HAYATI Journal of Biosciences 24 (2017) 142–148

Contents lists available at ScienceDirect

HAYATI Journal of Biosciences

journal homepage: http://www.journals.elsevier.com/hayati-journal-of-biosciences

Original Research Article

Where did Venomous Snakes Strike? A Spatial Statistical Analysis of Snakebite Cases in Bondowoso Regency, Indonesia

Farid Rifaie,[1*] Tri Maharani,[2] Amir Hamidy[3]

[1] Biodiversity Information Center, Research Center for Biology, Indonesian Institute of Sciences, Cibinong, Bogor, Indonesia.
[2] Faculty of Medicine, University of Brawijaya, Malang, Indonesia.
[3] Zoology Division, Research Center for Biology, Indonesian Institute of Sciences, Cibinong, Bogor, Indonesia.

ARTICLE INFO

Article history:
Received 18 April 2017
Received in revised form
5 September 2017
Accepted 8 September 2017
Available online 29 September 2017

KEYWORDS:
envenomation,
geocoding,
point pattern analysis,
spatial epidemiology

ABSTRACT

Snakebite envenomation in Indonesia is a health burden that receives no attention from stakeholders. The high mortality and morbidity rate caused by snakebite in Indonesia is estimated from regional reports. The true burden of this issue in Indonesia needs to be revealed even starting from a small part of the country. Medical records from a Hospital in Bondowoso Regency were the data source of the snakebite cases. Three spatial statistical summaries were applied to analyze the spatial pattern of snakebite incidents. The comparison between statistical functions and the theoretical model of random distributions shows a significant clustering pattern of the events. The pattern indicates that five subdistricts in Bondowoso have a substantial number of snakebite cases more than other regions. This finding shows the potential application of spatial statistics for the snakebite combating strategy in this area by identifying the priority locations of the snakebite cases.

1. Introduction

Snakebite envenomation is a recurrent medical emergency that causes serious illness and fatality. Victims surviving this deadly hazard suffer from physical and psychological sequelae (Gutiérrez *et al.* 2006; Cruz *et al.* 2009; Warrell 2010a; Williams *et al.* 2010). Snakebite incidence in developed countries is well managed and the casualty can be reduced substantially (Currie 2000; Cruz *et al.* 2009; Brown 2012). In contrast, snakebite is responsible for many casualties in developing countries, particularly in tropical regions of Asia, Africa, Latin America, and New Guinea (Chippaux 1998; Harrison *et al.* 2009; Williams *et al.* 2010; Gutiérrez *et al.* 2013). Agricultural workers are the most vulnerable population group to snake encounter when they are active in the field. This makes this hazard a public, occupational, and environmental health problem (Gutiérrez *et al.* 2006; Cruz *et al.* 2009; Harrison *et al.* 2009; Gutiérrez *et al.* 2010; Williams *et al.* 2010)

Nevertheless, public health authorities across the globe share limited recognition to this problem (Gutiérrez *et al.* 2006; Gutiérrez *et al.* 2010). Global attention to snakebite control and research program is disappointingly low (Cruz *et al.* 2009; Brown 2012; Gutiérrez *et al.* 2013). Efforts to gain support from global health communities are hindered by the lack of reliable epidemiologic data (Gutiérrez *et al.* 2010; Warrell 2010a). The legitimate extent of snakebites incidence is difficult to estimate because most cases are not reported (Belt *et al.* 1997; Chippaux 1998; Cheng & Currie 2004). In many developing countries, many victims opt to seek traditional medicine when they experience a snake attack (Chippaux 1998; Cruz *et al.* 2009). Therefore, the true burden of this issue is difficult to quantify (Alirol *et al.* 2010; Warrell 2010a).

An effort to cure the negative effects of snake toxins was started in 1892 when Albert Calmette developed antivenom treatment for snakebite (Cheng & Currie 2004; Williams *et al.* 2011). Since then, antivenom has been known as the most effective remedy for snake envenoming (Cruz *et al.* 2009; Warrell 2010a; Williams *et al.* 2011). Ironically, people who need it most generally cannot access this treatment. Firstly, they were not aware that antivenom was available or preferred the traditional healing (Warrell 2010a; Brown 2012). Secondly, they were unable to purchase the antivenom or to access the nearest health services because of remoteness of the location or high transportation costs (Belt *et al.* 1997; Rahman *et al.* 2010; Williams *et al.* 2011; Brown 2012). This situation is aggravated because of the lack of interest

* Corresponding author.
E-mail address: farid.rifaie@lipi.go.id (F. Rifaie).
Peer review under responsibility of Institut Pertanian Bogor.

https://doi.org/10.1016/j.hjb.2017.09.001

to advance antivenom technology by governments and pharmaceutical industries (Belt *et al.* 1997; Rahman *et al.* 2010; Brown 2012; Alirol *et al.* 2015). As a consequence, crisis in antivenom supply emerged particularly in Africa and Papua New Guinea and followed by unscrupulous marketing of unsafe and low-quality products (Theakston & Warrell 2000; Williams *et al.* 2011; Brown 2012; Alirol *et al.* 2015).

Snakebite cases would decline if snake encounter incidents could be avoided. This belief stimulated eradication campaigns of venomous snakes, which showed encouraging results in many parts of the world (Warrell 2010a). Nevertheless, this method had atrocious aftermaths where rats population were uncontrolled; and as a result, crops were devastated and outbreak of animal-borne diseases were rampant (Warrell 2010a). Promoting saver behaviors to community members is a better approach to reduce unexpected snake encounters by villagers (Gutiérrez *et al.* 2010; Warrell 2010a). Simple habits such as protecting lower legs and feet by using appropriate shoes, using flashlight or torch at night, and sleeping under a mosquito net are effective measures to minimize the risk of venomous snake (Warrell 2010a; Gutiérrez *et al.* 2013). Villagers show ambivalent attitudes toward these simple methods, but the methods have been applied in many regions with encouraging results.

An attempt to assess the global burden of snakebite was started in 1954 when Swaroop and Grab (1954) estimated that globally there were 30,000–40,000 deaths from snakebite per year. However, they recognized that this figure underestimated the real mortality rate because it was calculated based on hospital records and excluded central Europe and north Asia. In 1998, epidemiologic publications were used to extrapolate point incidences from areas within countries and suggested that more than 5 million snakebite incidences worldwide every year and cause 125,000 mortalities (Chippaux 1998). Latest appraisal based on epidemiologic literature, World Health Organization mortality data and gray literature estimated very wide ranges per year, 20,000–94,000 deaths from as high as 5.5 million snakebites (Kasturiratne *et al.* 2008). Nonetheless, both studies retain pitfalls in which the heterogeneity of the snakebites incidence within and between countries was neglected (Warrell 2010a). Household survey is a method that provides a much clearer figure about the true scale of this disease (Rahman *et al.* 2010; Mohapatra *et al.* 2011). National household surveys in Bangladesh and India suggested that mortality rate from snake envenoming can be three-fold higher than the latest global assessment in 2008 (Rahman *et al.* 2010; Mohapatra *et al.* 2011). Other national studies in Nigeria and Costa Rica confirmed that national snakebite epidemiology study provided a better picture of this issue (Sasa & Vazquez 2003; Nasidi 2007).

Indonesia is one of the countries that experience deficiency of knowledge of the snakebite envenoming where national epidemiology report is non-existent (Adiwinata & Nelwan 2015). Two peer reviewed publications only showed three snakebite records in Western Java and East Nusa Tenggara. Belt *et al.* (1997) during his fieldwork found 26 snakebite cases particularly by Russel's viper in Komodo, Rinca, Flores and Adonara Islands. In other hand, Adiwinata and Nelwan (2015) revealed 180 cases of snakebite in Bandung, West Java (1996–1998) and 42 cases in Jakarta (2004–2009) based on gray literatures. Without factual epidemiologic data, an integrated strategy that comprises preventive education, health workforce training, antivenom development and distribution cannot be established accordingly (Williams 2004; Gutiérrez *et al.* 2013).

It is important to realize that several key elements of the integrated strategy proposed by Gutiérrez *et al.* (2013) have strong geographic dimensions. The strategy will work properly if the target areas can be localized rigorously. One method that gains more recognition analyzing location-related phenomenon is geographic information system (GIS) (Gutiérrez 2016). The importance of geospatial data underpinning epidemiology and public health investigation can be traced back to John Snow's maps of cholera cases in London (Beletsky *et al.* 2016). A study in Costa Rica showed the application of GIS tools to understand a detailed variation of snakebites ratio between regions and locations regarding the accessibility condition to evacuate snakebite victims to a health center (Hansson *et al.* 2013).

The interest to study spatial pattern of disease prevalence and mortality led to the emerging of spatial epidemiology (Elliott & Wartenberg 2004; Waller & Gotway 2004; Ostfeld *et al.* 2005). In addition, the advancement of spatial epidemiology is bolstered by the integration of spatial statistics into GIS software (Jacquez 2000; Sipe & Dale 2003). Spatial statistics quantify geographic variation in geographic variables (Jacquez 2000), and suitable to identify disease clusters, separate pattern from noise and assess the significance of potential exposure (Waller & Gotway 2004). In brief, spatial statistical methods reduce spatial patterns to a few clear statistical inferences (Waller & Gotway 2004; Ripley 2005).

This article describes the use of spatial statistical methods to analyze the spatial patterns of snakebite incidence based on hospital registration in Bondowoso, Indonesia. An epidemiologic study of snakebite cases in one Indonesian regency would be an initial step toward unveiling the real picture of this problem in the country. Moreover, the implementation of spatial patterns analysis of snakebite incidence in Bondowoso could lead to an integrated action plan combating snakebite issue in a wider area in Indonesia. Therefore, the main objective of this study was to evaluate the spatial pattern of snakebites cases in Bondowoso, Indonesia and analyze its implementation for the prevention and management of this peril.

2. Materials and Methods

2.1. Study area and data

Bondowoso is a regency in East Java, Indonesia where its easternmost border with Banyuwangi Regency is only about 20 km away from Bali Strait. This regency is also bordered with Situbondo in the north and west and Jember in the south (Bondowoso 2015). The area of this regency is approximately 1560.10 km^2 and the population is around 757.000. Forty-one percent of people above 15 years old who have an occupation are working in the agriculture, forestry, and husbandry sectors (Bondowoso 2015).

Bondowoso is situated between three volcano complexes, Mount Argapura in the west, Mount Raung in the southeast and Mount Ijen in the east. The highest peak in this regency is 3287 m above sea level (masl) and the lowest point is only 73 masl. The average annual rainfall in this region is around 3000 mm, with the wettest occurs in January and the driest occurs in August. The regency consists of 23 subdistricts, where a community health center (Pusat Kesehatan Masyarakat/Puskesmas) can be found in each subdistrict. In addition, a public hospital (Dr H Koesnadi Public Hospital) is located in the capital of Bondowoso Regency.

The hospital has implemented the guideline for the management of snakebites (Warrell 2010b) since January 2015. As a consequence, the documentation of snakebite cases in this region was well administered on the medical records. The address of the victims was also registered in the records and was used as a proxy for the location of the snakebite incident. In addition, some patient mentioned the activity and detailed location of the incident. The geocoded data were then used for the spatial statistical analysis of snakebites during 2015 in Bondowoso.

2.2. Georeferencing snakebites data

Disease control in developing countries meets challenges due to lack of well-managed facilities such as paved streets, sewage systems and a reliable address system (Chang *et al.* 2009). The paucity of street names and house numbers in rural and newly developed areas conceives predicaments during emergency situation such as susceptible areas identification, site selection for health facilities and resources deployment (Chang *et al.* 2009; Beletsky *et al.* 2016). The inadequacy of reliable base map exacerbates effort to transform address data into geographic coordinates. High-resolution satellite imagery that can be accessed from GoogleEarth (Google Inc. Mountain View, CA, U.S.) is an alternative approach for urban and rural areas identification (Chang *et al.* 2009; Beletsky *et al.* 2016). Other advancements in the GIS technology that support spatial health application include open source GIS software (QGIS) and participatory mapping (OpenStreetMap) (Haklay & Weber 2008; OpenStreetMap contributors 2015; QGIS Development Team 2016).

The transformation of snakebite cases based on patients address into geographic coordinates system harnessed the capability of QGIS integrating all these spatial data resources. Administration boundaries map up to village level was loaded into QGIS along with Google satellite image and OpenStreetMap data from OpenLayers plugin. The position of a snakebite incident was located in the middle of a village polygon. When a patient provided a more detailed location of the occurrence, such as on a paddy field, by the river or a path, the Google satellite image and OpenStreetMap were used to identify this more specific site.

Although some patient address incorporated house number and street name, but the unavailability of reference map hindered geolocating process as far as the house position. As a consequence, this geocoding process constitutes error or uncertainty (Wieczorek *et al.* 2004; Guralnick *et al.* 2006). The uncertainty indicates the level of accuracy and precision of the geocoding process. Most of the uncertainty source in this study was the extent of the village (Wieczorek *et al.* 2004). The uncertainty was determined by calculating the radius of a circle from the point to the maximum distance of an administration boundary (Wieczorek *et al.* 2004; Garcia-Milagros & Funk 2010). When a more detailed location was described, the radius of uncertainty would be shorter, which indicates a better accuracy of the point determination.

2.3. Spatial statistical analysis of snakebite incidents

Spatial distribution of points representing certain geographic phenomenon presents valuable information on various aspects of their occurrence (Haase 1995; Bivand *et al.* 2013). The summary statistics of spatial points distribution may disclose processes underlying observed point arrangement (Wiegand *et al.* 2013; Velázquez *et al.* 2016). Statistical inference of spatial data presents a brief and concise description of an event (Illian *et al.* 2008; Wiegand *et al.* 2013). Therefore, information contained in the spatial pattern is reduced into single number or function (Velázquez *et al.* 2016). The implementation of numerous summary statistics accommodates multiple aspects of a point pattern to be obtained (Wiegand *et al.* 2013; Velázquez *et al.* 2016).

Summary functions were developed based on measuring the distance between points and can be categorized into nearest neighbor distances, empty space distances and pairwise distances (Baddeley 2010). A function that measures the distribution of distances from an arbitrary point to its nearest event is G function (Baddeley 2010; Bivand *et al.* 2013). On the other side, F function measures the average space left between events and represents the empty space distances (Baddeley 2010; Bivand *et al.* 2013). Both summary statistics characterize the expected value of distribution (intensity) of a point pattern throughout the area, which indicate the first-order spatial distribution process (Wiegand & Moloney 2004; Perry *et al.* 2006; Zhang *et al.* 2014). In contrast, second-order summary statistics illustrate that the spatial covariance of pairs of points and all inter-point distances within radius r are considered on the calculation (Velázquez *et al.* 2016). A function that represents second-order properties of a point pattern is Ripley's K function (Zhang *et al.* 2014). The K function calculates the number of points within a given distance (Baddeley 2010; Bivand *et al.* 2013). The three functions were used to draw summary of key statistical properties of the snakebite cases in Bondowoso. In addition, basic statistical method to measure geographic distribution such as mean center and standard distributional ellipse were evaluated to provide a better picture about snakebites distribution patterns.

The implementation of a null hypothesis would be the next step of spatial point pattern analysis (Wiegand *et al.* 2016). A stochastic null model is a representation of events with a uniform and independent distribution on a region (Gatrell *et al.* 1996; Perry *et al.* 2006; Ngowi *et al.* 2010; Bivand *et al.* 2013). This theoretical model for a spatial point pattern is known as complete spatial randomness (CSR; Bivand *et al.* 2013). Under this circumstance, nonrandom patterns can be either clustered (aggregated) or regular (dispersed) (Haase 1995). Nevertheless, the hypothesis of CSR is improbable in various environments because of the nature of the event (Diggle & Chetwynd 1991; Ngowi *et al.* 2010). In an epidemiologic context, the characteristic of population density, which varies across space, is the main factor allowing an event departs from the CSR. When an event is observed to have a spatial clustering, it could be due to the natural background variation in the population or a real biological effect (Ngowi *et al.* 2010). In this circumstance, the stochastic null hypothesis can be described as no spatial clustering (Ngowi *et al.* 2010; Wiegand *et al.* 2016).

Model testing is the final step of a point pattern analysis that would reveal whether the empirical summary function is consistent with the null hypothesis or indicates significant departure at certain spatial scales (Wiegand *et al.* 2016). The simulation envelope approach is the most well-known model testing (Velázquez *et al.* 2016; Wiegand *et al.* 2016). Simulations of multiple random point patterns were generated according to CSR and produce the maximum and minimum empirical values (Baddeley 2010; Baddeley *et al.* 2014; Velázquez *et al.* 2016; Wiegand *et al.* 2016). The region between the highest and the lowest value is typically indicating the 2.5^{th} and 97.5^{th} percentiles of the null model and presented in a gray shade (Baddeley 2010; Wiegand *et al.* 2016). In this study, the envelopes were constructed based on 99 simulations of random point patterns. The empirical summary statistic was plotted in a solid black line and would show a distinct evidence whether it consistence with or wanders outside the simulation envelopes.

3. Results

In 2015, there were 61 victims of snakebites and admitted to Bondowoso Public Hospital. However, one patient came from Situbondo Regency and therefore was excluded in this analysis. All victims showed a unique ID card number, name and address that suggested there was no patient suffered from snake attack for multiple times in a different period.

The addresses of all victims were well documented not only up to village level, but also smaller informal administration unit such as Neighborhood Association (Rukun Tetangga) and Community Association (Rukun Warga). Nevertheless, the geocoding of the address could not accommodate this information because there has not been any geographic reference of that administration unit across Indonesia. Twenty-three patients gave more detailed information about the location of incident (13 cases in paddy field, 4 cases in banana or coffee plantation and 6 cases in or around their houses). The geocoding process produces uncertainty values between 0.25 and 7 km with the average value of 1.8 km.

Furthermore, there were only 31 victims who indicated their occupation, in which 23 of them are farmers or temporary workers who work in agricultural areas. The remaining eight victims are employees of private companies, domestic workers, and students. The number of cases per month varied between two incidents (October 2015) and nine incidents (July 2015), and the average is five cases per month. The bar charts of monthly snakebite occurrences in Bondowoso (Figure 1) show that the prevalence of snake attacks are higher in the dry season (April to August).

Unfortunately, only 24 patients provided information that led to identification of the snake. The white-lipped pit viper (*Trimeresurus albolabris*) is the most dominant snake in which 19 people became the victim of this species. In contrast, only four patients were bitten by the Javan spitting cobra (*Naja sputatrix*) and one person was attacked by the Malayan krait (*Bungarus candidus*). The snakes bit more hands (32 people) than legs (15 victims) or heads (2 persons). The medical record did not indicate which part of the body was bitten by snake for other 13 patients. Almost all victims described that they accidentally encountered the snake when they were working or passing by the locations of the snakebites. Only 2 persons recounted that they actively confronted the snake which then led to the accident. Nonetheless, there was no indication that a victim was intently looking for a snake for a commercial reason.

The incidence of snakebites took place in 43 villages, which are under the administration of 15 subdistricts. Figure 2 shows the distribution map of snakebite cases in Bondowoso. The map illustrates that there is a clear clustering pattern in Bondowoso, Tenggarang, and Curahdami subdistricts, in which 20, seven and five incidents were recorded, respectively. The position of the mean center is in Tenggarang subdistrict, and the standard deviational ellipse orientation is aligned with the position of the three subdistricts. Other subdistricts that have high number of cases are Tlogosari and Pujer with six and four cases, respectively. The two subdistricts are in the eastern end of the standard deviational ellipse. Moreover, 44 points are located inside the standard deviational ellipse area, and 16 others are outliers. Although most outliers are situated around the standard deviational ellipse, three points are located in Botolingo and Klabang subdistricts in the northeastern part of the regency.

Three summary statistics applied in this study show significant pattern of departure from the CSR. Figure 3 indicates the comparison of empirical functions ($\widehat{G}(r)$, $\widehat{F}(r)$, and $\widehat{K}(r)$) to their respective theoretical expectation (red dashed line) and simulation envelopes

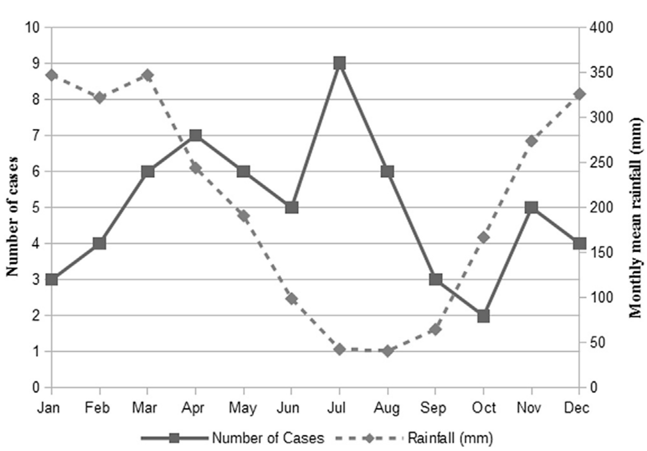

Figure 1. Patterns of snakebite cases and monthly average rainfall in Bondowoso.

(gray shade). The graph suggests that all empirical functions show a significant clustering pattern. The G and Ripley's K functions demonstrate that the observed point pattern starts departing the envelopes from that of the finest scale (0–100 m). On the other hand, the empirical F function leaves the envelope at 1 km scale. Although the observed K function of the snakebite cases is getting further away from the envelope as the distance is increasing, the G and F empirical functions are getting closer to the null model at 2 and 5 km scale, respectively.

Summary statistics that represent nearest neighbor, empty space, and pairwise distances confirm that there is a significant aggregation pattern of snakebites in Bondowoso Regency. This result is consistent with the basic spatial statistic parameters that exhibit the aggregation of incidents in Bondowoso, Tenggarang, and Curahdami subdistricts. This region is lowland area (250–300 masl) where the dominant land use is rice field. Bondowoso subdistrict is the most populated area with over 67,000 inhabitants (Bondowoso, 2015). Likewise, Tlogosari and Tenggarang have more than 40,000 populations, which make them among top five populated areas in Bondowoso Regency.

4. Discussions

Indonesia is a tropical country with most populations relying on agricultural sector. This condition makes snakebite one of the major predicaments for most Indonesian populations. Nonetheless, national data about snakebite incidents is not available and the fatality rates were only estimated based on regional data (Chippaux 1998; Kasturiratne *et al.* 2008). Efforts to bring awareness to as many stakeholders as possible must be initiated before any snakebite prevention and management programs can be implemented. The improvement of medical records of snakebite cases that follow the guidance from World Health Organization (Warrell 2010b) is the first step to unveil the legitimate state of this burden in Indonesia. In 2015, Bondowoso Public Hospital started this effort and Ministry of Health, East Java regional office is duplicating this implementation to other public hospitals.

The medical records of snakebite patients provide myriad valuable data, including spatial data in the form of patients address. The geocoding of the patients address into geographic coordinate is based on an assumption that the accident occurred within territory of the village of the victim. This premise posses weakness because a victim could be working or traveling in neighboring village when a venomous snake stroke. In addition, the points are located in the center of the village, but rice field and populated area are spread throughout the village territory. The average of uncertainty that reach 1.8 km and the maximum uncertainty of 7 km pinpoint the level of accuracy of the geocoding process.

In Indonesia, there are informal administration units smaller than village. Neighborhood Association and Community Association are two informal administration units, which their existence is endorsed by Indonesian government and accommodated in the Indonesian ID card address system. As a consequence, these administration units are documented in the patient's medical record. Unfortunately, there is no reference map that contains the geographic coordinate of these administration units. In contrast, people in rural area recognize Kampung or Dusun (hamlet) as an entity of single residential area. The information of geographic location of hamlets can be found in the Indonesian topography map, but the medical records do not contain data about hamlet where the patients reside. The acquisition of community association coordinate data through volunteered geographic information will be the focus of the future research. In the same way, the collection of locality details such as the name of hamlet and more precise description of the locality details such as the

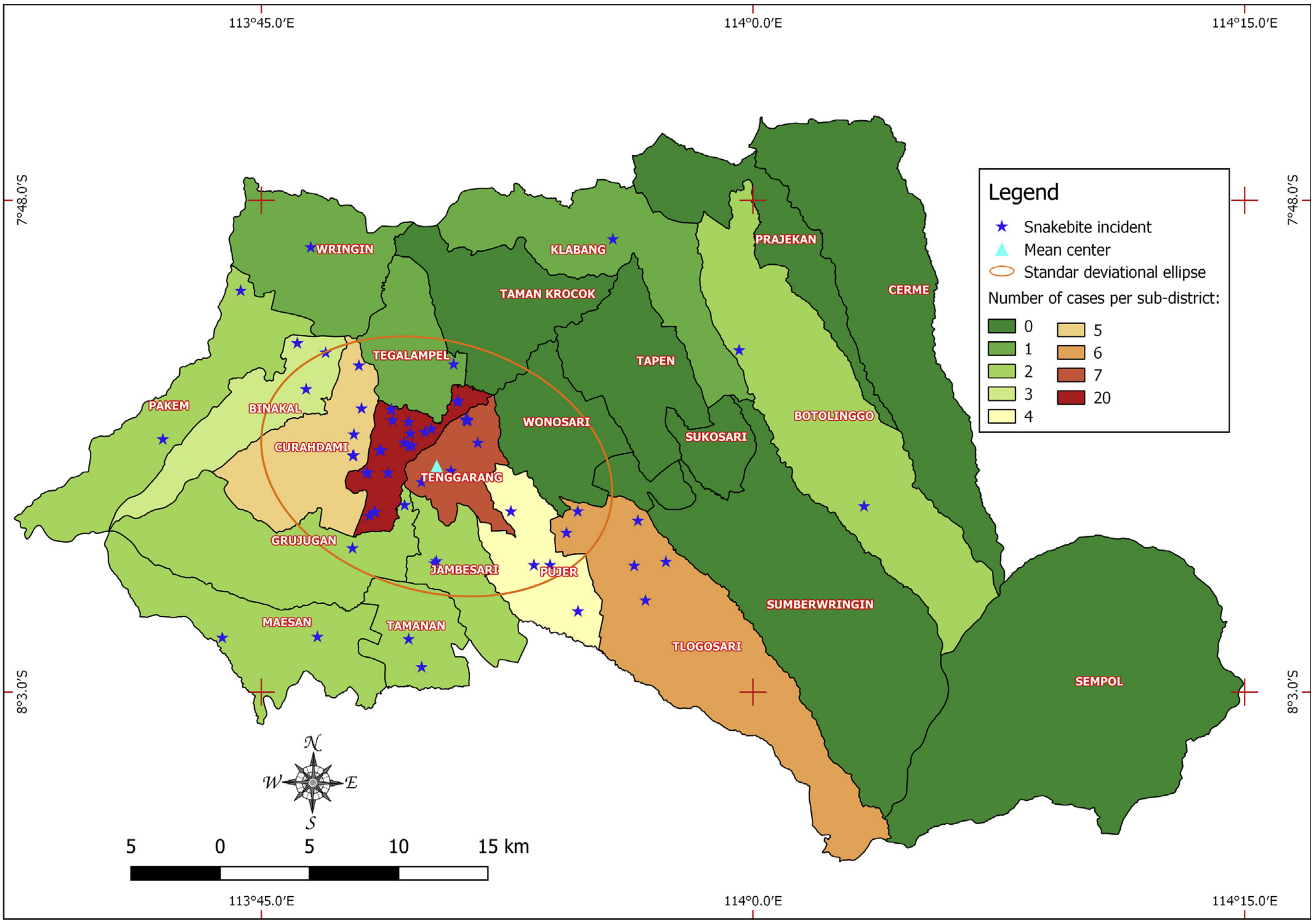

Figure 2. The distribution map of snakebite incidents in Bondowoso with basic statistical information.

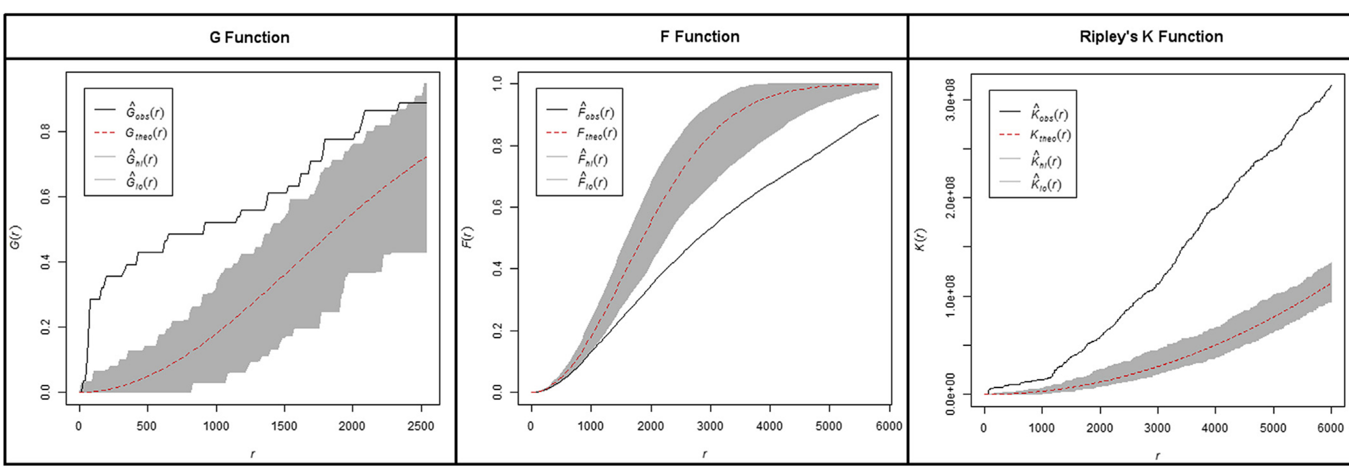

Figure 3. Three summary statistics that show the departure of empirical functions (black lines) from the null model (gray areas), the red dashed line illustrates the theoretical function.

orientation and distance of the rice field from the nearest hamlet must be included in the medical record. This additional information could reduce the uncertainty value below 500 m.

Nevertheless, the point pattern of snakebites in Bondowoso shows a clear clustering pattern in the southwest part of Bondowoso Regency. The standard deviational ellipse indicates that five neighboring subdistricts, which are in a line from west to east, suffer more incidents than other subdistricts. Forty-two snakebite victims are from Bondowoso, Curahdami, Tenggarang, Pujer, and Tlogosari subdistricts, compared with only 18 victims from the remaining subdistricts. This is supported by three summary statistics that show departure from simulation envelopes with 96%

level of confidence. Although G and F functions display reconciliation with the null model in the furthest and finest scale, respectively, but they diverge from the simulation envelopes in most distances. In contrast, Ripley's K function demonstrates the clustering distribution in all scales, and the observed summary function wonders further away as the distance increases.

The five subdistricts with higher snakebite incidents are located in the foot slope of Mount Argapura and Mount Raung. Fertile volcanic soil combining with the availability of water from the mount springs makes this region an excellent agricultural land and also a suitable habitat for venomous snake species. A higher population of venomous snake particularly white-lipped pit viper in five subdistricts is an interesting fact that would be the subject of a future research. The fact that most victims were bitten in the hand suggests that people are inadvertent with the presence of a snake when they are working or playing in the field. Therefore, prevention efforts should become the priority by delivering educational campaigns and the promotion of first aid intervention (Gutiérrez *et al.* 2013). The campaign should emphasize the awareness of people about the abundance of venomous snakes in their area, the locations and situations with high probability of snake encounter, the utilization of boots and gloves to protect legs and hands, and the knowledge of snakebite emergency management. The public health centers, which can be found in every subdistrict, could become the base for this campaign. The preparedness of health workforce in the five subdistricts public health centers to manage snakebite cases should become the priority of the alleviation of this burden. Correspondingly, the availability of antivenom in this region must be secured ensuring all people suffering envenomation from snakebite receive a suitable treatment (Gutiérrez *et al.* 2013).

The seasonal pattern of snakebite cases in Bondowoso differs from the patterns in Bangladesh and India where the snakebite cases have a positive relationship with the precipitation and temperature (Rahman *et al.* 2010; Mohapatra *et al.* 2011). In Bondowoso, the highest number of snakebites occurs during the dry season from April to August, in which the monthly average rainfall is low. In addition, the temperature in Bondowoso does not fluctuate considerably (the lowest is 23.6°C on July and the highest is 25.4°C on November), which indicates no strong relationship between snakebites and temperature.

The only possible reason for higher incidents in this season is that more agricultural activities take place during the dry season (Rahman *et al.* 2010). During this period, a transition between harvesting the rice, leaving the field barren for several weeks and beginning a new crop season makes more people active in rice fields. It is common for Javanese villagers to play or collect grass for their cattle when the rice fields are barren. There was no evidence that the victim is a snake hunter who tried to capture the snake. It is more likely that the combination of high populations and agricultural activities make more snake encounters in these subdistricts. The situation in Bondowoso, Indonesia is congruous with the condition in most developing countries in which farmers are the most vulnerable population group to snake envenomation.

Conflict of Interest Statement

All authors have no conflicts of interest to report.

Acknowledgements

The authors thank the director of the Dr. H. Koesnadi Hospital, Bondowoso and the head of Subdivision of Collaboration and Information, Research Center for Biology for supporting this research collaboration. They also thank Sri K. Wijaya for reviewing the early English manuscript and the reviewers for constructive feedbacks. This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

References

Adiwinata R, Nelwan E. 2015. Snakebite in Indonesia. *Acta Med Indones* 47:358–65.
Alirol E, Lechevalier P, Zamatto F, Chappuis F, Alcoba G, Potet J. 2015. Antivenoms for snakebite envenoming: what is in the research pipeline? *PLoS Negl Trop Dis* 9, e0003896.
Alirol E, Sharma SK, Bawaskar HS, Kuch U, Chappuis F. 2010. Snake bite in South Asia: a review. *PLoS Negl Trop Dis* 4:e603.
Baddeley A. 2010. Analysing spatial point patterns in R. Australia: CSIRO, Australia.
Baddeley A, Diggle PJ, Hardegen A, Lawrence T, Milne RK, Nair G. 2014. On tests of spatial pattern based on simulation envelopes. *Ecol Monogr* 84:477–89.
Beletsky L, Arredondo J, Werb D, Vera A, Abramovitz D, Amon JJ, Brouwer KC, Strathdee SA, Gaines TL. 2016. Utilization of Google enterprise tools to georeference survey data among hard-to-reach groups: strategic application in international settings. *Int J Health Geogr* 15:1.
Belt PJ, Malhotra A, Thorpe RS, Warrell DA, Wuster W. 1997. Russell's viper in Indonesia: snakebite and systematics. In: *Symposia of the Zoological Society of London*. London: The Society, London. pp. 219–34., 1960–1999.
Bivand RS, Pebesma EJ, Gómez-Rubio V. 2013. Applied spatial data analysis with R. Springer.
Bondowoso S. 2015. Regional Statistics of Bondowoso Regency 2015. Bondowoso: Statistics Bondowoso, Bondowoso. Available at: https://bondowosokab.bps.go.id/website/pdf_publikasi/Statistik-Daerah-Kabupaten-Bondowoso-2015.pdf. [Accessed 21 July 2016].
Brown NI. 2012. Consequences of neglect: analysis of the Sub-Saharan African snake antivenom market and the global context. *PLoS Negl Trop Dis* 6:e1670.
Chang AY, Parrales ME, Jimenez J, Sobieszczyk ME, Hammer SM, Copenhaver DJ, Kulkarni RP. 2009. Combining Google Earth and GIS mapping technologies in a dengue surveillance system for developing countries. *Int J Health Geogr* 8:1.
Cheng AC, Currie BJ. 2004. Venomous snakebites worldwide with a focus on the Australia-Pacific region: current management and controversies. *J Intensive Care Med* 19:259–69.
Chippaux JP. 1998. Snake-bites: appraisal of the global situation. *Bull World Health Organ* 76:515.
Cruz LS, Vargas R, Lopes AA. 2009. Snakebite envenomation and death in the developing world. *Ethn Dis* 19:42.
Currie BJ. 2000. Snakebite in tropical Australia, Papua New Guinea and Irian Jaya. *Emerg Med* 12:285–94.
Diggle PJ, Chetwynd AG. 1991. Second-order analysis of spatial clustering for inhomogeneous populations. *Biometrics*:1155–63.
Elliott P, Wartenberg D. 2004. Spatial epidemiology: current approaches and future challenges. *Environ Health Perspect*:998–1006.
Garcia-Milagros E, Funk VA. 2010. Improving the use of information from museum specimens: Using Google Earth© to georeference Guiana Shield specimens in the US National Herbarium. *Front Biogeogr* 2:71–7.
Gatrell AC, Bailey TC, Diggle PJ, Rowlingson BS. 1996. Spatial point pattern analysis and its application in geographical epidemiology. *Trans Inst Br Geogr* 21: 256–74.
Guralnick RP, Wieczorek J, Beaman R, Hijmans RJ. 2006. BioGeomancer: Automated georeferencing to map the world's biodiversity data. *PLoS Biol* 4:e381.
Gutiérrez JM. 2016. Understanding and confronting snakebite envenoming: the harvest of cooperation. *Toxicon* 109:51–62.
Gutiérrez JM, Theakston RDG, Warrell DA. 2006. Confronting the neglected problem of snake bite envenoming: the need for a global partnership. *PLoS Med* 3: e150.
Gutiérrez JM, Warrell DA, Williams DJ, Jensen S, Brown N, Calvete JJ, Harrison RA. 2013. The need for full integration of snakebite envenoming within a global strategy to combat the neglected tropical diseases: the way forward. *PLoS Negl Trop Dis* 7:e2162.
Gutiérrez JM, Williams D, Fan HW, Warrell DA. 2010. Snakebite envenoming from a global perspective: towards an integrated approach. *Toxicon* 56:1223–35.
Haase P. 1995. Spatial pattern analysis in ecology based on Ripley's K-function: introduction and methods of edge correction. *J Veg Sci*:575–82.
Haklay M, Weber P. 2008. Openstreetmap: user-generated street maps. *IEEE Pervasive Comput* 7:12–8.
Hansson E, Sasa M, Mattisson K, Robles A, Gutiérrez JM. 2013. Using geographical information systems to identify populations in need of improved accessibility to antivenom treatment for snakebite envenoming in Costa Rica. In: Chippaux J-P (Ed.). *PLoS Negl Trop Dis*, 7. e2009.
Harrison RA, Hargreaves A, Wagstaff SC, Faragher B, Lalloo DG. 2009. Snake envenoming: a disease of poverty. *PLoS Negl Trop Dis* 3.
Illian J, Penttinen A, Stoyan H, Stoyan D. 2008. Statistical analysis and modelling of spatial point patterns. John Wiley & Sons.
Jacquez GM. 2000. Spatial analysis in epidemiology: nascent science or a failure of GIS? *J Geogr Syst* 2:91–7.
Kasturiratne A, Wickremasinghe AR, de Silva N, Gunawardena NK, Pathmeswaran A, Premaratna R, Savioli L, Lalloo DG, de Silva HJ. 2008. The global burden of snakebite: a literature analysis and modelling based on regional estimates of envenoming and deaths. *PLoS Med* 5:e218.

Mohapatra B, Warrell DA, Suraweera W, Bhatia P, Dhingra N, Jotkar RM, Rodriguez PS, Mishra K, Whitaker R, Jha P. 2011. Snakebite mortality in India: a nationally representative mortality survey. *PLoS Negl Trop Dis* 5:e1018.
Nasidi A. 2007. Snakebite as a serious Public Health problem for Nigeria and Africa. Available at: http://www.who.int/bloodproducts/animal_sera/A.Nasidi.pdf. [Date accessed: 15 March 2016].
Ngowi HA, Kassuku AA, Carabin H, Mlangwa JE, Mlozi M, Mbilinyi BP, Willingham AL. 2010. Spatial clustering of porcine cysticercosis in Mbulu district, northern Tanzania. *PLoS Negl Trop Dis* 4:e652.
OpenStreetMap contributors. 2015. OpenStreetMap [Internet]. The OpenStreetMap Foundation. Available at: http://www.openstreetmap.org. [Date accessed: 3 September 2015].
Ostfeld RS, Glass GE, Keesing F. 2005. Spatial epidemiology: an emerging (or re-emerging) discipline. *Trends Ecol Evol* 20:328–36.
Perry GL, Miller BP, Enright NJ. 2006. A comparison of methods for the statistical analysis of spatial point patterns in plant ecology. *Plant Ecol* 187:59–82.
QGIS Development Team. 2016. Quantum GIS Geographic Information System. Open Source Geospatial Foundation. Available at: http://qgis.osgeo.Org. [Date accessed: 3 May 2016].
Rahman R, Faiz MA, Selim S, Rahman B, Basher A, Jones A, d'Este C, Hossain M, Islam Z, Ahmed H. 2010. Annual incidence of snake bite in rural Bangladesh. *PLoS Negl Trop Dis* 4:e860.
Ripley BD. 2005. Spatial statistics. John Wiley & Sons.
Sasa M, Vazquez S. 2003. Snakebite envenomation in Costa Rica: a revision of incidence in the decade 1990–2000. *Toxicon* 41:19–22.
Sipe NG, Dale P. 2003. Challenges in using geographic information systems (GIS) to understand and control malaria in Indonesia. *Malar J* 2:36.
Swaroop S, Grab B. 1954. Snakebite mortality in the world. *Bull World Health Organ* 10:35.
Theakston R, Warrell D. 2000. Crisis in snake antivenom supply for Africa. *The Lancet* 356:2104.
Velázquez E, Martínez I, Getzin S, Moloney KA, Wiegand T. 2016. An evaluation of the state of spatial point pattern analysis in ecology. *Ecography* 39:001–14.
Waller LA, Gotway CA. 2004. Applied spatial statistics for public health data. John Wiley & Sons.
Warrell DA. 2010a. Snake bite. *The Lancet* 375:77–88.
Warrell DA. 2010b. Guidelines for the management of snake-bites. New Delhi, India: WHO Regional Office for South-East Asia, New Delhi, India.
Wieczorek J, Guo Q, Hijmans R. 2004. The point-radius method for georeferencing locality descriptions and calculating associated uncertainty. *Int J Geogr Inf Sci* 18:745–67.
Wiegand T, Grabarnik P, Stoyan D. 2016. Envelope tests for spatial point patterns with and without simulation. *Ecosphere* 7.
Wiegand T, He F, Hubbell SP. 2013. A systematic comparison of summary characteristics for quantifying point patterns in ecology. *Ecography* 36:92–103.
Wiegand T, Moloney KA. 2004. Rings, circles, and null-models for point pattern analysis in ecology. *Oikos* 104:209–29.
Williams D. 2004. Snakebite in Papua New Guinea: facts & fiction. In: Williams D, Jensen S, Winkel KD (Eds.). *Clin Manag Snakebite Papua N Guin*. Papua New Guinea: Independent Publishing, Papua New Guinea. pp. 5–32. Available at: http://www.kingsnake.com/aho/pngsmc/contents.html. [Date accessed: 25 May 2016].
Williams D, Gutiérrez JM, Harrison R, Warrell DA, White J, Winkel KD, Gopalakrishnakone P. 2010. The global snake bite initiative: an antidote for snake bite. *The Lancet* 375:89–91.
Williams DJ, Gutiérrez J-M, Calvete JJ, Wüster W, Ratanabanangkoon K, Paiva O, Brown NI, Casewell NR, Harrison RA, Rowley PD. 2011. Ending the drought: new strategies for improving the flow of affordable, effective antivenoms in Asia and Africa. *J Proteomics* 74:1735–67.
Zhang J, He C, Zhou Y, Zhu S, Shuai G. 2014. Prior-knowledge-based spectral mixture analysis for impervious surface mapping. *Int J Appl Earth Obs Geoinf* 28:201–10.