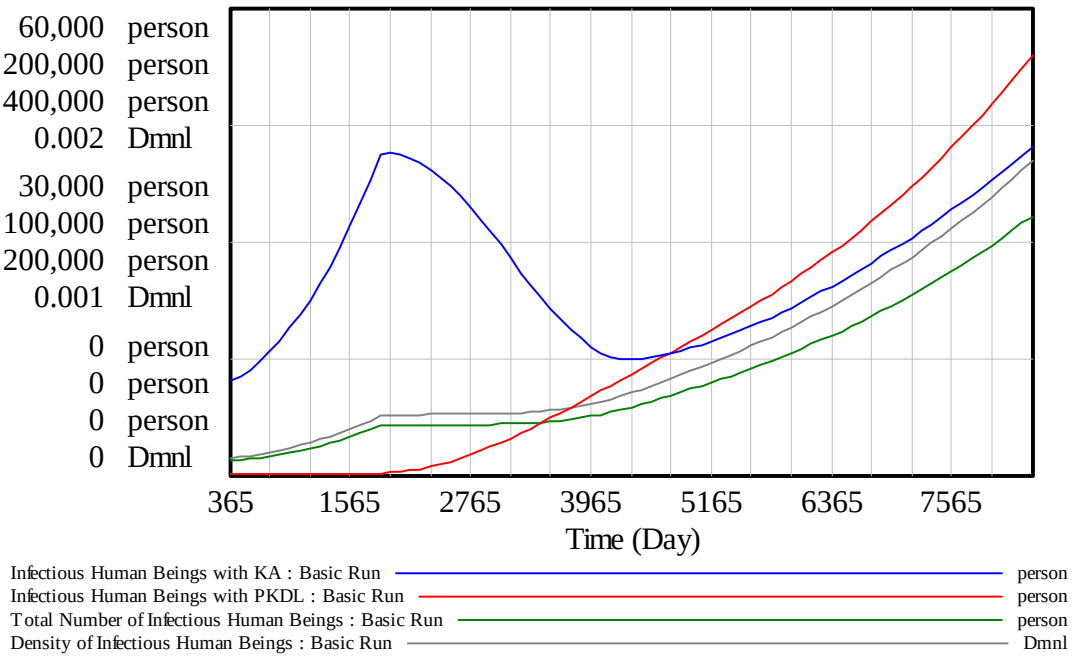


Figure 7.8: Comparison between the infectious human beings with KA, with PKDL density of infectious human beings

The prevalence of infection people (Density of Infected Human Beings) causes the infectious bite rate of adult female sand flies. We will now analyze the behavior in the sand fly sector of the two variables (1) Infectious Bite Rate of AFSF, (2) Infectious Adult Female Sand Flies.

The starting point to analyze the 'Infectious Bite Rate of AFSF' in the sand fly sector is the stock of susceptible adult female sand fly population (Susceptible Adult Female Sand Flies). The population of susceptible adult female sand flies (Susceptible Adult Female Sand Flies) is constant, because both the inflow (Maturation Rate) and the outflows (Biting Rate of AFSF, Death Rate of SAFSF) are equal (the net change of this stock is zero).

When the susceptible adult female sand flies (Susceptible Adult Female Sand Flies) bite infected human beings at the rate of infection of sand flies (Infectious Bite Rate of AFSF). The 'Infectious Bite Rate of AFSF' accumulates in the stock of 'Latent Sand Flies'. The behavior of latent sand flies population in figure 7.11 is a result of the net change of this population (the infectious bite rate of AFSF – (the conversion rate of AFSF + the death rate of latent sand flies)).

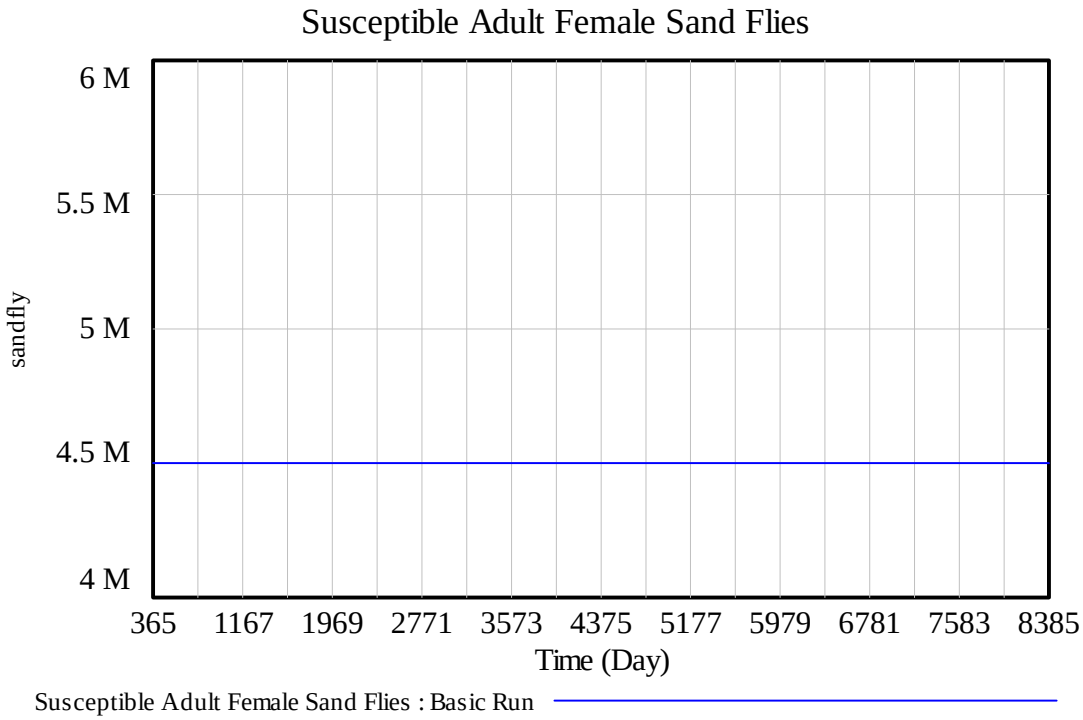


Figure 7.9: The susceptible adult female sand flies population

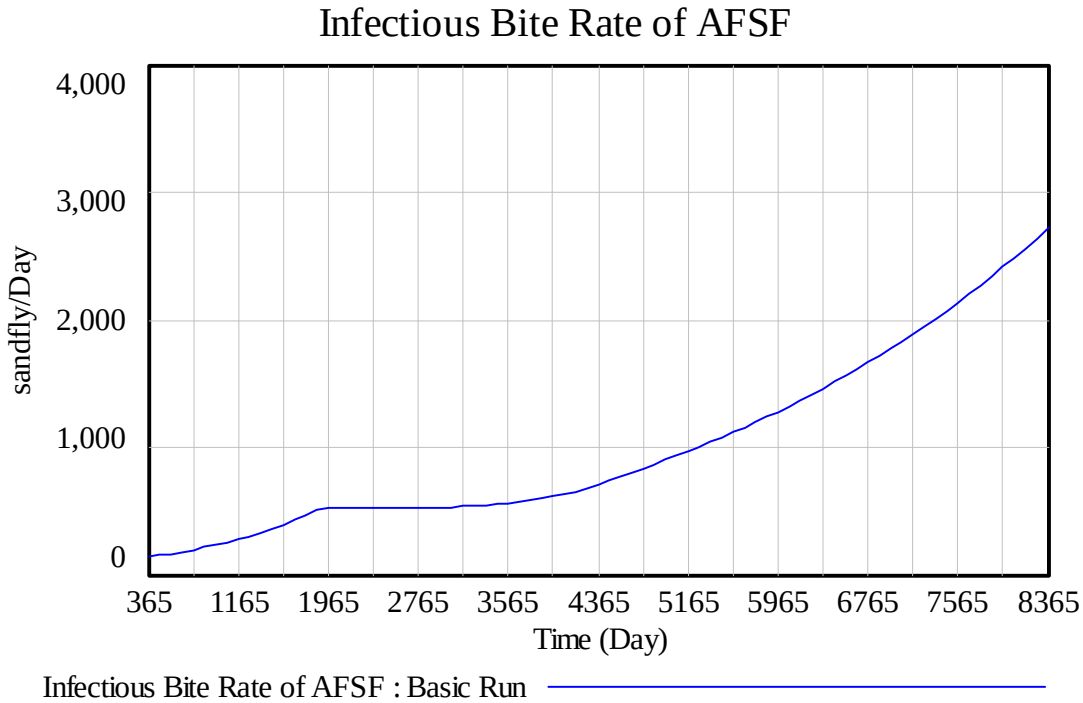


Figure 7.10: The infection rate of adult female sand flies

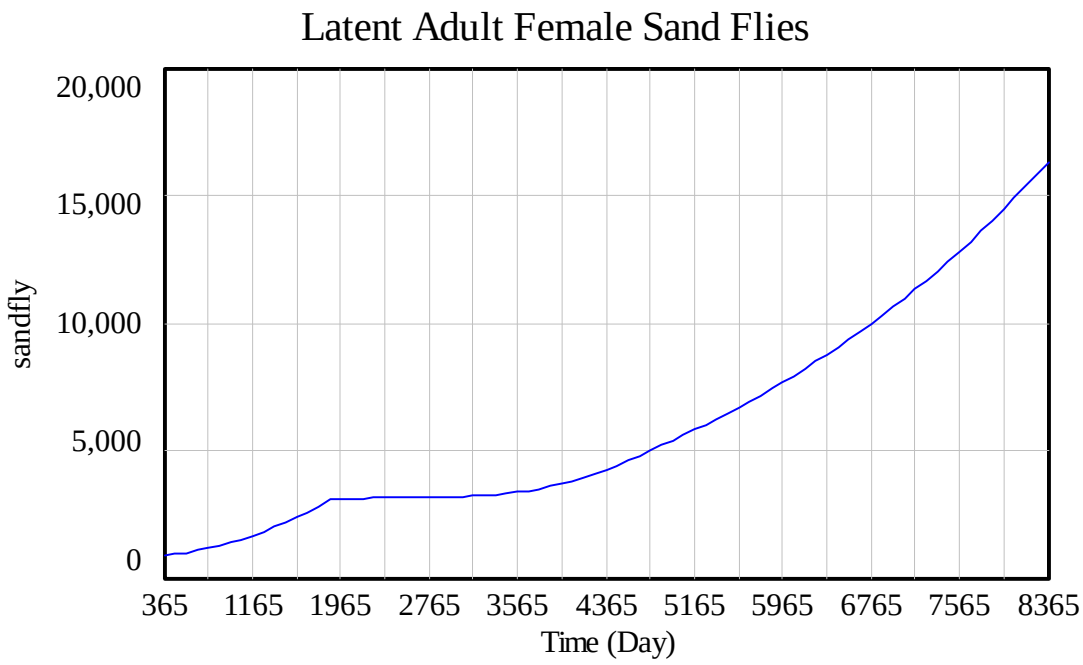


Figure 7.11: The latent adult female sand flies population

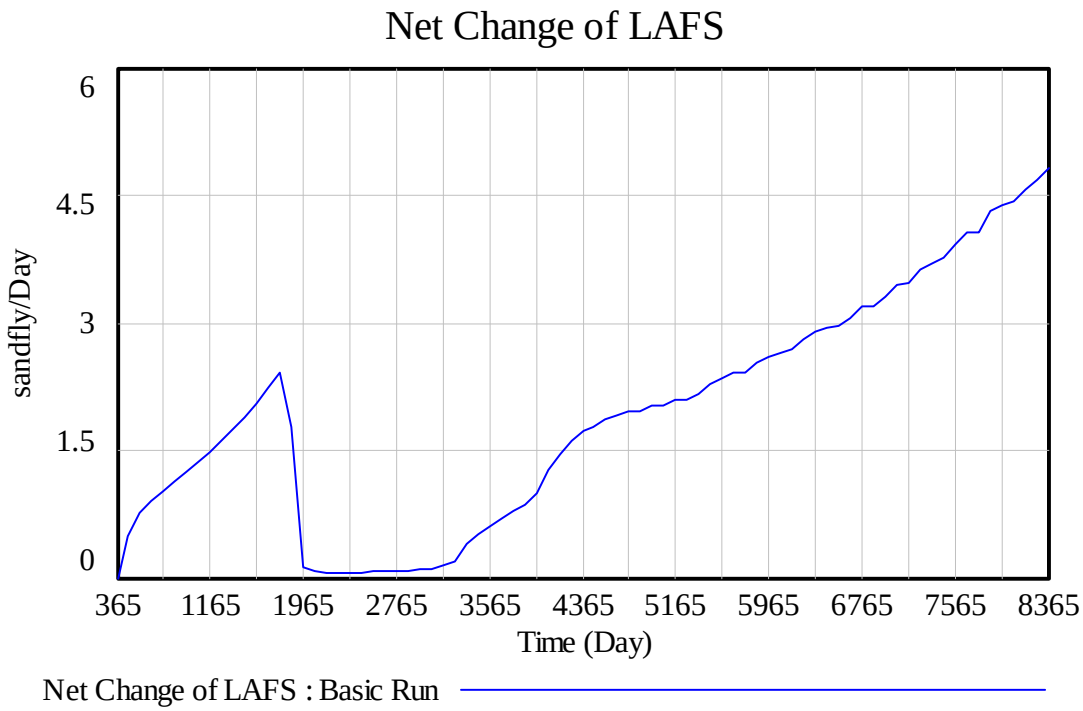


Figure 7.12: The net change of latent adult female sand flies population

As shown in figure 7.12, when the net change of latent sand flies is zero the number of latent sand flies is constant and it is constant when the net change of latent human beings is positive (>1) (the infectious bite rate of AFS exceeds the conversion rate of adult female sand flies and the death rate of latent sand flies). The conversion rate of adult female sand flies enters the sand flies which is the population of infectious adult female sand flies. The behavior of infectious adult female sand flies (see figure 7.13) is a result of the net change of infectious adult female sand flies (the conversion rate of adult female sand flies – (the death rate of infectious adult female sand flies + natural death of adult female sand flies)). Figure 7.14 shows as long as the net change of infectious adult female sand flies is positive (the conversion rate of adult female sand flies exceeds the death rate of infectious adult female sand flies sand the natural death of adult female sand flies) the stock of 'Infectious Sand Flies' increases and it is constant as long as the net change of infectious adult female sand flies is zero (the conversion rate of adult female sand flies equals to the death rate of infectious adult female sand flies and the natural death of adult female sand flies).

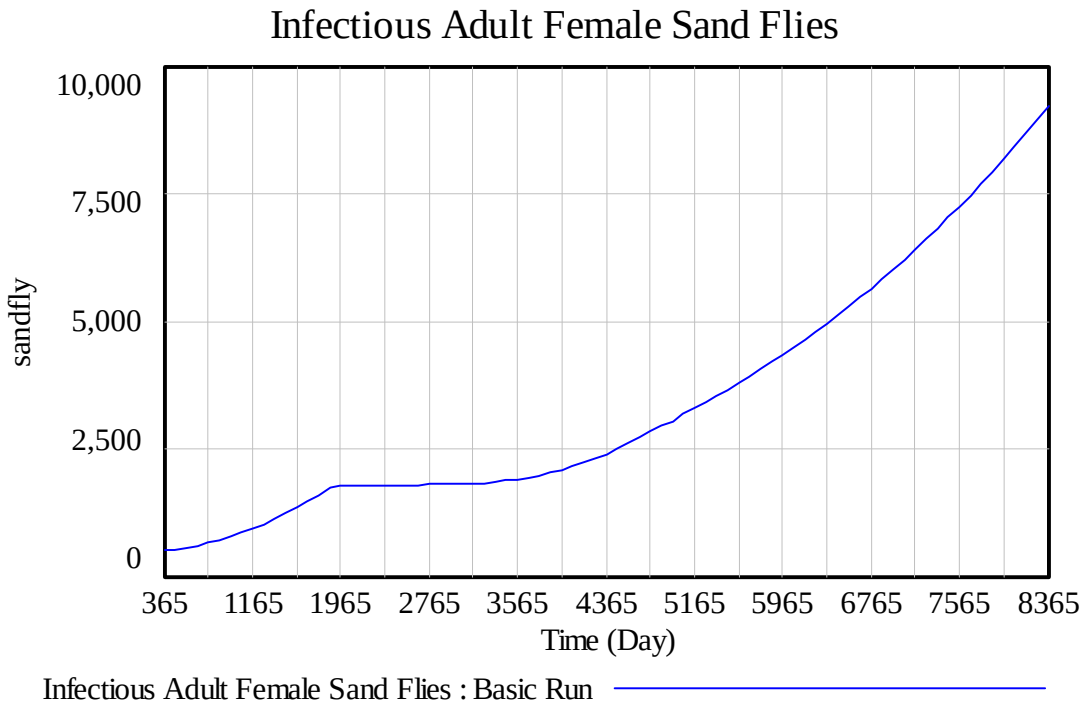


Figure 7.13: The infectious adult female sand flies population

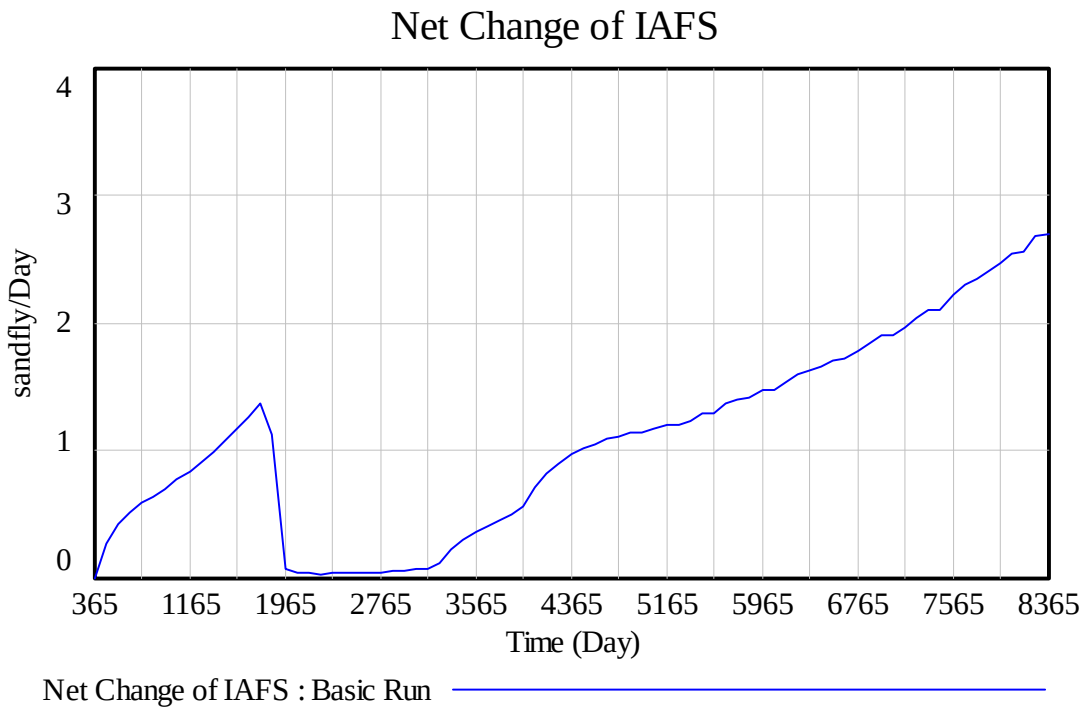


Figure 7.14: The net change of infectious adult female sand flies population

It is assumed that the infectious adult female sand flies' population bites human beings after the average time between blood meals which then generates the number of infectious bites per day. The 'Number of Infectious Bites per Day' causes the infection of Kala-azar among susceptible human beings with probability to transmit the disease for human beings (Transmission Probability for Human Being per Bite) at the rate of infection human beings (Infection Rate of HB). This rate increases the human beings and decreases the susceptible human beings' population (see figure 7.16) to the population of latent human beings (see figure 7.17). In figure 7.17, initially the number of latent human beings increases slowly, because the infection rate of human beings exceeds the out flows from the latent human being population, in day 1965 the infection rate of human beings starts declining because the number of susceptible human beings is diminished while the number of infectious bites per day is constant even though the number of latent human beings keeps growing. The increase of latent human beings increases the rate at which human beings flow out from this population, by day 2365, the outflow from this population exceeds the infection rate of human beings, therefore, the latent human beings decreases after day 2765. This decrease lower the out flows from latent human beings.

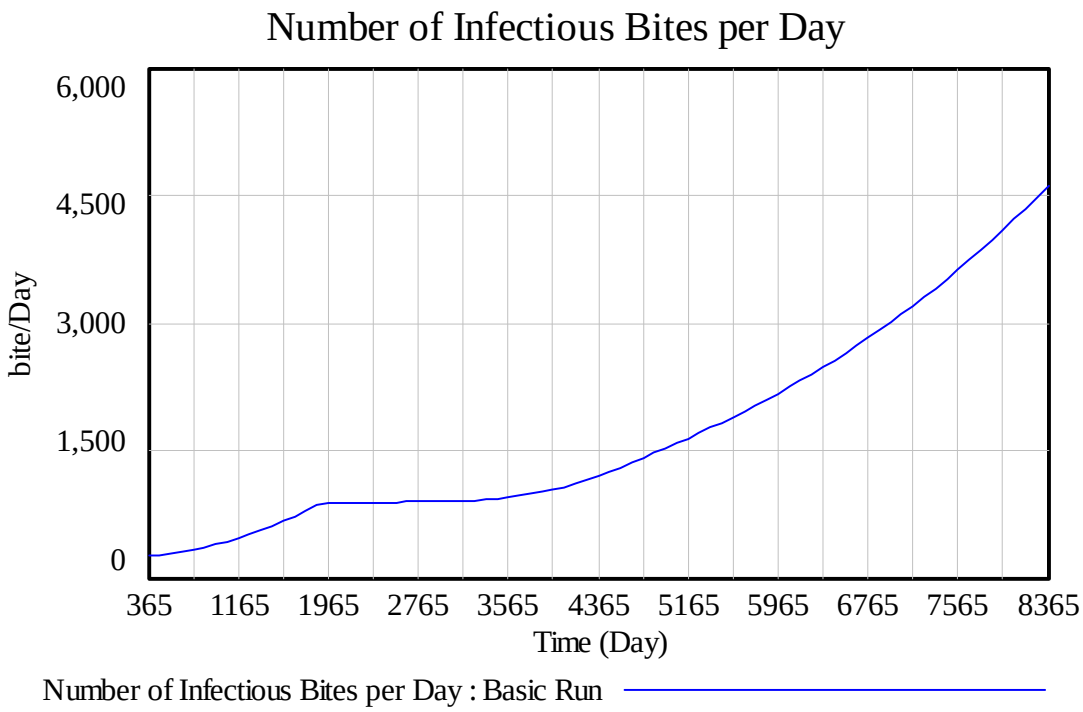


Figure 7.15: The number of infectious bite per day

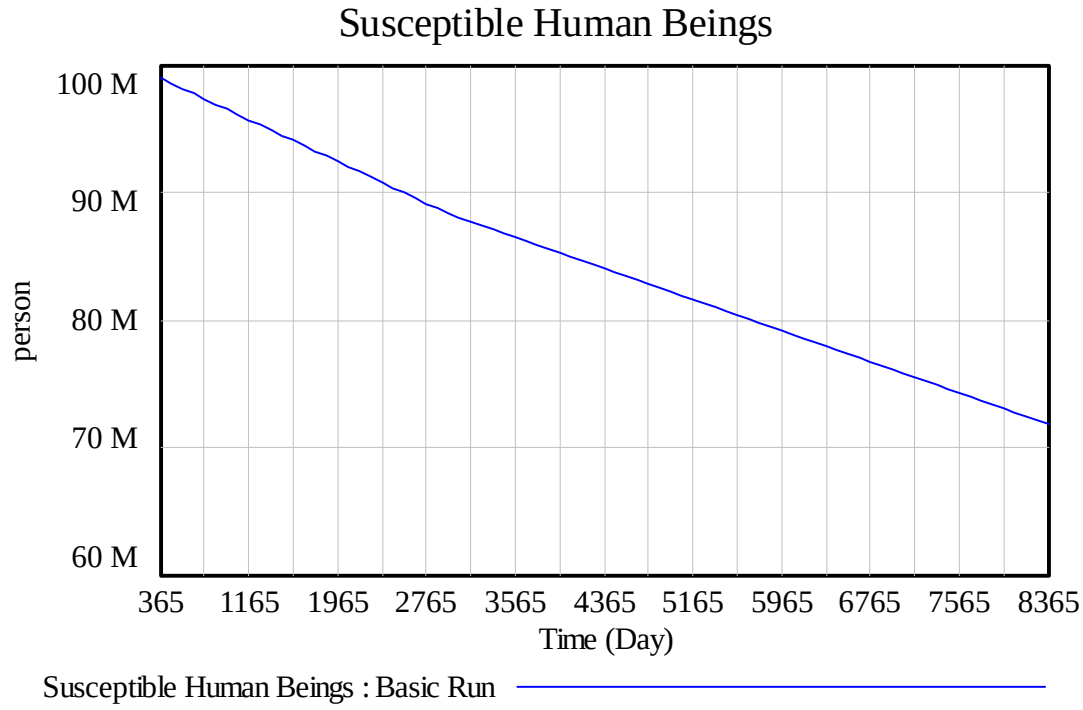


Figure 7.16: The susceptible human beings population

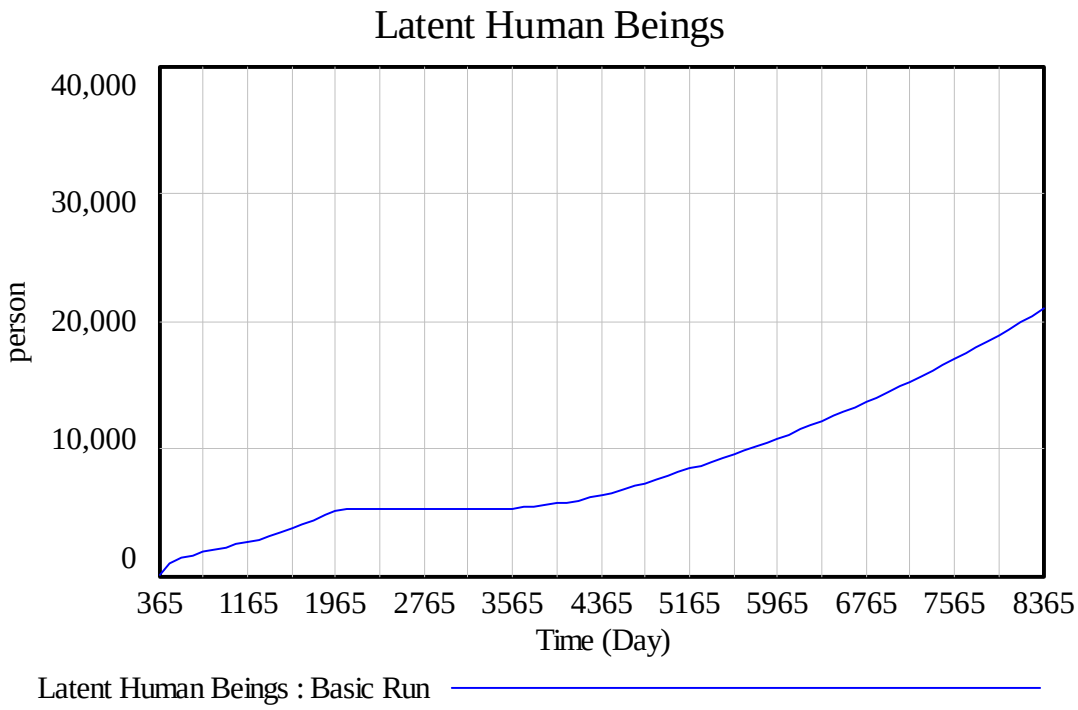


Figure 7.17: The latent human beings population

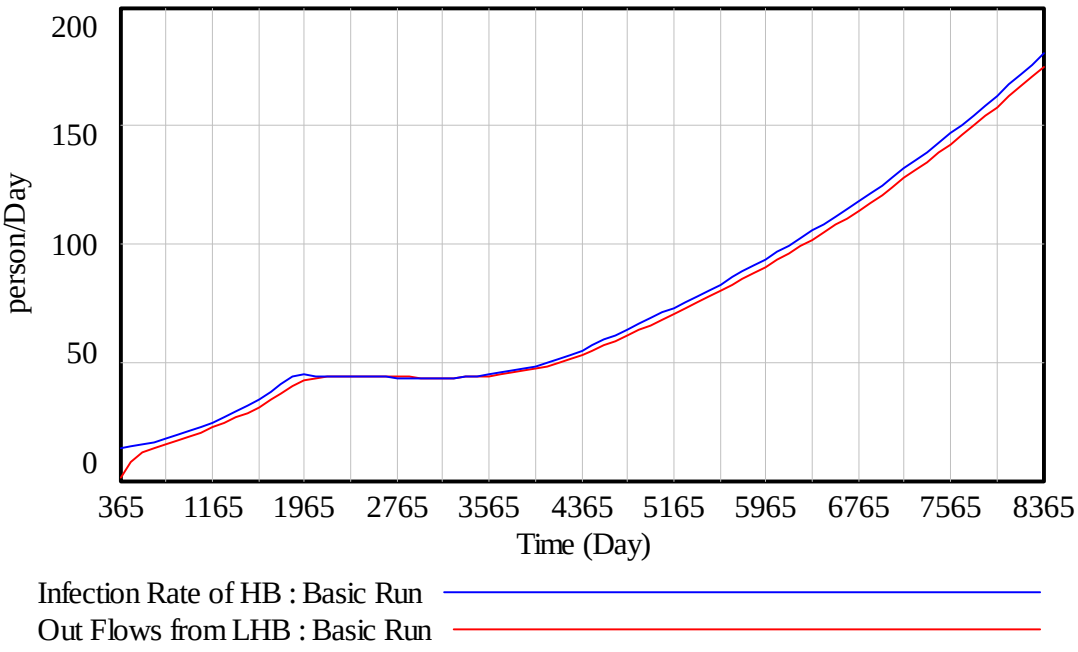


Figure 7.18: comparison between the infection rate of human beings and the sum of the out flows from latent human beings

And on day 2966, it becomes constant (see figure 7.7) because the sum of the out flows from this stock become equal to the infection rate of human beings (the net change of this stock become zero) as shown in figure 7.18. When the latent human beings become (see figure 7.17) constant, the out flows from this population become constant too (see figure 7.18). After day 3565 (see figure 7.18), the infection rate of human beings increases because the number of infection bite per day increases (see figure 7.15). This infection rate exceeds the out flows from the latent human (see figure 7.18), therefore, the number of latent human beings keeps growing until day 8385 (year 2025). In figure 6.1 section 6, the out flows from the latent human beings are the conversion rate of human beings and the natural death of latent human beings. The rate of conversion rate of human beings (inflow) increases the infectious human beings population.

As it is examined in the beginning of this section the infectious human beings with Kala-azar increases in the beginning, because the growth of the conversion rate of human beings which is caused by the increase of latent human beings. Thus, the growth in the number of infectious human beings with Kala-azar causes an increase in the recovery rate of human beings from Kala-azar. The increase in the number of human beings infected with Kala-azar in the beginning from day 365 (year 2002) to 2190 day (year 2007) increases the fraction of human beings seek Kala-azar treatment (see figure 7.19), because it is assumed that the prevalence of infection in human beings (Density of Infectious Human Beings) has positive effect on the fraction of human beings seeking Kala-azar treatment[4] but with certain limit as shown in figure 7.20. Therefore, the recovery rate from Kala-azar increases rapidly after day 2190 (year 2007). This growth in the recovery of human beings from Kala-azar exceeds the conversion rate of human beings (inflow) so that the number of infectious human beings with Kala-azar starts declining to 14819 at day 4465 (year 2012).

Moreover, the increase in the recovery rate of human beings from Kala-azar leads to the growth in the number of infectious human beings with PKDL rapidly. The increase in the number of PKDL cases increases the density of infectious human beings too. Thus growth of the density of infectious human beings increases sharply which causes increase in the rate at which sand flies

[4] Because there is no documentation that mention when the start point of increasing the fraction of human beings that take kala-azar treatment therefore I use the model to estimate the effect of prevalence of infection among human beings to replicate the historical data.

become infected and that leads to more infectious adult female sand flies. The increase in number of infectious sand flies causes the increase in the number of infectious bite per day, and this explains the increase in the infection rate of human beings after day 3565, as shown in figure 7.18. In fact, the conversion rate of human beings is the output lag behind its input (the infection rate of human beings) by the time of incubation for human beings (see figure 7.21).

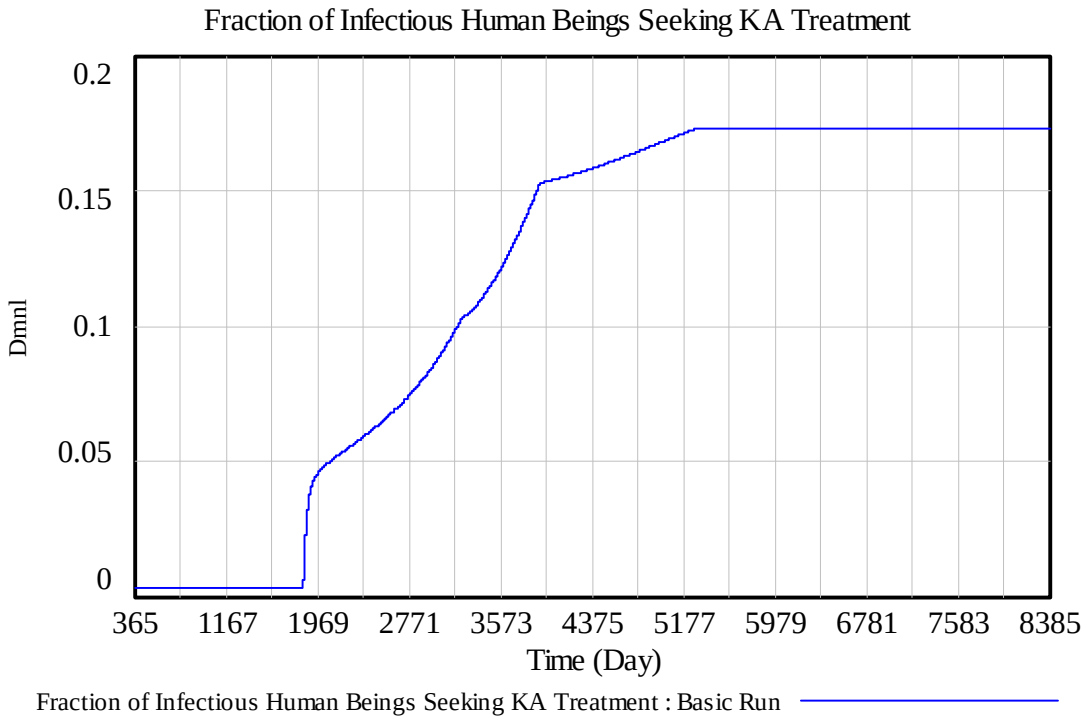


Figure 7.19: The fraction of infectious human beings seeking Kala-azar treatment

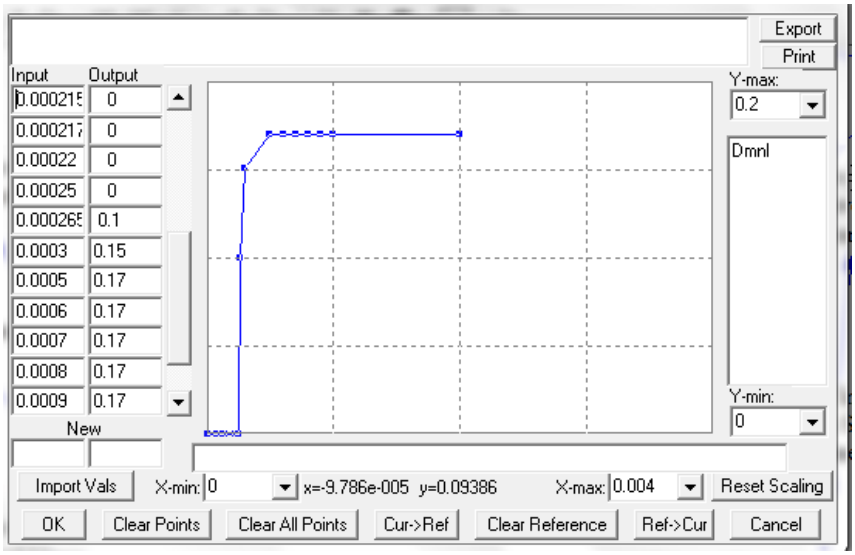


Figure 7.20: The graph function of the effect of density of infectious human beings on fraction of infectious human beings seeking KL treatment

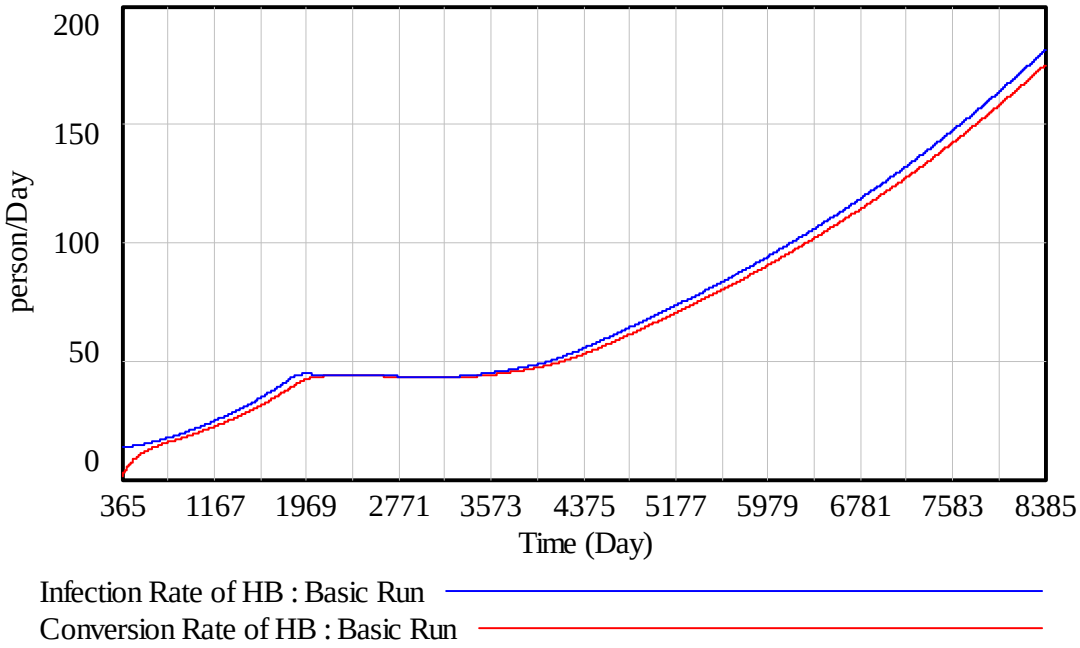


Figure 7.21: Comparison between the infection rate and the conversion rate of human beings

From the analysis of the simulation results, it is clearly observed that how the Kala-azar disease is a cyclic effect and the number of infectious human beings is projected to increase due to the increase in the number of infectious human beings with PKDL, because there is two major positive feedback loops underlying the spread of Kala-azar.

8. Testing

In this section, we will summarize some of the tests which are conducted to the Kala-azar model. Testing of the model will be to assess both of its structure and its behavior.

8.1 Structure Assessment Test

The structure assessment test is conducted to confirm that whether the developed model structure we provided is consistent and relevant with the knowledge of the real system, in another way each variable in our model must correspond to a meaningful concept in the real system. Testing of the Kala-azar model structure occurred during the process of building the model structure. The model structure is based on the literature review which of vector born disease such as malaria and yellow fever which provided the basis for the model structure described in section 6. Generally, the structure of Kala-azar model revolves around an epidemic model structure for populations of human beings and sand flies.

For instance, the “Conversion Rate of HB = Latent Human Beings/Incubation Time of HB”. Practically, when the infected female sand flies bit human beings then they become latent for the incubation time period of 120 days (mentioned in literature). Therefore, the structure of the model depicts the real world situation.

8.2 Dimensional Consistency Test

Testing the dimensional consistency of a model simply means checking whether the left hand and the right hand for each equation have the same units of measurement or not. Vensim DSS version 5.77 is used to develop the underlying model, and this software has the ability to perform the unit consistency check. And for this, the predefined ‘unit check’’ function is used. Where, it is ensured that all the variables have the correct units while developing the model.

Not only this, but the units are also checked by myself referring towards the available relevant literature.

8.3 Parameter Assessment Test

This test is performed to check whether each variable in the model has a clear real-life meaning and whether its value is consistent with the relevant numerical knowledge of the system. This test has been carried out on two different levels: conceptual, and numerical.

Testing the conceptual meaning for each variable is difficult to examine, but for the Kala-azar model it is performed during the modeling process where literature is reviewed to find out more description about the system. While testing each numerical value in the model, most of the parameters' values in the human beings' sector are obtained from literature, and some of them are assumed or estimated. Table 1 identifies the parameters' values and their sources that are used in the human beings sector.

Name of Parameter	**Value**	Source
Incubation Time for HB	120 day	(India 2011)
Transmission Probability for Human Beings per Bite	0.09	Assumed
Fraction of Death due to KA	4e-006	Assumed
Fraction of Death of Human Beings	4e-005	Assumed
Fraction of Human Beings Dvlp PKDL	0.1	(WHO 2011d)
Fraction of Death Due PKDL	4e-008	Assumed
Average time to Seek KA Treatment	15	Assumed
Time to Recover from KA	30 day	(India 2011)
Average Time to Develop PKDL	182.5	(India 2011)
Average time to Seek PKDL Treatment	20	Assumed
Time to Recover From PKDL	120	(India 2011)
HDI	.519	(UNDP 2010)

Particularly, the parameters' values used in understanding the dynamic development in the sand fly population over the stages come from laboratory experiment (Kasap and Alten 2006) to observe the effect of temperature on number of eggs laid and noted when eggs hatch, time to mature to reach adult age and fraction of death per day when temperature is 25 C degree. The following table-2 identifies the parameters' value and their source in the sand flies sector.

Name of Parameter	Value	Source
Number of Egg per Sand Fly	22.65	(Kasap and Alten 2006)
Oviposition Time	6.25	(Kasap and Alten 2006)
Maturation Time	37.46	(Kasap and Alten 2006)
Egg Survival Fraction	.2565	Estimated

Young Survival Fraction	0.45	Estimated
Adult Survive Fraction1	0.9	Estimated
Adult Survival Fraction2	0.85	Estimated
Adult Survival Fraction3	0.8	Estimated
Average Time Between Blood Meals	2	estimated
Number of Bite per Sand Fly	1	Assumed
Transmission Probability for Sand Fly per Bite	1	Assumed
Incubation or (Digestion) Time for SF	6 day	(WHO 2011a)

8.4 Extreme Condition Tests

The extreme condition test is intended to examine whether the underlying Kala-azar model behaves realistically when the variables take extreme values such as zero or infinity. This test is performed on certain variables in the model to extreme values; this test is conducted on the two sectors.

8.4.1 Extreme Condition Tests for Human Beings Sector

We have conducted the extreme condition tests in the human beings sector for each of the following variables: (1) Susceptible Human Beings, (2) Infectious Human Beings with KA, and (3) Infectious Human Beings with PKDL.

If the initial value of susceptible human beings equals zero, the infection rate of human beings becomes equal to zero over time. Therefore, it is expected that the number of the people infected with Kala-azar (Infectious Human Beings with KA) decreases and the number of people infected with PKDL (Infectious Human Beings with PKDL) diminishes as well.

But if the initial value of 'Infectious Human Beings with KA' initially equals zero, it is expected that the number of infection with Kala-azar increases slowly and peak at day 6365, before it decreases, and the number of infectious human beings with PKDL is expected to increase very slowly.

And, test if the initial values of infectious human beings with Kala-azar and with PKDL are initially zero. It is expected that the number of infectious human beings with Kala-azar (Infectious Human Beings with KA) and the number of infectious human beings with PKDL (Infectious Human

Beings with PKDL) have the general behavior pattern as in the previous test (the initial value of infectious human beings with Kala-azar equals zero) but a little bit slowly. While conducting the three tests, figure 8.1 displays the behavior generated as it is expected for the infected human beings population with Kala-azar, infected human with PKDL population, and population of infected adult female sand flies.

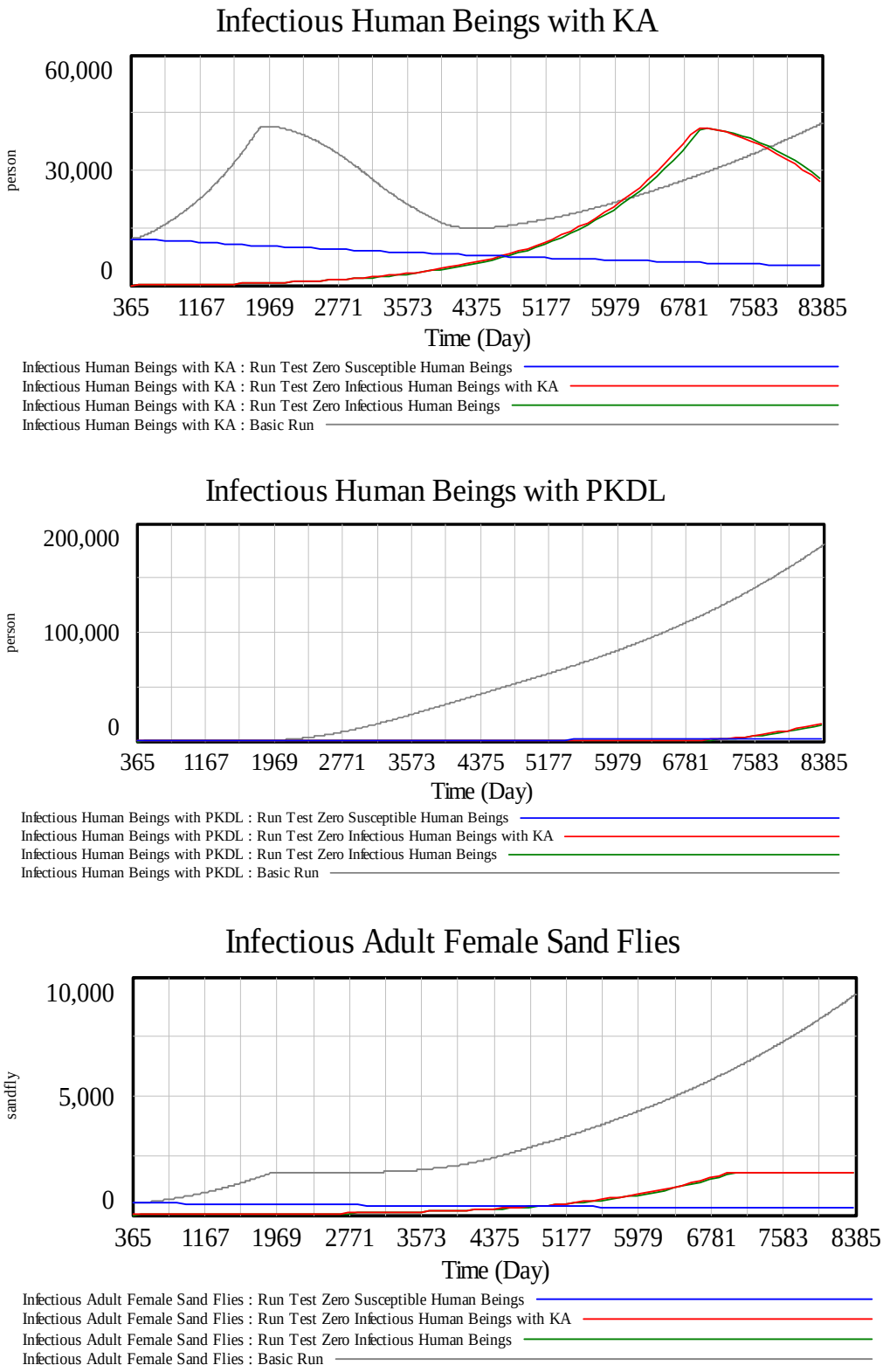


Figure 8.1: The result of the extreme condition tests for human beings sector

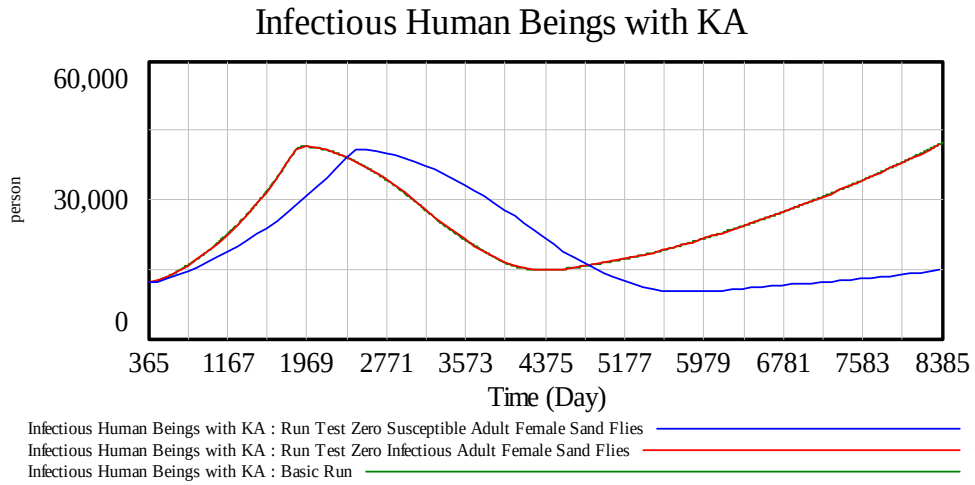
8.4.2 Extreme Condition Tests for Sand Flies Sector

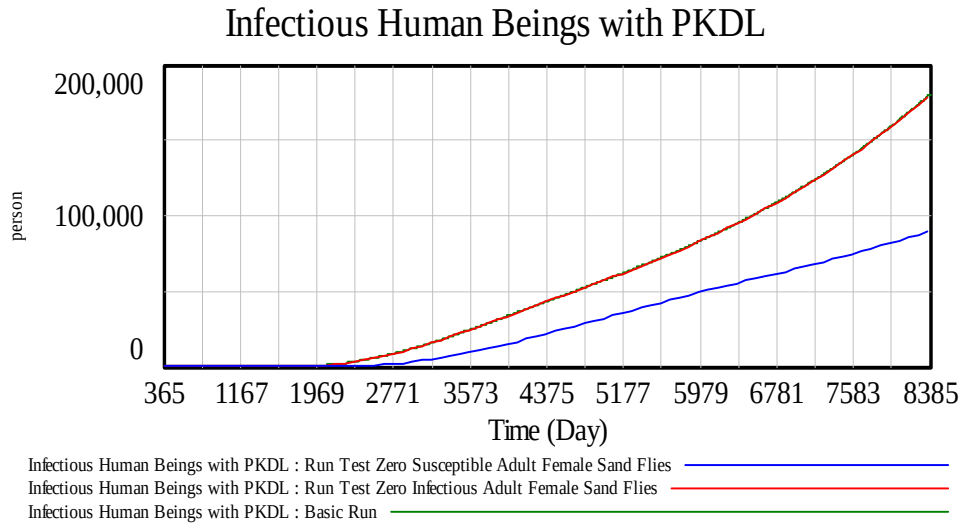
This test is performed on certain variables in sand fly sector to extreme values. For each of the following variables: (1) Susceptible Adult Female Sand Flies, (2) Infectious Adult Female Sand Flies.

If we set the initial value of ‘’Susceptible Adult Female Sand Flies’’ to zero, it is expected that the infectious bite rate of adult female sand flies grows but below the basic run behavior. Therefore, we expect that the number of infectious human beings with kala-azar and with PKDL follow the same trend but at slow rate.

If the initial value for “Infectious Adult Female Sand Flies” is set to zero, it is expected that there will be no change in the infection rate of adult female sand flies, as it just jumps from zero at the beginning. Therefore, it is expected that there will be no change in the number of infected human beings population with kala-azar, and also it is expected that there will be no change in the number of infected human beings with PKDL.

Figure 8.2 shows the behavior after the conducting the extreme condition test on the two variables.





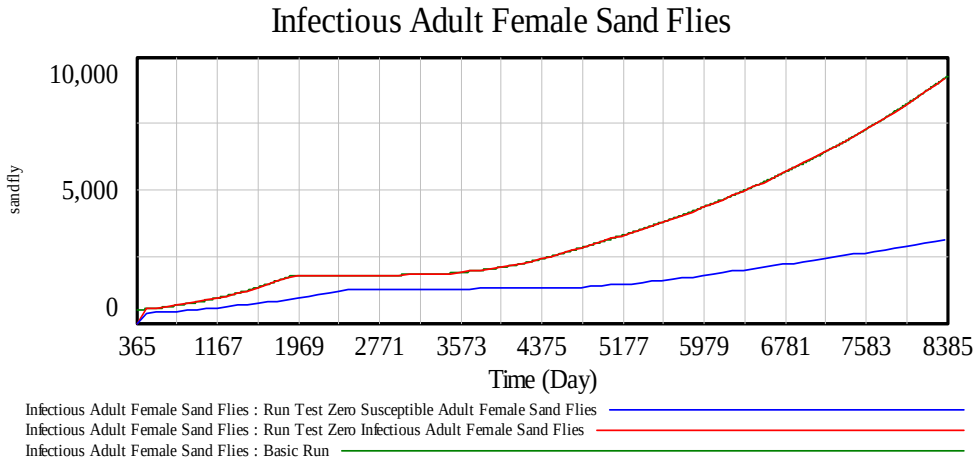


Figure 8.2: The result of extreme condition tests for sand flies sector

8.5 Sensitivity Analysis

8.5.1 Sensitivity Test on Numerical Values

To test, how the Kala-azar model behaves when we change the numerical values for each of the following variables: (1) Incubation Time for HB, (2) and Transmission Probability for Human Being per Bite.

Test the numerical value of incubation time for human beings

Figure 8.3 shows the generated behaviors when the incubation time period for human beings increases and decreases by 25%.

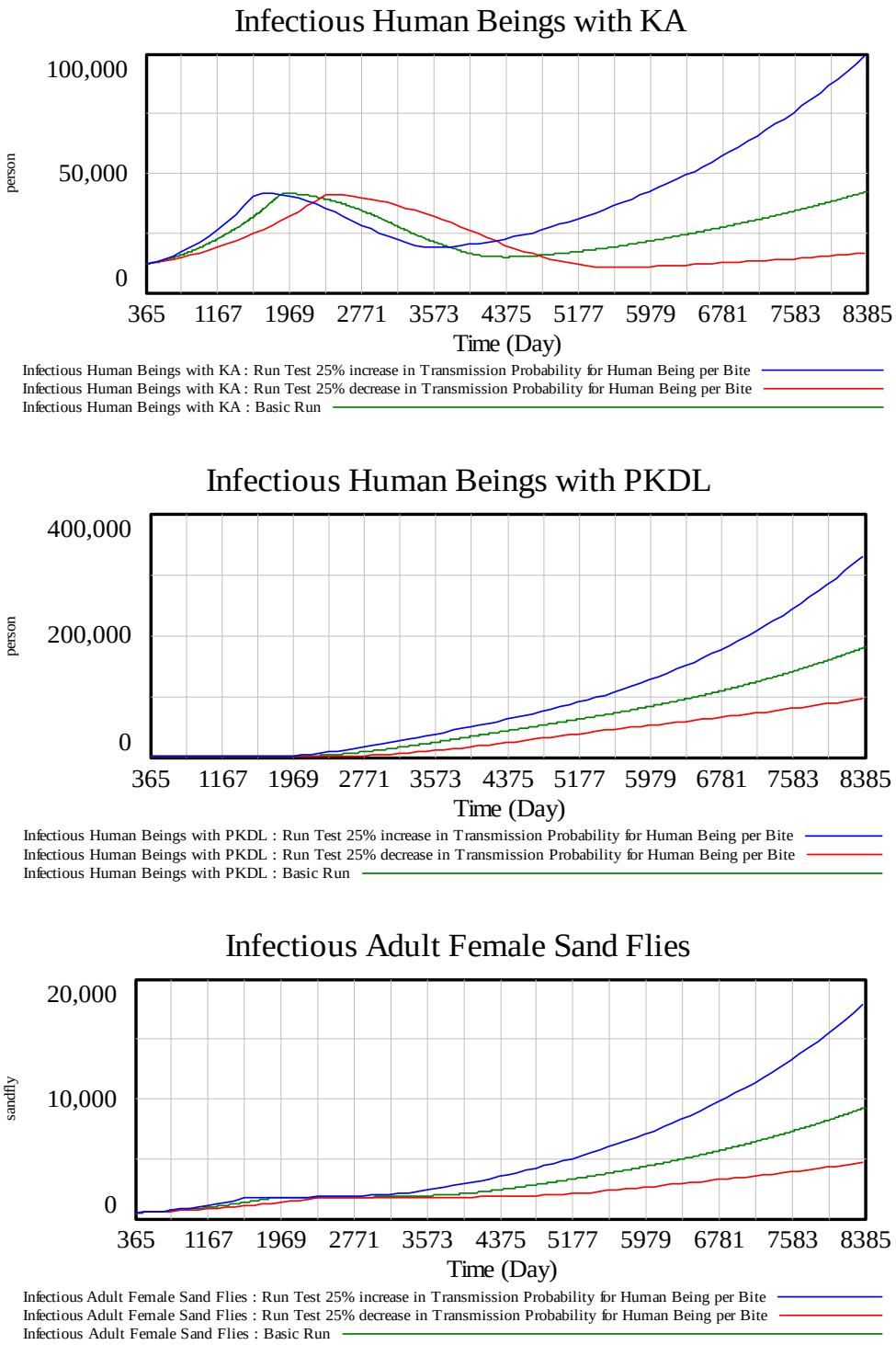


Figure 8.3: The result of test the numerical value of transmission probability for human beings

Test the numerical value of transmission probability for human beings

Figure 8.4 shows the generated behaviors when ‘Transmission Probability for Human Beings’ is Set to .1 and .25 respectively.

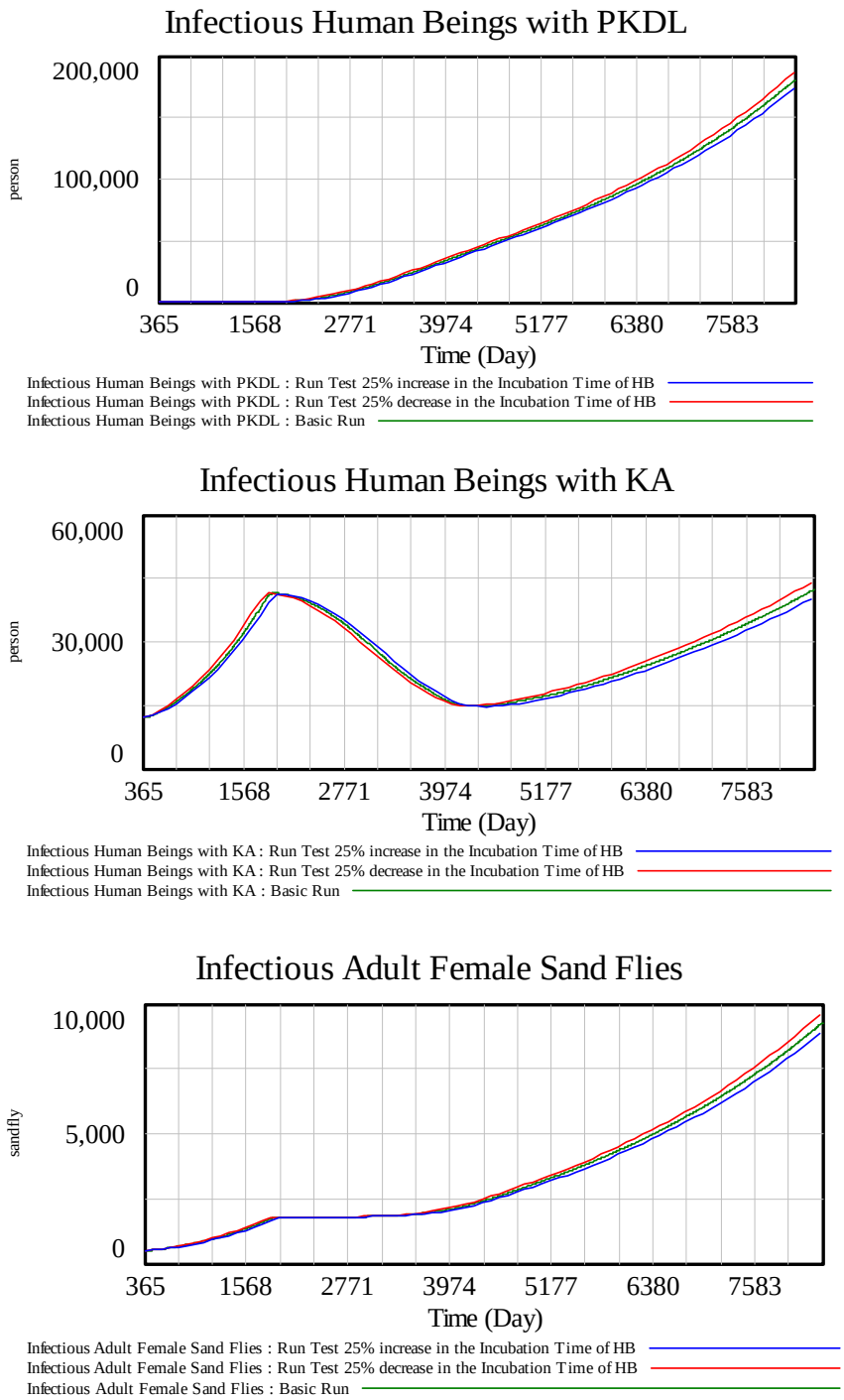


Figure 8.4: The result of test the numerical value of incubation time of human beings

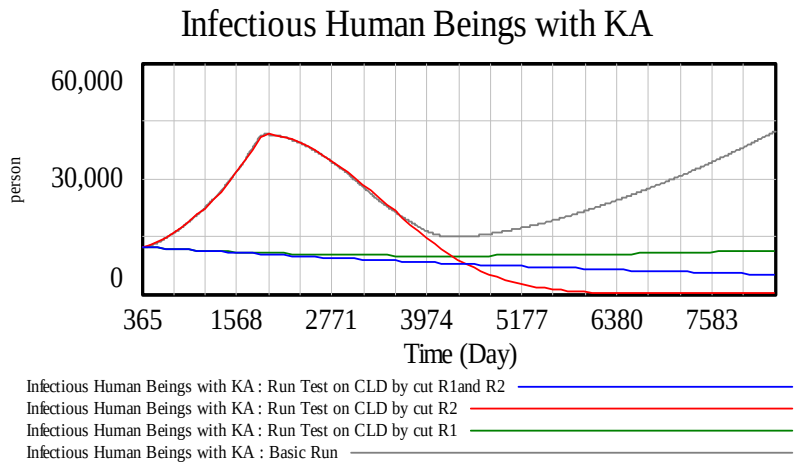
8.5.2 Sensitivity Test on CLD

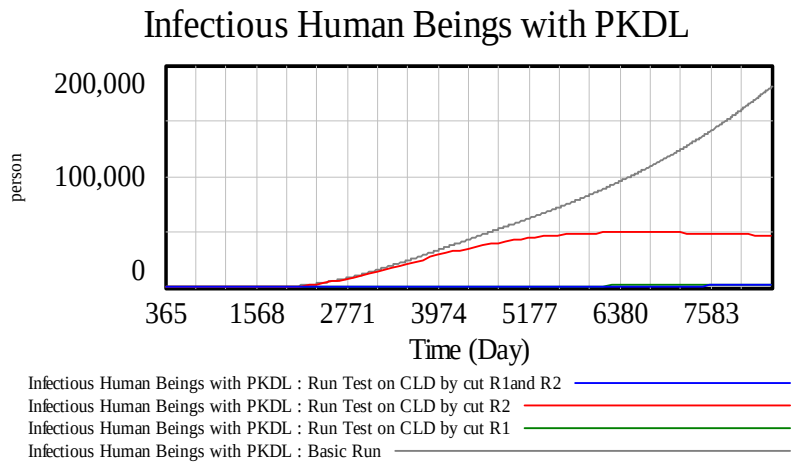
In order to test our hypothesis that we formulate in section-5, in this section we will test the effect of the positive feedback loops (R1 and R2) in figure 5.2.

First, cutting the two positive feedback loops R1and R2 while testing i.e. if the prevalence of infected human beings with Kala-azar and with PKDL has no effect on the rate at which female sand flies becomes infected (Infectious Bite Rate of AFSF). It is expected that the number of infectious human beings with Kala-azar and the number of infectious human beings with PKDL will dramatically be reduced.

Secondly, we test the model when we cut the positive feedback loop R2, i.e. if the prevalence of PKDL infection has no effect on the rate at which adult female sand flies become infected (Infectious Bite Rate of AFSF), in another way the infection people with PKDL are not source of infectious for sand flies in which the PKDL has no role in the spread of the Kala-azar, it is expected that the number the number of Kala-azar cases is growing rapidly until day 2190 (year 2007) where upon it starts declining and diminish by day 8385(year 2025), while it is expected that the number of PKDL cases is rising from 10 person in (year 2002) day 365 to 47000 persons only in (year 2025) day 8385(see Figure 8.5).

Thirdly, we test the model when cutting the positive feedback loop R1 i.e. if the Kala-azar has no effect on the rate at which adult female sand flies become infected (Infectious Bite Rate of AFS), which means the infected human beings with Kala-azar are not infectious to adult female sand flies. It expected that the number of people infectious with Kala-azar decrease even the PKDL is exiting because in the beginning the number of people infectious with PKDL is very small and actually the number of people infectious with Kala-azar is the main reason for spreading the Kala-azar and PKDL as well. Figure 8.5 shows the post test generated behaviors. The generated behaviors are up to the expectations.





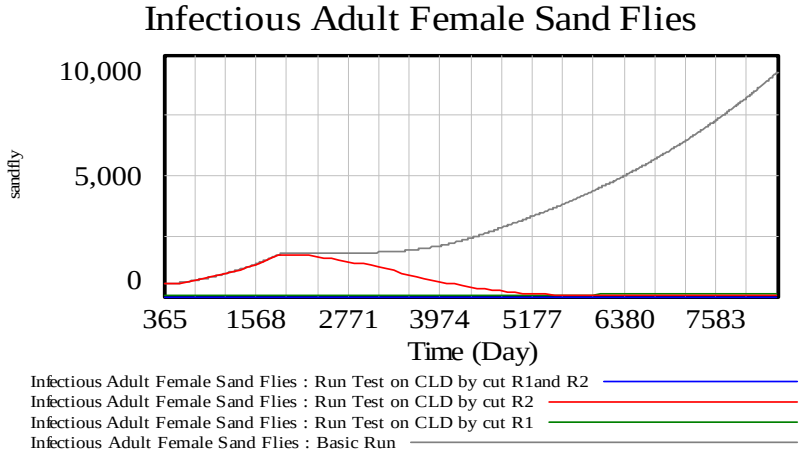


Figure 8.5: result from test constant Density of Infectious Human Beings

8.6 Behavior Reproduction Test

This test compares the simulated behaviors of the model to the actual behavior of the system. To test whether the developed model reproduces the problematic behavior of the system as compared to the real life. Because, for the model to be useful with respect of the model purpose it must generate the underlying problematic behavior.

Displayed behaviors in figure 7.1 shows the simulation results replicate the historical data for the number of infected human beings with Kala-azar.

9. Policy Analysis

9.1 Introduction

The policies we introduce in this study paper focus on: (1) offering an educational program for the families potentially affected by Kala-azar in India, (2) or improving the human beings life condition in Indian rural, since there is no vaccine available and the treatment is costly and onerous and may cause drugs and pesticides resistance. The drugs and pesticides resistance cause major challenges to the ambitious goal of eliminating Kala-azar (WHO 2011d).

In this section we will describe how the suggested policies are implemented in the Kala-azar model, and then test them.

9.2 Policy 1: Public Health Education:

By launching effective campaigns to educate human beings on basic health, the proposed policy is aimed at providing public awareness about the disease, its treatment, and ways to keep people safe from sand flies' bite by using net and with chemical IRS (Indoor Residual Spraying).

For the policy requirements, the following structure is added to the model developed which is portrayed in the following figure 9.1. This policy is an adaptation of a policy to control malaria in Kenya (Matteo Pedercini, Santiago Movilla Blanco et al. 2011).

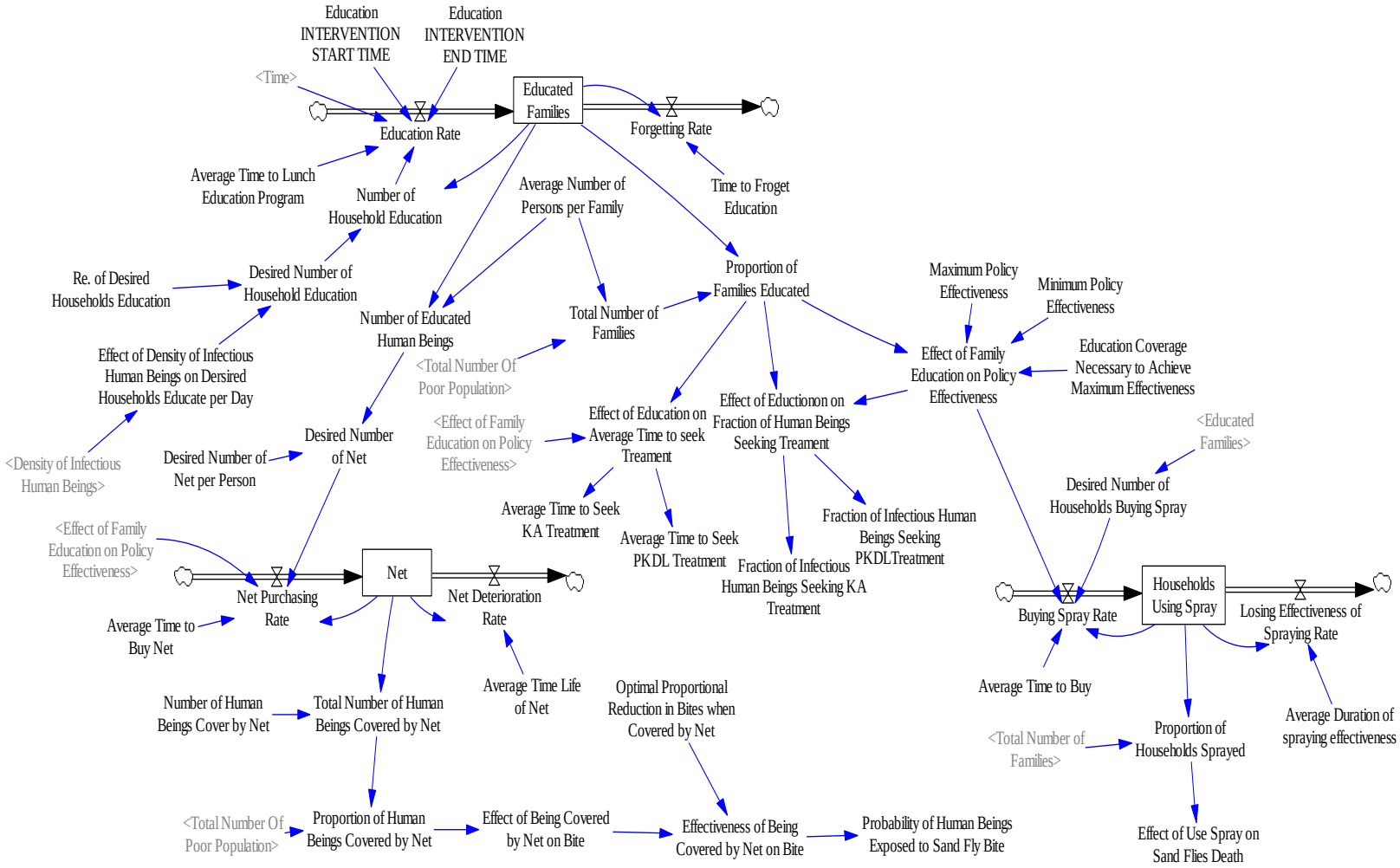


Figure 9.1: The education program policy structure

In general, a number of families (Number of Household Education) are offered the educational program on an average time to lunch education program 'Average Time to Lunch Education Program' at 'Education Rate'. The 'Education Rate' accumulates in the stock of 'Educated Families', and the stock of 'Educated Families' is depleted by 'Forgetting Rate'.

The 'Number of Household Education' is represented by the following equation:

Number of Household Education= Desired Number of Household Education-Educated Family

We create a feedback from the "Density of Infectious Human Beings" to effect on the reference of desired number of educated household 'Re. of Desired Household Education'. This is because we need the information about the projected density of infected people to identify the desired number of family need to be educated.

For this policy, we calculate the effect of family education on policy effectiveness as formulated in the equation below follow (Matteo Pedercini, Santiago Movilla Blanco et al. 2011).

Effect of Family Education on Policy Effectiveness = min (1, (Minimum Policy Effectiveness+
(Maximum Policy Effectiveness-
Minimum Policy Effectiveness)*
(Proportion of Families Educated /
Education Coverage Necessary to Achieve Maximum Effectiveness)))

where

Proportion of Families Educated = Educated Families/Total Number of Families

The education coverage necessary to achieve maximum effectiveness (Education Coverage Necessary to Achieve Maximum Effectiveness) is assumed to be equal 1. And the maximum effectiveness (Maximum Policy Effectiveness) is equal to 1 while the minimum effectiveness (Minimum Policy Effectiveness) is 0.25.

Since the education program provides the public awareness about the disease by explaining how to avoid sand flies' bite, identify the disease symptoms and its treatment, and also how to control sand fly.

In this section we will examine the effect of three actions of the education program on the number of infectious human beings with Kala-azar and with PKDL.

9.2.1 Action 1 – Use of Net:

In the model, we assume that the amount of educated families (Educated Families) determines the “Desired Number of Net” that people will buy, as in figure 7.1.

The number of educated people (Number of Educated Human Beings) is equal to the number of educated families (Educated Families) (measured by household) multiplied by the average number of people per family, i.e. the number of person per household (Average Number of Persons per Family).

The ‘Desired Number of Net’ is equal to the number of educated people (Number of Educated Human Beings) multiplied by desired number of net per person (Desired Number of Net per Person) (equal to1). But of course not all of the educated people will buy the net so that we multiply the ‘Desired Number of Net’ by ‘Effect of Family Education on Policy Effectiveness’’.

We assume people will buy net at (Purchasing Net Rate). Thus ‘Purchasing Net Rate’ accumulates in the stock of net (Net). The number of net (Net) is reduced by discard rate (Net Deterioration Rate) after an average life time of net (Average Life Time of Net). These two rates are represented by the following equation:

Purchasing Net Rate= (Desired Number of Net*Effect of Family Education on Policy Effectiveness-Net) /Average Time to Buy Net

Net Deterioration Rate= Net/Average Time Life of Net

Where, the ‘Average Time to Buy Net’ and ‘Average Time Life of Net’ is assumed to be constant.

To determine the actual number of net that people will buy after the average time to buy net (Average Time to Buy Net), we subtract the number of exiting net ’Net’ from the ‘’Desired Number of Net * Effect of Family Education on Policy Effectiveness’’.

The number of people covered by a net (Number of Human Beings Covered by Net) is 1 person; therefore the total number of people covered by net (Total Number of Human Beings Covered by

Net) is equal to the number of net ‘Net’ multiplied by ‘Number of Human Beings Covered by Net’.

When human beings are covered by a net that reduces the probability of human beings being exposed to sand files’ bite. Therefore, it is assumed that the ‘’Proportion of Human Beings Covered by Net’’ has an effect on the probability of human beings being exposed to sand flies’ bite (see figure 7.1). Figure 9.2 shows the graph function of the ‘’Effect of Being Covered by Net on Bite’’.

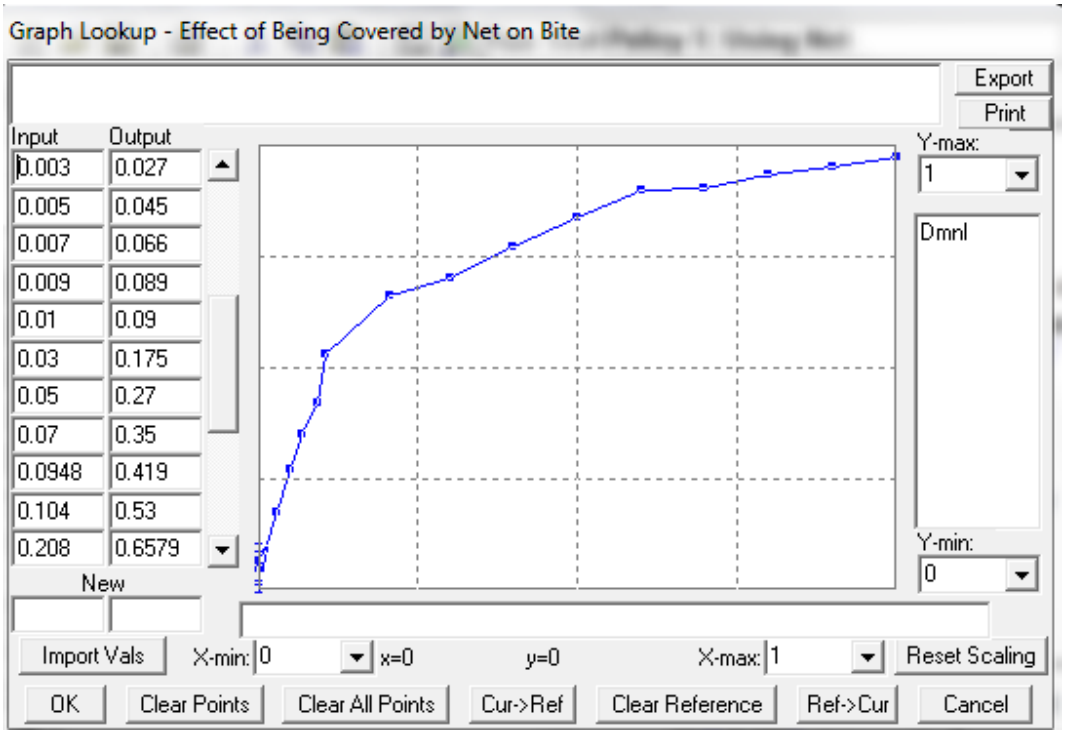


Figure 9.2: The effect of Being Covered by Net on Bite

And the ‘’Effectiveness of Being Covered by Net on Bite’’ is formulated as in the equation below:

Effectiveness of Being Covered by Net on Bite = Effect of Being Covered by Net on Bite *
Optimal Proportional Reduction in Bites when Covered by Net

Then the ‘’Probability of Human Beings Exposed to Sand Fly Bite’’ is multiplied by (1- Effectiveness of Being Covered by Net on Bite).

Thus ’1- Effectiveness of Being Covered by Net on Bite’ has a positive effect on the ‘’Probability of Human Beings Exposed to Sand Fly Bite’’. Because, the increase in the ’’ Effectiveness of Being Covered by Net on Bite ‘’ decreases the ‘’Probability of Human Beings Exposed to Sand fly Bite’’.

if the educational program achieves the goal of using net that alone will have an effect on the ’Probability of Human Beings Exposed to Sand fly Bite’’ (see figure 9.3), that has a dramatic impact by reducing the number of people infected with Kala-azar to 300 persons on day 8385 (year 2025) (see figure 9.4), and using net will also reduce the number of human beings infected with PKDL form day 4195 and reach 67000 persons at day 8385 (year 2025) (see figure 9.5).

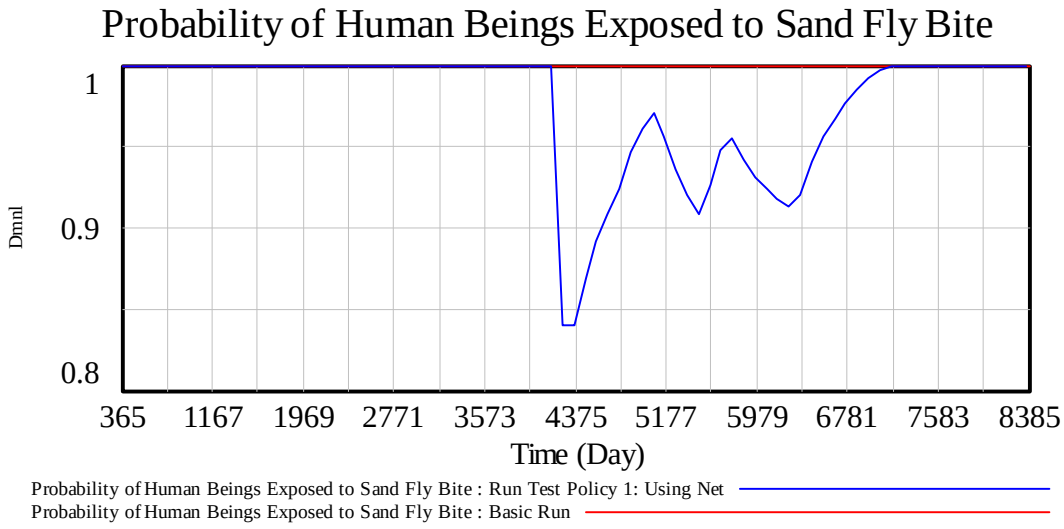


Figure 9.3: The effect of being covered by net on probability of human beings exposed to sand flies bite

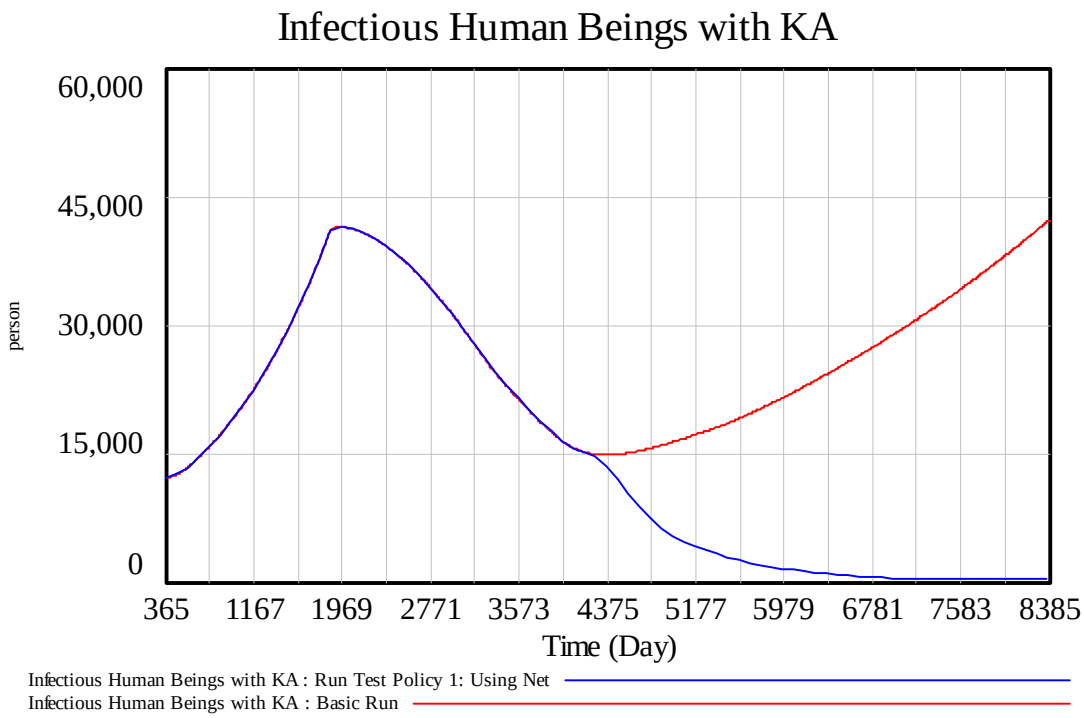


Figure 9.4: The effect of using net (Action-1) on the infectious human beings with Kala-azar

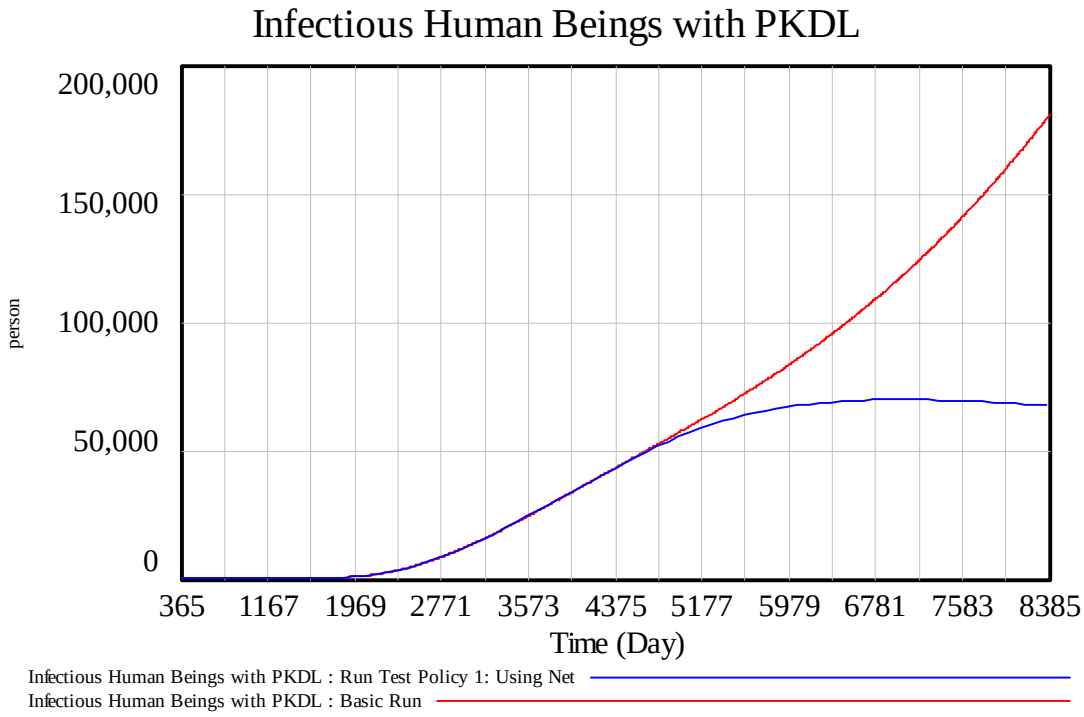


Figure 9.5: The effect of using net (Action-1) on the infectious human beings with PKDL

9.2.2 Action-2 – Identification and Treatment of Disease:

In the policy structure, we implement the second aim which is to educate people to identify the disease symptoms and treatment. We assume that the proportion of families educated has an effect on the average time to seek treatment for both Kala-azar and PKDL as well its effect on the fraction of people seeking treatment.

We assume that an increase in the proportion of families educated will reduce their time to seek treatment and will increase the fraction of people accepting treatment. Figure 9.6 shows the graph function of the effect of the proportion of educated families on time to seek treatment and figure 9.7 shows the graph function of the effect of the proportion of educated families on fraction of human beings accepting treatment.

Figure 9.8 and figure 9.9 show how the education program, i.e. the impact of awareness among human beings about the disease's symptoms and its treatment on the average time to seek treatment for Kala-azar and PKDL (see figure 9.8) and on the fraction of human beings seeking treatment (see figure 9.9), so that the number of human beings infected with Kala-azar (see figure 9.10) figure and also the number of PKDL will be reduce (see figure 9.11).

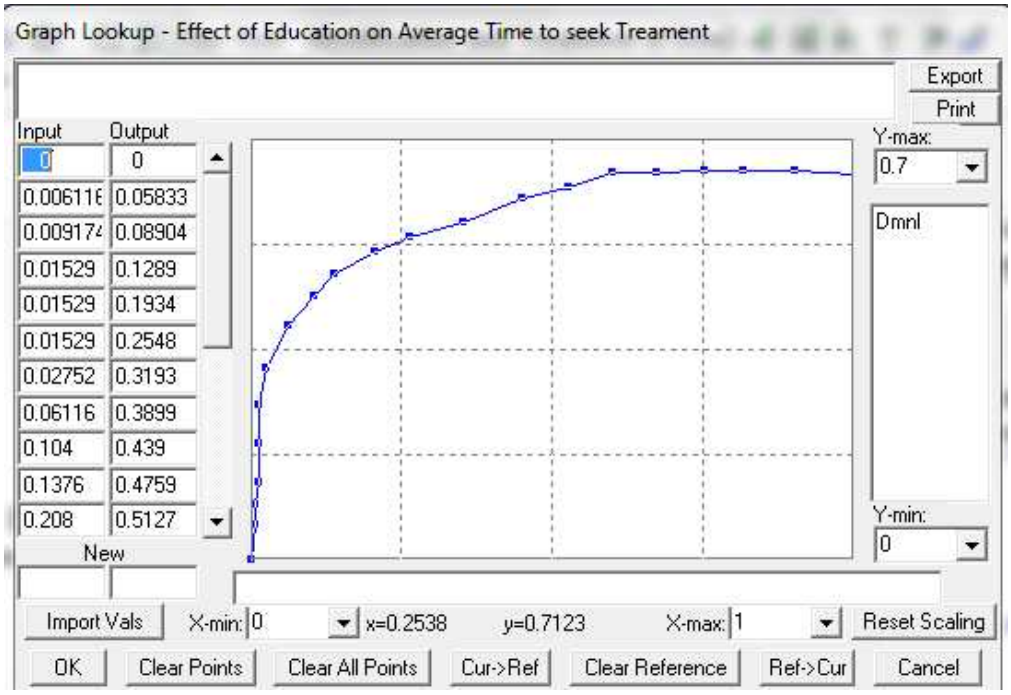


Figure 9.6: The graph function of the effect of identification and treatment of disease on the average time to seek treatment

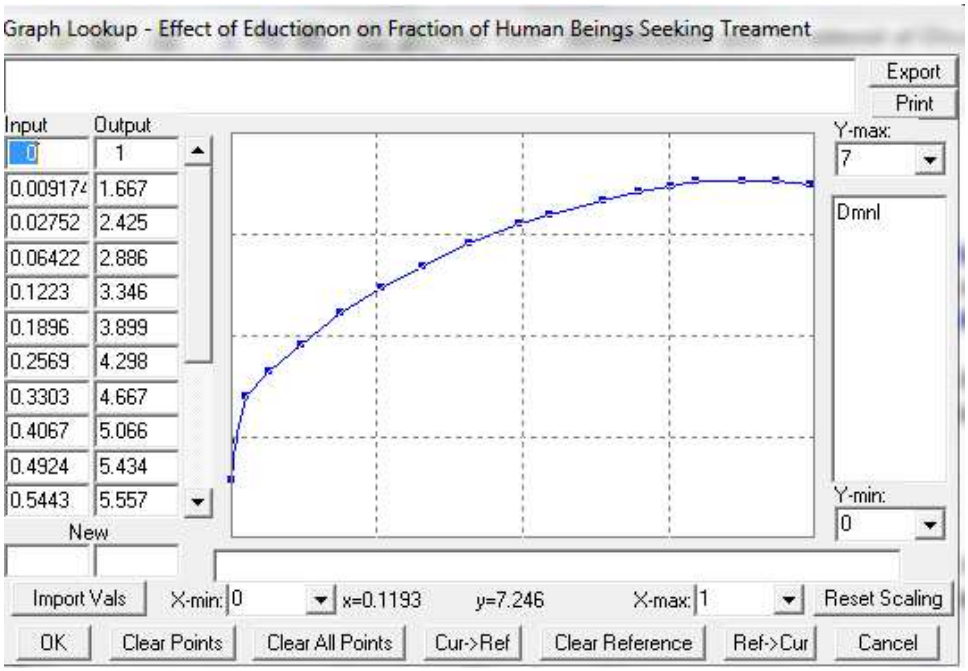


Figure 9.7: The graph function of the effect of identification and treatment of disease on the fraction of human beings accepting treatment

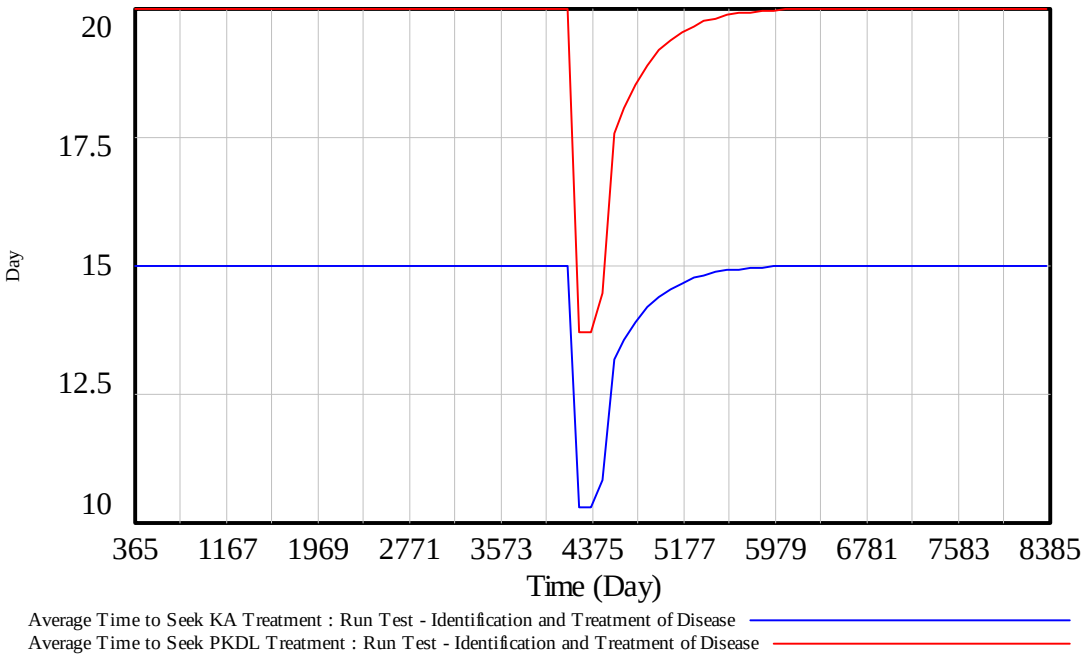


Figure 9.8: The effect of identification and treatment of disease (Action-2) on average time to seek treatment

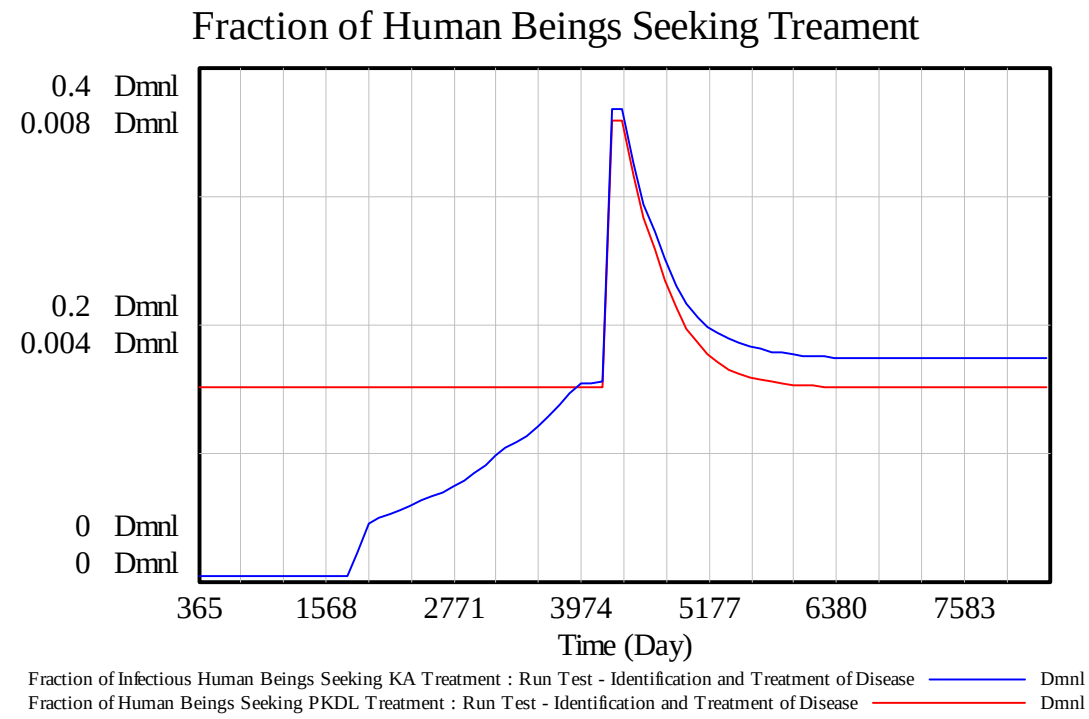


Figure 9.7: The effect of identification and treatment of disease on the fraction of human beings seeking treatment

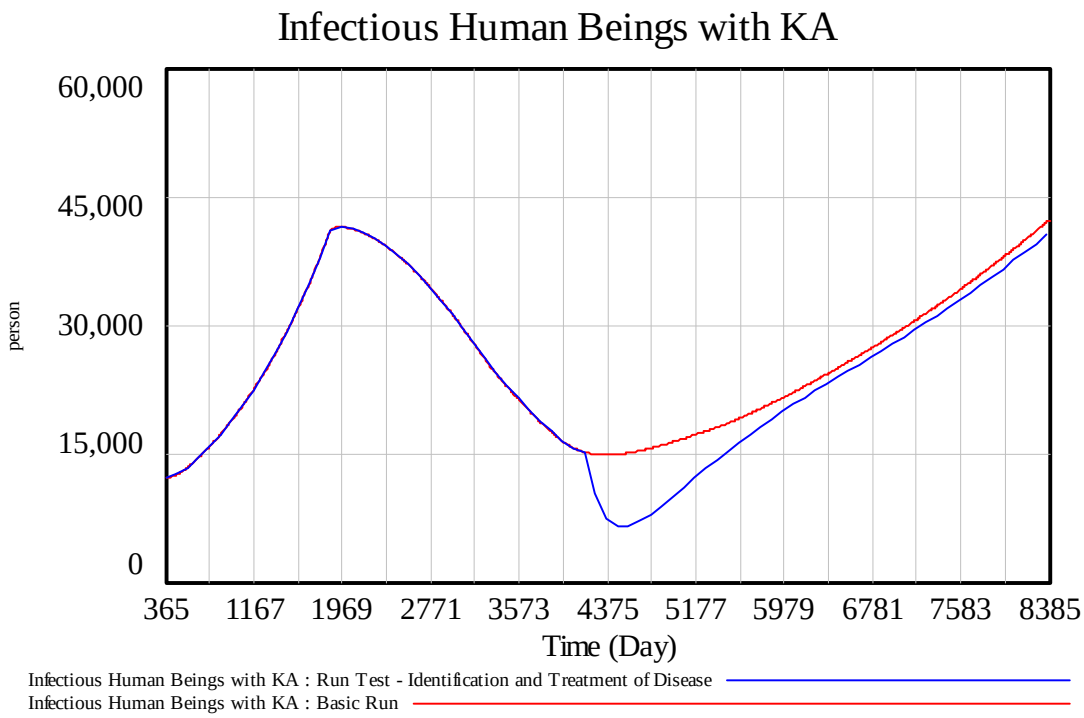


Figure 9.8: The effect of identification and treatment of disease on the infectious human beings with KA

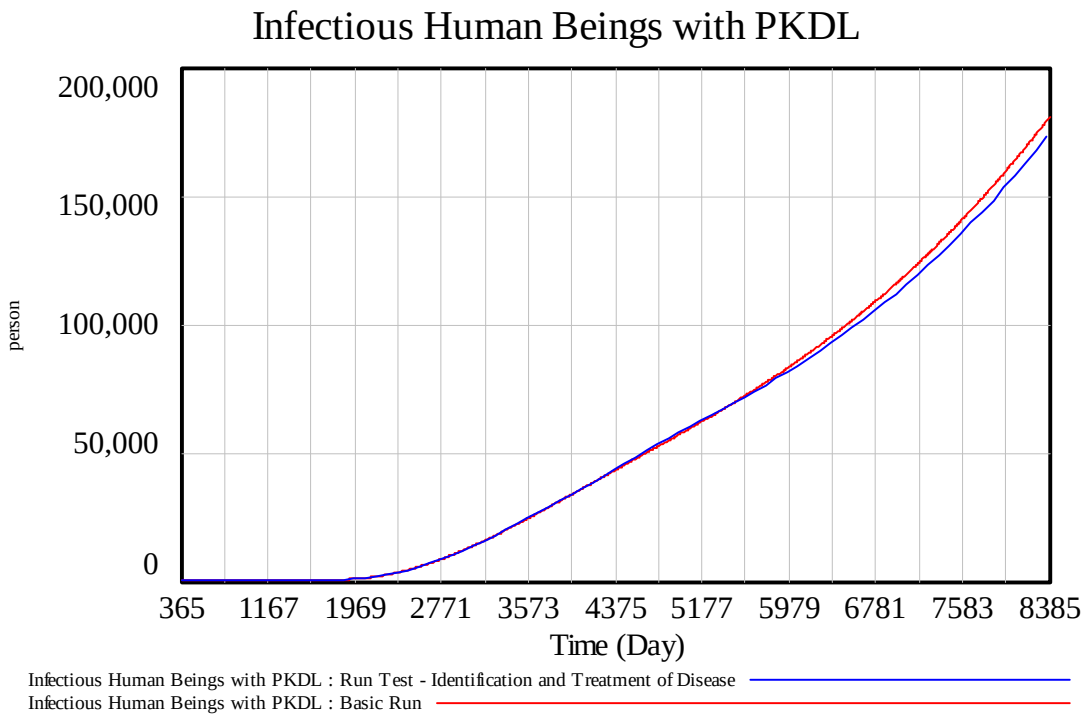


Figure 9.9: The effect of identification and treatment of disease on the infectious human beings with PKDL

9.2.3 Action 3 – Use of chemical IRS (Indoor Residual Spraying):

In addition to that, we assume the educational programs will increase the number of households that use indoor spray which then will reduce the number of sand flies inside and in the vicinity of their houses.

In the model, we let the number of educated families (Educated Families) equal to the number of households desired to buy spray (Desired Number of Households Buying Spray). We assume that they will buy it within an average time of 7 days after they have decided that they will buy it. Of course, not all of them will buy spray, so we represent the rate of buying spray by the following equation:

Buying Spray Rat = (Desired Number of Households Buying Spray*
Effect of Family Education on Policy Effectiveness-
Households Using Spray)/Average Time to Buy

The proportion of households using spray (Proportion of Households Sprayed) is calculated as below:

Proportion of Households Sprayed = Households Using Spray / Total Number of Families

The rate at which people buy the chemical IRS (Buying Spray Rat) accumulates in the stock of 'Households Using Spray'. The stock of 'Households Using Spray' is reduced by 'Losing Effectiveness of Spraying Rate'.

It is assumed that ''Proportion of Households Sprayed'' has an effect on adult sand fly death ''Adult Death Fraction 1''and ''Adult Death Fraction 3'' (see figure 9.10), because we assume that the adult female sand fly during digesting her meal are not accessible. Figure 9.11 shows the results of using spray on the number of infectious human beings with Kala-azar and figure 9.12 shows the result of using spray on the number of infectious human beings with PKDL.

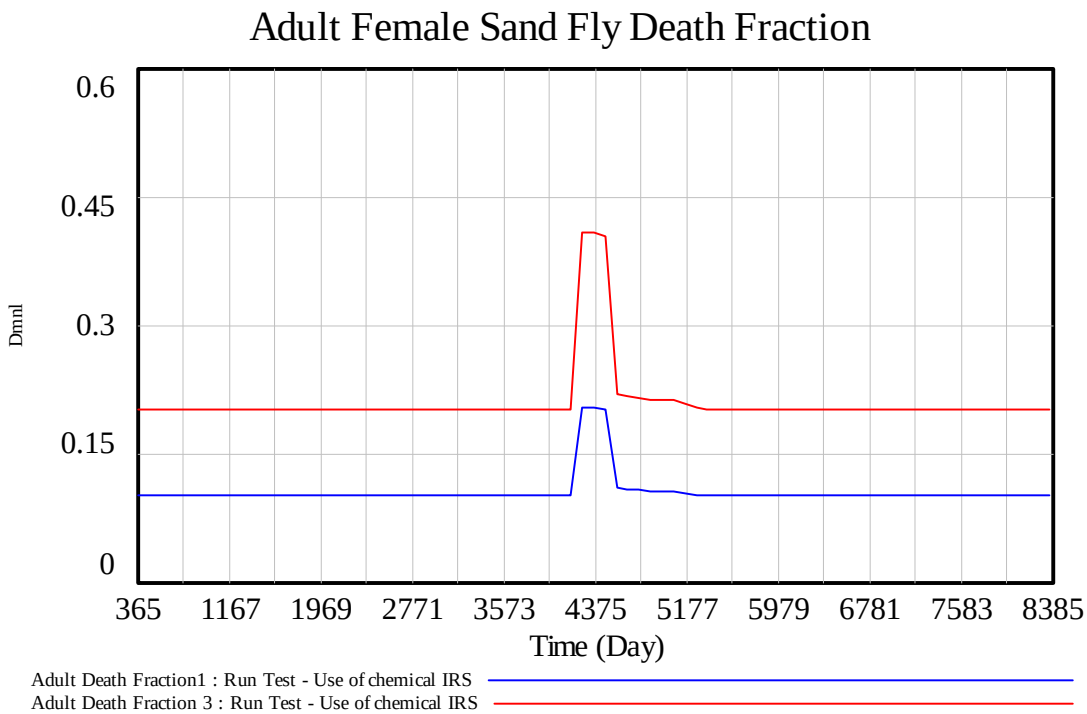


Figure 9.10: The effect of Use of chemical IRS on adult death fraction 1 and on adult death fraction 3

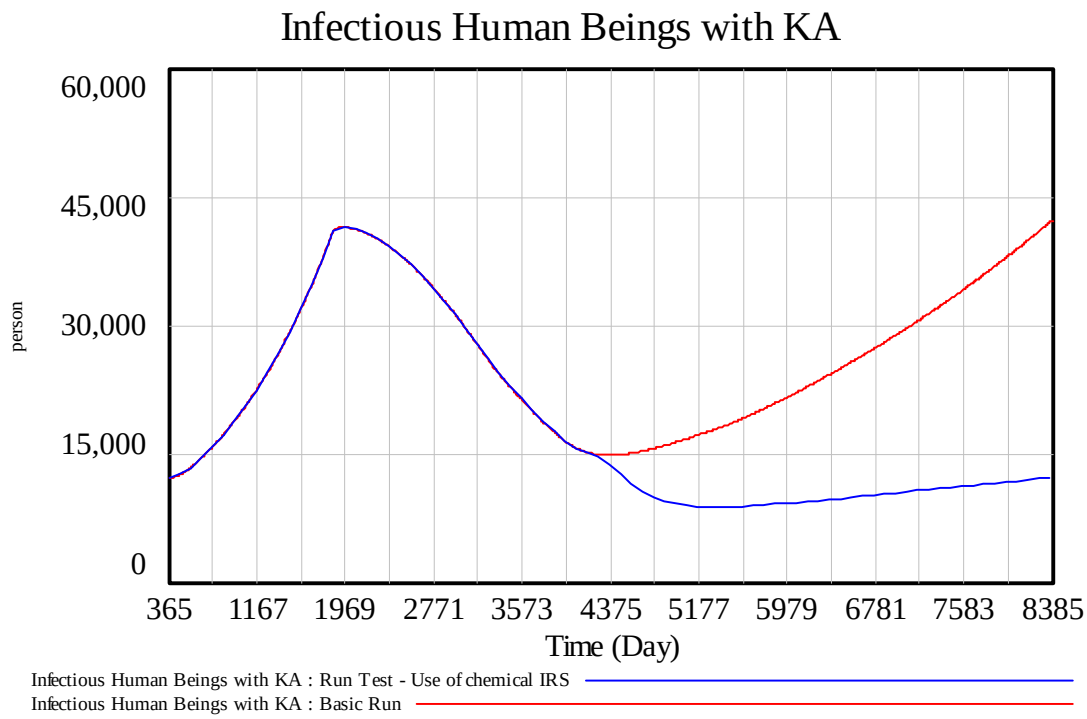


Figure 9.11: The effect of use of chemical IRS on the infectious human beings with Kala-azar

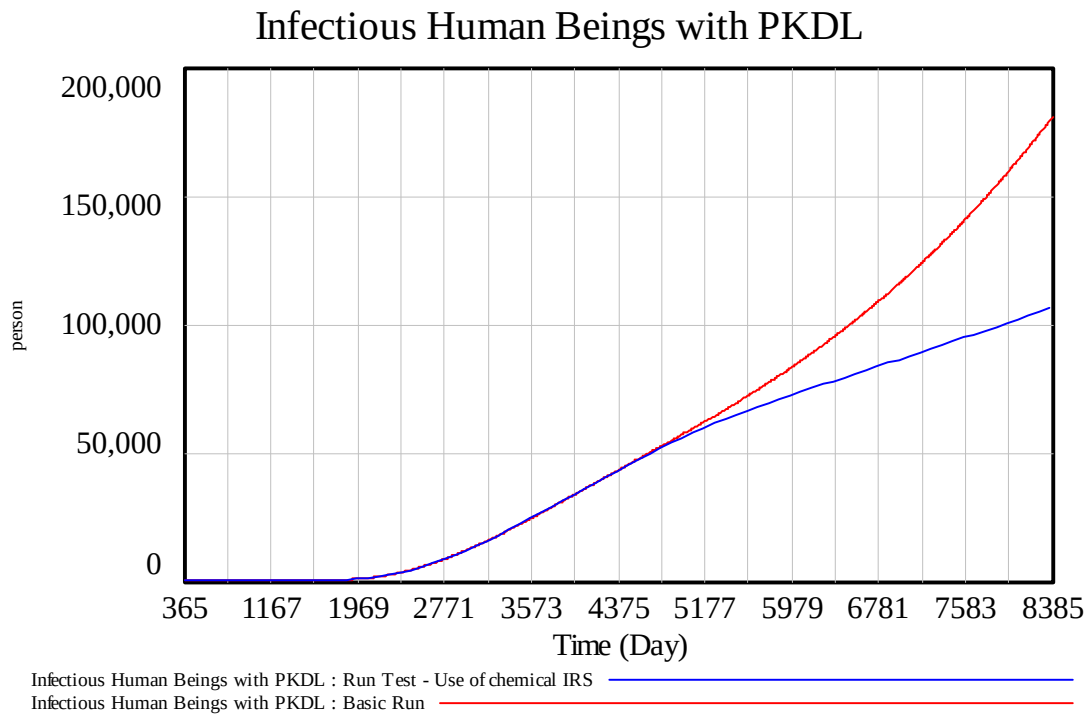


Figure 9.12: The effect of use of chemical IRS on the infectious human beings with PKDL

Figure 9.13 shows the result of combining the three actions under policy1. The results depicts that the educational program has an effective impact on controlling the underlying disease that effectively will reduce the number of human beings infected by Kala-azar zero. And the number of infected human beings with PKDL will decrease approximately by 2025 and eventually diminish to zero thereafter (figure 9.14).

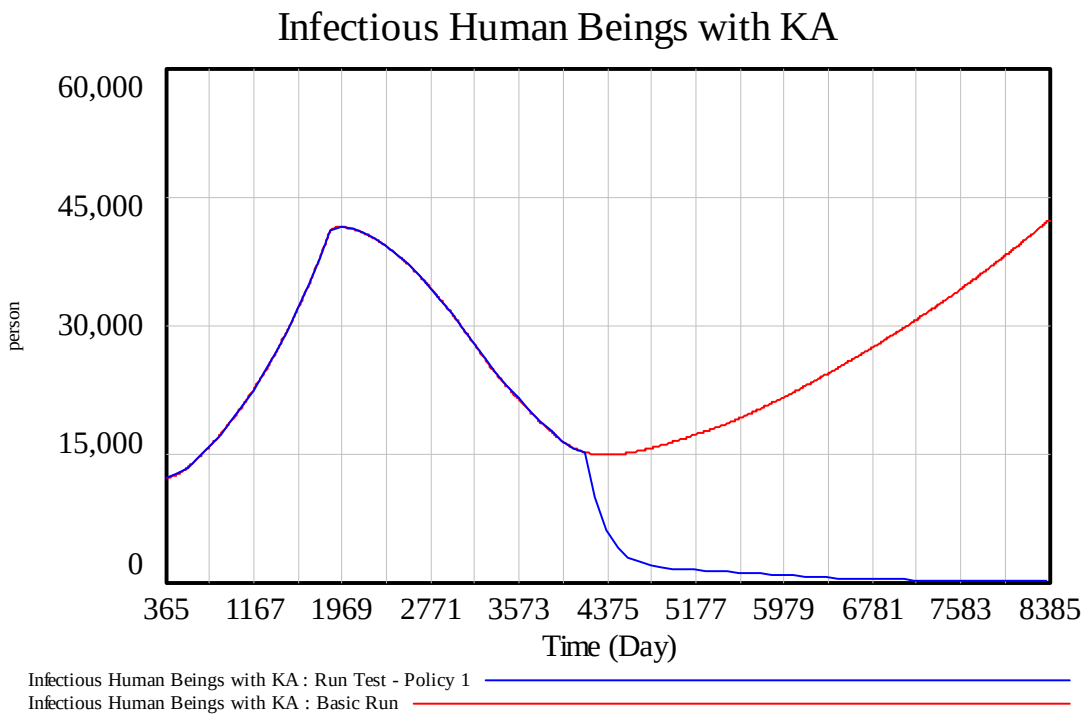


Figure 9.13: The effect of combine the three actions of policy 1 on the infectious human beings with Kala-azar

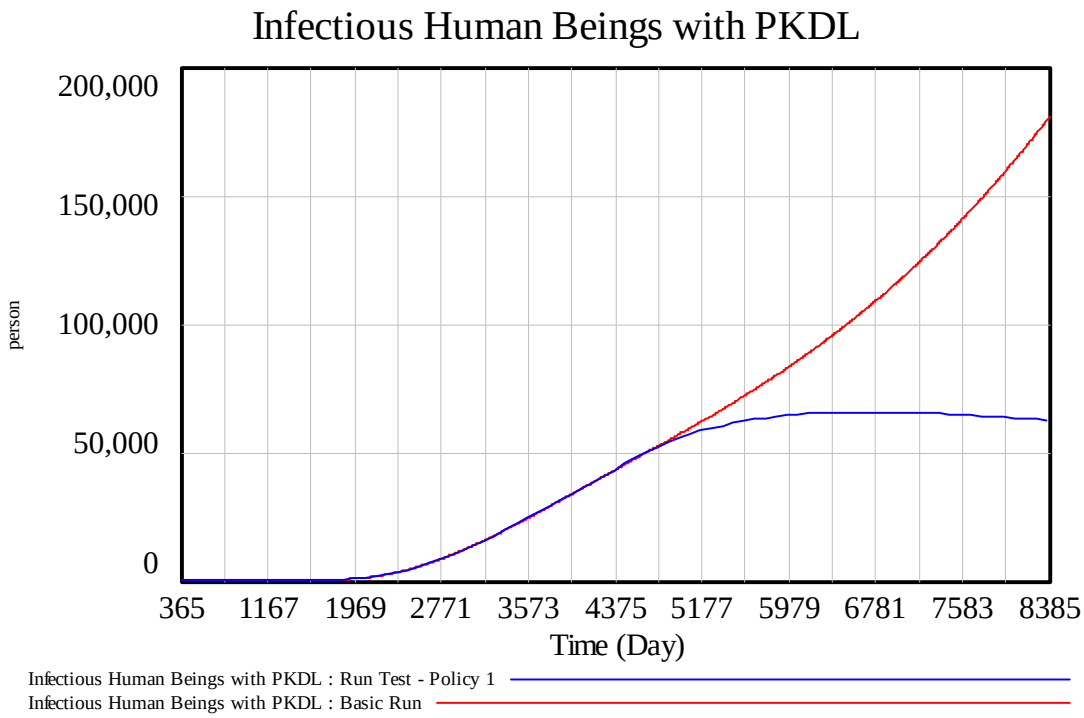


Figure 9.14: The effect of combine the three actions of policy 1 on the infectious human beings with PKDL

From the policy testing it appears that increasing the awareness of the disease and treatment alone (Action 2) cannot reduce the Kala-azar. But the combination of the educational program shows the best results in eliminating the Kala-azar cases. It is recommended to implement the policy for launching public health educational program. No doubt it is time taking and costly as well, but in the long run it will give the required results in terms of saving human lives. One suggestion could be to do the proper cost and benefit analysis to minimize the associated costs.

9.3 Policy 2: Improving the HDI:

To eliminate the disease completely we need to increase the HDI (Human Development Index) of human beings because increase in the HDI will improve the human beings' life style in India as one of the main factor for this disease is poverty, literacy and lack of resources to make proper arrangements to prevent this disease.

Figure 9.15 shows that if the HDI increase from.519 to .65 by year 2012 it is expected that the probability to expose to sand fly bite will be reduces to .7, therefore, the Kala-azar will be eliminate (see figure 9.16) and the PKDL will reduce by 8385 (see figure 9.17) .

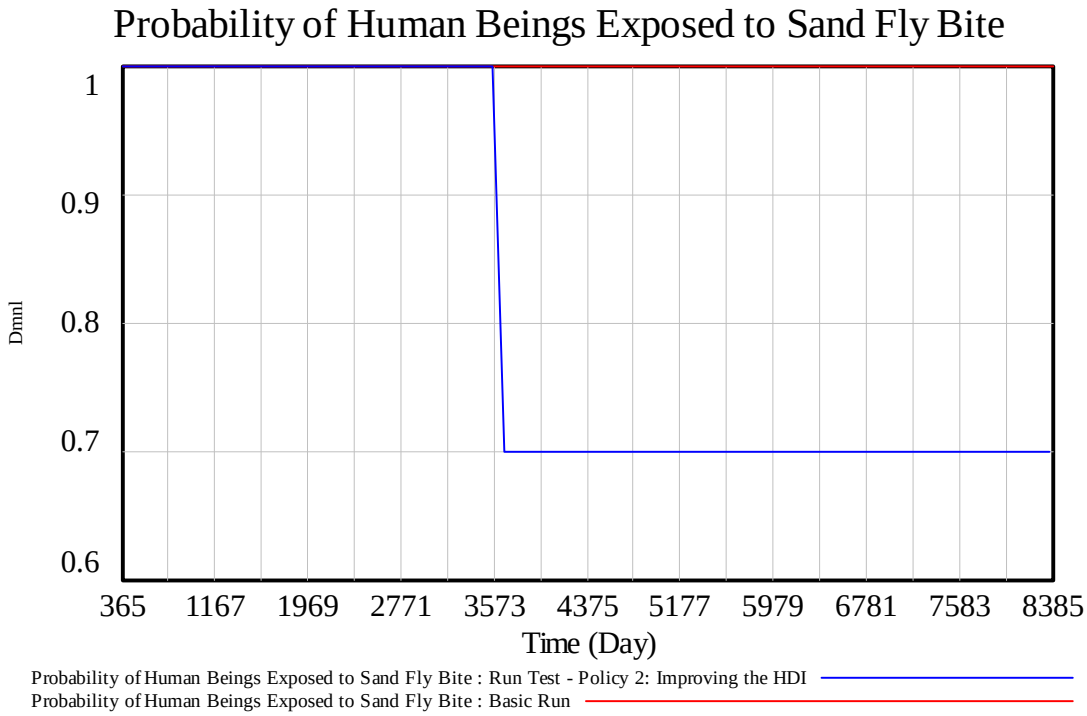


Figure 9.15: The effect of improving the HDI on probability of human beings exposed to sand fly bite

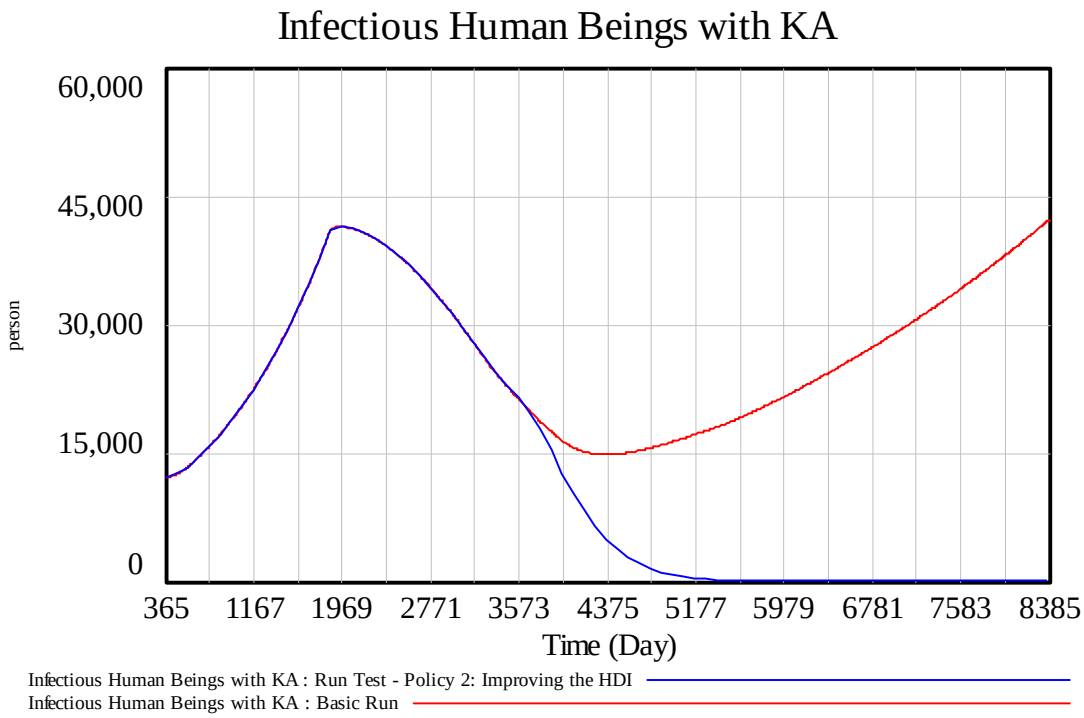


Figure 9.16: The effect of improve the HDI on the infectious human beings with Kala-azar

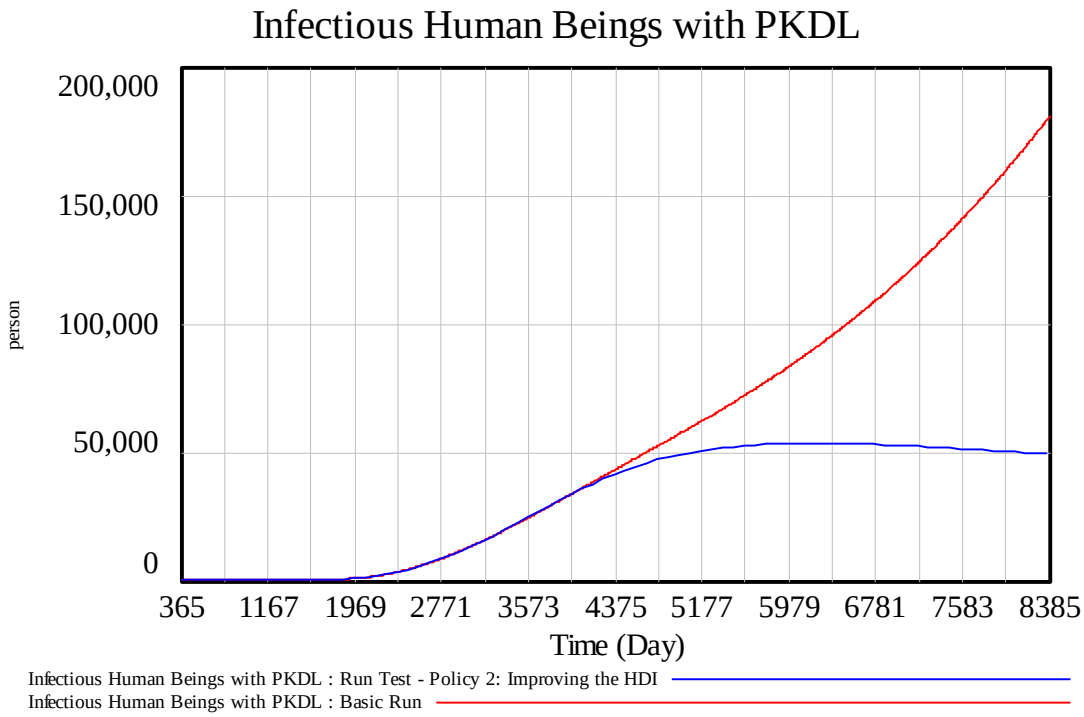


Figure 9.17: The effect of improve the HDI on the infectious human beings with PKDL

We can conclude the result of the two policies as figure 9.18 compares the effect of each policy on the infectious human beings with Kala-azar, and Figure 9.19 compares the result of infectious human beings with PKDL.

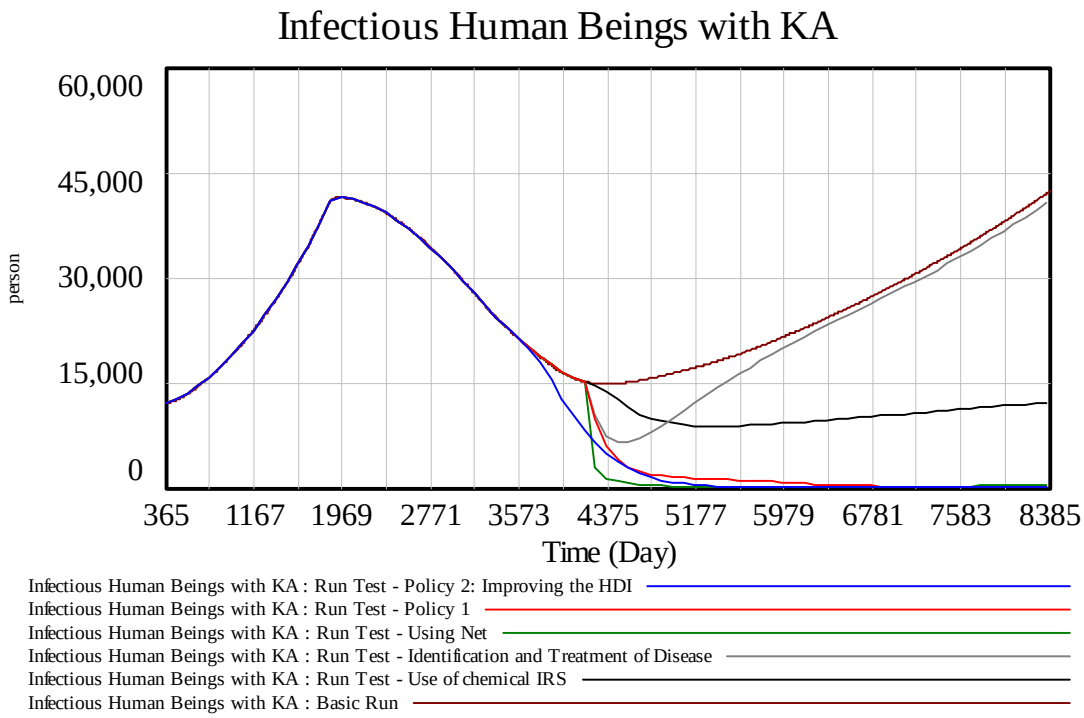


Figure 9.18: Policy Comparison for Kala-azar

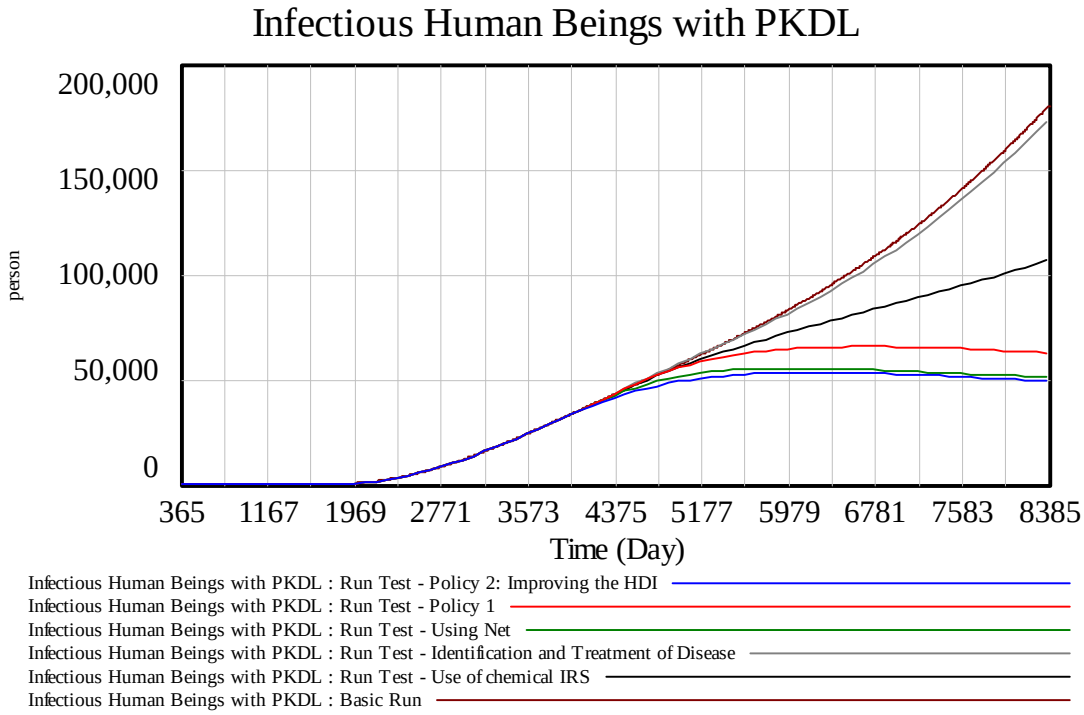


Figure 9.19: Comparison for PKDL

10. Conclusion

This research work focuses on studying the Kala-azar disease in India, where the aim is to find out robust policies to control the spread of the disease.

System Dynamics Method has been used to study the Kala-azar disease. The developed model describes the epidemiological dynamics of the disease for the populations of human beings and sand flies. And it also shows the spread of the disease among human beings population occurs through the bite of adult female sand flies previously infected by biting and sucking blood of an infectious human beings. In addition, the model provided deeper understanding to the disease as being a cyclical effect. In our hypothesis and analysis, we demonstrated how infected people with Kala-azar and PKDL could impact on the spread of the Kala-azar and there is positive feedback mechanism that causes the prevalence of Kala-azar or PKDL among human beings which involves the population of adult female sand flies.

From the simulation it is projected that the Kala-azar epidemic will develop (as indicated in Model Analysis Section 7, figure 7.1). The number of infected people will increase sharply by year 2025.

The result of testing the hypothesis, it shows that the two positive feedback loops (R1,R2) are responsible for generating the behavior of the basic run (or base run) and the prevalence of PKDL will cause an increase in the number of infected human beings with Kala-azar.

In achieving the underlying goal of removing this disease, two policies are suggested, implemented and tested; the results support the suggested policies of: (1) proper promotional campaigns to reduce Kala-azar disease, (2) improving HDI. The results give us reason to believe that by implementing the two policies proposed, we will prevent (or reduce significantly) the future spread of the Kala-azar and PKDL. And thus will stop suffer from the needless illness and death which will also improve the HDI.

Primary limitations of the study were the lack of historical data about the development of PKDL cases, and also few assumptions were made while developing the model like: (1) Constant

Development of sand flies, (2) no birth and immigration among human beings, (3) constant death fraction from kala-azar and PKDL, (4) constant incubation time for human beings. In future, these limitations will be addressed and to have the proper data some research teams will be made to find out the actual data. The model may also be further developed in the structural to study the impact of kala-azar on human health, demographics, social, economic development, and the temperature effects on sand flies.

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12. Appendix - I

Appendix 1: Define the stability of sand fly population

Based on our assumption that the sand flies population is stable in all the stages which means that all its stock are unchanged, and for a stock to be in equilibrium the net rate of change must be zero implying the total inflow is just balance by the total out flows; therefore we need to initialize all of the stocks in the sand flies sector in equilibrium state, to do so we define the initial value for each stock that let the total inflow of each stock is equal to the total out flows.

By the following equations it shows an example of how we define the initial value for the Female Egg:

The Female Egg Population in equilibrium means:

Egg Production Rate=Hatching Rate+ Egg Discard Rate

Since each of the two outflows (Hatching Rate and Egg Discard Rate) are function of the stock of the Female Egg Population then we can write the equation above as flowing

Egg Production Rate = Female Eggs*Egg Survival Fraction/OvipositionTime +
Female Eggs*Egg Discard Fraction/OvipositionTime

then,

Female Eggs = Egg Production Rate * OvipositionTime

And we follow the same way to define the initial value for the other stocks in the sand fly sector.

We define the rate at which young female sand fly produce (Sand Fly Production Rate) as

Sand Fly Production Rate = Initial Hatching Rate*Number of Sand Fly per Egg

Where, the ‘Initial Hatching Rate’ is equal to the numerical value of ‘Hatching Rate’ because of the simultaneous problem.

13. Appendix - II

Uninfected Adult Female Sand Flies= INTEG (

"Non-Infectious Bite Rate of AFSF"-Death Rate UAFSF-Digestion Rate of NIAFSF,

"Non-Infectious Bite Rate of AFSF"*IncubationTime of SFl)

~ sandfly

"Non-Infectious Bite Rate of AFSF"=

Biting Rate of AFSF*Number of Bites per Sand Fly*(1-Density of Infectious Human Beings)*Transmission Probability for Female Sand Fly per Bite

~ sandfly/Day

Infectious Bite Rate of AFSF=

Biting Rate of AFSF*Density of Infectious Human Beings*Number of Bites per Sand Fly*\

Transmission Probability for Female Sand Fly per Bite

~ sandfly/Day

Buying Spray Rate=

(Desired Number of Households Buying Spray*Effect of Family Education on Policy Effectiveness\

-Households Using Spray)/Average Time to Buy

~ household/Day

Effectiveness of Being Covered by Net on Bite=

Effect of Being Covered by Net on Bite*Optimal Proportional Reduction in Bites when Covered by Net

~ Dmnl

~ (1-Proppting of people having Net)+Proppting of people having Net*(1-optimal \

proportional reduction in bites when under itn

*Effect of Family education on policy effectiveness)*0

Effect of Being Covered by Net on Bite= WITH LOOKUP (

Proportion of Human Beings Covered by Net,

([(0,0)-(1,1)],(0,0),(1e-005,9.8e-005),(3e-005,0.026),(9e-005,0.085),(0.0001,0.09),(0.0005,0.04),(0.0007,0.065),(0.0009,0.085),(0.001,0.095),(0.003,0.027),(0.005,0.045),(0.007,0.066),(0.009,0.089),(0.01,0.09),(0.03,0.175),(0.05,0.27),(0.07,0.35),(0.0948012,0.419),(0.103976,0.53),(0.207951,0.657895),(0.3,0.7),(0.4,0.77),(0.5,0.835),(0.6,0.896),(0.7,0.9),(0.8,0.93),(0.9,0.95),(1,0.97)))

~ Dmnl

Effect of Education on Average Time to seek Treament= WITH LOOKUP (

Proportion of Families Educated*Effect of Family Education on Policy Effectiveness,

([(0,0)-(1,0.7)],(0,0),(0.00611621,0.0583333),(0.00917431,0.0890351),(0.0152905,0.128947),(0.0152905,0.193421),(0.0152905,0.254825),(0.0275229,0.319298),(0.0611621,0.389912),(0.103976,0.439035),(0.137615,0.475877),(0.207951,0.512719),(0.262997,0.534211),(0.351682,0.561842),(0.452599,0.601754),(0.525994,0.620175),(0.602446,0.641667),(0.672783,0.641667),(0.752294,0.644737),(0.816514,0.647807),(0.902141,0.644737),(1.00306,0.638596)))

~ Dmnl

"Ref. Number of Bites per Sand Fly"=1

~ bite/sandfly

Number of Bites per Sand Fly="Ref. Number of Bites per Sand Fly"*Probability of Human Beings Exposed to Sand Fly Bite

~ bite/sandfly

Number of Household Education=Desired Number of Household Education-Educated Families

~ household

Desired Number of Household Education=

"Re. of Desired Households Education"*1*Effect of Density of Infectious Human Beings on Dersired Households Educate per Day*0

~ household

~ *0.00025

Education Rate=IF THEN ELSE(Time<Education INTERVENTION START TIME :OR: Time>Education INTERVENTION END TIME\

, 0, (Number of Household Education/Average Time to Lunch Education Program))

~ household/Day

Net Purchasing Rate=(Desired Number of Net*Effect of Family Education on Policy Effectiveness-Net)/Average Time to Buy Net

~ net/Day

Average Time to Lunch Education Program= 1

~ Day

Initial Hatching Rate=5e+006

~ egg/Day

Death Rate of NIAFSF= Non Infectious Adullt Female Sand Flies*Adult Death Fraction 3/Average Life Span

~ sandfly/Day

Natural Death Rate of IAFSF= Infectious Adult Female Sand Flies*Adult Survival Fraction3/Average Life Span

~ sandfly/Day

Adult Death Fraction1= (1-Adult Survival Fraction1)*Effect of Use of Spray on Fraction of Sand Flies Death

~ Dmnl

Adult Death Fraction2= (1-Adult Survival Fraction2)

~ Dmnl

Death Rate UAFSF= Uninfected Adult Female Sand Flies*Adult Death Fraction2/Digestion Time of Sand Flies

~ sandfly/Day

Natural Death Rate of NIAFSF= Non Infectious Adullt Female Sand Flies*Adult Survival Fraction3/Average Life Span

~ sandfly/Day

Death Rate of IAFSF= Infectious Adult Female Sand Flies*Adult Death Fraction 3/Average Life Span

~ sandfly/Day

Death Rate of SAFSF= Susceptible Adult Female Sand Flies*Adult Death Fraction1/Average Time Between Blood Meals

~ sandfly/Day

Death Rate of LAFSF= Latent Adult Female Sand Flies*Adult Death Fraction2/IncubationTime of SFl

~ sandfly/Day

Adult Death Fraction 3= ((1-Adult Survival Fraction3))*Effect of Use of Spray on Fraction of Sand Flies Death

~ Dmnl

Young Death Fraction per Day= 1-Young Survival Fraction

~ Dmnl

Egg Discard Fraction= 1-Egg Survival Fraction

~ Dmnl

Egg Discard Rate= Female Eggs*Egg Discard Fraction/OvipositionTime

~ egg/Day

Young Death Rate= Young Female Sand Flies*Young Death Fraction per Day/Maturation Time

~ sandfly/Day

Young Female Sand Flies= INTEG (Sand Fly Production Rate-Differrent in Sand Fly Production Rate-Maturation Rate-Young Death Rate\,

Sand Fly Production Rate*Maturation Time)

~ sandfly

Digestion Time of Sand Flies= 6

~ Day

Digestion Rate of NIAFSF= Uninfected Adult Female Sand Flies*Adult Survival Fraction2/Digestion Time of Sand Flies

~ sandfly/Day

Effect of Eductionon on Fraction of Human Beings Seeking Treament= WITH LOOKUP (Proportion of Families Educated*Effect of Family Education on Policy Effectiveness,([(0,0)-(1,7)],(0,1),(0.00917431,1.66667),(0.0275229,2.42544),(0.0642202,2.88596),(\

0.122324,3.34649),(0.189602,3.89912),(0.256881,4.29825),(0.330275,4.66667),(0.406728\,5.06579),(0.492355,5.43421),(0.544343,5.55702),(0.636086,5.83333),(0.697248,5.98684\),(0.752294,6.04825),(0.798165,6.17105),(0.874618,6.17105),(0.932722,6.17105),(0.990826\,6.07895)))

~ Dmnl

"Re.Average Time to Seek PKDL Treatment"= 20

~ Day

Probability of Human Beings Exposed to Sand Fly Bite=Reference of Probability of Human Beings Exposed to Sand Fly Bite*Effect of HDI on Probability of Human Exposed to Sand Fly Bite*(1-Effectiveness of Being Covered by Net on Bite)

~ Dmnl

Time to Recover From PKDL= 120

~ Day

"Re. of Desired Households Education"= 100000

~ household

Diffrent= (Initial Hatching Rate-Hatching Rate)*Number of Sand Fly per Egg

~ sandfly/Day

"R.Average Time to Seek KA Treatment"= 15

~ Day

Average Time to Seek KA Treatment= "R.Average Time to Seek KA Treatment"*(1-Effect of Education on Average Time to seek Treament\)

~ Day

Fraction of Infectious Human Beings Seeking KA Treatment=(0.003+Effect of Density of Infectious Human Beings on Fraction of Infectious Human Beings Seeking KA Treatment\)*Effect of Eductionon on Fraction of Human Beings Seeking Treament

~ Dmnl

Differrent in Sand Fly Production Rate= max(Diffrent,0)

~ sandfly/Day

Average Time to Seek PKDL Treatment="Re.Average Time to Seek PKDL Treatment"*(1-Effect of Education on Average Time to seek Treament\)

~ Day

Fraction of Human Beings Seeking PKDL Treatment= 0.003*Effect of Eductionon on Fraction of Human Beings Seeking Treament

~ Dmnl

Education Coverage Necessary to Achieve Maximum Effectiveness= 1

~ Dmnl

Education INTERVENTION END TIME= 4380*0+(365)/2*0+3825+365+365/2

~ Day

Education INTERVENTION START TIME= 3825+365

~ Day

Educated Families= INTEG (Education Rate-Forgetting Rate,0)

~ household

Average Duration of spraying effectiveness= 3

~ Day

Average Number of Persons per Family= 6

~ person/household

Effect of Family Education on Policy Effectiveness = min(1,(Minimum Policy Effectiveness+(Maximum Policy Effectiveness-Minimum Policy Effectiveness\)*(Proportion of Families Educated/Education Coverage Necessary to Achieve Maximum Effectiveness)))

~ Dmnl

Average Time Life of Net= 365

~ Day

Average Time to Buy= 7

~ Day

Average Time to Buy Net= 2

~ Day

Maximum Policy Effectiveness= 1

~ Dmnl

Minimum Policy Effectiveness= 0.25

~ Dmnl

Households Using Spray = INTEG (Buying Spray Rate-Losing Effectiveness of Spraying Rate, 0)

~ household

Total Number of Human Beings Covered by Net=Number of Human Beings Cover by Net*Net

~ person

Desired Number of Households Buying Spray= Educated Families

~ household

Optimal Proportional Reduction in Bites when Covered by Net= 0.98

~ Dmnl

Effect of Use of Spray on Fraction of Sand Flies Death= WITH LOOKUP (Proportion of Households Sprayed,([(0,0)-(0.01,3)],(0,1),(5e-005,1.001),(6e-005,1.002),(7e-005,1.003),(8e-005,1.004)\,(9e-005,1.005),(0.0001,1.006),(0.0002,1.007),(0.0003,1.008),(0.0004,1.009),(0.0005\,1.01),(0.0006,1.0209),(0.0007,1.031),(0.0008,1.04),(0.0009,1.05),(0.001,1.06),(0.002\,1.069),(0.003,1.078),(0.004,1.087),(0.005,1.099),(0.006,2.017),(0.007,2.0285),(0.008\,2.0369),(0.009,2.0493)))

~ Dmnl

Tolal Population at Risk= (1.65e+008)

~ person

Total Number of Families=Total Number Of Poor Population/Average Number of Persons per Family

~ household

Net= INTEG (Net Purchasing Rate-Net Deterioration Rate, 0)

~ net

Net Deterioration Rate= Net/Average Time Life of Net

~ net/Day

Number of Human Beings Cover by Net= 1

~ person/net

Forgetting Rate= Educated Families/Time to Froget Education

~ household/Day

Losing Effectiveness of Spraying Rate= Households Using Spray/Average Duration of spraying effectiveness

~ household/Day

Desired Number of Net=Number of Educated Human Beings*Desired Number of Net per Person

~ net

Desired Number of Net per Person= 1

~ net/person

Effect of Density of Infectious Human Beings on Dersired Households Educate per Day= \WITH LOOKUP (Density of Infectious Human Beings,

([(0,0)-(0.1,100)],(1e-006,2),(3e-006,4),(4e-006,5),(5e-006,6),(6e-006,7),(7e-006,8),(8e-006,10),(9e-005,11),(0.0001,12),(0.0002,13),(0.0003,14),(0.0004,15),(0.0005,16),(0.0006,17),(0.0007,18),(0.0008,19),(0.0009,20),(0.001,21),(0.002,22),(0.003,23),(0.004,25),(0.005,30),(0.006,33),(0.007,35),(0.008,37),(0.009,40),(0.01,50),(0.02,60),(0.03,70),(0.04,80),(0.05,90),(0.06,95),(0.07,95),(0.09,100),(0.1,100)))

~ Dmnl

Time to Froget Education= 360

~ Day

Total Number Of Poor Population= 0*(2.5e+006)+4.5e+006*0+Tolal Population at Risk*0.6

~ person

Proportion of Families Educated= Educated Families/Total Number of Families

~ Dmnl

Number of Educated Human Beings= Educated Families*Average Number of Persons per Family

~ person

Proportion of Human Beings Covered by Net= Total Number of Human Beings Covered by Net/Total Number Of Poor Population

~ Dmnl

Proportion of Households Sprayed= Households Using Spray/Total Number of Families

~ Dmnl

Infection Rate of HB=Number of Infectious Bites per Day*Fraction of Susceptible Human Beings*Transmission Probability for Human Being per Bite

~ person/Day

Conversion Rate of HB= Latent Human Beings/Incubation Time of HB

~ person/Day

Infectious Human Beings with KA= INTEG (Conversion Rate of HB-Death Due KA Rate of HB-Natural Death Rate of IHB with KA-Recovery Rate From KA\,12140)

~ person

Infectious Human Beings with PKDL= INTEG (PKDL Development Rate-Death due PKDL Rate of HB-Natural Death Rate of IHB with PKDL- Recovery Rate From PKDL,10)

~ person

Recovery Rate From KA=Infectious Human Beings with KA*Fraction of Infectious Human Beings Seeking KA Treatment\(Average Time to Seek KA Treatment+Time to Recover From KA)

~ person/Day

Recovery Rate From PKDL= Infectious Human Beings with PKDL*Fraction of Human Beings Seeking PKDL Treatment/(Average Time to Seek PKDL Treatment+Time to Recover From PKDL)

~ person/Day

Latent Human Beings= INTEG (Infection Rate of HB-Conversion Rate of HB-Natural Death Rate of LHB, 100)

~ person

Reference of Probability of Human Beings Exposed to Sand Fly Bite= 1

~ Dmnl

Average Time to Develop PKDl= 182.5

~ Day

Average Time to Fully Recover= 5*365

~ Day

PKDL Development Rate= Semi Recovered Human Beings*Fraction of Semi Recovered Human Beings Dvlp PKDL/Average Time to Develop PKDl

~ person/Day

Natural Death Rate of LHB= Latent Human Beings*Fraction of Death of Human Being

~ person/Day

Natural Death Rate of SHB= Susceptible Human Beings*Fraction of Death of Human Being

~ person/Day

Natural Death Rate of SRHB= Semi Recovered Human Beings*Fraction of Death of Human Being

~ person/Day

Fully Recovered Human Beings= INTEG (Full Recovery Rate+Recovery Rate From PKDL-Natural Death Rate of FRHB,10000)

~ person

Full Recovery Rate= Semi Recovered Human Beings*(1-Fraction of Semi Recovered Human Beings Dvlp PKDL)/Average Time to Fully Recover

~ person/Day

Transmission Probability for Human Being per Bite=0.09

~ person/bite

~ .18

Death Due KA Rate of HB= Infectious Human Beings with KA*Fraction of Death Due KA of HB

~ person/Day

Death Due to KA Human Beings= INTEG (Death Due KA Rate of HB, 200)

~ person

Death due PKDL Rate of HB= Infectious Human Beings with PKDL*Fraction of Death Due PKDL

~ person/Day

Density of Infectious Human Beings= Total Number of Infectious Human Beings/Total Number of Human Beings at Risk

~ Dmnl

Fraction of Death of Human Being= 4e-005

~ 1/Day

Fraction of Semi Recovered Human Beings Dvlp PKDL= 0.1

~ Dmnl

Effect of HDI on Probability of Human Exposed to Sand Fly Bite= WITH LOOKUP (HDI,
([(0,0)-(1,1)],(0.5,1),(0.55,1),(0.6,0.85),(0.65,0.7),(0.7,0.65),(0.75,0.55),(0.8,0.45\
),(0.85,0.35),(0.9,0.15),(0.95,0),(1,0)))

~ Dmnl

Effect of Density of Infectious Human Beings on Fraction of Infectious Human Beings Seeking KA Treatment\
= WITH LOOKUP (Density of Infectious Human Beings,

([(0,0)-(0.004,0.2)],(0,0),(7.35758e-005,0),(7.36364e-005,0),(0.000110388,0),(0.000148358,0),(0.0001522,0),(0.000172209,0),(0.000192218,0),(0.000198806,0),(0.0002,0),(0.00021,0),(0.000215,0),(0.000217,0),(0.00022,0),(0.00025,0),(0.000265,0.1),(0.0003,0.15),(0.0005,0.17),(0.0006,0.17),(0.0007,0.17),(0.0008,0.17),(0.0009,0.17),(0.001,0.17), (0.002,0.17)))

~ Dmnl

Total Number of Infectious Human Beings= Infectious Human Beings with KA+Infectious Human Beings with PKDL

~ person

Semi Recovered Human Beings= INTEG (Recovery Rate From KA-PKDL Development Rate-Full Recovery Rate-Natural Death Rate of SRHB,500)

~ person

Fraction of Death Due KA of HB= 4e-006

~ 1/Day

Fraction of Death Due PKDL= 4e-008

~ 1/Day

Total Number of Poor Human Beings= 0.6*Total Number of Human Beings at Risk

~ person

Fraction of Susceptible Human Beings= Susceptible Human Beings/Total Number of Human Beings at Risk

~ Dmnl

Total Number of Human Beings at Risk= (1.65e+008)

~ person

Natural Death Rate of FRHB= Fully Recovered Human Beings*Fraction of Death of Human Being

~ person/Day

Natural Death Rate of IHB with KA= Infectious Human Beings with KA*Fraction of Death of Human Being

~ person/Day

HDI= IF THEN ELSE(Time<(3285+365),0.519,0.65)*0+0.519*1

~ Dmnl

Incubation Time of HB= 120

~ Day

Time to Recover From KA= 30

~ Day

Natural Death Rate of IHB with PKDL= Infectious Human Beings with PKDL*Fraction of Death of Human Being

~ person/Day

Susceptible Human Beings= INTEG (-Infection Rate of HB-Natural Death Rate of SHB,1*(Total Number of Poor Human Beings-(Latent Human Beings+Infectious Human Beings with KA+ Semi Recovered Human Beings+Death Due to KA Human Beings+Infectious Human Beings with PKDL+Fully Recovered Human Beings)))

~ person

Number of Infectious Bites per Day=Number of Bites per Sand Fly*Infectious Adult Female Sand Flies/Average Time Between Blood Meals

~ bite/Day

Adult Survival Fraction1= 0.9

~ Dmnl

Adult Survival Fraction2= 0.85

~ Dmnl

Adult Survival Fraction3= 0.8

~ Dmnl

Average Life Span= 4

~ Day

Average Time Between Blood Meals= 2

~ Day

Conversion Rate of IAFSF= Latent Adult Female Sand Flies*Adult Survival Fraction2/IncubationTime of SFl

~ sandfly/Day

Egg Production Rate=Egg Laying Rate of AFSF*Number of Egg per Sand Fly

~ egg/Day

Egg Survival Fraction= 0.2565

~ Dmnl

Female Eggs= INTEG (Egg Production Rate-Egg Discard Rate-Hatching Rate,Egg Production Rate*OvipositionTime)

~ egg

Hatching Rate= Female Eggs*Egg Survival Fraction/OvipositionTime

~ egg/Day

Sand Fly Production Rate= Initial Hatching Rate*Number of Sand Fly per Egg

~ sandfly/Day

IncubationTime of SFl= 6

~ Day

Infectious Adult Female Sand Flies= INTEG (Conversion Rate of IAFSF-Death Rate of IAFSF-Natural Death Rate of IAFSF,Conversion Rate of IAFSF*Average Life Span)

~ sandfly

Latent Adult Female Sand Flies= INTEG (Infectious Bite Rate of AFSF-Conversion Rate of IAFSF-Death Rate of LAFSF,

Infectious Bite Rate of AFSF*IncubationTime of SFl)

~ sandfly

Egg Laying Rate of AFSF= Conversion Rate of IAFSF+Digestion Rate of NIAFSF

~ sandfly/Day

Maturation Rate= Young Female Sand Flies*Young Survival Fraction/Maturation Time

~ sandfly/Day

Maturation Time= 43.715-OvipositionTime

~ Day

Non Infectious Adullt Female Sand Flies= INTEG (Digestion Rate of NIAFSF-Death Rate of NIAFSF-Natural Death Rate of NIAFSF,

Digestion Rate of NIAFSF*Average Life Span)

~ sandfly

Number of Egg per Sand Fly= (22.65/2)

~ egg/sandfly

Number of Sand Fly per Egg= 1

~ sandfly/egg

OvipositionTime= 6.25

~ Day

Biting Rate of AFSF= Susceptible Adult Female Sand Flies*Adult Survival Fraction1/Average Time Between Blood Meals

~ sandfly/Day

Susceptible Adult Female Sand Flies= INTEG (Maturation Rate-Death Rate of SAFSF-Biting Rate of AFSF,(Maturation Rate*Average Time Between Blood Meals))

~ sandfly

Transmission Probability for Female Sand Fly per Bite= 1*0.5*0+1

~ sandfly/bite

Young Survival Fraction= 0.45

~ Dmnl

****

.Control

**********~

Simulation Control Parameters

FINAL TIME = 8385

~ Day

~ The final time for the simulation.

INITIAL TIME = 365

~ Day

~ The initial time for the simulation.

SAVEPER = 100

~ Day [0,?]

~ The frequency with which output is stored.

TIME STEP = 0.0078125

~ Day [0,?]

~ The time step for the simulation.

\\\---/// Sketch information - do not modify anything except names

V300 Do not put anything below this section - it will be ignored

*View 1

$192-192-192,0,Times New Roman|12||0-0-0|0-0-0|0-0-255|-1--1--1|-1--1--1|96,96,100,0

10,1,Female Eggs,-242,46,47,22,3,131,0,0,0,0,0,0

10,2,Young Female Sand Flies,-239,223,55,18,3,131,0,0,0,0,0,0

10,3,Susceptible Adult Female Sand Flies,22,219,60,20,3,131,0,0,0,0,0,0

12,4,48,-20,42,10,8,0,3,0,0,-1,0,0,0

1,5,7,1,4,0,0,22,0,0,0,-1--1--1,,1|(-150,44)|

1,6,7,4,100,0,0,22,0,0,0,-1--1--1,,1|(-61,44)|

11,7,48,-98,44,6,8,34,3,0,0,1,0,0,0

10,8,Egg Production Rate,-98,71,49,19,40,3,0,0,-1,0,0,0

12,9,48,-450,46,10,8,0,3,0,0,-1,0,0,0

1,10,12,9,4,0,0,22,0,0,0,-1--1--1,,1|(-404,46)|

1,11,12,1,100,0,0,22,0,0,0,-1--1--1,,1|(-323,46)|

11,12,48,-362,46,6,8,34,3,0,0,1,0,0,0

10,13,Hatching Rate,-362,65,55,11,40,3,0,0,-1,0,0,0

1,14,16,3,4,0,0,22,0,0,0,-1--1--1,,1|(-72,222)|

1,15,16,2,100,0,0,22,0,0,0,-1--1--1,,1|(-151,222)|

11,16,1692,-111,222,6,8,34,3,0,0,1,0,0,0

10,17,Maturation Rate,-111,241,51,11,40,3,0,0,-1,0,0,0

12,18,48,-241,382,10,8,0,3,0,0,-1,0,0,0

1,19,21,18,4,0,0,22,0,0,0,-1--1--1,,1|(-241,343)|

1,20,21,2,100,0,0,22,0,0,0,-1--1--1,,1|(-241,271)|

11,21,48,-241,307,8,6,33,3,0,0,4,0,0,0

10,22,Young Death Rate,-175,307,58,11,40,3,0,0,-1,0,0,0

12,23,48,23,383,10,8,0,3,0,0,-1,0,0,0

1,24,26,23,4,0,0,22,0,0,0,-1--1--1,,1|(14,344)|

1,25,26,3,100,0,0,22,0,0,0,-1--1--1,,1|(14,270)|

11,26,48,14,307,8,6,33,3,0,0,4,0,0,0

10,27,Death Rate of SAFSF,87,307,65,19,40,3,0,0,-1,0,0,0

10,28,Uninfected Adult Female Sand Flies,482,115,64,24,3,131,0,0,0,0,0,0

10,29,Latent Adult Female Sand Flies,504,366,64,22,3,131,0,0,0,0,0,0

12,30,48,266,364,10,8,0,3,0,0,-1,0,0,0

1,31,33,29,4,0,0,22,0,0,0,-1--1--1,,1|(390,365)|

1,32,33,30,100,0,0,22,0,0,0,-1--1--1,,1|(302,365)|

11,33,48,334,365,6,8,34,3,0,0,1,0,0,0

10,34,Infectious Bite Rate of AFSF,334,392,53,19,40,3,0,0,-1,0,0,0

10,35,Non Infectious Adullt Female Sand Flies,770,112,68,24,3,131,0,0,0,0,0,0

10,36,Infectious Adult Female Sand Flies,786,364,64,23,3,131,0,0,0,0,0,0

1,37,39,35,4,0,0,22,0,0,0,-1--1--1,,1|(666,113)|

1,38,39,28,100,0,0,22,0,0,0,-1--1--1,,1|(582,113)|

11,39,1164,624,113,6,8,34,3,0,0,1,0,0,0

10,40,Digestion Rate of NIAFSF,624,149,55,19,40,3,0,0,-1,0,0,0

1,41,43,36,4,0,0,22,0,0,0,-1--1--1,,1|(683,365)|

1,42,43,29,100,0,0,22,0,0,0,-1--1--1,,1|(600,365)|

11,43,252,638,365,6,8,34,3,0,0,1,0,0,0

10,44,Conversion Rate of IAFSF,638,392,62,19,40,3,0,0,-1,0,0,0

12,45,48,1003,359,10,8,0,3,0,0,-1,0,0,0

1,46,48,45,4,0,0,22,0,0,0,-1--1--1,,1|(957,359)|

1,47,48,36,100,0,0,22,0,0,0,-1--1--1,,1|(879,359)|

11,48,48,915,359,6,8,34,3,0,0,1,0,0,0

10,49,Natural Death Rate of IAFSF,915,386,55,19,40,3,0,0,-1,0,0,0

12,50,48,232,221,10,8,0,3,0,0,-1,0,0,0

1,51,53,50,4,0,0,22,0,0,0,-1--1--1,,1|(187,219)|

1,52,53,3,100,0,0,22,0,0,0,-1--1--1,,1|(111,219)|

11,53,48,147,219,6,8,34,3,0,0,1,0,0,0

10,54,Biting Rate of AFSF,147,246,64,19,40,3,0,0,-1,0,0,0

1,55,54,33,0,0,0,0,0,64,0,-1--1--1,,1|(246,309)|

12,56,48,506,529,10,8,0,3,0,0,-1,0,0,0

1,57,59,56,4,0,0,22,0,0,0,-1--1--1,,1|(497,490)|

1,58,59,29,100,0,0,22,0,0,0,-1--1--1,,1|(497,418)|

11,59,48,497,454,8,6,33,3,0,0,4,0,0,0

10,60,Death Rate of LAFSF,570,454,65,19,40,3,0,0,-1,0,0,0

12,61,48,479,-33,10,8,0,3,0,0,-1,0,0,0

1,62,64,61,4,0,0,22,0,0,0,-1--1--1,,1|(484,1)|

1,63,64,28,100,0,0,22,0,0,0,-1--1--1,,1|(484,65)|

11,64,48,484,33,8,6,33,3,0,0,4,0,0,0

10,65,Death Rate UAFSF,540,33,48,19,40,3,0,0,-1,0,0,0

12,66,48,785,532,10,8,0,3,0,0,-1,0,0,0

1,67,69,66,4,0,0,22,0,0,0,-1--1--1,,1|(785,492)|

1,68,69,36,100,0,0,22,0,0,0,-1--1--1,,1|(785,418)|

11,69,48,785,455,8,6,33,3,0,0,4,0,0,0

10,70,Death Rate of IAFSF,858,455,65,19,40,3,0,0,-1,0,0,0

12,71,48,764,-39,10,8,0,3,0,0,-1,0,0,0

1,72,74,71,4,0,0,22,0,0,0,-1--1--1,,1|(762,-6)|

1,73,74,35,100,0,0,22,0,0,0,-1--1--1,,1|(762,59)|

11,74,48,762,25,8,6,33,3,0,0,4,0,0,0

10,75,Death Rate of NIAFSF,835,25,65,19,40,3,0,0,-1,0,0,0

10,76,Number of Egg per Sand Fly,-112,-57,62,19,8,3,0,0,0,0,0,0

10,77,Egg Laying Rate of AFSF,-20,-22,72,19,8,3,0,0,0,0,0,0

1,78,76,8,1,0,0,0,0,64,0,-1--1--1,,1|(-104,-2)|

1,79,77,8,0,0,0,0,0,64,0,-1--1--1,,1|(-55,19)|

10,80,Egg Survival Fraction,-390,-6,40,19,8,3,0,0,0,0,0,0

10,81,Egg Discard Fraction,-341,-68,55,19,8,131,0,0,0,0,0,0

1,82,80,81,1,0,0,0,0,64,0,-1--1--1,,1|(-376,-35)|

10,83,OvipositionTime,-486,-13,52,11,8,3,0,0,0,0,0,0

10,84,Maturation Time,-61,377,52,11,8,3,0,0,0,0,0,0

1,85,84,17,1,0,0,0,0,64,0,-1--1--1,,1|(-32,344)|

1,86,2,17,1,0,0,0,0,64,0,-1--1--1,,1|(-181,254)|

1,87,2,22,0,0,0,0,0,64,0,-1--1--1,,1|(-210,262)|

10,88,Young Death Fraction per Day,-184,391,55,19,8,3,0,0,0,0,0,0

1,89,88,22,0,0,0,0,0,64,0,-1--1--1,,1|(-181,351)|

10,90,Young Survival Fraction,-70,325,49,19,8,3,0,0,0,0,0,0

1,91,90,17,0,0,0,0,0,64,0,-1--1--1,,1|(-90,285)|

10,92,Transmission Probability for Female Sand Fly per Bite,503,233,78,28,8,3,0,0,0,0,0,0

1,93,92,34,1,0,0,0,0,64,0,-1--1--1,,1|(459,255)|

10,94,Adult Death Fraction1,94,409,59,19,8,3,0,0,0,0,0,0

10,95,Adult Survival Fraction1,189,324,45,19,8,3,0,0,0,0,0,0

1,96,95,54,0,0,0,0,0,64,0,-1--1--1,,1|(171,291)|

1,97,95,94,1,0,0,0,0,64,0,-1--1--1,,1|(153,373)|

1,98,94,27,0,0,0,0,0,64,0,-1--1--1,,1|(91,364)|

1,99,3,27,1,0,0,0,0,64,0,-1--1--1,,1|(60,252)|

1,100,3,54,1,0,0,0,0,64,0,-1--1--1,,1|(103,192)|

10,101,Average Time Between Blood Meals,151,156,71,19,8,3,0,0,0,0,0,0

1,102,101,54,1,0,0,0,0,64,0,-1--1--1,,1|(146,187)|

10,103,IncubationTime of SFl,668,471,49,19,8,3,0,0,0,0,0,0

1,104,103,44,1,0,0,0,0,64,0,-1--1--1,,1|(655,441)|

1,105,29,44,1,0,0,0,0,64,0,-1--1--1,,1|(568,332)|

1,106,28,40,1,0,0,0,0,64,0,-1--1--1,,1|(554,83)|

10,107,Adult Survival Fraction2,734,497,45,19,8,3,0,0,0,0,0,0

1,108,107,44,0,0,0,0,0,64,0,-1--1--1,,1|(690,449)|

10,109,Adult Death Fraction2,591,532,59,19,8,3,0,0,0,0,0,0

1,110,109,60,0,0,0,0,0,64,0,-1--1--1,,1|(582,499)|

1,111,107,109,0,0,0,0,0,64,0,-1--1--1,,1|(676,510)|

1,112,29,60,1,0,0,0,0,64,0,-1--1--1,,1|(547,401)|

10,113,Adult Survival Fraction2,709,43,50,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

10,114,Adult Death Fraction2,588,-41,64,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

1,115,28,65,0,0,0,0,0,64,0,-1--1--1,,1|(507,77)|

1,116,114,65,0,0,0,0,0,64,0,-1--1--1,,1|(567,-9)|

1,117,113,40,0,0,0,0,0,64,0,-1--1--1,,1|(670,90)|

10,118,Adult Survival Fraction3,1063,473,45,19,8,3,0,0,0,0,0,0

10,119,Adult Death Fraction 3,862,541,59,19,8,3,0,0,0,0,0,0

1,120,119,70,0,0,0,0,0,64,0,-1--1--1,,1|(860,504)|

1,121,118,49,1,0,0,0,0,64,0,-1--1--1,,1|(1007,423)|

1,122,118,119,1,0,0,0,0,64,0,-1--1--1,,1|(974,517)|

1,123,36,49,1,0,0,0,0,64,0,-1--1--1,,1|(842,331)|

1,124,36,70,1,0,0,0,0,64,0,-1--1--1,,1|(822,400)|

10,125,Average Life Span,958,469,59,11,8,3,0,0,0,0,0,0

1,126,35,75,0,0,0,0,0,64,0,-1--1--1,,1|(799,71)|

10,127,Adult Survival Fraction3,992,47,50,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

12,128,48,1002,110,10,8,0,3,0,0,-1,0,0,0

1,129,131,128,4,0,0,22,0,0,0,-1--1--1,,1|(956,110)|

1,130,131,35,100,0,0,22,0,0,0,-1--1--1,,1|(873,110)|

11,131,48,915,110,6,8,34,3,0,0,1,0,0,0

10,132,Natural Death Rate of NIAFSF,915,137,55,19,40,3,0,0,-1,0,0,0

1,133,35,132,1,0,0,0,0,64,0,-1--1--1,,1|(842,83)|

1,134,127,132,0,0,0,0,0,64,0,-1--1--1,,1|(958,86)|

10,135,Digestion Rate of NIAFSF,-15,-110,59,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

10,136,Conversion Rate of IAFSF,102,-100,58,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

1,137,136,77,0,0,0,0,0,64,0,-1--1--1,,1|(46,-64)|

1,138,135,77,1,0,0,0,0,64,0,-1--1--1,,1|(-16,-48)|

1,139,80,13,0,0,0,0,0,64,0,-1--1--1,,1|(-378,26)|

1,140,1,13,1,0,0,0,0,64,0,-1--1--1,,1|(-303,9)|

12,141,48,-443,227,10,8,0,3,0,0,-1,0,0,0

1,142,144,2,4,0,0,22,0,0,0,-1--1--1,,1|(-326,227)|

1,143,144,141,100,0,0,22,0,0,0,-1--1--1,,1|(-402,227)|

11,144,48,-364,227,6,8,34,3,0,0,1,0,0,0

10,145,Sand Fly Production Rate,-364,246,52,19,40,3,0,0,-1,0,0,0

1,146,83,13,0,0,0,0,0,64,0,-1--1--1,,1|(-431,22)|

12,147,48,-253,-109,10,8,0,3,0,0,-1,0,0,0

1,148,150,147,4,0,0,22,0,0,0,-1--1--1,,1|(-259,-70)|

1,149,150,1,100,0,0,22,0,0,0,-1--1--1,,1|(-259,-2)|

11,150,48,-259,-34,8,6,33,3,0,0,4,0,0,0

10,151,Egg Discard Rate,-192,-34,59,11,40,3,0,0,-1,0,0,0

1,152,81,151,1,0,0,0,0,64,0,-1--1--1,,1|(-267,-42)|

1,153,1,151,1,0,0,0,0,64,0,-1--1--1,,1|(-219,3)|

10,154,Number of Sand Fly per Egg,-324,166,54,19,8,3,0,0,0,0,0,0

1,155,154,145,0,0,0,0,0,64,0,-1--1--1,,1|(-341,199)|

10,156,Initial Hatching Rate,-364,276,50,19,8,2,1,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

1,157,156,145,0,1,0,0,0,64,0,-1--1--1,,1|(-364,268)|

10,158,Initial Hatching Rate,-438,167,46,19,8,3,0,0,0,0,0,0

1,159,90,88,0,0,0,0,0,64,0,-1--1--1,,1|(-121,354)|

1,160,83,1,0,0,0,0,0,64,1,-1--1--1,,1|(-372,14)|

1,161,145,2,1,0,0,0,0,64,0,-1--1--1,,1|(-311,253)|

1,162,103,29,0,0,0,0,0,64,1,-1--1--1,,1|(594,423)|

1,163,125,36,0,0,0,0,0,64,1,-1--1--1,,1|(887,426)|

1,164,125,35,0,0,0,0,0,64,1,-1--1--1,,1|(870,303)|

1,165,83,84,1,0,0,0,0,64,0,-1--1--1,,1|(-242,457)|

10,166,Adult Death Fraction 3,886,-49,64,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

1,167,166,75,0,0,0,0,0,64,0,-1--1--1,,1|(864,-17)|

10,168,Density of Infectious Human Beings,385,258,70,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

10,169,Number of Bites per Sand Fly,273,268,67,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

1,170,169,33,0,0,0,0,0,64,0,-1--1--1,,1|(303,317)|

12,171,48,-236,101,10,8,0,3,0,0,-1,0,0,0

1,172,174,171,4,0,0,22,0,0,0,-1--1--1,,1|(-236,130)|

1,173,174,2,100,0,0,22,0,0,0,-1--1--1,,1|(-236,184)|

11,174,48,-236,157,8,6,33,3,0,0,4,0,0,0

10,175,Differrent in Sand Fly Production Rate,-183,157,68,19,40,3,0,0,-1,0,0,0

10,176,Diffrent,-360,117,25,11,8,3,0,0,0,0,0,0

1,177,13,176,0,0,0,0,0,64,0,-1--1--1,,1|(-362,84)|
1,178,158,176,0,0,0,0,0,64,0,-1--1--1,,1|(-400,141)|
1,179,154,176,0,0,0,0,0,64,0,-1--1--1,,1|(-341,142)|
1,180,176,175,0,0,0,0,0,64,0,-1--1--1,,1|(-300,129)|
1,181,158,144,0,0,0,0,0,64,0,-1--1--1,,1|(-398,200)|
10,182,Effect of Use of Spray on Fraction of Sand Flies Death,107,494,93,26,8,130,0,3,-
1,0,0,0,128-128-128,0-0-0,|12||128-128-128
1,183,182,94,0,0,0,0,0,64,0,-1--1--1,,1|(101,454)|
10,184,Effect of Use of Spray on Fraction of Sand Flies Death,1645,586,62,28,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|12||128-128-128
10,185,Effect of Use of Spray on Fraction of Sand Flies Death,877,623,62,28,8,2,0,3,-
1,0,0,0,128-128-128,0-0-0,|12||128-128-128
1,186,185,119,0,0,0,0,0,64,0,-1--1--1,,1|(869,584)|
1,187,83,151,1,0,0,0,0,64,0,-1--1--1,,1|(-411,-80)|
1,188,84,22,0,0,0,0,0,64,0,-1--1--1,,1|(-112,345)|
1,189,84,2,0,0,0,0,0,64,1,-1--1--1,,1|(-141,308)|
1,190,101,3,0,0,0,0,0,64,1,-1--1--1,,1|(93,184)|
10,191,Digestion Time of Sand Flies,648,5,56,19,8,3,0,0,0,0,0,0
1,192,191,40,0,0,0,0,0,64,0,-1--1--1,,1|(637,70)|
1,193,103,60,1,0,0,0,0,64,0,-1--1--1,,1|(623,484)|
1,194,101,27,0,0,0,0,0,64,0,-1--1--1,,1|(121,225)|
10,195,Average Life Span,916,57,46,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128
1,196,195,132,0,0,0,0,0,64,0,-1--1--1,,1|(915,90)|
1,197,125,70,1,0,0,0,0,64,0,-1--1--1,,1|(880,438)|
1,198,125,49,1,0,0,0,0,64,0,-1--1--1,,1|(945,434)|
1,199,191,65,1,0,0,0,0,64,0,-1--1--1,,1|(545,34)|
1,200,195,75,0,0,0,0,0,64,0,-1--1--1,,1|(883,44)|
1,202,49,201,0,0,0,0,0,64,0,-1--1--1,,1|(903,338)|
1,203,70,201,0,0,0,0,0,64,0,-1--1--1,,1|(871,373)|
1,214,44,213,0,0,0,0,0,64,0,-1--1--1,,1|(690,326)|
1,215,201,213,0,0,0,0,0,64,0,-1--1--1,,1|(811,262)|

1,216,168,33,0,0,0,0,0,64,0,-1--1--1,,1|(359,311)|

12,217,48,279,115,10,8,0,3,0,0,-1,0,0,0

1,218,220,28,4,0,0,22,0,0,0,-1--1--1,,1|(388,115)|

1,219,220,217,100,0,0,22,0,0,0,-1--1--1,,1|(318,115)|

11,220,48,353,115,6,8,34,3,0,0,1,0,0,0

10,221,"Non-Infectious Bite Rate of AFSF",353,142,63,19,40,3,0,0,-1,0,0,0

1,222,54,221,0,0,0,0,0,64,0,-1--1--1,,1|(243,197)|

1,223,169,221,0,0,0,0,0,64,0,-1--1--1,,1|(308,210)|

1,224,168,221,0,0,0,0,0,64,0,-1--1--1,,1|(370,206)|

1,225,92,221,0,0,0,0,0,64,0,-1--1--1,,1|(426,186)|

1,226,221,28,1,0,0,0,0,64,0,-1--1--1,,1|(461,140)|

1,227,103,28,0,0,0,0,0,64,1,-1--1--1,,1|(579,301)|

\\\---/// Sketch information - do not modify anything except names

V300 Do not put anything below this section - it will be ignored

*View 2

$192-192-192,0,Times New Roman|12||0-0-0|0-0-0|0-0-255|-1--1--1|-1--1--1|96,96,100,0

10,1,Susceptible Human Beings,-473,267,62,29,3,131,0,0,0,0,0,0

10,2,Latent Human Beings,-196,266,61,29,3,131,0,0,0,0,0,0

10,3,Infectious Human Beings with KA,89,267,61,29,3,131,0,0,0,0,0,0

10,4,Semi Recovered Human Beings,470,268,61,28,3,131,0,0,0,0,0,0

10,5,Infectious Human Beings with PKDL,765,269,61,28,3,131,0,0,0,0,0,0

12,6,48,-475,118,10,8,0,3,0,0,-1,0,0,0

1,7,9,6,4,0,0,22,0,0,0,-1--1--1,,1|(-475,151)|

1,8,9,1,100,0,0,22,0,0,0,-1--1--1,,1|(-475,213)|

11,9,48,-475,182,8,6,33,3,0,0,4,0,0,0

10,10,Natural Death Rate of SHB,-405,182,62,19,40,3,0,0,-1,0,0,0

12,11,48,-202,117,10,8,0,3,0,0,-1,0,0,0

1,12,14,11,4,0,0,22,0,0,0,-1--1--1,,1|(-202,150)|

1,13,14,2,100,0,0,22,0,0,0,-1--1--1,,1|(-202,212)|

11,14,48,-202,181,8,6,33,3,0,0,4,0,0,0

10,15,Natural Death Rate of LHB,-132,181,62,19,40,3,0,0,-1,0,0,0

12,16,48,84,112,10,8,0,3,0,0,-1,0,0,0

1,17,19,16,4,0,0,22,0,0,0,-1--1--1,,1|(84,146)|

1,18,19,3,100,0,0,22,0,0,0,-1--1--1,,1|(84,211)|

11,19,48,84,179,8,6,33,3,0,0,4,0,0,0

10,20,Natural Death Rate of IHB with KA,162,179,70,19,40,3,0,0,-1,0,0,0

12,21,48,461,107,10,8,0,3,0,0,-1,0,0,0

1,22,24,21,4,0,0,22,0,0,0,-1--1--1,,1|(461,143)|

1,23,24,4,100,0,0,22,0,0,0,-1--1--1,,1|(461,211)|

11,24,48,461,177,8,6,33,3,0,0,4,0,0,0

10,25,Natural Death Rate of SRHB,531,177,62,19,40,3,0,0,-1,0,0,0

12,26,48,760,104,10,8,0,3,0,0,-1,0,0,0

1,27,29,26,4,0,0,22,0,0,0,-1--1--1,,1|(760,141)|

1,28,29,5,100,0,0,22,0,0,0,-1--1--1,,1|(760,211)|

11,29,48,760,176,8,6,33,3,0,0,4,0,0,0

10,30,Natural Death Rate of IHB with PKDL,838,176,70,19,40,3,0,0,-1,0,0,0

1,31,33,2,4,0,0,22,0,0,0,-1--1--1,,1|(-293,266)|

1,32,33,1,100,0,0,22,0,0,0,-1--1--1,,1|(-376,266)|

11,33,2316,-334,266,6,8,34,3,0,0,1,0,0,0

10,34,Infection Rate of HB,-334,293,55,19,40,3,0,0,-1,0,0,0

1,35,37,3,4,0,0,22,0,0,0,-1--1--1,,1|(-10,266)|

1,36,37,2,100,0,0,22,0,0,0,-1--1--1,,1|(-98,266)|

11,37,2156,-54,266,6,8,34,3,0,0,1,0,0,0

10,38,Conversion Rate of HB,-54,293,54,19,40,3,0,0,-1,0,0,0

1,39,41,4,4,0,0,22,0,0,0,-1--1--1,,1|(338,272)|

1,40,41,3,100,0,0,22,0,0,0,-1--1--1,,1|(202,272)|

11,41,908,261,272,6,8,34,3,0,0,1,0,0,0

10,42,Recovery Rate From KA,261,299,48,19,40,3,0,0,-1,0,0,0

1,43,45,5,4,0,0,22,0,0,0,-1--1--1,,1|(660,268)|

1,44,45,4,100,0,0,22,0,0,0,-1--1--1,,1|(567,268)|

11,45,1020,610,268,6,8,34,3,0,0,1,0,0,0

10,46,PKDL Development Rate,610,295,59,19,40,3,0,0,-1,0,0,0

10,47,Death Due to KA Human Beings,88,458,60,28,3,131,0,0,0,0,0,0

1,48,50,47,4,0,0,22,0,0,0,-1--1--1,,1|(63,399)|

1,49,50,3,100,0,0,22,0,0,0,-1--1--1,,1|(63,326)|

11,50,2556,63,363,8,6,33,3,0,0,4,0,0,0

10,51,Death Due KA Rate of HB,120,363,57,19,40,3,0,0,-1,0,0,0

10,52,Fraction of Susceptible Human Beings,-480,365,75,25,8,131,0,0,0,0,0,0

1,53,1,52,0,0,0,0,0,64,0,-1--1--1,,1|(-476,311)|

1,54,52,34,0,0,0,0,0,64,0,-1--1--1,,1|(-408,329)|

10,55,Number of Infectious Bites per Day,-347,380,68,19,8,3,0,0,0,0,0,0

1,56,55,34,0,0,0,0,0,64,0,-1--1--1,,1|(-343,343)|

10,57,Infectious Adult Female Sand Flies,-300,507,64,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

1,58,57,55,0,0,0,0,0,64,0,-1--1--1,,1|(-322,450)|

10,59,Number of Bites per Sand Fly,-410,474,62,19,8,3,0,0,-1,0,0,0

1,60,59,55,0,0,0,0,0,64,0,-1--1--1,,1|(-383,432)|

10,61,Transmission Probability for Human Being per Bite,-203,386,81,19,8,3,0,0,0,0,0,0

1,62,61,34,0,0,0,0,0,64,0,-1--1--1,,1|(-263,343)|

10,63,Probability of Human Beings Exposed to Sand Fly Bite,-440,580,78,28,8,131,0,0,0,0,0,0

10,64,HDI,-457,777,16,11,8,3,0,0,0,0,0,0

10,65,Incubation Time of HB,-56,369,60,19,8,3,0,0,0,0,0,0

1,66,2,38,1,0,0,0,0,64,0,-1--1--1,,1|(-146,310)|

1,67,65,38,0,0,0,0,0,64,0,-1--1--1,,1|(-56,337)|

1,68,1,10,0,0,0,0,0,64,0,-1--1--1,,1|(-439,224)|

1,69,2,15,1,0,0,0,0,64,0,-1--1--1,,1|(-156,223)|

1,70,3,20,0,0,0,0,0,64,0,-1--1--1,,1|(125,223)|

1,71,4,25,0,0,0,0,0,64,0,-1--1--1,,1|(499,223)|

1,72,5,30,0,0,0,0,0,64,0,-1--1--1,,1|(800,223)|

1,73,3,42,1,0,0,0,0,64,0,-1--1--1,,1|(160,316)|

10,74,Fraction of Death Due KA of HB,-50,441,56,19,8,3,0,0,0,0,0,0

1,75,74,51,0,0,0,0,0,64,0,-1--1--1,,1|(28,404)|

1,76,3,51,0,0,0,0,0,64,0,-1--1--1,,1|(103,313)|

10,77,Average Time to Seek KA Treatment,353,393,72,19,8,3,0,0,0,0,0,0

10,78,Time to Recover From KA,403,354,54,19,8,3,0,0,0,0,0,0

1,79,78,42,0,0,0,0,0,64,0,-1--1--1,,1|(337,328)|

1,80,77,42,0,0,0,0,0,64,0,-1--1--1,,1|(311,350)|

10,81,Fraction of Infectious Human Beings Seeking KA Treatment,241,432,87,28,8,3,0,0,0,0,0,0

1,82,81,42,0,0,0,0,0,64,0,-1--1--1,,1|(250,367)|

1,83,4,46,1,0,0,0,0,64,0,-1--1--1,,1|(528,310)|

10,84,Fully Recovered Human Beings,613,524,61,28,3,131,0,0,0,0,0,0

1,85,87,84,4,0,0,22,0,0,0,-1--1--1,,1|(477,524)|

1,86,87,4,100,0,0,22,0,0,0,-1--1--1,,1|(477,344)|

11,87,2492,477,398,8,6,33,3,0,0,4,0,0,0

10,88,Full Recovery Rate,533,398,45,19,40,3,0,0,-1,0,0,0

1,89,91,84,4,0,0,22,0,0,0,-1--1--1,,1|(763,524)|

1,90,91,5,100,0,0,22,0,0,0,-1--1--1,,1|(763,348)|

11,91,2508,763,406,8,6,33,3,0,0,4,0,0,0

10,92,Recovery Rate From PKDL,819,406,48,19,40,3,0,0,-1,0,0,0

10,93,Average Time to Develop PKDl,698,356,54,19,8,3,0,0,0,0,0,0

10,94,Average Time to Fully Recover,564,473,54,19,8,3,0,0,0,0,0,0

10,95,Fraction of Semi Recovered Human Beings Dvlp PKDL,679,436,83,28,8,3,0,0,0,0,0,0

1,96,93,46,0,0,0,0,0,64,0,-1--1--1,,1|(659,329)|

1,97,95,46,1,0,0,0,0,64,0,-1--1--1,,1|(622,340)|

1,98,95,88,1,0,0,0,0,64,0,-1--1--1,,1|(578,403)|

1,99,94,88,0,0,0,0,0,64,0,-1--1--1,,1|(551,441)|

1,100,4,88,0,0,0,0,0,64,0,-1--1--1,,1|(499,331)|

12,101,48,989,267,10,8,0,3,0,0,-1,0,0,0

1,102,104,101,4,0,0,22,0,0,0,-1--1--1,,1|(943,268)|

1,103,104,5,100,0,0,22,0,0,0,-1--1--1,,1|(860,268)|

11,104,48,901,268,6,8,34,3,0,0,1,0,0,0

10,105,Death due PKDL Rate of HB,901,295,57,19,40,3,0,0,-1,0,0,0

10,106,Density of Infectious Human Beings,224,640,65,19,8,3,0,0,0,0,0,0

10,107,Effect of Density of Infectious Human Beings on Fraction of Infectious Human Beings Seeking KA Treatment,236,544,121,28,8,3,0,0,0,0,0,0
1,108,106,107,0,0,0,0,0,64,0,-1--1--1,,1|(228,603)|
1,109,107,81,0,0,0,0,0,64,0,-1--1--1,,1|(237,494)|
10,110,Total Number of Human Beings at Risk,-576,437,70,19,8,3,0,0,0,0,0,0
1,111,110,52,0,0,0,0,0,64,0,-1--1--1,,1|(-537,408)|
10,112,Infectious Human Beings with KA,235,828,60,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128
10,113,Infectious Human Beings with PKDL,360,814,65,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128
10,114,Total Number of Human Beings at Risk,156,739,75,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128
10,115,Total Number of Infectious Human Beings,302,727,79,19,8,3,0,0,0,0,0,0
1,116,112,115,0,0,0,0,0,64,0,-1--1--1,,1|(264,783)|
1,117,113,115,0,0,0,0,0,64,0,-1--1--1,,1|(334,776)|
1,118,114,106,0,0,0,0,0,64,0,-1--1--1,,1|(185,695)|
1,119,115,106,0,0,0,0,0,64,0,-1--1--1,,1|(267,688)|
10,120,Time to Recover From PKDL,909,492,54,19,8,3,0,0,0,0,0,0
10,121,Average Time to Seek PKDL Treatment,1001,426,72,19,8,3,0,0,0,0,0,0
10,122,Fraction of Human Beings Seeking PKDL Treatment,976,342,83,19,8,3,0,0,0,0,0,0
1,123,5,92,1,0,0,0,0,64,0,-1--1--1,,1|(798,327)|
1,124,122,92,0,0,0,0,0,64,0,-1--1--1,,1|(903,371)|
1,125,121,92,0,0,0,0,0,64,0,-1--1--1,,1|(904,415)|
1,126,120,92,0,0,0,0,0,64,0,-1--1--1,,1|(869,453)|
10,127,Fraction of Death Due PKDL,948,214,56,19,8,3,0,0,0,0,0,0
1,128,127,105,0,0,0,0,0,64,0,-1--1--1,,1|(928,248)|
1,129,5,105,1,0,0,0,0,64,0,-1--1--1,,1|(820,312)|
1,130,47,1,0,0,0,0,0,64,1,-1--1--1,,1|(-185,365)|
1,131,84,1,0,0,0,0,0,64,1,-1--1--1,,1|(77,397)|
1,132,3,1,0,0,0,0,0,64,1,-1--1--1,,1|(-185,267)|
1,133,5,1,0,0,0,0,0,64,1,-1--1--1,,1|(153,268)|

1,134,2,1,0,0,0,0,0,64,1,-1--1--1,,1|(-327,266)|
1,135,4,1,0,0,0,0,0,64,1,-1--1--1,,1|(5,267)|
10,136,Total Number of Poor Human Beings,-640,369,71,19,8,3,0,0,-1,0,0,0
1,137,136,1,0,0,0,0,0,64,1,-1--1--1,,1|(-570,326)|
1,138,110,136,0,0,0,0,0,64,0,-1--1--1,,1|(-602,408)|
10,139,Fraction of Death of Human Being,-349,110,65,19,8,3,0,0,0,0,0,0
1,140,139,10,0,0,0,0,0,64,0,-1--1--1,,1|(-373,140)|
10,141,Fraction of Death of Human Being,-90,101,69,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128
10,142,Fraction of Death of Human Being,194,89,69,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128
10,143,Fraction of Death of Human Being,576,102,69,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128
10,144,Fraction of Death of Human Being,883,98,69,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128
1,145,144,30,0,0,0,0,0,64,0,-1--1--1,,1|(864,131)|
1,146,143,25,0,0,0,0,0,64,0,-1--1--1,,1|(557,133)|
1,147,142,20,0,0,0,0,0,64,0,-1--1--1,,1|(180,127)|
1,148,141,15,0,0,0,0,0,64,0,-1--1--1,,1|(-108,134)|
12,149,48,609,696,10,8,0,3,0,0,-1,0,0,0
1,150,152,149,4,0,0,22,0,0,0,-1--1--1,,1|(609,657)|
1,151,152,84,100,0,0,22,0,0,0,-1--1--1,,1|(609,583)|
11,152,48,609,620,8,6,33,3,0,0,4,0,0,0
10,153,Natural Death Rate of FRHB,679,620,62,19,40,3,0,0,-1,0,0,0
10,154,Fraction of Death of Human Being,711,705,69,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128
1,155,154,153,0,0,0,0,0,64,0,-1--1--1,,1|(697,669)|
1,156,84,153,1,0,0,0,0,64,0,-1--1--1,,1|(652,565)|
10,157,Average Time Between Blood Meals,-213,465,76,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128
1,158,157,55,0,0,0,0,0,64,0,-1--1--1,,1|(-275,426)|

1,159,63,59,0,0,0,0,0,64,0,-1--1--1,,1|(-426,529)|
10,160,Effect of HDI on Probability of Human Exposed to Sand Fly Bite,-442,667,90,28,8,3,0,0,0,0,0,0
1,161,64,160,0,0,0,0,0,64,0,-1--1--1,,1|(-451,737)|
1,162,160,63,0,0,0,0,0,64,0,-1--1--1,,1|(-441,630)|
10,163,Reference of Probability of Human Beings Exposed to Sand Fly Bite,-649,586,85,28,8,3,0,0,0,0,0,0
1,164,163,63,0,0,0,0,0,64,0,-1--1--1,,1|(-547,583)|
10,165,Effect of Being Covered by Net on Bite,-440,627,60,19,8,2,1,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128
10,166,Effectiveness of Being Covered by Net on Bite,-661,678,93,27,8,130,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128
1,167,166,63,0,0,0,0,0,64,0,-1--1--1,,1|(-558,632)|
10,168,Effect of Education on Average Time to seek Treament,1070,497,78,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128
10,169,Effect of Education on Average Time to seek Treament,373,497,78,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128
1,170,169,77,0,0,0,0,0,64,0,-1--1--1,,1|(364,451)|
1,171,168,121,0,0,0,0,0,64,0,-1--1--1,,1|(1040,466)|
10,172,Effect of Eductionon on Fraction of Human Beings Seeking Treament,1204,352,83,28,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128
1,173,172,122,0,0,0,0,0,64,0,-1--1--1,,1|(1096,347)|
10,174,Effect of Eductionon on Fraction of Human Beings Seeking Treament,426,592,83,28,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128
1,175,174,81,0,0,0,0,0,64,0,-1--1--1,,1|(338,516)|
10,176,Time,-318,819,26,11,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128
1,177,176,64,0,0,0,0,0,64,0,-1--1--1,,1|(-386,798)|
10,178,"Re.Average Time to Seek PKDL Treatment",1198,442,74,19,8,3,0,0,0,0,0,0
1,179,178,121,0,0,0,0,0,64,0,-1--1--1,,1|(1105,434)|
10,180,"R.Average Time to Seek KA Treatment",429,462,65,19,8,3,0,0,0,0,0,0
1,181,180,77,0,0,0,0,0,64,0,-1--1--1,,1|(396,432)|

10,189,"Ref. Number of Bites per Sand Fly",-582,496,68,19,8,3,0,0,0,0,0,0

1,190,189,59,0,0,0,0,0,64,0,-1--1--1,,1|(-499,485)|

1,196,30,195,1,0,0,0,0,64,0,-1--1--1,,1|(899,143)|

1,197,105,195,0,0,0,0,0,64,0,-1--1--1,,1|(935,222)|

1,198,92,195,0,0,0,0,0,64,0,-1--1--1,,1|(893,278)|

\\\---/// Sketch information - do not modify anything except names

V300 Do not put anything below this section - it will be ignored

*View 3

$192-192-192,0,Times New Roman|12||0-0-0|0-0-0|0-0-255|-1--1--1|-1--1--1|96,96,100,0

10,1,Educated Families,724,103,40,20,3,3,0,0,0,0,0,0

12,2,48,460,112,10,8,0,3,0,0,-1,0,0,0

1,3,5,1,4,0,0,22,0,0,0,-1--1--1,,1|(633,112)|

1,4,5,2,100,0,0,22,0,0,0,-1--1--1,,1|(520,112)|

11,5,48,577,112,6,8,34,3,0,0,1,0,0,0

10,6,Education Rate,577,131,48,11,40,3,0,0,-1,0,0,0

12,7,48,977,108,10,8,0,3,0,0,-1,0,0,0

1,8,10,7,4,0,0,22,0,0,0,-1--1--1,,1|(919,108)|

1,9,10,1,100,0,0,22,0,0,0,-1--1--1,,1|(811,108)|

11,10,48,865,108,6,8,34,3,0,0,1,0,0,0

10,11,Forgetting Rate,865,127,49,11,40,3,0,0,-1,0,0,0

10,12,Desired Number of Household Education,440,257,68,19,8,131,0,0,-1,0,0,0

10,13,Education INTERVENTION END TIME,640,48,61,28,8,3,0,0,-1,0,0,0

1,14,13,6,0,0,0,0,0,64,0,-1--1--1,,1|(606,91)|

10,15,Education INTERVENTION START TIME,498,47,61,28,8,3,0,0,-1,0,0,0

1,16,15,6,0,0,0,0,0,64,0,-1--1--1,,1|(540,92)|

10,17,Time,412,84,26,11,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

1,18,17,6,0,0,0,0,0,64,0,-1--1--1,,1|(480,103)|

1,19,1,11,1,0,0,0,0,64,0,-1--1--1,,1|(773,90)|

10,20,Time to Froget Education,955,184,48,19,8,3,0,0,-1,0,0,0

1,21,20,11,0,0,0,0,0,64,0,-1--1--1,,1|(909,155)|

10,22,Number of Educated Human Beings,572,296,67,19,8,3,0,0,0,0,0,0

10,23,Average Number of Persons per Family,760,195,82,19,8,3,0,0,-1,0,0,0

1,24,23,22,0,0,0,0,0,64,0,-1--1--1,,1|(672,242)|

1,25,1,22,0,0,0,0,0,64,0,-1--1--1,,1|(651,194)|

10,26,Proportion of Families Educated,965,259,58,19,8,3,0,0,0,0,0,0

1,27,1,26,1,0,0,0,0,64,0,-1--1--1,,1|(849,177)|

10,28,Total Number of Families,790,286,54,19,8,3,0,0,-1,0,0,0

1,29,28,26,0,0,0,0,0,64,0,-1--1--1,,1|(868,273)|

1,30,23,28,0,0,0,0,0,64,0,-1--1--1,,1|(772,233)|

10,31,Tolal Population at Risk,1615,-3,57,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

10,32,Desired Number of Net,510,406,54,19,8,3,0,0,0,0,0,0

10,33,Desired Number of Net per Person,342,413,76,19,8,3,0,0,-1,0,0,0

1,34,33,32,0,0,0,0,0,64,0,-1--1--1,,1|(430,409)|

1,35,22,32,0,0,0,0,0,64,0,-1--1--1,,1|(544,344)|

10,36,Effect of Family Education on Policy Effectiveness,1196,349,64,28,8,3,0,0,0,0,0,0

10,37,Education Coverage Necessary to Achieve Maximum Effectiveness,1437,351,75,28,8,3,0,0,-1,0,0,0

1,38,37,36,0,0,0,0,0,64,0,-1--1--1,,1|(1317,350)|

10,39,Maximum Policy Effectiveness,1211,255,54,19,8,3,0,0,-1,0,0,0

1,40,39,36,0,0,0,0,0,64,0,-1--1--1,,1|(1205,290)|

10,41,Minimum Policy Effectiveness,1333,267,52,19,8,3,0,0,-1,0,0,0

1,42,41,36,0,0,0,0,0,64,0,-1--1--1,,1|(1278,299)|

1,43,26,36,1,0,0,0,0,64,0,-1--1--1,,1|(1061,302)|

10,44,Net,551,501,40,20,3,3,0,0,0,0,0,0

12,45,48,306,504,10,8,0,3,0,0,-1,0,0,0

1,46,48,44,4,0,0,22,0,0,0,-1--1--1,,1|(465,504)|

1,47,48,45,100,0,0,22,0,0,0,-1--1--1,,1|(361,504)|

11,48,48,413,504,6,8,34,3,0,0,1,0,0,0

10,49,Net Purchasing Rate,413,531,49,19,40,131,0,0,-1,0,0,0

12,50,48,754,508,10,8,0,3,0,0,-1,0,0,0

1,51,53,50,4,0,0,22,0,0,0,-1--1--1,,1|(706,503)|

1,52,53,44,100,0,0,22,0,0,0,-1--1--1,,1|(623,503)|

11,53,48,662,503,6,8,34,3,0,0,1,0,0,0

10,54,Net Deterioration Rate,662,530,56,19,40,3,0,0,-1,0,0,0

10,55,Average Time to Buy Net,269,555,54,19,8,3,0,0,-1,0,0,0

1,56,55,49,0,0,0,0,0,64,0,-1--1--1,,1|(336,543)|

1,57,32,49,1,0,0,0,0,64,0,-1--1--1,,1|(465,463)|

10,58,Effect of Family Education on Policy Effectiveness,211,482,64,28,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

1,59,58,49,1,0,0,0,0,64,0,-1--1--1,,1|(326,480)|

10,60,Average Time Life of Net,705,605,59,19,8,3,0,0,-1,0,0,0

1,61,60,54,0,0,0,0,0,64,0,-1--1--1,,1|(687,573)|

1,62,44,54,1,0,0,0,0,64,0,-1--1--1,,1|(591,537)|

10,63,Total Number of Human Beings Covered by Net,529,620,78,19,8,3,0,0,0,0,0,0

1,64,44,63,1,0,0,0,0,64,0,-1--1--1,,1|(538,559)|

10,65,Number of Human Beings Cover by Net,340,620,68,19,8,3,0,0,-1,0,0,0

1,66,65,63,0,0,0,0,0,64,0,-1--1--1,,1|(422,620)|

10,67,Proportion of Human Beings Covered by Net,518,717,75,19,8,3,0,0,0,0,0,0

1,68,63,67,0,0,0,0,0,64,0,-1--1--1,,1|(524,661)|

10,69,Tolal Population at Risk,2047,27,57,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

10,70,Effectiveness of Being Covered by Net on Bite,938,725,101,28,8,131,0,0,0,0,0,0

10,71,Optimal Proportional Reduction in Bites when Covered by Net,872,630,73,28,8,3,0,0,-1,0,0,0

1,72,71,70,0,0,0,0,0,64,0,-1--1--1,,1|(900,671)|

10,73,Total Number Of Poor Population,653,337,60,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

1,74,73,28,0,0,0,0,0,64,0,-1--1--1,,1|(714,313)|

10,75,Total Number Of Poor Population,362,721,60,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

1,76,75,67,0,0,0,0,0,64,0,-1--1--1,,1|(425,719)|

10,77,Effect of Being Covered by Net on Bite,721,717,77,19,8,3,0,0,0,0,0,0

1,78,67,77,0,0,0,0,0,64,0,-1--1--1,,1|(611,717)|
10,79,Effect of Education on Average Time to seek Treament,837,395,71,28,8,131,0,0,0,0,0,0
10,80,Effect of Eductionon on Fraction of Human Beings Seeking
Treament,1016,430,83,28,8,3,0,0,0,0,0,0
10,81,Households Using Spray,1644,520,48,25,3,131,0,0,0,0,0,0
12,82,48,1377,513,10,8,0,3,0,0,-1,0,0,0
1,83,85,81,4,0,0,22,0,0,0,-1--1--1,,1|(1546,513)|
1,84,85,82,100,0,0,22,0,0,0,-1--1--1,,1|(1436,513)|
11,85,48,1491,513,6,8,34,3,0,0,1,0,0,0
10,86,Buying Spray Rate,1491,539,59,11,40,131,0,0,-1,0,0,0
10,87,Desired Number of Households Buying Spray,1484,416,82,19,8,131,0,0,0,0,0,0
10,88,Educated Families,1663,416,35,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128
1,89,88,87,0,0,0,0,0,64,0,-1--1--1,,1|(1604,416)|
1,90,36,86,1,0,0,0,0,64,0,-1--1--1,,1|(1341,456)|
1,91,87,86,1,0,0,0,0,64,0,-1--1--1,,1|(1492,472)|
12,92,48,1903,498,10,8,0,3,0,0,-1,0,0,0
1,93,95,92,4,0,0,22,0,0,0,-1--1--1,,1|(1841,500)|
1,94,95,81,100,0,0,22,0,0,0,-1--1--1,,1|(1735,500)|
11,95,48,1784,500,6,8,34,3,0,0,1,0,0,0
10,96,Losing Effectiveness of Spraying Rate,1784,527,76,19,40,3,0,0,-1,0,0,0
10,97,Average Duration of spraying effectiveness,1822,630,69,19,8,3,0,0,0,0,0,0
10,98,Average Time to Buy,1435,612,54,19,8,3,0,0,0,0,0,0
1,99,98,86,0,0,0,0,0,64,0,-1--1--1,,1|(1461,577)|
1,100,97,96,0,0,0,0,0,64,0,-1--1--1,,1|(1805,585)|
1,101,81,96,1,0,0,0,0,64,0,-1--1--1,,1|(1707,558)|
10,102,Effect of Use of Spray on Fraction of Sand Flies Death,1696,724,91,19,8,3,0,0,0,0,0,0
10,103,Proportion of Households Sprayed,1651,632,67,19,8,3,0,0,0,0,0,0
1,104,81,103,0,0,0,0,0,64,0,-1--1--1,,1|(1646,572)|
10,105,Total Number of Families,1476,692,58,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128
1,106,103,102,0,0,0,0,0,64,0,-1--1--1,,1|(1669,671)|

10,107,Effect of Density of Infectious Human Beings on Dersired Households Educate per Day,297,336,94,28,8,3,0,0,0,0,0,0

10,108,Density of Infectious Human Beings,168,418,70,19,8,130,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

1,109,108,107,0,0,0,0,0,64,0,-1--1--1,,1|(218,385)|

1,110,107,12,0,0,0,0,0,64,0,-1--1--1,,1|(369,295)|

1,111,26,79,0,0,0,0,0,64,0,-1--1--1,,1|(910,317)|

1,112,26,80,0,0,0,0,0,64,0,-1--1--1,,1|(986,333)|

1,113,105,103,0,0,0,0,0,64,0,-1--1--1,,1|(1556,664)|

1,114,36,80,0,0,0,0,0,64,0,-1--1--1,,1|(1112,386)|

10,115,"Re. of Desired Households Education",223,262,72,19,8,3,0,0,0,0,0,0

1,116,115,12,0,0,0,0,0,64,0,-1--1--1,,1|(326,259)|

1,117,44,49,1,0,0,0,0,64,0,-1--1--1,,1|(495,537)|

10,118,Number of Household Education,537,192,68,19,8,3,0,0,0,0,0,0

1,119,1,118,1,0,0,0,0,64,0,-1--1--1,,1|(649,159)|

1,120,12,118,0,0,0,0,0,64,0,-1--1--1,,1|(482,228)|

1,121,118,6,0,0,0,0,0,64,0,-1--1--1,,1|(555,163)|

10,122,Average Time to Lunch Education Program,385,175,75,19,8,3,0,0,0,0,0,0

1,123,122,6,0,0,0,0,0,64,0,-1--1--1,,1|(487,151)|

1,124,81,86,1,0,0,0,0,64,0,-1--1--1,,1|(1561,564)|

1,125,77,70,0,0,0,0,0,64,0,-1--1--1,,1|(810,719)|

10,126,Effect of Family Education on Policy Effectiveness,648,393,64,28,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

1,127,126,79,0,0,0,0,0,64,0,-1--1--1,,1|(732,393)|

\\\---/// Sketch information - do not modify anything except names

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*View 4

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