Research Article GU J Sci 32(2): 595-606 (2019)

Gazi University

Journal of Science

http://dergipark.gov.tr/gujs

Reducing the Impact of Cutaneous Leishmaniasis Disease by Domestic Animals and Tilapia Fish: A System Dynamics Model

Seyma KURT[1], Saadettin Erhan KESEN[1,*]

[1]*Konya Technical University, Faculty of Engineering and Natural Sciences, Industrial Engineering Department, Selçuklu, KONYA*

Article Info

Received: 24/12/2018
Accepted: 14/012019

Keywords

Leishmaniasis
Sandflies
Tilapia
System dynamics
Zooprophylaxis

Abstract

The purpose of this paper is to seek ways in reducing incidence of vector borne disease called leishmaniasis on humans. Frequently encountered in East Mediterranean and Southeastern Anatolian region of Turkey due to risk factors including poverty, malnutrition, lack of sanitation and defrostration, leishmaniasis disease is transmitted by sandflies' (vector) bites to humans. In addition to the zooprophylaxis effect in which domestic animals acting as dead-end hosts are used to alleviate the incidence on humans, we also incorporate the Tilapia fish population into the model to observe its effect in terms of relieving the vector bites on humans. We elaborate dynamic behavior and feedback loop structure of the system under study with three blood meal hosts: rodents, humans, and domestic animals. Proposed model is simulated throughout a period of 1000 days. We conduct sensitivity analysis by changing the rates of vector biting and the number of larvae eaten by Tilapia fish which influence the transmission of the disease. Results indicate that basic reproductive number R_0 and its prevalence in humans decreases as the size of domestic animal and the sandflies larvae eaten by Tilapia fish increases.

1. INTRODUCTION

Leishmaniasis is a certain type of disease induced by parasites of the Leishmania. The disease is transmitted after female sandfly bites humans [1]. The three main ways that the disease can present are cutaneous, mucocutaneous, and visceral. Although the form of cutaneous exists with skin ulcer, mucocutaneous form can more seriously damage human body with ulcers in the mouth, skin or nose. Visceral type also begins with skin ulcer but then fever, lower red blood cell, enlargement in liver and spleen may be detected. Among the three common types of the disease, cutaneous form is the most common [2].

As of 2017, 12 to 15 million people are estimated to get infected with the disease in 98 countries with all around the continents including South and Central America, Africa, Asia, and partly in Southern Europe and 350 million people are under risk according to report of World Health Organization (WHO). Leishmaniasis disease is recognized as a serious health problem as it damages the human skin seriously which lasts about one year in the case that no medication is taken. Southern part of Turkey is also threatened by the disease as over 3 million Syrian refugees migrated to Turkey due to instability in Middle East and they carry a number of diseases involving leishmaniasis [3].

An animal reservoir (rodent) transmits the disease to sandflies [4,5]. Once an infected female sandfly (also known as Phlebotomine) injects the parasites a host rodent its life cycle begins. Parasites are collected by any other sandfly through blood meal. Parasites change their forms in the sandfly body and are transferred to a new host, and life span goes on. Infection in a human exists while a female sandfly carrying the parasites has taken a blood meal from his/her body [6]. Although there are instances in which humans are of a reservoir host, these are seen very rare. Up to now, there exists no preventive effective medical treatment

*Corresponding author, e-mail: sekesen@ktun.edu.tr

or vaccine against leishmaniasis. Treatments techniques are limited to using nets with insecticides over windows and doors or insect repellents. Therefore, it is crucial to reduce bite incidence on humans by which controlling, capturing or diverting the vectors carrying the disease. Reduction of vector bites on humans in a fashion that animals are used as dead-end hosts is called zooprophylaxis. The literature abounds with field studies which consider the zooprophylaxis effect on variety of vector related diseases [7-12]. Because of the rise in the domestic animal size, blood meal providers also increase and this leads to an increase in the number and recovery rate of the sandflies and negatively impacts the number of human bites. Other way to divert vector bites from humans is the use of Tilapia fish. Tilapia fish is farmed in special pools in order to alleviate the damage to fruit orchards and humans caused by sandflies in the places where sandflies are present [13]. They are purposefully farmed to control sandflies which carry leishmaniasis parasites as they consume sandflies' larvae.

Literature is mainly divided into types to understand the behavior and spread of the contagious diseases: mathematical models and simulation models. Mathematical models are powerful since they can provide important insights in predicting, controlling and particularly eliminating such diseases. Researchers have paid a great deal of attention to develop mathematical models involving deterministic and stochastic ones. Readers are referred to the works of [14-18] for further details.

[18] develops a susceptible-infectious-susceptible model describing the spreading dynamics of leishmaniasis. Their model considers a vector population and a variety of populations of different mammals. They establish the system's equilibrium conditions and basic reproduction number. [17] introduces a mathematical model considering the seasonality of the vector population and the splitting of the latent term from infection to symptoms on humans. They also show a generic definition of the basic reproductive number R_0. [16] develops a model regarding the dynamics of transmission of American Cutaneous Leishmaniasis (ACL) including a population of accidental hosts for parasites throughout the species which are reservoir hosts. [19] presents a mathematical model of cutaneous leishmainasis transmission estimating the disease incidence relied upon real data.

The majority of the above mentioned studies regarding leishmaniasis take the interaction among people, sandflies and rodents (i.e., reservoir) by assuming that humans are able to act the role of disease host. However, in fact, humans are accidental hosts, sandflies become the vector and the rodents are thought the main reservoir of the disease. None of the earlier studies integrates the feedback loop effect of the blood meal rise on improving the survival rates of the sandflies. To the best of our knowledge, the use of Tilapia to mitigate the bites on humans has not been treated so far. Thus, it is necessary to consider all the five groups including sandflies, humans, rodents, domestic animals and Tilapia for more precise and accurate predictive model.

The collaborative effects of zooprophylaxis and Tilapia are evaluated by system dynamics (SD) approach. In contrast to conventional mathematical model which is a collection of first or higher order of algebraic and differential equations as well as initial values of the instance, Firstly proposed by Jay W. Forrester in 1958, SD is increasingly popular approach which enables us to understand and model the behavior of the complex systems over time [20,21]. In fact, SD allows modelers to simplify complicated tasks, whereby integrating real data by differential and algebraic equations. SD modeling is a straightforward and scientific method which helps to map the feedback structure of the key variables. This paper, for what we believe to be the first time, studies the cumulative effects of usage of domestic animals (e.g., goat, lamb, hare) as dead-end hosts and use of Tilapia to mitigate the transmission of leishmaniasis on humans.

2. METHODS AND SIMULATION

Creation of dynamic modeling of a system along with its processes is rather intuitive and in pursuit of a order of thoughts and actions which might be applied for any other system and process. SD model starts with mapping the interconnection between key variables and then constructing causal loop diagrams. Following the description of casual loop diagram, every model is elaborated by defining stock and flow variables with auxiliary variables to understand the behavior of the system considered under the conditions which is preset. Please see Figure 1.

3. EPIDEMIC MODEL

The introduced model is deterministic (i.e., all parameter values are known beforehand) with continuous and fixed time advance. Our SD analysis is a graphical representation of interactions of five subsystems which intervene in infection of CL, namely, humans (incidental hosts), sandflies (or vector), rodents (or main reservoir), domestic animals (i.e., dead-end-host) and Tilapias.

In order to be able to run the SD model, we need to make a number of assumptions. For each group considered, assumptions are properly defined as follows:

3.1. Human Population

We divide human population in two subsystems depending on infection condition: (i) the Susceptible Humans are the ones who are susceptible to the disease (neither infected nor immune), the recovered humans are also added to this subsystem, and (ii) the Infected Humans get infected by the disease after an infected sandfly bites and transmit the parasites to a member of this subset.

During the simulation period, birth and death rates of humans are assumed to be fixed, unequal, and comparable. They do not die due to the infection. After a specific period of time, they recover and become susceptible to the disease again. Although they may get infected from the sandflies, they cannot transmit the disease to the sandflies.

3.2. Sandfly Population

The population of sandfly is also categorized in two subsystems: (i) the *Susceptible Sandflies* who are susceptible to the disease (neither infected nor immune), the recovered sandflies are again added to this subsystem, and (ii) the *Infected Sandflies* are those get infected after biting an infected rodent.

Sandflies can bite rodents, domestic animals, and humans at different rates but these are kept fixed during follow-up period [22]. *Bite R*, *Bite A*, *Bite H* and correspond to these rates, respectively. For sensitivity analysis purposes, the values of these rates vary to interpret model outputs.

Since a female sandfly needs to breed with blood once in a week (or 7 days) and after it is breed by on any of the blood meal supplier, it does not be in search of feed again from another during a week, leading to the Eq. (1).

$$Bite\ A + Bite\ H + Bite\ R = \frac{1}{7} \tag{1}$$

Sandflies are assumed to recover providing that they discharge the parasites totally to get susceptible again. Rate of recovery is therefore set to 1/7.

Sandflies' birth rate is higher than their death rate by intrinsic growth rate denoted by rm ($rm = Sandfly\ Birth\ Rate - Sandfly\ Death\ Rate$) [23]. They do not die due to the disease. Dynamic population behavior enables them to infect rodents and humans. Indeed, Sandfly Birth Rate relies upon the feeding success of the female sandfly [24]. Their whole life cycle vary 3 to 10 weeks subject to the species, environmental factors, and temperature as well [25].

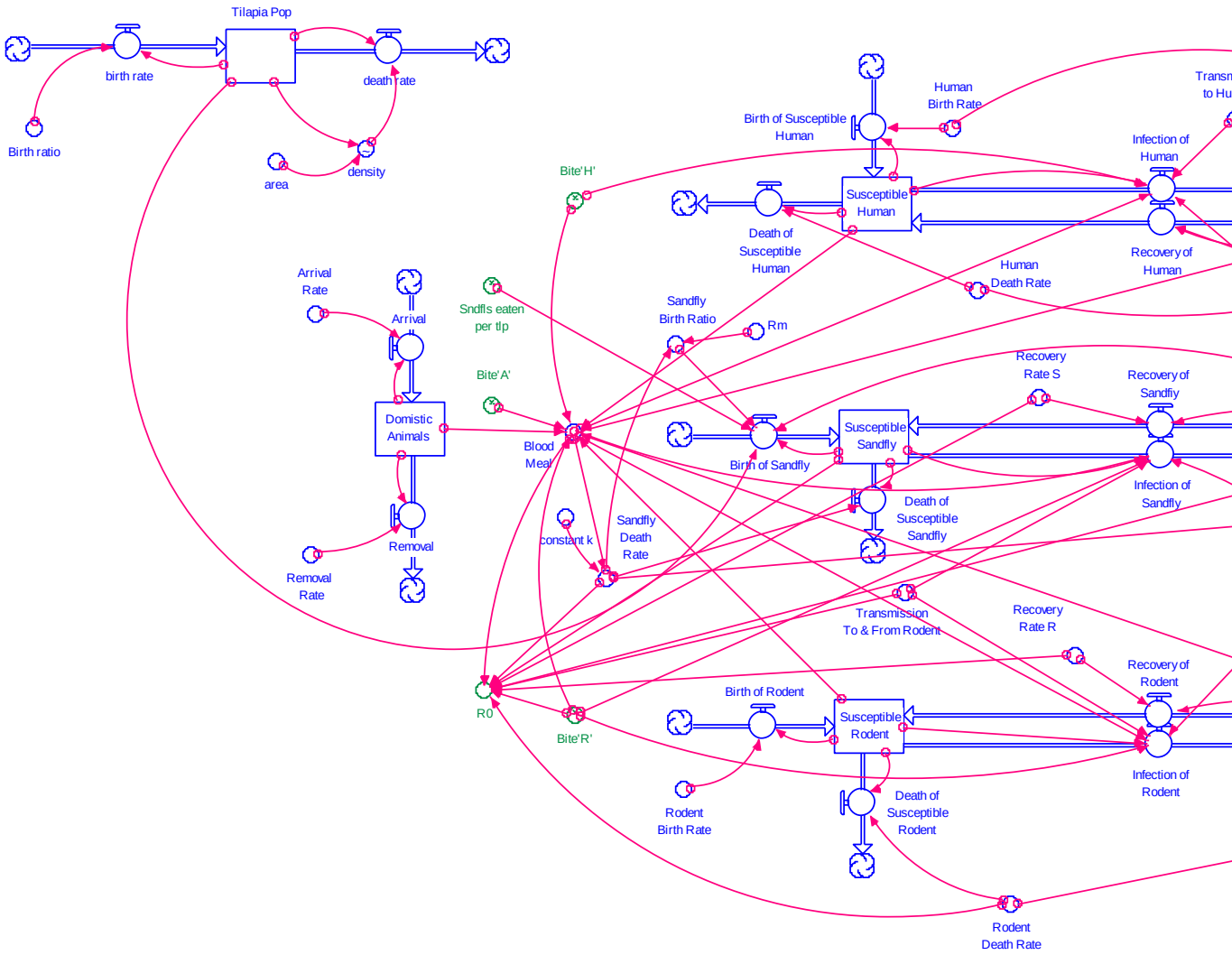

Figure 1. *Mapping of the system dynamics model of CL, using iThink building blocks*

3.3. Rodent Population

The availability of rodents (rats) in Middle East and North Africa is a major concern and is of healthcare issue in that these species can protect humans from the leishmaniasis by harboring parasites. As is the case human and sandfly population, rodent population consists of two compartments: (i) the *Susceptible Rodents* that are susceptible to leishmaniasis disease, recovered rodents are also added to this category and (ii) the *Infected Rodents* that get infected by the infected sandfly's bite, they can transmit the parasites to susceptible sandflies again.

The average life time of a rodent is approximately 14 months (14x30 days). They are bitten by sandflies at a constant rate. Their death and birth rates are closer to each other and comparable (readers are referred to Table 1). They can recover from the disease to be susceptible again. They may be infected from the sandflies or do infect them. The disease does not kill them.

3.4. Domestic Animal Population

Unlike the other three population types, domestic animal population is a single compartment with entities which can never be infected from the bites of sandflies nor do infect sandflies. They are bitten by sandflies at constant rate. The size of population is kept intact during the follow-up period. The population size can be changed by tuning the removal and arrival rates that also include the death and birth rates accordingly (readers are referred to Figure 1).

3.5. Tilapia Population

Tilapia population is different from other subsystems in that they do not have any effect in transmission of the disease. They eat sandflies' larvae to curb their reproduction rate. As they are farmed in a special pools close to sandfly swarm. Their birth rate is constant but death rate is dependent upon the amount of food in the pool. Birth rate is higher than death rate at the beginning but death rate increases as a result of increase in the size of population due to the carrying capacity of the environment. At some point in time, the size of Tilapia population reaches its equilibrium. In this model, three types of blood meals, involving domestic animals, humans, and rodents are utilized. The amount of blood meal is calculated as in Eq. (2).

$$Blood\ Meal = A \times (Bite\ A) + H \times (Bite\ H) + R \times (Bite\ R) \quad (2)$$

where A, H, and R stand for total population sizes of domestic animals, humans, and rodents respectively.

Table 1. *Values of model parameters*

Parameters	Parameter Values	Reference(s)
Infection probability to and from rodents	0.25	[18]
Infection probability to human	0.3	[18]
Birth rate of sandfly	Rm + death rate of sandfly	See above
Recovery rate of sandfly	1/7	See above
Recovery rate of rodent	1/(12x30)	-
Death rate of rodent	1/(14x30)	[5]
Birth rate of rodent	1/(14x30)+0.001	See above
Birth rate of human	10/(65x365)	-
Death rate of human	1/(65x365)	-
Recovery rate of human	1/365	-
Arrival	Variable	User controlled
Removal	Variable	User controlled
Tilapia birth rate	0.02	-
Tilapia death rate	Function of carrying capacity	-
Number of sandfly larvae eaten per Tilapia	Variable	-

Infection quantities of humans, sandflies, and rodents per unit of time are calculated by the following Eqs (3)-(5) respectively.

$$Infection\ of\ Humans = \frac{Bite\ H \times Infected\ Sandflies \times Susceptible\ Humans \times Infection\ probability\ to\ Humans}{Blood\ Meal} \quad (3)$$

$$Infection\ of\ Sandflies = \frac{Bite\ R \times Infection\ probability\ to\ and\ from\ Rodents \times Susceptible\ Sandflies \times Infected\ Rodents}{Blood\ Meal} \quad (4)$$

$$Infection\ of Rodents = \frac{Bite\ R \times Infection\ probability\ to\ and\ from\ Rodents \times Susceptible\ Rodents \times Infected\ Sandflies}{Blood\ Meal} \quad (5)$$

Readers are referred to Figure 1 to see the interdependencies between these quantities (i.e., flows) and other parameters with population sizes (i.e., stocks). Sandflies, humans, domestic animals, rodent and Tilapia populations are assumed to be dynamic. The number of sandfly that die each day is controlled as a function of the blood meal available and is expressed as in Eq. (6).

$$Sandfly\ Death\ Rate = \alpha\left[1 + \beta \times e^{-k(Blood\ Meal)}\right] \quad (6)$$

Our model starts with two infected rodents. It then computes the size of domestic animals, humans, sandflies and Tilapia that may vary each day (i.e., both infected and infecting),
where

$$\max(Sandfly\ Death\ Rate) = \lim_{Blood\ Meal \to 0} \alpha\left[1 + \beta \times e^{-k(Blood\ Meal)}\right] = \alpha(1 + \beta)$$

and

$$\min(Sandfly\ Death\ Rate) = \lim_{Blood\ Meal \to \infty} \alpha\left[1 + \beta \times e^{-k(Blood\ Meal)}\right] = \alpha.$$

Parameters α and β are determined in a fashion that $1/[\alpha(1+\beta)]$ = minimum survival of female sandfly in case of no or little blood meal. $1/\alpha$ =maximum survival of female sandlfy with sufficient blood meal. As we know that sandflies live between 3 to 10 weeks, α and β parameters are easily calculated. The constant term k is a smoothing factor and it represents the relation between blood meal and death rate of female sandfly. Its value is empirically determined to best model the sandfly death rate. According to [23] intrinsic growth rate ranges from 0.098 to 0.007 depending on the environmental conditions, such as humidity and temperature. We set rm to 0.0098. Bite rates ($Bite\ A$, $Bite\ R$ and $Bite\ H$) are kept constant and regardless of the varying population sizes during the follow-up period but their values is subject to change for sensitivity analysis.

4. MODEL IMPLEMENTATION

We implement our model using iThink software v9.0.2 (iThink Software 2009). iThink is visual modeling software that enables users to conceptualize and represent dynamic systems in functional environment. It integrates words with a simple set of icons. The icons are generic in nature, the purpose being to create a universal language. Such a language allows people with different viewpoints and specialized expertise to jointly contribute to building a collective, systematic understanding, designing effective performance initiatives become a hit (more likely) miss proposition. It provides modelers with simple, flexible and effective way of building blocks from causal feed-back loops and stock-flow diagrams. [26]. Three important building blocks are arrows, flows (rates), and stocks (levels). Arrows are used to specify that the value of the destination variable is affected by the source variable. The associations between system variables are constructed and causal feedback loops are established. Mathematical or graphical functions are written by the help of equation editor. SD framework involves two main elements: (i) stocks/levels (ii) and flows/rates. Stocks are used to accumulate things/entities and are static. Flows/rates represent the amount of things and entities per unit of time flowing in or out of stock variables. In our model, levels are: *Infected Humans, Susceptible Humans*, *Infected Sandflies, Susceptible Sandflies*, *Infected Rodents, Susceptible Rodents*, *Tilapias and Domestic Animals Population*. Flows are depicted by arrows with valves

on it. The levels of stocks are only changed by flows (See Figure 1). The remaining variables are auxiliary ones, which are either constant or not.

5. EXPERIMENTAL FINDINGS

The impact of Tilapia fish can be evaluated in terms of reduction in the incidence on humans, and in its persistence as defined by the basic reproductive number R_0. The basic reproduction number (R_0) is used to determine the transmission power of a disease. In our epidemiological model, R_0 defines the number of secondary infections as a single infected rodent is introduced to a totally susceptible rodent population. From the graphical model of Figure 1, one can infer that a single infected rodent will infect the number of sandflies given below:

$$\frac{Bite\ R\times(Trans\ Prob\ to\ and\ from\ Rodents)\times Sandflies}{(Rodent\ Recovery\ Rate+Rodent\ Death\ Rate)\times(Blood\ Meal)}$$

sandflies that then will infect

$$\frac{Bite\ R\times(Trans\ Prob\ to\ and\ from\ Rodents)}{(Sandfly\ Recovery\ Rate+Sandfly\ Death\ Rate)}$$

The multiplication of these two quantities will produce R_0 given by Eq. (7).

$$\frac{(Bite\ R)^2\times(Trans\ Prob\ to\ and\ from\ Rodents)^2\times Sandflies}{(Rodent\ Recovery\ Rate+Rodent\ Death\ Rate)\times(Sandfly\ Recovery\ Rate+Sandfly\ Death\ Rate)\times(Blood\ Meal)} \quad (7)$$

To evaluate the effect of animal use and Tilapia effect, we first want to give details about the Tilapia population. As is given in Table 1, Tilapia birth rate is assumed to be constant at the value of 0.02 but death rate is proportion of the number of Tilapia to the area of farming pool. As can be depicted in Figure 2, the population starts with 35 Tilapias but a dramatic increase is seen in the first 750 days due to high availability in amount of food per Tilapia. Following the 750 days, the increase rate diminishes and the population reaches its equilibrium point which is about 325 because of the carrying capacity and environmental/physical restrictions.

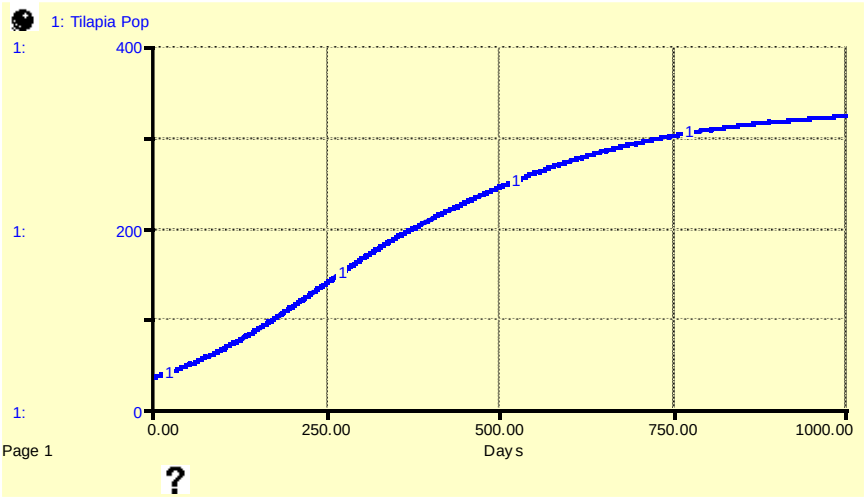

Figure 2. *The change of Tilapia population during follow-up period*

To investigate and dissect the cumulative effect of use of animal (zooproplaxis) and use of Tilapia on the transmission of disease leishmaniasis (prevalence in humans), we divide our analysis into three parts.

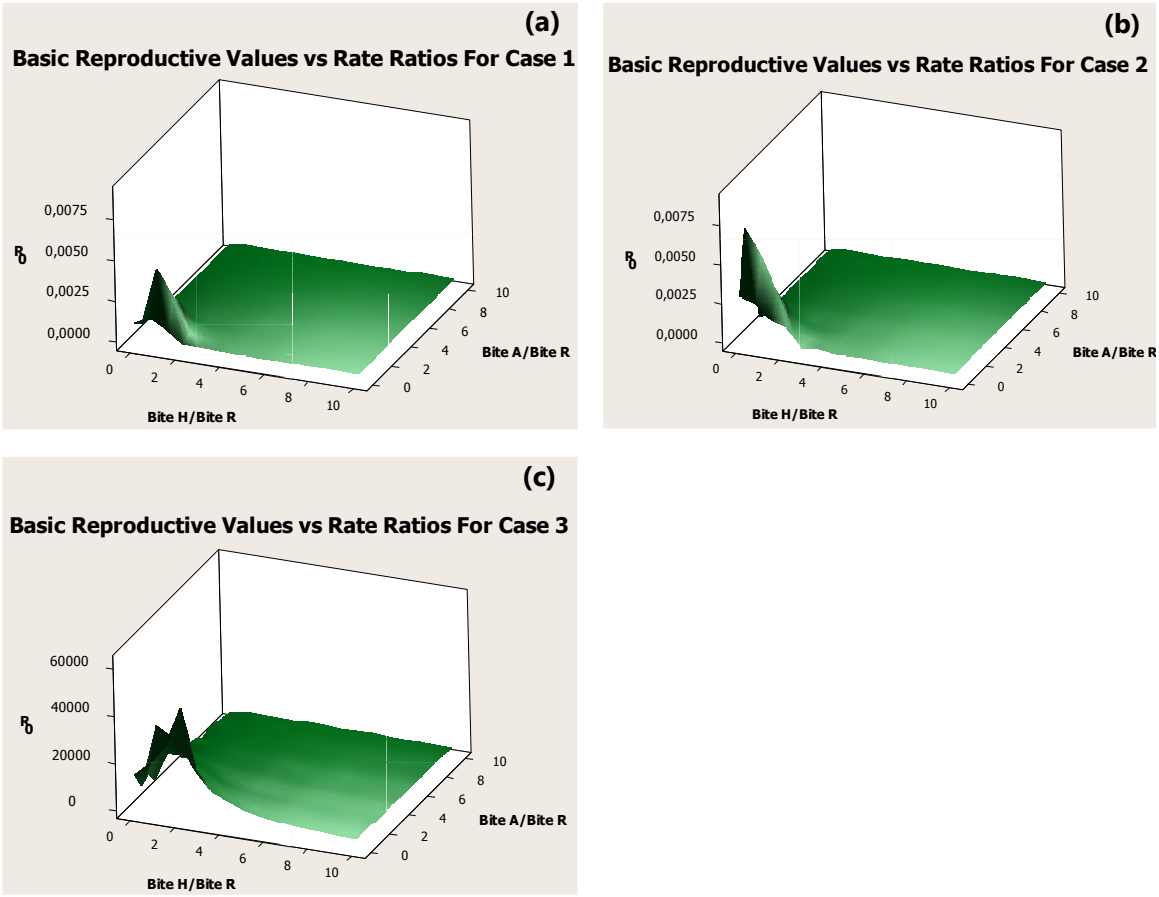

Figure 3. *The surface of basic reproductive values versus different bite rate ratios; a) the number of larvae eaten is 4 b) the number of larvae eaten is 2 c) the number of larvae eaten is 0*

The first analysis is mainly based on the behavior of basic reproductive rate (R_0) depending on various biting rate ratios and the number of larvae eaten per Tilapia. As can be understood from Eq. (1), we have no or little influence on Bite R, we prefer to change the unitless rate ratios; $(Bite\ H/Bite\ R)$, $(Bite\ A/Bite\ R)$ for various number of sandfly larvae eaten by each Tilapia. Remaining parameters are kept fixed. The initial size of populations of the domestic animals, sandflies, and rodents are equal and set to 1000. Every predefined increase of $(Bite\ H/Bite\ R)$ and $(Bite\ A/Bite\ R)$ is meant to reduce or dilute transmission of the disease since the R_0 relies mainly upon $Bite\ R$ and the blood meal available shown in Eq. 7.

Experiments depicted in Figure 3(a) are conducted with the assumption that the number of sandflies larvaes eaten by each Tilapia is four. In this case (case 1) it is seen that R_0 is at lowest value ranging from 0 to 00025 among three cases. R_0 value as low as this means that incidence of the disease or prevalence on humans are quite low. It is also seen in Figure 3(a) that when $(Bite\ H/Bite\ R)$ and $(Bite\ A/Bite\ R)$ are very small R_0 reaches its maximum 0.0025. This result is not surprising because relatively bigger value of $Bite\ R$ against $Bite\ A$ and $Bite\ H$ and increases the transmission of the disease. When $(Bite\ H/Bite\ R)$ and $(Bite\ A/Bite\ R)$ are relatively large, the R_0 dramatically reduces nearly to 0.

Experiments depicted in Figure 3(b) are conducted with the assumption that the number of sandflies larvaes eaten by each Tilapia is two. In this case, similar pattern to case 1 is observed. In this case (case 2) it is seen that R_0 value ranges from 0 to 0.0075, which is little higher than case 1. R_0 value as low as this means that incidence of the disease or prevalence on humans are still quite low. It is also seen in Figure 3(b) that when $(Bite\ H/Bite\ R)$ and $(Bite\ A/Bite\ R)$ are very small R_0 reaches its maximum 0.0075. This result is expected in that relatively bigger value of $Bite\ R$ against $Bite\ A$ and $Bite\ H$ and increases the transmission of the disease. When $(Bite\ H/Bite\ R)$ and $(Bite\ A/Bite\ R)$ are relatively large, the R_0 dramatically reduces nearly to 0.

In Figure 3(c), experiments are carried out in the case that the number of sandflies' larvae eaten by each Tilapia is zero (case 3) (i.e., Tilapia effect is removed). The results are not surprising but its magnitude is quite higher. When Tilapia effect is disregarded, the increase in R_0 is booming. R_0 value reaches 40.000. This value leads to its strong persistence and maximum prevalence on humans when $(Bite\ H/Bite\ R)$ and $(Bite\ A/Bite\ R)$ are very small. When the rate ratios of $(Bite\ H/Bite\ R)$ and $(Bite\ A/Bite\ R)$ increases, substantial decrease in R_0 is detected but it is still very higher as compared to first and second cases.

In the second part of the analysis, we examine the effect of Tilapia population on the behavior of the disease. Throughout the analysis we set bite ratios $Bite\ A = Bite\ R = Bite\ H = 1/21$. For this purpose, the susceptible and infected humans are plotted against two different number of sandflies' larvae eaten by each Tilapia during the follow-up period of 1000 days. Figure 4(a) shows the number of infected (blue curve) and susceptible (red curve) humans throughout 1000 days when Tilapia population is not present. As can be easily seen from Figure 4(a), the number infected humans is relatively lower until day 80 but there exists a dramatic increase between day 80 and day 160. Following day 160, the number of infected human continues to surge linearly until the end of 1000 days. Conversely, the number of susceptible human goes to zero. Until day 80, slight increase is seen in the number of susceptible human. After day 80, however, the sharp decrease occurs until day 80, no susceptible human is left in the population. This is due to the fact that number of infected sandfly increases similar to the pattern of human population. Due to the space limitations, sandlfy population plot is not presented.

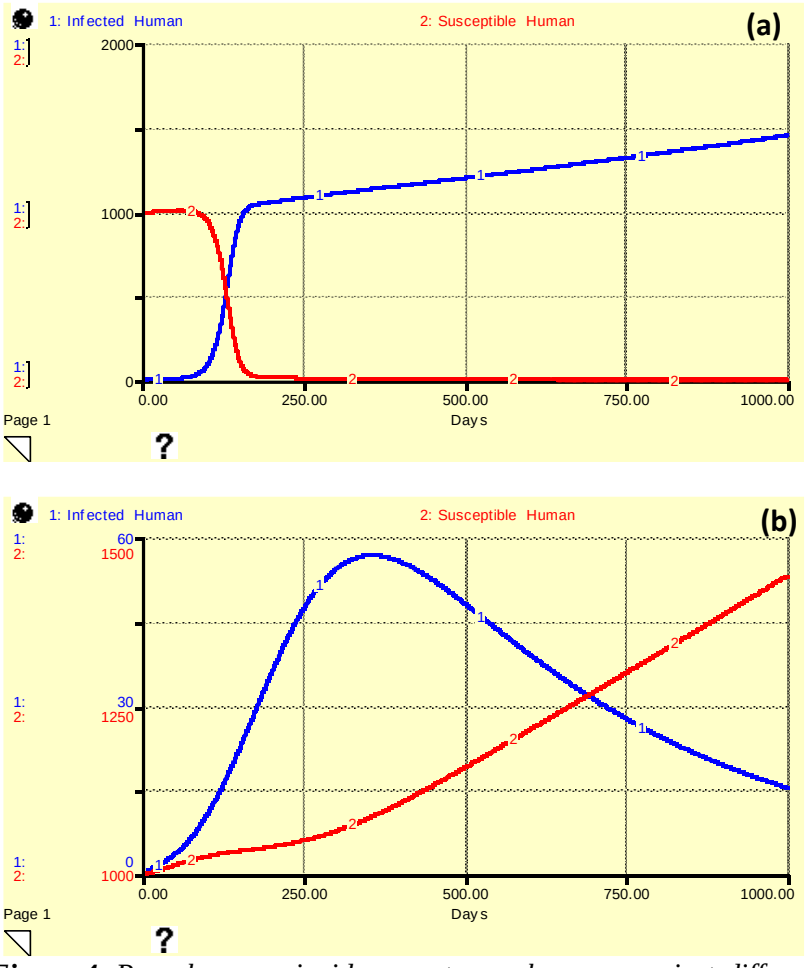

Figure 4. *Prevalence or incidence rates on humans against different number of larvae eaten by single Tilapia; a) The number of larvae eaten is 0 b) The number of larvae eaten is 2*

Figure 4(b) plots the number of infected and susceptible human over the follow-up period when the number of sandfly larvae eaten by each Tilapia fish is two. From Figure 4(b) it is observed that the number of

infected human remarkably increases and reaches its peak value of 57 at day 350 and then starts dropping down as low as 15 at the end of follow-up period. The number of susceptible humans, on the other hand, increases relatively lower slope until day 250, after which the number of susceptible human increases with relatively higher slope with a final value of 1446. This result reveals that Tilapia population has a big magnitude in reducing (even eradicating) the persistence of the disease leishmainasis on humans. In addition the use of domestic animals as dead-end hosts, proper installment of special farming pools in which Tilapia fish is farmed has significant effect in the transmission of this infection.

We finally study the effect of the domestic animals population on R_0. In particular, we would like to see if any rise in the size of domestic animals will resist zooprophylaxis dilution effect, which is due mostly to the increase in blood meal. For this analysis, we set $Bite\ A = Bitte\ R = Bite\ H = 1/21$. We also assume that there is no Tilapia effect (i.e., the number of larvae eaten by each Tilapia is zero.) and the initial number of rodent population and the initial number of human population is set to 1000. In order to see the effect of domestic animal size on R_0 value, we make an increment of 500 in domestic animal size starting from 0 to 6500. Figure 5 plots the R_0 values for different number domestic animal size. As can be seen from Figure 5, R_0 value is convex (it is a decreasing function of domestic animal size). It is seen that R_0 value is quite higher when no domestic animal is available. When the population size of domestic animals increases, however, there exists a sharp decrease in R_0 value up to 1000. For higher sizes of domestic animals, the slope of the curves decreases but it continues to decrease.

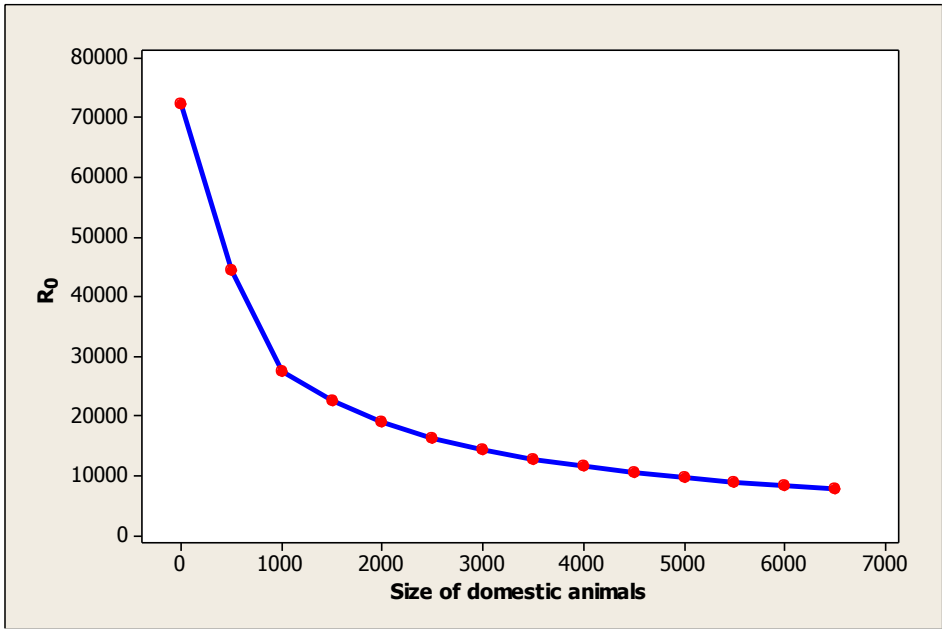

Figure 5. *Basic reproductive number (R_0) values against different sizes of domestic animals*

6. DISCUSSIONS

Leishmaniasis is one of the infectious diseases which is caused by the bite of female sandfly to humans and is endemic in the Mediterranean region, Asia, and Africa. According to the World Health Organization (WHO), the leishmaniasis is considered as one of the seven most severe tropical disease and emerges as a serious world health problem presenting a broad range of clinical manifestation with a potentially deadly result. In between 12 to 15 million people are estimated to get infected in the world, and 350 million are under risk of developing the disease. 1.5 to 2 million people gets infected in each year and 700.000 people are dying of the disease each year.

Specifically, in Turkey, the new cases increase in that Turkey hosted about 3 million refugees, most of whom are mainly settled at either homes or camps in the south and southeastern region of Turkey [3]. In spite of its threats, there is no vaccine or prophylactic medication available. Preventive ways from the disease is rather primitive, involving nets with insecticides or insect repellents.

With engineering perspective, this paper addresses the issue of alleviating the persistence or incidence of the disease on humans by the use of domestic animals and Tilapia fish. The cumulative effects of Tilapia fish and domestic animals, for what we believe to be the first time, are studied in the literature. To this end, we develop epidemiological model of cutaneous type of leishmaniasis with system dynamics approach. In the model, five different population, including sandflies (infected and susceptible), rodents (infected and susceptible), humans (infected and susceptible), domestic animals and Tilapias are taken into account. Dynamic interactions between each population are thoroughly established. Experimental results reveal that basic reproductive number can be reduced by the use of domestic animals and Tilapias. Results also show that Tilapias have big impact in alleviating the persistence and incidence of the disease on humans.

Acknowledgements
This paper is produced by the first author's MSc thesis from Graduate School of Konya Technical University. We would like to send our best gratitude to Saddam Hocine Bouzegag for his valuable help during the modeling process of the epidemiological system dynamics model.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

REFERENCES

[1] Lane, R.P., Crosskey, R.W., "Medical insects and arachnids", Chapman and Hall, London, 78–119, (1993).

[2] Postigo, J.A., "Leishmaniasis in the world health organization eastern Mediterranean region", Int. J. Antimicrob. Agents 36:(1), 62–65, (2010).

[3] Ozkeklikci A, Karakus M, Ozbel Y, "The new situation of cutaneous leishmaniasis after Syrian civil war in Gaziantep city, Southeastern region of Turkey". Acta Trop**,** 166: 35–38, (2017).

[4] Nowak, R., "Walker's Mammals of the World", Baltimore Johns Hopkins University Press, Baltimore, Maryland , (1999).

[5] Murray, L., Dalal, S., Rico, P., Chenault, V., "Evaluation of the estrous cycle in the sand rat, (Psammomys obesus), An Animal Model of Nutritionally Induced Diabetes Mellitus", J. Vet. Res. , 8: 7–15. (2004).

[6] Killick-Kendrick, R. (Ed.), "The Leishmaniasis in Biology and Medicine", vol. I.Academic Press, London, 263–290, (1987).

[7] Service, M.W., "Agricultural Development and Arthropod-borne Diseases: a Review", Rev. Saude Publica, 25(3): 165–178, (1991).

[8] Bettini, S., Romi, R., "Zooprophylaxis: old and new problems", Parassitologia , 40(4): 423–430, (1998).

[9] Bøgh, C., Clarke, S.E., Walraven, G.E., Lindsay, S.W., "Zooprophylaxis artefact or reality? A paired-cohort study of the effect of passive zooprophylaxis on malaria in The Gambia", Trans. R. Soc. Trop. Med. Hyg., 96 (6): 593–596, (2002).

[10] Chelbi, I., Kaabi, B., Derbali, M., Ahmed, S.B., Dellagi, K., Zhioua, E., "Zoopro-phylaxis: impact of breeding rabbits around houses on reducing the indoor abundance of Phlebotomus papatasi", Vector Borne Zoonotic Dis., 8(6): 741–747, (2008).

[11] Kaburi, J.C., Githuto, J.N., Muthami, L., Ngure, P.K., Mueke, J.M., Mwandawiro, C.S., "Effects of long-lasting insecticidal nets and zooprophylaxis on sandfly feeding behaviour and density in Mwea, central Kenya", J. Vector Borne Dis., 46(3):184–190, (2009).

[12] Kaabi, B., Ahmed, S.B-h., "Assessing the effect of zooprophylaxis on zoonotic cutaneous leishmaniasis disease: A system dynamics approach", BioSystems, 114(3): 253-260, (2013).

[13] Petr, T., "Interactions between fish and aquatic macrophytes in inland waters. A review", FAO Fisheries Technical Papers. , 396: (2000)

[14] Reithinger, R., Espinoza, J.C., Davies, C.R., "The transmission dynamics of canine american cutaneous leishmaniasis in Huanuco Peru", Am. J. Trop. Med. Hyg, 69(5): 473–480, (2003).

[15] Palatnik-de-Sousa, C.B., Batista-de-Melo, L.M., Borja-Cabrera, G.P., Palatnik, M.,Lavor, C.C., "Improving methods for epidemiological control of canine visceral leishmaniasis transmission dynamics of leishmaniasis based on a mathematical model. Impact on the incidence of the canine and human disease", Ann.Brazil. Acad. Sci., 76(3): 583–593, (2004).

[16] Chaves, L.F., Hernandez, M., "Mathematical modelling of American cutaneous leishmaniasis: incidental hosts and threshold conditions for infection persistence", Acta Trop., 92: 245–252, (2004).

[17] Bacaer, N., Guernaoui, S., "The epidemic threshold of vector-borne diseases with seasonality. The case of cutaneous leishmaniasis in Chichaoua, Morocco", J.Math. Biol., 53(3): 421–436, (2006).

[18] Agyingi, E.O., Ross, D.S., Bathena, K., "A model of the transmission dynamics of leishmaniasis", J. Biol. Syst., 19(2): 237–250, (2011).

[19] Rabinovich, J.E., Feliciangeli, M.D., "Parameters of leishmania braziliensis trans-mission by indoor Lutzomyia ovallesi in Venezuela", Am. J. Trop. Med. Hyg., 70: 373–382, (2004).

[20] Meadows, D.H., "Thinking in Systems: A premier", Chelsea Green Publishing, Vermont, (2008).

[21] Sterman, J.D., "Business dynamics: System thinking and modeling for a complex world", The McGraw Hill, New York, (2000).

[22] Helal, H., Ben-Ismail, R., Bach-Hamba, D., Sidhom, M., Bettini, S., Ben Rachid, M.S., "An entomological survey in the focus of zoonotic cutaneous leishmania-sis (Leishmania major) of Sidi Bouzid (Tunisia) in 1985", Bull. Soc. Pathol. Exot.Filiales ,80(3): 349–356, (1987).

[23] Kasap, O.E., Alten, B., "Comparative demography of the sand fly Phlebotomuspapatasi (Diptera: Psychodidae) at constant temperatures", J. Vector Ecol., 31(2): 378–385, (2006).

[24] Schlein, Y., Jacobson, R.L., "Sugar meals and longevity of the sandfly Phlebotomuspapatasi in an arid focus of leishmania major in the Jordan Valley", Med. Vet. Entomol., 13(1): 65–71, (1999).

[25] el Kordy, E., el Shafai, A., el Said, A., Kenawy, M.A., Shoukry, M., el Sawaf, B.M., "Adult diet as a factor affecting biology of the sandfly Phlebotomus papatasi(Diptera: Psychodidae)", J. Egypt Public Health Assoc. ,66(1–2): 159–172, (1991).

[26] Richmond, B., "An introduction to system thinking with iThink", (2013).