Asian Pacific Journal of Tropical Disease

journal homepage: http://www.apjtcm.com

Original article https://doi.org/10.12980/apjtd.7.2017D7-85

Goat movement network analysis and its implications for caprine brucellosis propagation in Nonthaburi Province, Thailand

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ARTICLE INFO

Article history:
Received 28 Apr 2017
Received in revised form 19 May 2017
Accepted 5 Jun 2017
Available online 17 Jul 2017

Keywords:
Mathematical modeling
Networking
Stochastic modeling
Caprine brucellosis propagation

ABSTRACT

Objective: To estimate the risk of brucellosis diffusion through goat movement network across Nonthaburi Province, Thailand.
Methods: A questionnaire-based survey was performed to collect movement data. A static weighted directed network was constructed and a spatial network distribution was plotted. Alternatively, a stochastic quantitative risk estimation was also calculated.
Results: A total of 114 goat farmers responded to the questionnaires. Twenty-two provinces across Thailand were identified in the network. The highest weighted-in- and weighted-out-degree centralities were observed in Bangkok and Kanchanaburi Province at 264 and 68, respectively. Moreover, the highest import risk of caprine brucellosis into Nonthaburi Province was found in Nakhon Pathom at 13.40 ± 1.93 whereas the highest export risk was noticed in Bangkok at 17.45 ± 1.05.
Conclusions: The identified provinces should be closely monitored especially in terms of animal movements. This study may help relevant authorities prioritize the high-risk areas and optimize control measures. Our methods could also be applied to other diseases or animal species in different geographical locations.

1. Introduction

Brucellosis is a worldwide distributed zoonotic disease resulting in both public health and economic impacts[1]. Epidemiologically, it is prevalent in more than 90% of the countries in Asia. In Thailand, animal brucellosis is ubiquitously distributed, and human cases have consecutively been reported[2].

Brucella spp., the pathogen causing brucellosis, is a Gram-negative intracellular facultative bacterium in the phylum of Proteobacteria, class Alphaproteobacteria[3]. *Brucella* contains 11 different species; four of which have been recognized as zoonotic agents including *Brucella melitensis*, *Brucella abortus*, *Brucella suis* and *Brucella canis*[4]. Moreover, *Brucella melitensis* has been reported to cause the most severe symptoms in humans[1]. Animal brucellosis is mainly transmitted by reproduction[5] whereas zoonotic transmission occurs from an ingestion of contaminated animal products such as milk[6].

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Foundation Project: Supported by Faculty of Veterinary Science, Mahidol University (Grant No. 7/2017).
The journal implements double-blind peer review practiced by specially invited international editorial board members.

Animal movement is one of the risk factors for brucellosis transmission in animals[7,8]. The movement of animals with different sources and destinations is represented as a network. Network analysis, therefore, is a useful tool for estimating the risk related to disease transmission[9]. In Thailand, animal movement network analysis has been applied to assess the potential for infectious disease diffusion in backyard chickens[10,11] and cattle[12]. However, the network of goat movement concerning the propagation of brucellosis has never been described.

Network analysis has been used in a variety of settings such as infectious disease surveillance system, disease transmission pathway or even prediction of further epidemics and planning preventive interventions[9]. For example, the technique was applied to explore a traditional cattle trade network in Thailand and to address diseases spread probability[12].

Another useful method for estimating the risk of disease diffusion regarding animal movement is the quantitative risk modeling. This approach has been used to assess the entry of contagious bovine pleuropneumonia (CBPP) through live cattle imported from Northwestern Ethiopia[13]. In Zambia, quantitative risk modeling was developed to evaluate the potential of bovine theileriosis importation into Luapula Province via live cattle movements[14].

Accordingly, network analysis and risk modeling should be concurrently applied in the risk estimation due to animal movements. In Thailand, the highest number of brucellosis outbreaks was notified in Nonthaburi Province for eight and twelve times in 2014 and 2015, respectively. Among these outbreaks, three-fourths were reported in goat populations[15]. Nonthaburi is one of the neighbored provinces of Bangkok in the northwest direction. Moreover, it is a part of the greater Bangkok Metropolitan Area (BMA) and regarded as the second most populous province after the capital city, Bangkok[16]. The present study thus aimed to estimate the risk of brucellosis diffusion through goat movement networks across this province and to use the analysis results to guide policy makers in dealing with brucellosis transmission.

2. Materials and methods

2.1. Field data collection

A questionnaire-based survey was performed in June 2016 to retrieve data regarding goat movements including general demographic data, number and type of goats, and goat movement history within one-year period. In addition, a written consent form was signed by individuals prior to beginning the interview. However, the responders were allowed to terminate the interview whenever they felt uncomfortable with the questions.

2.2. Weighted network of goat movements

A static weighted directed network was constructed to illustrate how goats moved across Nonthaburi Province. A node referred to a province, and a directed tie represented a direction of movement. The network was weighted by the frequency that farmers moved goats along each tie.

Weighted-in- and weighted-out-degree centralities[17] were calculated to quantify the intensity of goat movements between Nonthaburi and other provinces. The weighted-in-degree centrality of province i denoted number and frequency of goat movements toward that province as shown in equation (1):

$$C^{W}_{D-in}(i) = k_i^{in} \times \overline{S_i^{in}} \quad (1)$$

where k_i^{in} is the number of ties moving toward province i and $\overline{S_i^{in}}$ is the average frequency of all goat movements toward the province.

On the other hand, the weighted-out-degree centrality of province i represents number and frequency of goat movements departing from that province as explained in equation (2):

$$C^{W}_{D-out}(i) = k_i^{out} \times \overline{S_i^{out}} \quad (2)$$

where k_i^{out} is the number of ties leaving province i and $\overline{S_i^{out}}$ is the average frequency of all goat movements departing the province.

Our network analysis was performed within the package 'igraph' version 1.0.1[18] in the computer language program R version 3.3.2[19]. The network was subsequently mapped for better illustration with a geographical information system application QGIS version 2.18[20].

2.3. Quantitative risk modeling

A mathematical model based on the frequency of goat movements across Nonthaburi Province and the prevalence of brucellosis was built to evaluate the possibility of importation and exportation of caprine brucellosis between Nonthaburi and other provinces via goat movements. A prevalence of brucellosis at herd level from January to August 2016 was provided by Bureau of Disease Control and Veterinary Services, Department of Livestock Development of Thailand. A Poisson distribution was used to simulate the frequency of goat movements. The import and export risks of caprine brucellosis were modeled as shown in equations (3) and (4):

$$P_i^{imp} \sim Prev_i \times Pois\ (\lambda_{i,n}) \quad (3)$$

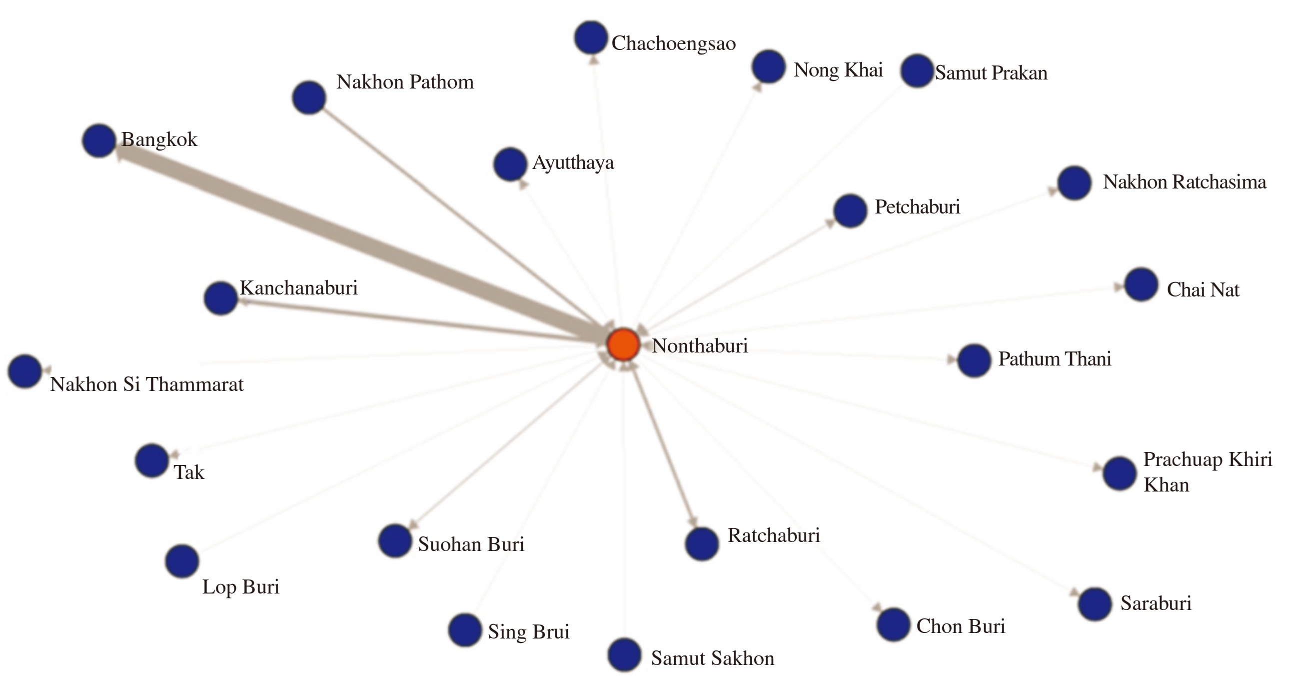

Figure 1. A static sociogram representing weighted directed network of goat movements in Nonthaburi Province, Thailand.
Nodes refer to provinces and ties denote goat movement activities. The thickness of the ties relates to the weight of each tie. The arrow heads represent the direction of goat movements. Labels indicated in the nodes are names of the provinces.

where P_i^{imp} is the risk of introducing brucellosis from province i into Nonthaburi. Parameter $Prev_i$ represents the prevalence of brucellosis in province i and $\lambda_{i,n}$ is the mean frequency of goat movements from province i into herd n in Nonthaburi Province.

$$P_i^{exp} \sim Prev_N \times Pois(\lambda_{N,n}) \quad (4)$$

where P_i^{exp} represents the risk of exporting brucellosis from Nonthaburi Province to province i. Parameter $Prev_N$ denotes the prevalence of brucellosis in Nonthaburi Province and $\lambda_{N,n}$ is the mean frequency of goat movements from herd n in Nonthaburi to province i.

The models were projected in 1 000 simulations in programing language R version 3.3.2 (R development core team, 2016).

3. Results

3.1. The surveyed respondents

In total, 114 goat farmers responded to the questionnaires; the majority was male farmers (79.8%). Mean age of the respondents was 53.6 years old (SD = 14.1). Considering educational level, 50.0% and 36.8% finished primary and secondary school, respectively. General demographic data of the interviewees are detailed in Table 1.

3.2. Goat movement network

The goat movement network contained 22 nodes with 21 weighted ties. Goats from Nonthaburi Province were mainly exported to Bangkok with weighted-in-degree centrality of 264 whereas those in this province were mostly imported from Kanchanaburi Province with weighted-out-degree centrality of 68. The top five goat importers and exporters across Nonthaburi Province are demonstrated in Table 2. To better illustrate the network, a sociogram and a spatial movement map are presented in Figures 1 and 2, respectively.

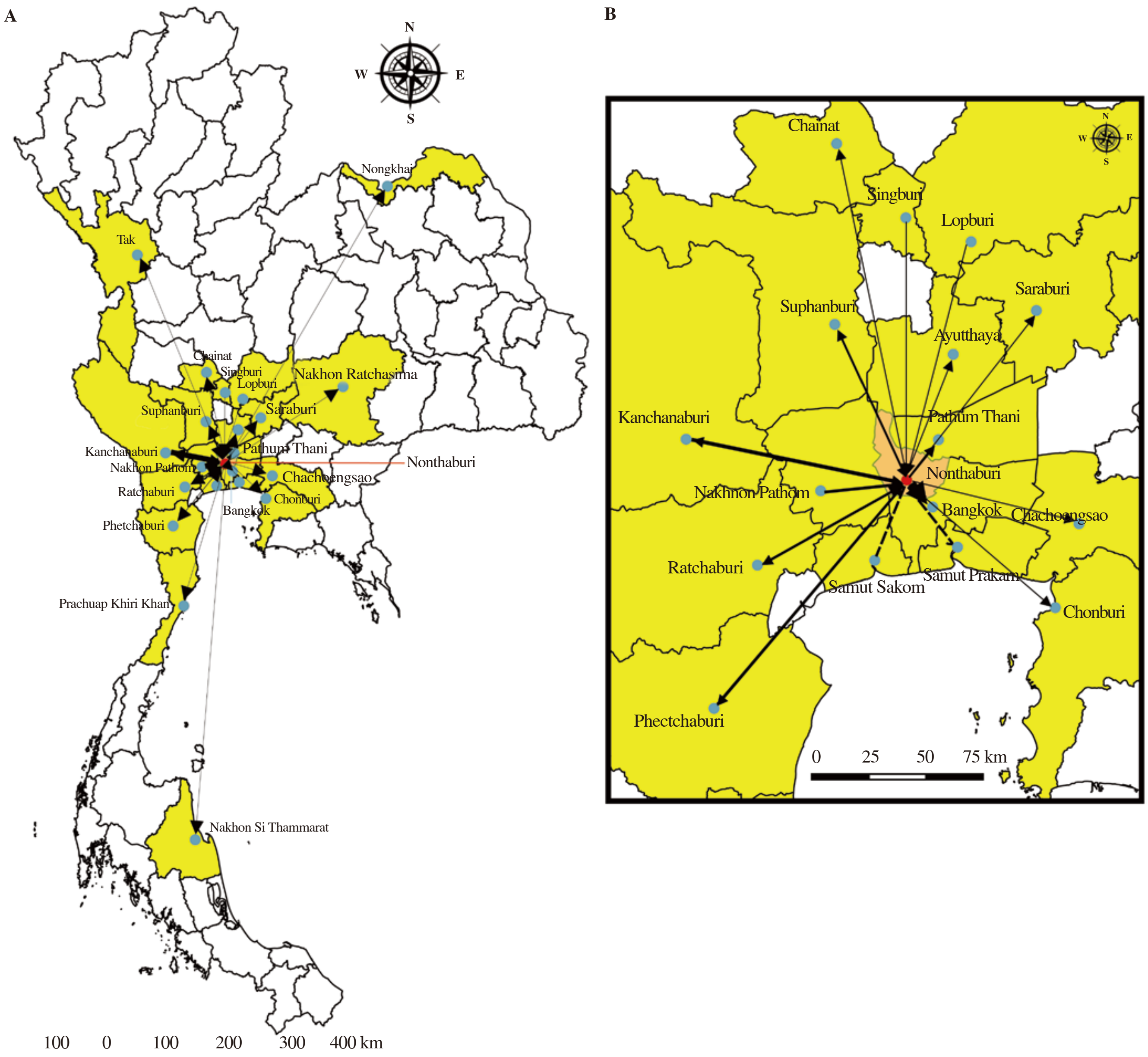

Figure 2. The map of Thailand depicting geographical distribution of goat movements in the network (A) and the magnified map focusing on Nonthaburi and surrounding provinces (B).

Table 1

General demographic data of the respondents (n = 114).

Variables	Number of respondents (%)
Sex	
Male	91 (79.8)
Female	23 (20.2)
Age	
< 20 years	1 (0.9)
20–40 years	30 (26.3)
41–60 years	53 (46.5)
> 60 years	24 (21.0)
No data	6 (5.3)
Education	
Primary school	57 (50.0)
Secondary school	42 (36.8)
Bachelor's degree	7 (6.2)
No data	8 (7.0)
Goat rearing experience	
< 10 years	53 (46.5)
10–20 years	42 (36.8)
21–30 years	10 (8.8)
> 31 years	7 (6.1)
No data	2 (1.8)

Table 2

Weighted degree centrality of top five goat importers and exporters across Nonthaburi Province, Thailand.

Weighted-in-degree centrality (import goats from Nonthaburi Province)			Weighted-out-degree centrality (export goats to Nonthaburi Province)		
Geocode	Province	Score	Geocode	Province	Score
TH-10	Bangkok	264	TH-71	Kanchanaburi	68
TH-72	SuphanBuri	11	TH-73	Nakhon Pathom	50
TH-76	Petchaburi	11	TH-70	Ratchaburi	49
TH-70	Ratchaburi	10	TH-72	Suphanburi	15
TH-13	PathumThani	7	TH-16	Lop Buri	4

3.3. Risk estimation of caprine brucellosis propagation via goat movements

According to our quantitative risk estimation, Nakhon Pathom Province had the highest risk to transport goats with brucellosis to Nonthaburi Province at the risk level of 13.40 while the goats with brucellosis in Nonthaburi Province were likely to be delivered to Bangkok at the risk level of 17.45. The risk of caprine brucellosis importation into goat populations in Nonthaburi and the diffusion of caprine brucellosis via goat exportation from Nonthaburi to other provinces are shown in Table 3.

Table 3

The top five quantitative risk of caprine brucellosis exportation and importation across Nonthaburi Province, Thailand.

Export risk from Nonthaburi Province (risk in exporting goats from Nonthaburi Province)			Import risk to Nonthaburi Province (Risk in importing goats into Nonthaburi province)		
Geocode	Province	Mean ± SD	Geocode	Province	Mean ± SD
TH-10	Bangkok	17.45 ± 1.05	TH-73	Nakhon Pathom	13.40 ± 1.93
TH-72	Suphan Buri	0.72 ± 0.23	TH-71	Kanchanaburi	12.13 ± 1.49
TH-76	Petchaburi	0.72 ± 0.22	TH-72	Suphan Buri	5.73 ± 0.61
TH-70	Ratchaburi	0.67 ± 0.20	TH-70	Ratchaburi	1.86 ± 0.47
TH-13	Pathum Thani	0.46 ± 0.18	TH-13	Pathum Thani	1.23 ± 0.18

4. Discussion

This study conducted network analysis technique and quantitative risk modeling to acquire the possibility of caprine brucellosis propagation through goat movement networks across Nonthaburi Province.

In our network analysis, weighted degree centrality indicated both number of connections and frequency of goat movements among sources and destinations (Figure 1). Weighted-in-degree centrality demonstrated that Bangkok was the major goat importer from Nonthaburi Province whereas Kanchanaburi Province is the largest goat exporter to this province as advised by weighted-out-degree centrality (Table 2). According to the information from office of Islamic Affairs Committee of Bangkok Metropolis[21], approximately 6.5 million Islamic people lived in Thailand. Of those, almost 10% (around 600 000 people) resided in Bangkok. Goats have been traded and slaughtered as a part of Islamic rites throughout the year[22]; this would be the reason why Bangkok possessed the highest number of goat importation from Nonthaburi Province. Furthermore, Kanchanaburi Province was the main source of goat supplying to Nonthaburi Province. According to data from Kanchanaburi Provincial Livestock Office, goat production in this province was considered a large scale as it could produce 26 500 goats per annum[23]. As a result, Kanchanaburi Province might act as a main goat supplier in this area. A further study on motivation and preference in the selection of goat providers in terms of socio-economic aspects has been strongly suggested.

It is also noticeable that the goat movements were mainly occurred among nearby provinces, such as Nonthaburi, Bangkok, and Kanchanaburi Provinces, compared to more remote province like Nakhon Si Thammarat. Economically, a short-distance transportation was preferred if supply was sufficient to demand. However, goat transportation into the different regions was also noticed in the present study (Figure 2). Averagely, goats were transported to Nonthaburi Province by 76 km while they traveled farther during exportation (96.2 km). These findings indicated that the farmers in Nonthaburi Province tended to import goats from nearby provinces and export goats to remote destinations. The same movement patterns were previously described in the study of traditional cattle trade network in Tak Province, Thailand[12].

The result of export risk analysis, suggested by our quantitative risk modeling, was in line with the weighted-in-degree centrality. It was found that Bangkok was identified to possess the greatest risk, as a designated province, of exporting goats from Nonthaburi Province. Besides, caprine brucellosis may be imported into Nonthaburi from Nakhon Pathom Province at the highest risk, instead of Kanchanaburi Province (Table 3). This result was inconsistent with the network analysis in terms of weighted-out-degree centrality. In our risk modeling, we also considered the prevalence of brucellosis in each province which was neglected in the network analysis. This was the reason why we need more than one method to estimate the risk of disease propagation.

We literally acknowledged these three limitations in this study. First, the goat identification system such as ear tag was not obligatory in Thailand. Therefore, it was very difficult for authorities to follow the movements of an individual goat. In addition, we could not also track back to the actual origins of the goats using unique identification number. Second, animal movement data derived in the present study was solely based on interviews. We were unable to follow each farm in order to observe the actual sources and destinations of the goats due to limited budgets and resources. A previous study, conducted to observe the movement of backyard chicken traders in another province in Thailand, did follow the traders with a satellite tracking device. They found that these traders traveled to catch chickens with the average distance of 4–25 km[11]. For this reason, tracking devices are recommended in further studies in order to follow the movements of the goats in this study. Moreover, the device can provide a detailed and insightful information on the actual routes used in the transportation or even time spent on this activity. Third, most farmers interviewed had never recorded any data regarding their goat rearing activities, contributing to possible recall bias. Consequently, we asked them to inform their business within the past one year to reduce these recall effects. However, the trade network observed in this study seemed to be concretely formed. Therefore, the farmers were likely to purchase and sell goats with their usual sources and destinations.

The identified provinces with high trade activities should be closely monitored especially in terms of animal movements. This study may help relevant authorities prioritize the high-risk area and optimize control measures. Network analysis and quantitative risk modeling were compatible in quantifying the risk of disease spread as demonstrated in the case of caprine brucellosis. In addition, these methods could be applied to the study on other diseases or animal species in different geographical locations.

Conflict of interest statement

We declare that we have no conflict of interest.

Acknowledgments

This research was financially supported by Faculty of Veterinary Science, Mahidol University (Grant No. 7/2017). The funding source had no roles in design of this study, data collection, analysis and interpretation. We cordially thank the staff of Nonthaburi Provincial Livestock Office for their supports in the field surveys. Assistant Professor Atthaporn Roongsitthichai, Faculty of Veterinary Sciences, Mahasarakham University, was appreciated for English revision. Finally, we thank all participants for their cooperation.

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