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Developing a model for predicting the dynamics of cattle infestation by gastrointestinal nematodes in Aceh Province, Indonesia

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Abstract

High cases of gastrointestinal nematode (GIN) parasitism in cattle lead to substantial economic loss in grazing cattle in developing countries, including Indonesia, resulting from climatic change and poor sanitation. This research aimed to collect data from the field and subsequently develop a model to predict the dynamic of the infestation of cattle by GIN at various places (highlands and lowlands) in Aceh Province, Indonesia in February-August 2017 employing two approaches: a laboratory approach which collected and analysed cattle faeces and a survey approach. Simulation, Analysis, and Modeling Software II (SAAM II) was employed to conduct data analysis and develop a model for nematode infestation in cattle. This modeling software represented eggs per gram (EPG) of faeces influenced by rainfall. The results confirmed that rainfall inhibited larvae development in 91 days and reduced the number of eggs secreted by cattle in 20 days. Changes in the environment are believed to be an approach that can support avoiding an increase in EPG. The development of this basic model is expected to be the initial stage for a further and more advanced model to comprehensively enhance strategies to control GIN in cattle.

Keywords: Model, Control, Environment, Gastrointestinal nematodes, Cattle

1. Introduction

Gastrointestinal nematode (GIN) infection is an enduring issue in the global ruminant livestock industry, including in Indonesia [1-4]. Gastrointestinal nematode infection in livestock is a pervasive problem, resulting in insufficient productivity in the livestock industry, which has resulted in a reduction in ruminant productivity [5]. GIN infestation in sheep and cattle has reached USD 62.7 million/year [6]. Moreover, it costs USD 27.2 million/year for treatments and more than USD 43.8 million/year for disease control. Those particular economic losses are caused by daily weight loss up to 0.1 kg/day, reduced fertility with extended returns in relation to oestrus and long inter-calving. Conversely, the death of calves caused by GIN affects the productivity and fertility of cattle. For female cattle (cow), GIN infestation can have an impact on productivity and fertility naturally and decreases immunity against diseases [7].

The GIN infection route is divided into two stages, namely pre-infective and infective. These stages can occur directly within the host and indirectly within the intermediate host by reproducing productive parasites in the host body [8,9]. Therefore, the number of eggs at the infective stage during a certain period determines the number of potential parasites produced by the susceptible host. Additional characteristics such as cattle type, age and the nutrition of the host have a significant impact on the chance of parasites infecting and devastating host body. The research conducted by [9,10] indicated that environment (climatic changes) plays a pivotal role in

influencing parasite survival, especially egg and larvae transmission to the host. Microclimate such as sunlight, cloud shading, evaporation, wind, vegetation quantity and other factors such as disease management contributed to development, migration, survival, and the GIN infection rate in grazing ruminants [11].

There is increasing concern in relation to the continuous control of GIN in ruminants, particularly cattle, where cattle are considered for their dual economic functions, production, and reproduction, that they will be unable to exhibit resistance against infection [12,13] which occurs due to climatic change and results in an increase in parasite population [14] and resistance to anthelmintic caused by inappropriate grazing management [13,15].

Regarding the reasons mentioned above, effective, and appropriate management along with an understanding of GIN in the context of epidemiology outside the host and its environment are essential. There is an urgent need for good management to enable us to detect problems that are related to ruminants to avoid GIN infestation in grazing livestock, by using a mathematic model for predicting the impact and intensity of GIN transmissions [16].

The models developed by [13,17], recommended strategies applicable for GIN management, for instance, selective treatment methods for infected livestock and producing livestock that are resistant to parasite infestation. However, it is difficult to test the efficacy of the models' strategies, both in experiments and treatments due to its substantial cost and the difficulties in making proper comparisons. There are two other simulation models used for describing the interaction between parasites and host, specifically a simulation to predict parasite activities in the host and a simulation model describing cattle weight [18,19]. Nonetheless, these two models have disadvantages, for instance, one of the models cannot create a prediction regarding parasite activity whilst the other model can only use livestock weight as an explanation. We conducted this research to develop a new simulation model to describe a GIN interaction pattern in different environments which involve temperature, humidity, soil pH and rainfall. In this model, we focused on the GIN population dynamics and its activity in the host.

We developed a model by means of the compartment approach. This model is manageable, uncomplicated and allows us to reduce the components without eliminating the function to describe the interaction between compartments in the system. The interaction between compartments in this model is a code produced from a differential equation by applying all the information and data related to the system we have been investigating and displaying it in the graphics. An alternative method for disease control has been developed regarding the results of the model. Research has been conducted to examine the environmental factors affecting the pre-parasitic stage.

2. Materials and methods

2.1 Survey method

The survey was conducted in six regencies in Aceh Province comprising different environments, three regencies located in lowland areas and three other regencies located in highland areas. Physical environment (topography, temperature, humidity, soil pH, wet days, and rainfall) was measured. Samples such as cattle faeces, soil and stagnant water near the cages were collected. We also observed the grazing condition, feed, cages, cattle health and treatments, cattle age, and sex as well as the environmental management.

2.2 Laboratory analysis

Faecal, soil and stagnant water samples were examined using the centrifuge method to investigate the GIN eggs and the Withlock method to determine the number of eggs per gram (EPG).

a) Variables

CH	:	Rainfall (mm^{-1})
FL_A, FL_B, FL_C	:	Additional environmental factors
Tn	:	Soil
Lv	:	Larvae
S_p	:	GIN-infected cattle producing EPG in faeces

b) Parameters

k_{ch}CH	:	Rate of evaporating rainfall (mm^{-1})
k_{fla}, k_{flb}, k_{flc}	:	Rate of constant fraction of the additional environmental factors (min^{-1})
CH_{awal}	:	Rainfall at the beginning of the simulation (min^{-1})
$FL_{A\text{-}awal}$	:	Initial additional environmental factors (min^{-1})
Lv_{awal}	:	Initial larvae development (min^{-1})
a_{flb}	:	Response to rainfall value

k_{TnA}, k_{TnB} : Rate of constant fraction of soil compartment (min^{-1})
a_{Tn} : Response to changes in the soil
k_{LvA}, k_{LvB} : Rate of constant fraction of the larvae compartment (min^{-1})
k_{Sp} : Rate of constant fraction of the cattle compartment (min^{-1})
a_{Sp} : Response to the larvae development

2.3 Model methods

This software supports the development and statistical calibration of compartmental models describing a dynamic in a system and enables us to develop an agile and uncomplicated alternative structure of a model to fit with the result of the data [20]. This approach enables us to explore the data and to develop a new hypothesis to be examined by means of assays. The Simulation, Analysis, and Modeling (SAAM) software assisted the compartmental model to be presented in graphics using icons (Figure 1) and to drive the system automatically by means of employing a differential equation (Equation 1).

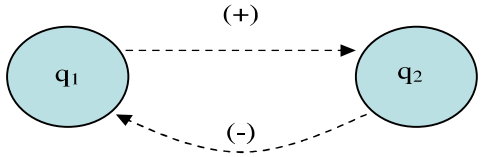

Figure 1 Schematic compartmental model using (SAAM II). [21]

2.4 Model development

2.4.1 Model for predicting annual rainfall

We began developing the model by creating a model to predict annual rainfall. This model aims to obtain the parameters predicted in the following simulation. The data was obtained from the Indonesian Agency for Meteorological, Climatological and Geophysical Agency in Aceh Province (Table 1).

Table 1 The average of rainfall in Aceh Province (2016-2017).

No	Month	Rainfall (mm/month)
1	October	350
2	November	250
3	December	212.5
4	January	175
5	February	150
6	March	137.5
7	April	125
8	May	125
9	June	75
10	July	90.6
11	August	106.2

Source: BMKG Aceh Province.

Data in Table 1 has been reorganised in order to follow the rainfall pattern from the highest to the lowest. In the model we developed, we assumed that rainfall has been influenced by several factors. Theoretically, there are factors affecting the rainfall: distance from water resource, differences in soil and water temperatures, wind direction, altitude, latitude, along with land and mountain areas. However, we simplified this model by dividing the factors into four compartments which influence each other.

By means of those simplifications, the rainfall factor in this model is presumed controlled by one key factor regulating interaction and fluctuation rates from three other compartments representing the amount of rainfall/unit time. Using this assumption, we developed the following differential equation:

$$dCH/dt = -k_{CH}CH\ (t) + CH_{awal} \quad (1)$$

$$dFL_A/dt = (-k_{fla}FL_A\ (t)\ CH\ (t)) + FL_{A\text{-}awal} + k_{flc}FL_C\ (t) \quad (2)$$

$$dFL_B/dt = -k_{flb}FL_B\,(t) + k_{fla}FL_A\,(t) \quad (3)$$

$$dFL_C/dt = -k_{flc}FL_C\,(t) + k_{flc}FL_B\,(t) \quad (4)$$

2.4.2 Model for larvae development and epg in faeces

In this model, we described the life cycle of the nematodes, from larvae to fertile adults, which transmit to and infect the cattle (Figure 2), as explained by [22]:

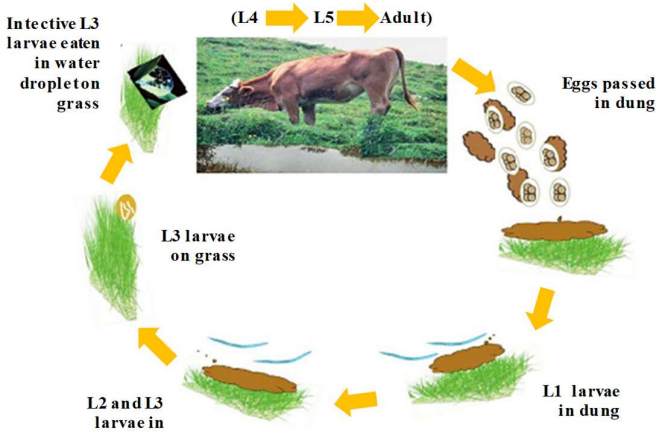

Figure 2 Nematode life cycle: nematode eggs contained in cattle faeces hatched to be infective larvae 1 (L1) on the soil and developed to be infective larvae, stage 2 and 3 (L2 and L3). They were eaten by the cattle and developed to be adults in the cattle's body (adopted from [22]).

As a result of the cycle described in Figure 2, we created a model with various simplifications, considering the difficulties in finding literatures explaining the process of the cycle.

We assumed that: (A) soil environment affects infective larvae development, (B) infective larvae have infected cattle through signal patterns, (C) infection caused by larvae determines the number of EPG in faeces, and (D) an increasing number of eggs followed by an increasing number of infective larvae. The assumptions were then described in the following differential equations:

$$dTn/dt = -k_{TnA}Tn(t) + a_{Tn}FLB\,(t) + a_{Tn}Lv\,(t) + -k_{TnB}Lv(t) + Lv_{awal} \quad (5)$$

$$dLv/dt \;\; = -k_{LvA}Lv(t) + a_{TnC}Tn\,(t) + a_{Lv}\,k_{LvB}Lv\,(t) \quad (6)$$

$$dSp/dt = -k_{Sp}Sp(t) + a_{SpB}Lv\,(t) \quad (7)$$

This model established that several factors such as soil environment changes, topography, humidity and soil pH were represented by Tn (Tn= soil) (Equation 5). The soil environment changes influenced by rainfall and additional environmental changes attributed to changes in larvae development, as represented by Lv (Equation 6). Subsequently, we needed to examine the infected cattle by releasing the nematode eggs represented by S (Equation 7), into the environment. In this compartment of the model, the development of the larva was indirectly affected by rainfall and additional environmental factors.

The simulation for EPG changes was initiated using 3500 nematode eggs. This simulation referred to the simulation developed by [23] by involving soil environmental changes ($k_{T}n_{A}Tn$) and the appearance of infective larvae ($k_{T}n_{B}Lv$) supported by the results of the rainfall and additional environmental changes ($a_{T}nFLB$), along with an increase in infective larvae ($a_{T}nLv$). Conversely, an increase in larvae population was influenced by environmental changes in the soil ($a_{T}nTn$). Furthermore, the reduction of infective larvae ($k_{L}v_{B}Lv$), is linked to undeveloped or mortal eggs ($k_{L}v_{A}Lv$, $k_{L}v_{B}Lv$) at phase L3.

We expected that this model could provide us with an explanation of the influence of infective larvae infestation ($k_{T}n_{B}Lv$) on the number of EPG in cattle faeces. The EPG produced was illustrated by the simulation model representing the infective larvae population dynamic in the soil. Therefore, in equation 6, we assumed that the population dynamic of the larva to fertile adults via the signal pattern was described as an infestation of infective larvae ($a_{S}pLv$), where we decided that the changes in the rainfall, soil environment and additional environmental factors also play a vital role in the infestation. The decrease in EPG in faeces was also influenced

by an unknown factor (k_SpSp). Therefore, by way of this response, the number of eggs released into the environment can be examined, as a result of equation 7.

The study of infective larvae affected by rainfall and environmental changes has contributed to an innovation: control strategy for GIN in cattle during larvae development/infective eggs. Accurate data regarding rainfall and temperature are important to predict the existence of nematode larvae on grassland, contributing to an increase in nematodiasis in cattle.

2.5 Data resource for the model

Data for modelling were obtained by observation in the field and also from several literature and references related to model development for GIN in cattle [23,24,25]. Other parameters were added post-simulation.

2.6 Software

This research developed a simulation model using SAAM II software [20] supported by the Runge-Kutta integrator and by the Gauss-Newton modification method for optimisation.

3. Results and discussion

3.1 Matching the rainfall factor to the model

Figure 3 presents the average rainfall in Aceh Province after analysis using SAAM II software. This result was subsequently analysed based on the coefficient variation (CV). The result illustrates that most of the parameters retained a coefficient variation <20% and an evaporating rainfall rate >20%. The results indicate that the parameters possessed good values, which can be utilised to develop the subsequent model.

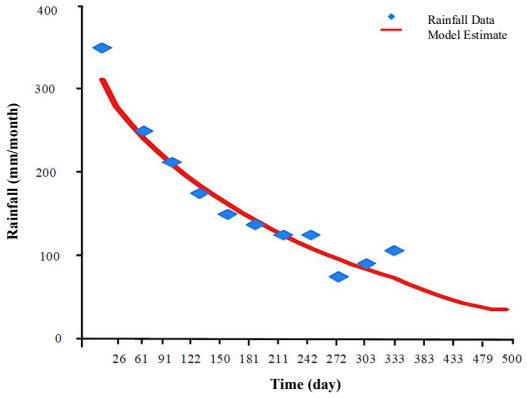

Figure 3 Simulation of the rainfall factor using SAAM II software.

Table 2 The rainfall factor value and its coefficient variation (CV).

Parameters/Unit (mm^{-1})	Value	CV (%)
kCCH: Constant rate of the additional rainfall factor	3583	11.27
kKCH: Rainfall intensity at the initial simulation	2,897.23	22.03*
kACH: Constant rate of the additional rainfall factor	285.64	12.29
kBCH: Constant rate of the additional rainfall factor	436	11.27

3.2 An environmental factors model on EPG increase

This model refers to the environmental factors influencing the increase in the EPG in faeces via the simulation by administering a dose of 3500 to L3 as a stimulator. In this stage, the model was developed by examining the changes in several parameters assumed to be environmental factors. Initially, the simulation works on the parameter evaluating the increase in EPG in faeces.

The primary aim of this parameter was to obtain the EPG the simulation data and match it with data obtained from the field. The simulation indicated that there was an increase in EPG by 1000 eggs at day 26 (Figure 4 A). Regarding the data obtained from the field (lowland area), the data is slightly similar, 1006 eggs (Table 3).

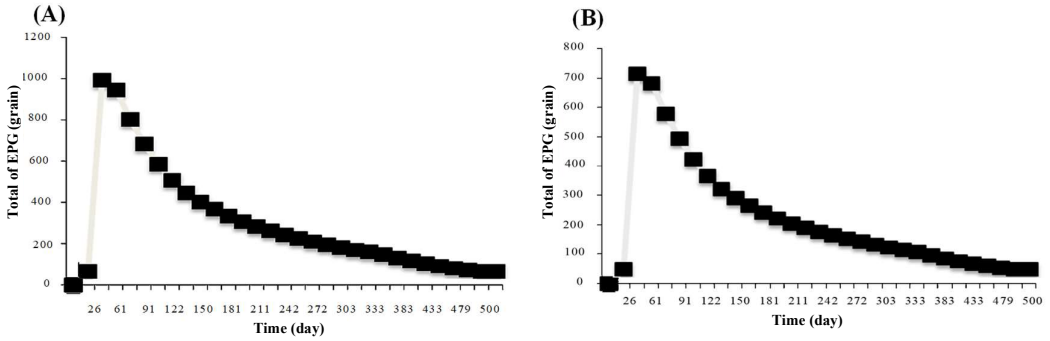

Figure 4 Result of the simulation developed by considering the changes in parameters assumed to be environmental factors, (A) describing the dynamics of EPG in cattle faeces in (A) the lowland area and (B) the highland area.

Simulation was repeated to describe the number of EPG in faeces in the highland area (Figure 4 B). Referring to the data obtained from the field (Table 3), where EPG = 727, the data in the simulation model is similar and reached up to 720 eggs at day 26.

Table 3 Data obtained from the field (lowland and highland areas) in Aceh Province.

Parameters	Value earned	
	Lowland	Highland
Rainfall (mm/year)**	1696	1682
EPG	1006	727
Total of EPG per cattle	230	255
Wet season (year)**	137	146
Topography (masl)*	25.1	1051
Humidity (%)*	71.1	60.4
Prevalence (%)	32.9	12.7
Temperature (°C)*	31.7	29.5
Soil pH *	5.7	5.9

Data were collected from: *field experiments (2017) and **BPS Aceh.

A simulation model to attain the changes in parameters at *aL2* and *aSp* and to examine the changes in parameters creating an increase in EPG in faeces, as presented in figure 5.

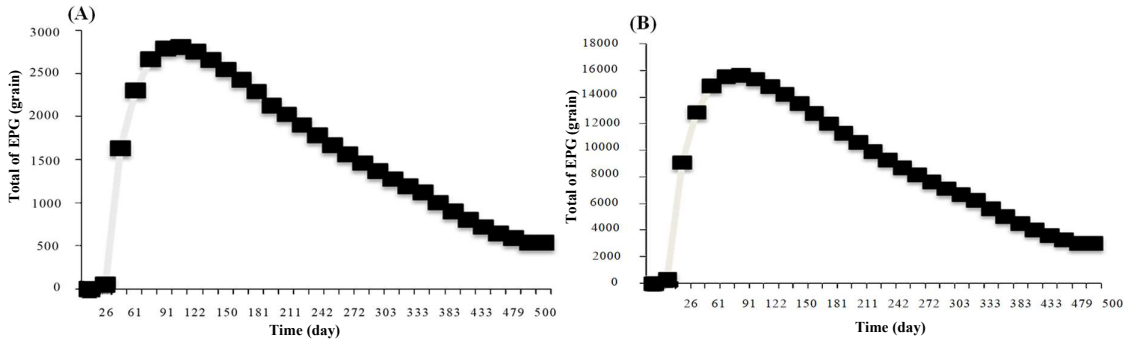

Figure 5 Results of the simulation developed by considering the changes in parameter (A) aL2 (10) and (B) aL2 (10) aSp (0.1) assumed to be environmental factors, describing an increase in EPG in cattle faeces.

Figure 5 illustrates a greater increase in EPG by 2810 eggs. However, the rate slowed down for 91 days. The result of this simulation was obtained by changing the parameter values of aL2 and aSp. The results reveal that the larvae stimulated by the initial 3500 eggs, reduced faeces excretion in 20 days. This finding agrees with the research of [26] who determined that the life cycle of GIN can take 15 days, whilst [27,28], mentioned that those nematodes can hatch in 2-7 days after being excreted onto soil.

The increase in excreted eggs occurred after the stimulation of L3 eaten by cattle through the feed (grass), where it was observed that three weeks after eating the larvae, there is an increase of EPG in faeces [29]. The interaction between parasites in the cattle was not only influenced by the correlation between the environment (climate), host and their life cycle, but also other factors, such as nematode population. The fluctuation in EPG appeared in cattle prior to giving birth, changes in the production system, traditional care of the cattle, cage sanitation and inappropriate treatment of the cattle [30].

Based on the results obtained from this model, we can explain that there were several alternatives in controlling GIN, for instance intensive nurturing of vulnerable cattle in an unpredicted season by prohibiting cattle grazing outside during the development of GIN. This treatment can prevent cattle from being infected. Integrated control can be employed as an alternative to control GIN by observing the development of larvae in the field and reducing the grazing on grassland where the grazing period is for 1 week only and 4-5 weeks in the cowshed and when being fed [31,32].

Environmental control is essential to inhibit parasite growth, including the growth of GIN. Climatic changes play a considerable role in parasite development, together with the host-parasite and host population dynamics [30,33-35]. Moreover, grassland and cowsheds also significantly contribute to the dynamics of disease appearance.

Integrated control can be applied by zero-grazing and by improving farmers' skills by way of presentations and training programmes pertaining to parasite control. It is crucial because parasites vary from time to time, depending on the location and condition where the parasites live. The application of an anthelmintic followed by health surveillance supported by a health officer can prevent cattle from being infested and minimise GIN growth. The development and innovation in the cattle care model and nurturing can also contribute to the reduction of GIN in cattle.

Based on the data analysis, it was determined that there were disadvantages associated with the model we developed, particularly in providing the various parameters related to climatic changes and environmental factors affecting the growth of GIN and also the difficulties in obtaining rainfall and temperature data in a short time span (daily or weekly), as most were provided as monthly data. Similarly, the limited data and literatures related to GIN development hindered our ability to complete the model. Therefore, several data needed to be estimated using the researchers' assumptions. The researchers' assumptions assisted us to model related environmental controls on the dynamics of nematode infestation in cattle on the highlands of Aceh Province. Concerning the environmental factors observed, such as the movement and development of nematode larvae, sustainable disease control can be developed. We believe that further research observing GIN integration patterns in cattle, including cattle raising management are essential if progress is to be made in combatting this critical issue.

4. Conclusion

The model enabled the changes in EPG in faeces affected by the changes in rainfall to be estimated. Additionally, the management of an increase in EPG can be applied by considering several parameters which are assumed to be environmental factors. By evaluating the EPG route outside the cattle's body, disease control can be correctly organised.

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