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ORIGINAL RESEARCH

The geographical prevalence and potential epidemiology of heartwater in Botswana: implications for planning control under climate change

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ABSTRACT

Heartwater caused by *Ehrlichia ruminantium* is a widespread animal health problem in Botswana. Although long known to be endemic, its current distribution and possible future occurrence in new areas within the country requires updating to help guide planned control in the midst of climate change. Thus an understanding of the spatial occurrence of the disease and its environmental risk factors is essential for control and management planning. The goal of this paper was to explore the current and potential spatial occurrence of heartwater across Botswana and its associated environmental factors. To reach this goal, geographical information systems were used to map the distribution of heartwater infection and also overlay infection data with interpolated environmental surfaces. The derived maps indicate both a widespread occurrence of infection and a marked variability in infection prevalence, with the south east and north eastern parts of the country having the highest incidence rates while the western part has the highest potential for disease occurrence. The results revealed the occurrence of heartwater in the east but absence in the west and also potential areas for disease outbreak, in which climate change alteration of environmental factors could trigger its establishment.

Keywords Botswana, *Ehrlichia ruminantium*, climate change, heartwater

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INTRODUCTION

The realization that species distribution is influenced by climate has resulted in increased emphasis on the need to acquire information in ways in which present distributions of organisms may be affected by climate change (Olwoch *et al.,* 2007). Climate change is expected to have direct and indirect impacts on African livestock. Direct impacts include increased ambient temperature, floods and droughts while indirect impacts include reduced availability of water and forage and changes in the conditions that promote the spread of diseases through increased contact between animals, or increased survival or availability of the disease agent or its intermediate host (Seo and Mendelsohn, 2006). The distribution and prevalence of vector-borne diseases such as those transmitted by ticks may be the most significant effects of climate change (Van den Bossche and Coetzer, 2008).

In response to this challenge, the issue of vector distribution has recently received attention. Numerous studies (Estrada-Pena, 2003; Olwoch *et al*. 2003) have attempted to predict the distribution of tick species based on major environmental factors that would influence this phenomenon. Ticks spend a large part of their life living off their host(s) and are thus subject to ambient temperature and humidity. Climatic conditions and vegetation influence the ecosystem and largely determine the distribution of ticks and their density (Alderink and McCauley, 1988; Barré and Garris, 1990; Pegram and Banda, 1990; Greenfield, 2011). Increased temperature as a result of climate change may shorten their life cycle but may increase their reproductive rate. High temperatures are likely to reduce their survival and mortality may increase under drier conditions. Rogers (1996) showed that suitable habitats for the *Rhipicephalus appendiculatus*, the primary vector of East Coast Fever (ECF), will have disappeared in most of the south-eastern part of its range and conversely, more suitable areas for its survival will appear in the western and central parts of Southern Africa. In southern Zambia, a positive association was found between El Niño events and an increased ECF seroprevalence as a result of the increased survival of the tick vector (Fandamu *et al*., 2005). Taken together, this information suggests that climate will continue to influence the dynamics of tick population and of the diseases they transmit by affecting the distribution of ticks and their seasonal occurrence.

Tick-borne diseases are one of the most important obstacles to the development of livestock production in Africa, with heartwater being among the most important, second only to East Coast fever (Provost and Bezuidenhout, 1987). Heartwater is an acute tick-borne disease of domestic and wild ruminants in Africa and the Caribbean (Camus *et al*., 1996) caused by the rickettsia *Cowdria ruminantium* and transmitted by *Amblyomma* ticks; *Amblyomma hebraeum* and *Amblyomma variegatum* (Provost and Bezuidenhout, 1987). Sharma *et al.* (2003) noted that *A. hebraeum* and *A.variegatum* are the main vectors of *Ehrlichia ruminantium* in Botswana. Therefore, the spatial distribution of heartwater in Botswana is dependent on occurrence of these vector species and also on environmental factors that influence their establishment and survival.

A. hebraeum and *A. variegatum* are particularly sensitive to environmental conditions because they require a microclimate with a relative humidity of at least 70% to avoid desiccation during their prolonged non-parasitic phases (Gray *et al*., 2009). The organism is therefore restricted to areas of moderate to high rainfall with good vegetation cover to maintain humid soil conditions throughout the driest times of the year (Coetzer *et al*., 1994). Thus, climate directly and indirectly influences tick survival, their habitat, and also the host animals. Consequently, climate variability and change may extend or curtail host-seeking tick activity and subsequently increasing or decreasing tick abundance and distribution. Climatic variation is expected to impact tick development rates and their seasonal activity patterns by altering the proportion of the tick population that is exposed to regulatory mechanisms such as diapauses and thus disease prevalence (Gray *et al*., 2009).

Accordingly, the sensitivity of the heartwater transmitting tick to temperature, humidity, vegetation cover, and other environmental factors imply that there is a geographical as well as temporal variation in heartwater incidences (Norval *et al*., 1994). Pascucci *et al*. (2007) noted that although the aetiology and symptoms of heartwater have been known for a long time, the epidemiology of the disease is not yet fully understood. The biology of the vectors (genus *Amblyomma*), presents many features linked with environmental conditions that affect the likelihood of occurrence of the disease in disease-free parts of Botswana such as the western region. Furthermore, the sporadic occurrence of the disease in areas traditionally free of the disease could probably be linked to increase in climate variability in the same manner that areas traditionally not prone to flooding, such as the western region, now experience some wet episodes. Norval *et al*. (1991) noted that information on seasonal occurrence of heartwater throughout its distribution range is necessary for the design of control strategies to limit livestock production losses due to heavy tick infestations. Though studies has been done to model species distribution ranges of ticks in Africa (Cumming 2000; Estrada-Pena *et al*., 2006 and their relation to climate change (Olwoch *et al*., 2007; Estrada-Pena 2003) this has not been done particularly for Botswana. This paper applied geographic information systems (GIS) to identify area at risk of *A.hebraeum* and *A.variegatum* infection in Botswana. Hendrickx *et al*. (2001) observed that the use of GIS in the management of African animal diseases offers opportunities in assisting decisions on allocation of resources, prioritization of control areas, and planning and management of field operations. The specific objectives of the present study were to: i) describe the geography of heartwater infection ii) investigate the large-scale ecological correlates of infection patterns iii) discuss the implications of the study results for the design and implementation of heartwater control in Botswana.

MATERIALS AND METHODS

Botswana is a land-locked country in southern Africa bordered by South Africa to the east and south, Namibia to the west and north, Zambia to the north and Zimbabwe to the north-east. It lies roughly between latitudes 18 and 27ºS and longitudes 20 and 29ºE, an area covered by approximately 582,000 square kilometers with a population of 2 million people (CSO 2011). The landscape is flat to gently rolling; the Kalahari Desert, located in Botswana's southwest, covers nearly 70 % of the country, with remaining areas being primarily tropical grassland and savanna (Khupe, 1996).

Botswana's climate is mainly semi-arid to arid due to its average position under the descending limb of the Hadley cell circulation (Bhalotra, 1987). Almost all rainfall occurs during the summer months of November to March: in early summer, the interior thermal low and moist north easterly flow deepen, allowing upper westerly waves to bring isolated rainfall but in mid to late summer, tropical easterly systems and continental troughs edge into Botswana (Bhalotra, 1987; Matirira and Jury, 1992).

Data

Data on confirmed positive cases of heartwater *per* agricultural region for the period 1987-2007 was obtained from Botswana National Veterinary Laboratory (BNVL) while climate data (rainfall, temperature, and humidity) for the representative meteorological stations within regions was obtained from the Department of Meteorological Services, Botswana. Vegetation and soils maps were obtained from the Department of Surveys and Mapping.

Analysis

Criteria for delineating areas suitable for A. hebraeum and A. variegatum survival

On average, climatic variables are better predictors of tick distribution than vegetation-derived variables (Cumming, 2002) and the distributions of ticks are not primarily limited by those of their hosts (Cumming, 1999). Thus the primary factor governing tick distribution is the direct effect of climate. Estrada-Pena *et al*. (2008) highlighted that temperature range for optimum habitat is narrower for *A. hebraeum* and that it prefers drier environments and localities with a marked seasonal drought. Regions in which *A. hebraeum* is established tend to have well-defined and intense dry season running from April to August. The absence of *A. hebraeum* in some areas has been attributed to high rainfall, low ambient temperatures or the absence of large wild ungulate species, which serve as alternative hosts (Norval, 1977a). On the other hand, *A.variegatum* is found in areas where rainfall is relatively high and the dry season is not severe (Estrada-Pena *et al*., 2008). Based on the above observations the following criteria were used to delineate potential heartwater areas in Botswana:
i) soils with good water retention (i.e non sandy soils), ii) vegetation type which is grasslands or tree savanna, iii) temperature range of 15 to 35°C, iv) annual rainfall of not less than 380 mm (Norval 1977 a, b), and v) humidity of not less than 70% (Gray *et al*., 2009).

Geoprocessing

Geoprocessing, which involved interpolation of confirmed cases of heartwater at district level using the inverse distance weighting method (IDW) and conversion of various layers from vector to raster, reclassification and intersection overlay based on the criteria above was done in ArcGIS 9.1 (Esri Redlands California USA) (Figures 1 and 2).

RESULTS

The incidence of heartwater was found to be concentrated in the south east and north eastern parts of the country (Figure 3). Figure 4 shows the relationship between heartwater incidence and soil water retention. The northern part of the country have soils with good water retention but was observed to have very low number of cases (1) of heartwater, whereas the north east and eastern part of the country through down the south eastern part of the country have good water retaining soils, and also high number of cases, with Francistown recording 19 to 20 cases and Gaborone in the south east recording the highest number of cases (21 to 23).

The south, south west and central part of the country have mostly poor water retention soils (sandy soils), but fewer cases in some places (e.g. Jwaneng with 7 cases). Figure 5 shows the relationship between heartwater incidence and rainfall. There was no spatial relationship between heartwater incidence and rainfall. For instance the northern part of the country (Kasane area) registered the highest rainfall (568 to 603mm) but had low incidence of heartwater. The same applies to the north western part towards the central, which have rainfall of 431 to 465 mm annually but low incidence. In some areas like Shakawe and Gantsi no case of heartwater was recorded. Nevertheless, Mochudi which fall in the same rainfall range had 9-10 cases of heartwater. The north eastern side (around Francistown) and the southern part around Gaborone, Molepolole and Jwaneng have annual rainfall range of 465 to 500mm with concurrent high incidence of heartwater registered in Gaborone (21-23 cases) and Francistown with (19 to 20 cases) but low in Jwaneng (7 cases). Tsabong and Palapye have the lowest rainfall (294-326 mm) and only 0 and 7 cases were observed respectively.

The western part (around Gantsi) and south western (around Tsabong) and Jwaneng in the south have low humidity (48-49%) and no cases were observed in Tsabong and Gantsi areas whilst Jwaneng had 7 cases. Most of the cases are clustered in the south east (around Gaborone, Molepolole, Mochudi and Lobatse) with humidity ranges of 53 to 54%. Francistown in the north east with humidity of 55 to 56% had 19 to 20 cases and in contrast Selibe Phikwe (in the eastern part) with humidity range of 57 to 58% had 6 cases of heartwater (Figure 6). The northern part of the country (around Maun) has the highest minimum temperature (16 to 17°C) but no case was registered. The south eastern part of the country had the highest number of cases with Gaborone (21-23), Molepolole (16), Lobatse (17) and Kanye (11-15) but these are has moderate minimum temperature range of 13 to 13°C (Figure 7). The eastern part (Selibe Phikwe area) has the highest maximum temperature rages (32-32°C) but only 2 to 5 cases were observed. Most cases were found to be clustered in the south east (Gaborone, Mochudi, Molepolole, Jwaneng and Kanye) with maximum temperature range of 30-30°C (Figure 8). Figure 9 shows the spatial relationship between vegetation type and heartwater incidence. The northern part of the country has grasslands and tree savannah vegetation type and low numbers of cases were observed especially Maun and Kasane (1). This vegetation type continues into the east and south eastern part of the country, however, in these parts high numbers of heartwater cases prevails.

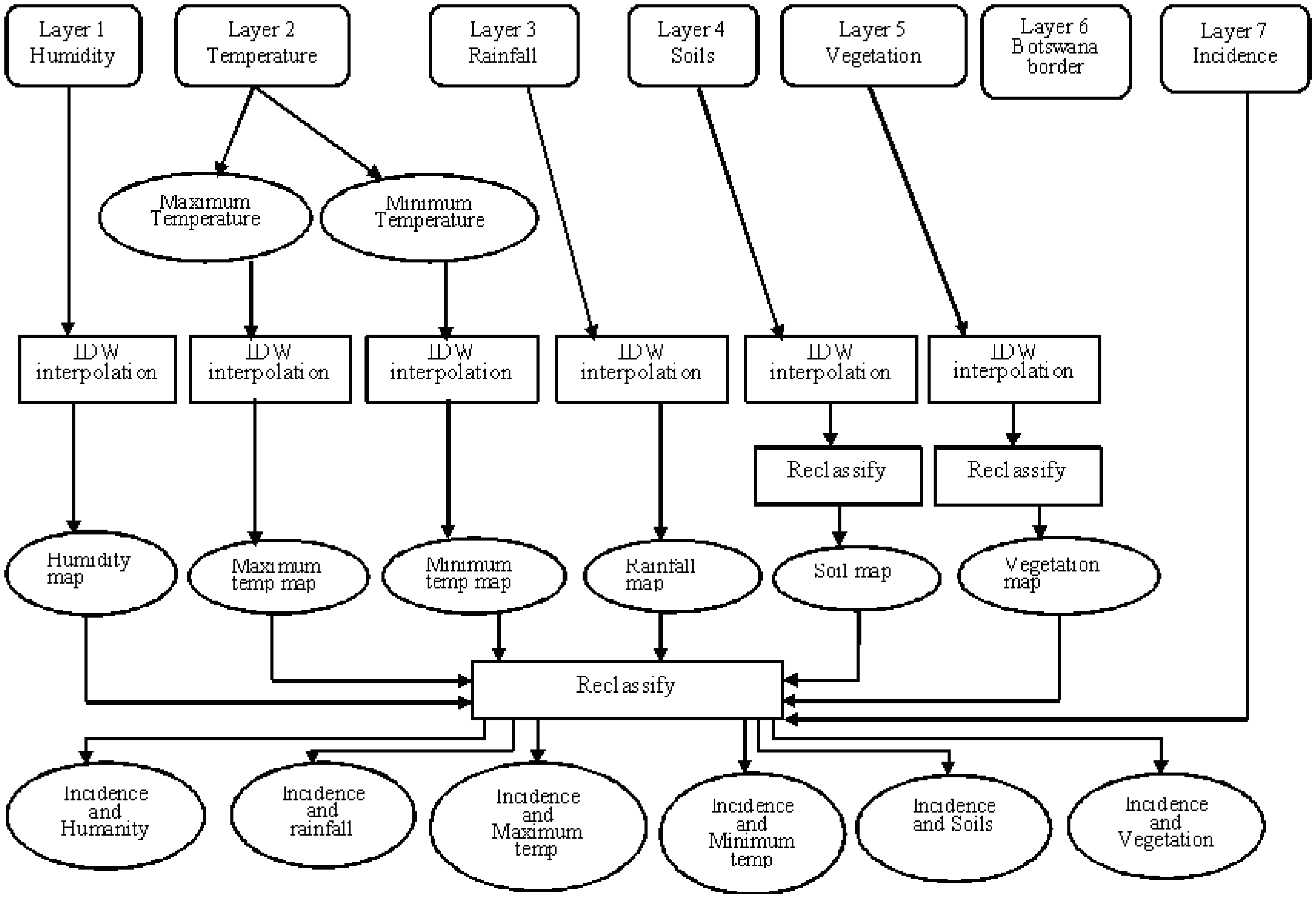


Figure 1: Spatial analysis flowchart to identify infected and affected areas

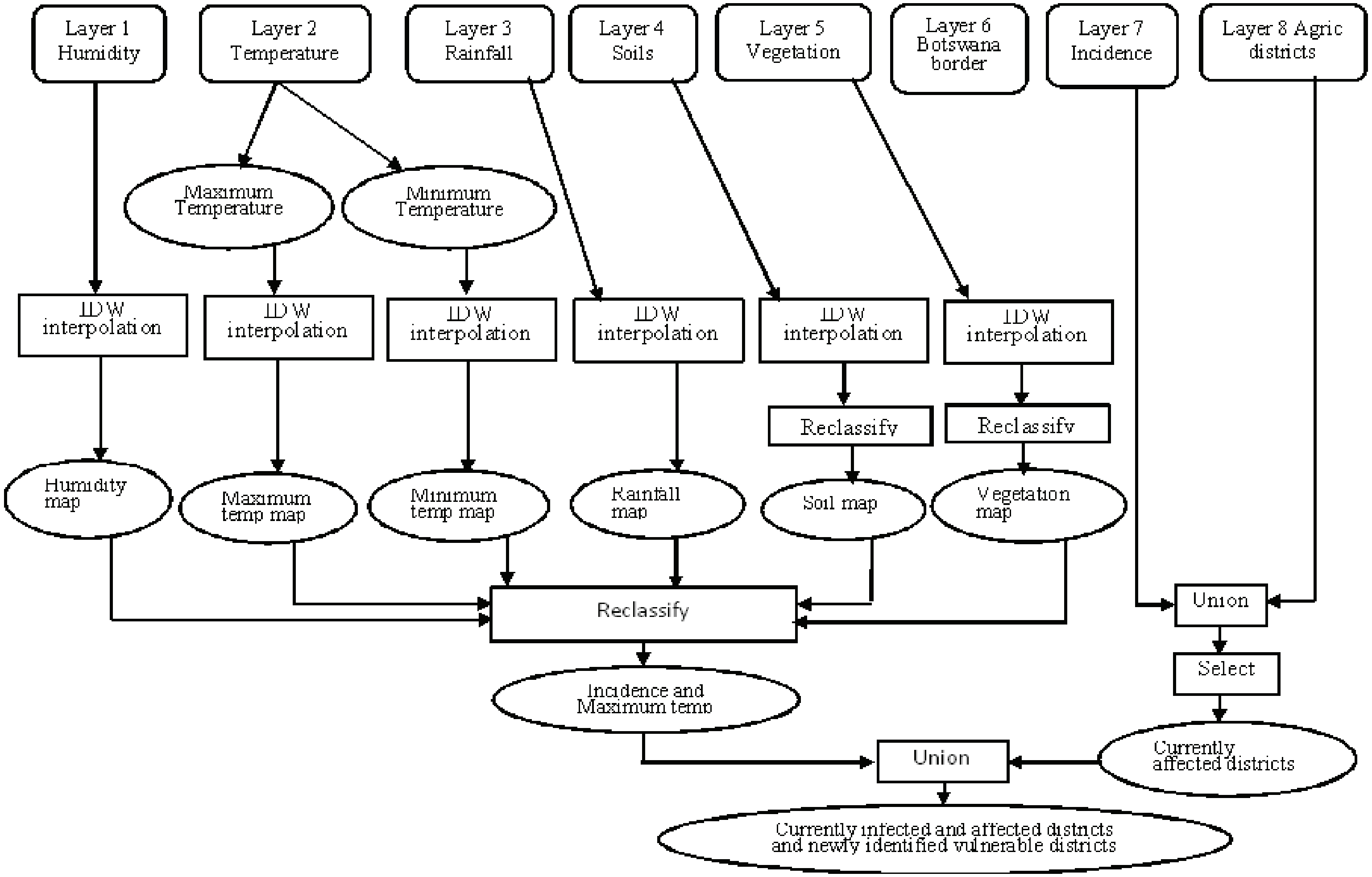


Figure 2: Spatial analysis flowchart to identify vulnerable and infected areas

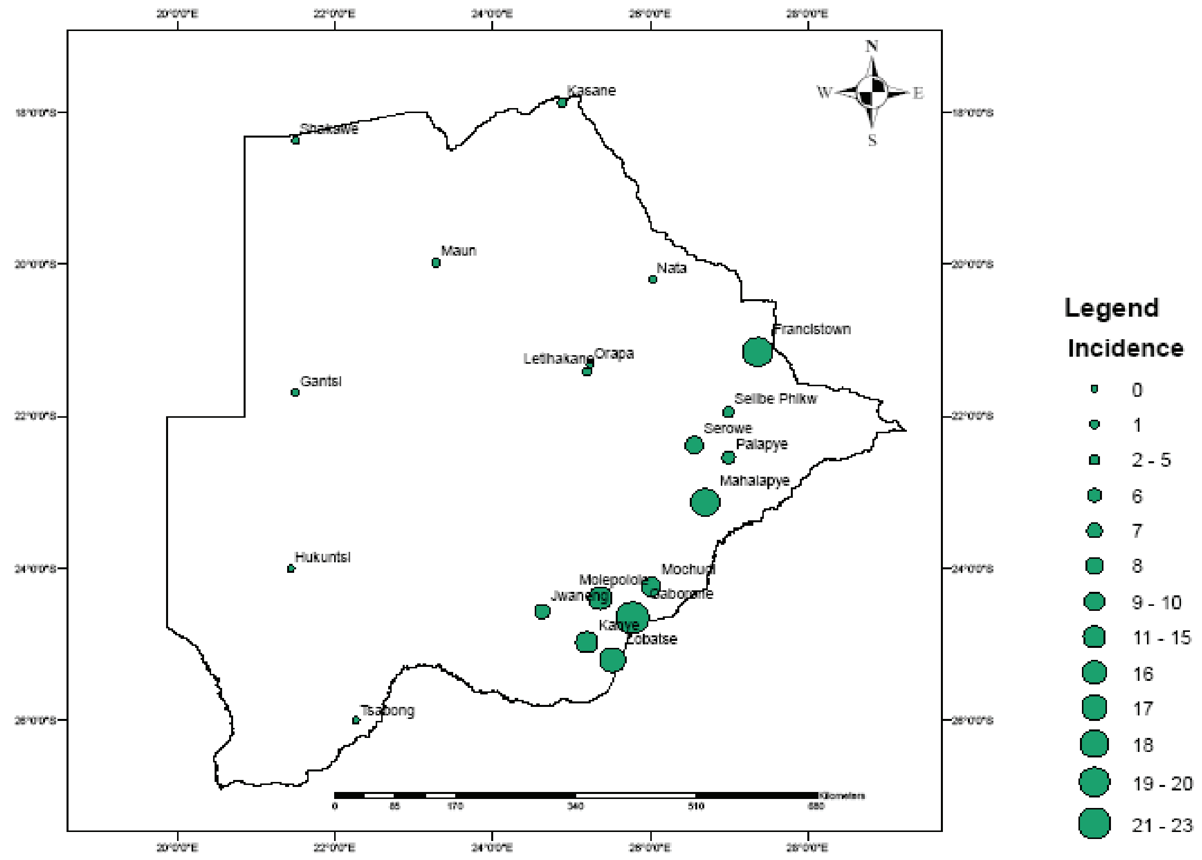


Figure 3. Heartwater occurrence across the country

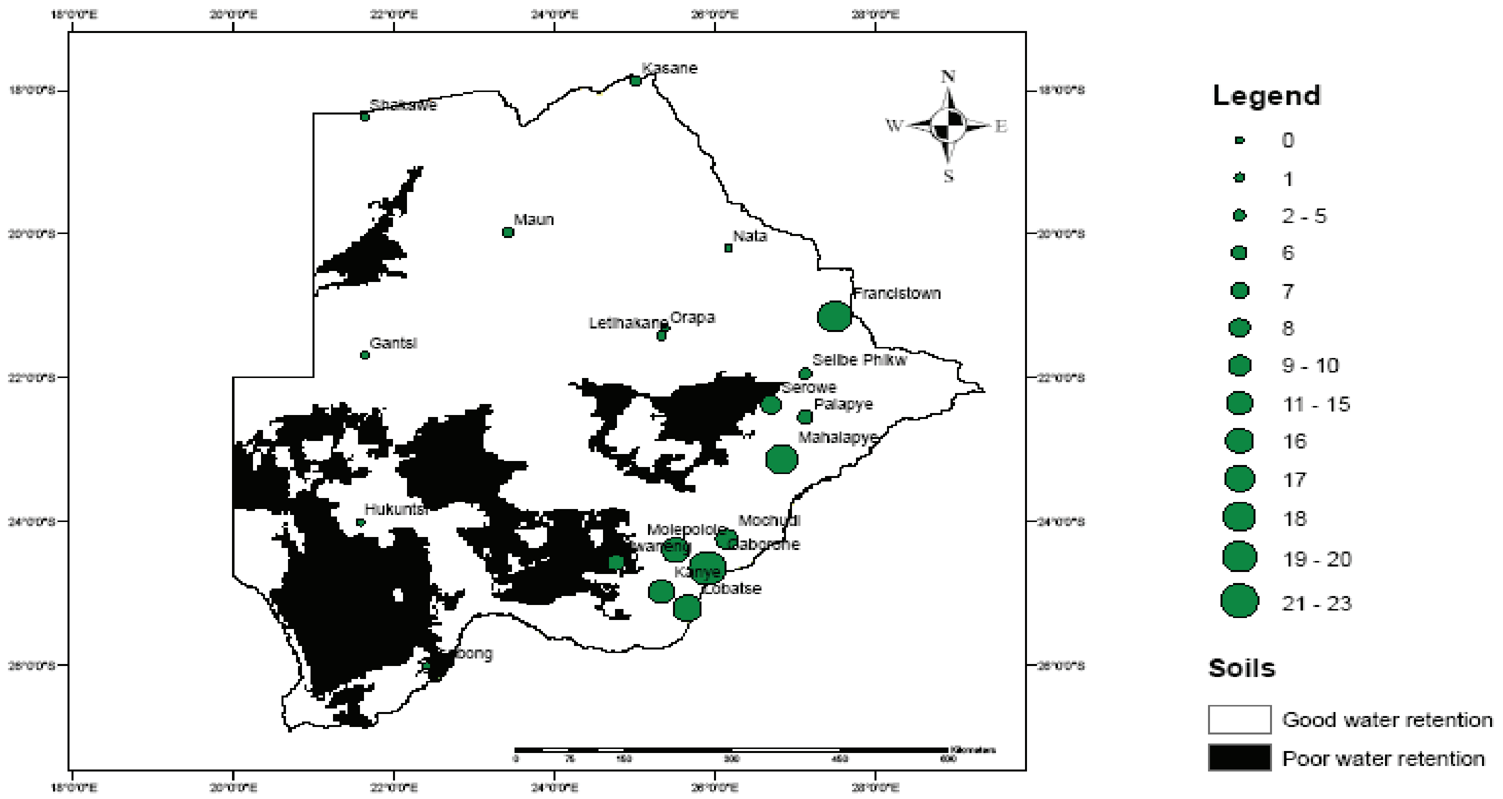


Figure 4. Spatial relationship between heartwater incidence and soil water retention

For instance, Francistown in the north east recorded 19-20 cases and Gaborone in the south east 21-23 cases. The west, central and southern part of the country have sparse tree and grassland vegetation type and this area which covers Tsabong/Hukuntsi and Jwaneng had 1, 0 and 7 cases each.

Figure 10 shows differential spatial vulnerability to heartwater across the country based on set criteria and overlay of all the environmental factors (i.e. Figures 3 to 8). The south east, south central, central west far north and some parts of the north east are most vulnerable to heartwater occurrence. The rest of the country is marginally vulnerable except the south west. Figure 11 shows currently affected areas together with predicted most vulnerable, marginally vulnerable, and less vulnerable areas to heartwater. Districts that show high potential vulnerability include Gantsi district and the upper parts of Ngamiland district while Kgalagadi district shows less vulnerability of all the districts. The affected districts are Chobe, North East, Central, Kweneng, Kgatleng, South East and Southern.

DISCUSSION

In general the boundaries to tick species ranges are more likely to be set by factors such as vegetation and climate (Cumming 1999). These factors together with soil type were investigated in the present study. There was no clear spatial relationship between heartwater incidence and rainfall, neither was a relationship observed with vegetation, but when all climatic variables were considered (Figure 11) a pattern emerged. This is not surprising since results from Cumming (2002) showed that on average climatic variables were better predictors of tick distribution than vegetation-related variables. In particular, the biology of *A. hebraeum* is intimately linked to temperature, rainfall and vegetation, suggesting that climatic data are a suitable basis from which to model its distribution (Cumming 2000). The present results based on the consideration of all climatic variables show that the eastern part of the country is currently affected by heartwater, in agreement with Walker et al (1978).

Norval (1977a) also noted that the eastern part of Botswana is the most vulnerable and suitable site for the establishment of heartwater vector. Extension message of Ministry of Agriculture regarding heartwater has always advised farmers to vaccinate livestock, especially small ruminants, relocated from the western part of the country to the east. The western (around Jwaneng) have high potential for heartwater occurrence as these areas have similar climatic, vegetative, and edaphic properties as the southern part where the disease is endemic as well as some parts of the north west except for high rainfall. Therefore, occasional flooding in the western parts as it occurred in 2000 could result in sporadic heartwater outbreaks in these areas. This scenario is confirmed by a report by Musuka *et al*. (2001) which recorded incidence of *A. hebraeum* in the sandveld region of Botswana. The possibility of rainfall decrease in the northwest because of climate change could result in outbreaks particularly that of *A. hebraeum*. Climate change is likely to increase the frequency of extreme events such as flooding, therefore heartwater control measures need to factor in climate change induced vulnerability to diseases such as heartwater in the aforementioned areas. The general consequences of climate is predicted to be a decrease in rainfall and an increase in temperature, for which in Southern Africa would results in increased drought frequencies and very hot weather (Reason and Mulenga, 1999; Cook *et al*., 2004). This scenario is likely to decrease the habitat of the vector tick. Increasing the temperature by 2 °C was forecasted to have damaging effects on the habitat structure of *Boophilus decratus, Amblyomma hebraeum, Rhipicephalus appendiculatus* and *Hyalomma truncatum* (Estrada-Pena 2003). In contrast Olwoch et al. (2007) noted that greater habitat suitability within Africa implies that not only that ticks will be able to live in more areas, but also their local abundances will increase in areas that are currently considered marginal habitat. For instance, a decrease in temperature was predicted by Estrada-Pena (2003) to promote habitat gain for every species except *H truncatum,* while an increase of 1°C was forecast to sustain a small but positive response in A. *hebraeum* and *B. decoloratus*.

In Botswana, the control of heartwater is based on the maintenance of an endemic stable situation. Endemic stability is the epidemiological state of a population in which clinical disease is rare, despite high levels of infection (Coleman *et al*., 2001). The development and maintenance of endemic stability for tick-borne diseases in cattle are thus dependent on an optimal relationship between cattle, the disease agent and ticks (Van den Bossche and Coetzer, 2008). Disruption of this optimal relationship as a result of climate change and subsequent alterations in the distribution and density of certain tick species and also in management practices such the replacement of indigenous tick load tolerant breeds with exotic ones, is likely to affect endemic stability and may result in outbreaks of disease. Nevertheless, modern tick control measures could allow cattle to be kept in endemic or epidemic to heartwater although this option will increase management costs.

CONCLUSION

As a contribution to understanding the relationship between environmental factors and spatial occurrence of heartwater and to place that understanding in the context of climate change, this paper explored heartwater spatial occurrence and its co-occurrence with various environmental factors in Botswana. The results agreed with earlier work denoting eastern occurrence of the disease and absence in the west. The findings importantly showed potential areas for heartwater outbreak, in which climate change induced weather extremes frequency and severity could trigger the establishment of the disease. The paper also highlighted the possibility of the current endemic stability of the diseases in the affected areas becoming an outbreak as conditions become more favourable for the heartwater vector. These results have important policy implications for future disease control strategies and policies as information could aid in stratifying areas by risk, and also in guiding implementation of intervention strategies for disease prevention and control.

Conflict of interest: None

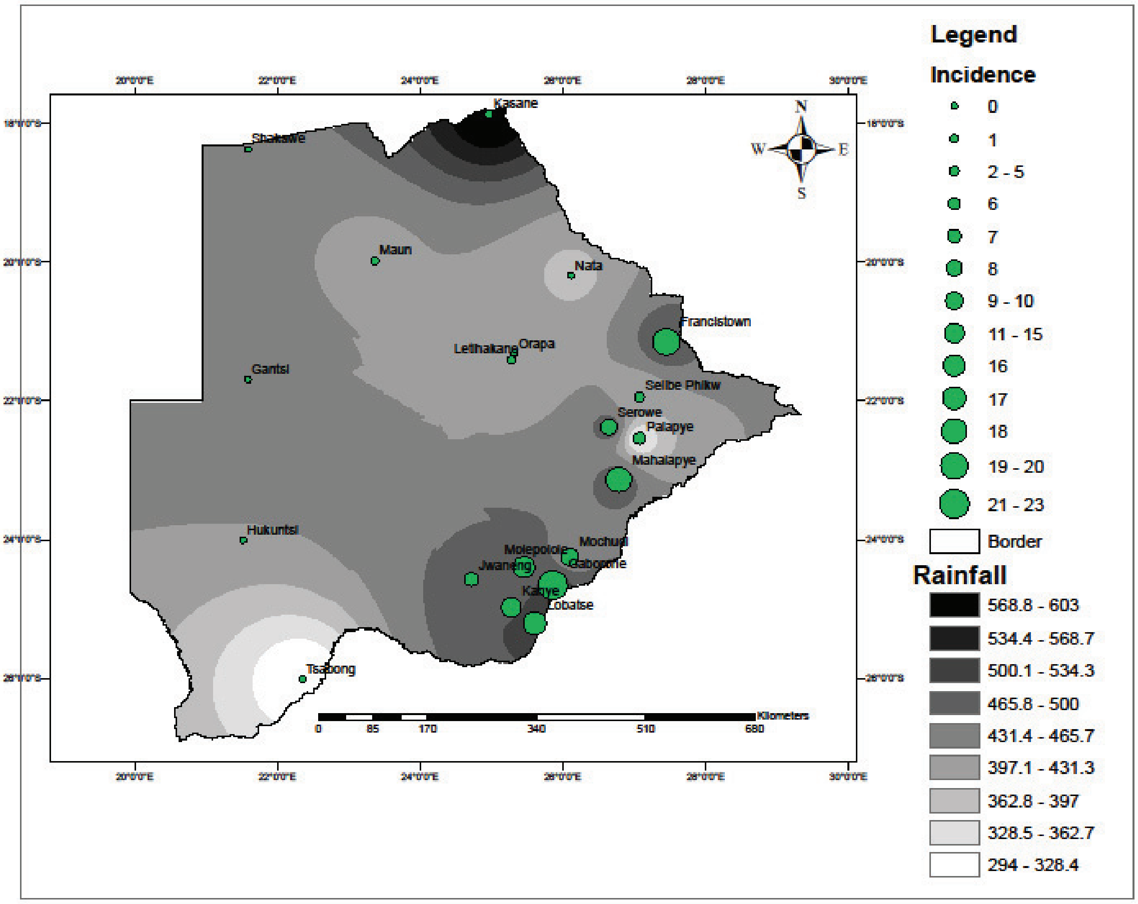
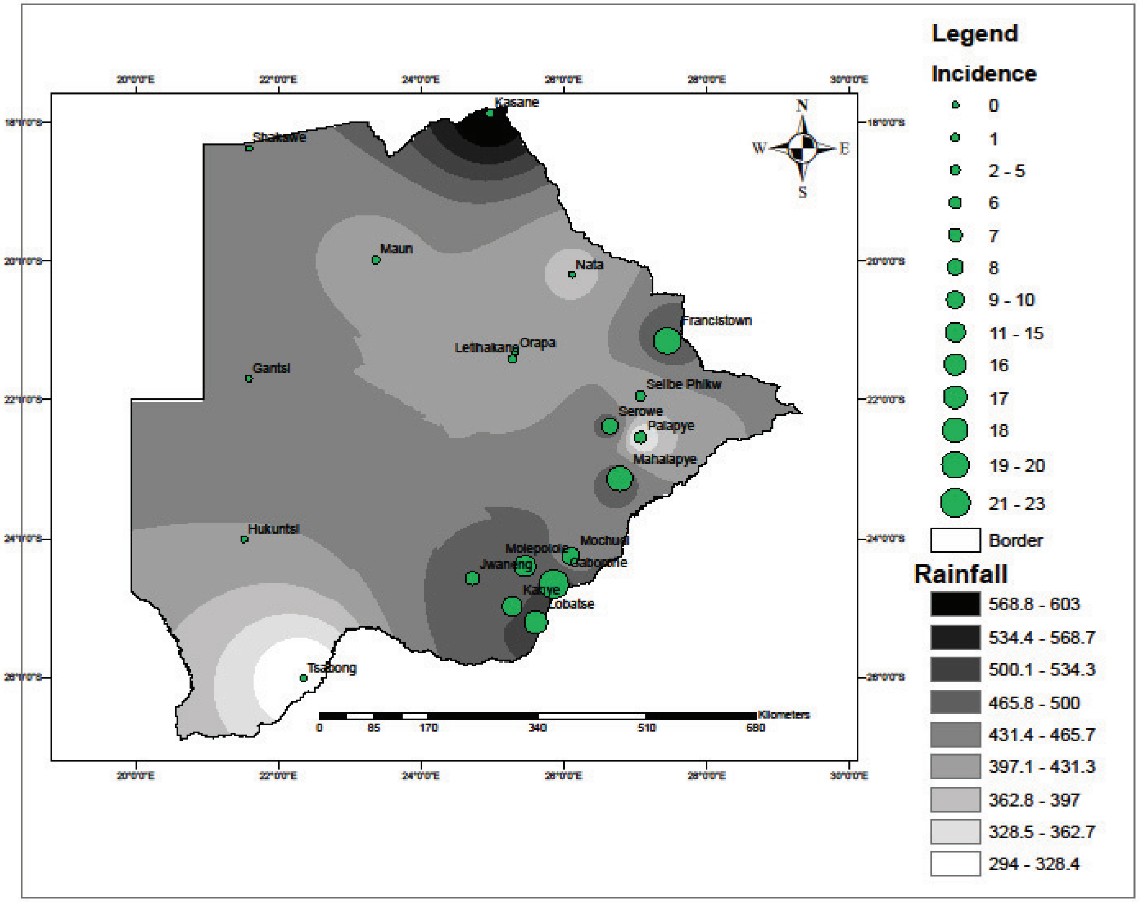


Figure. 5. Spatial relationship between heartwater incidence and rainfall amount



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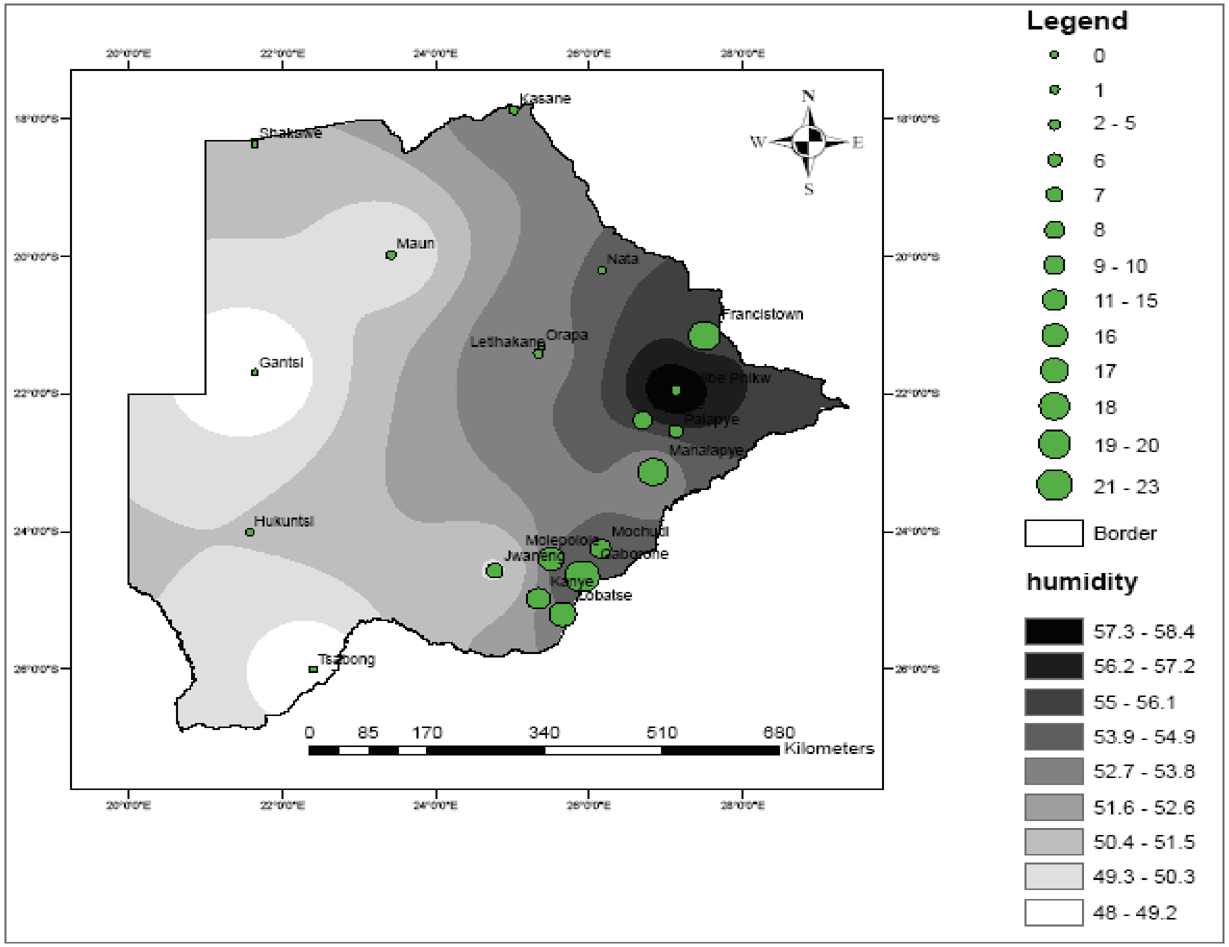

Figure. 6. Spatial relationship between heartwater incidence and humidity

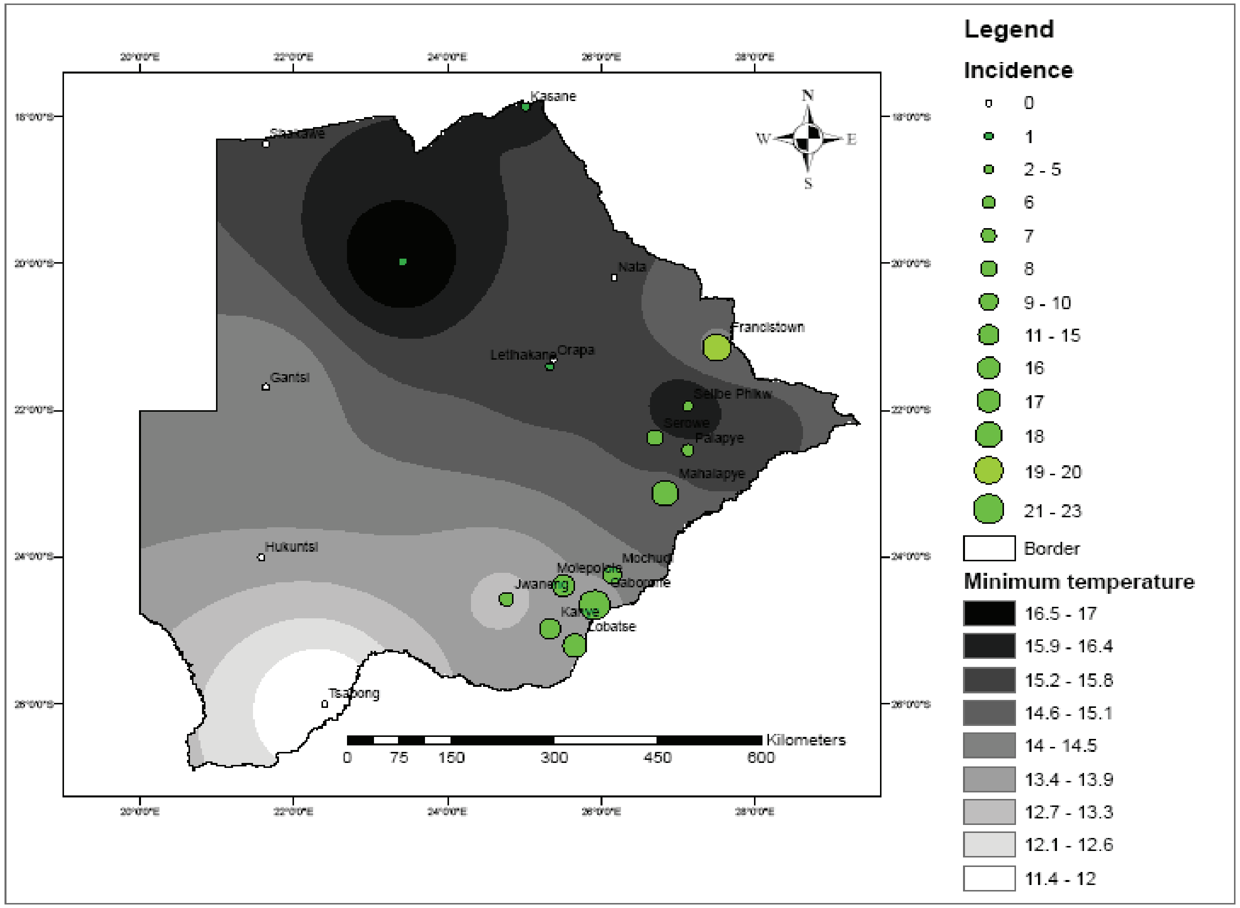

Figure 7. Spatial relationship between heartwater incidence and minimum temperature

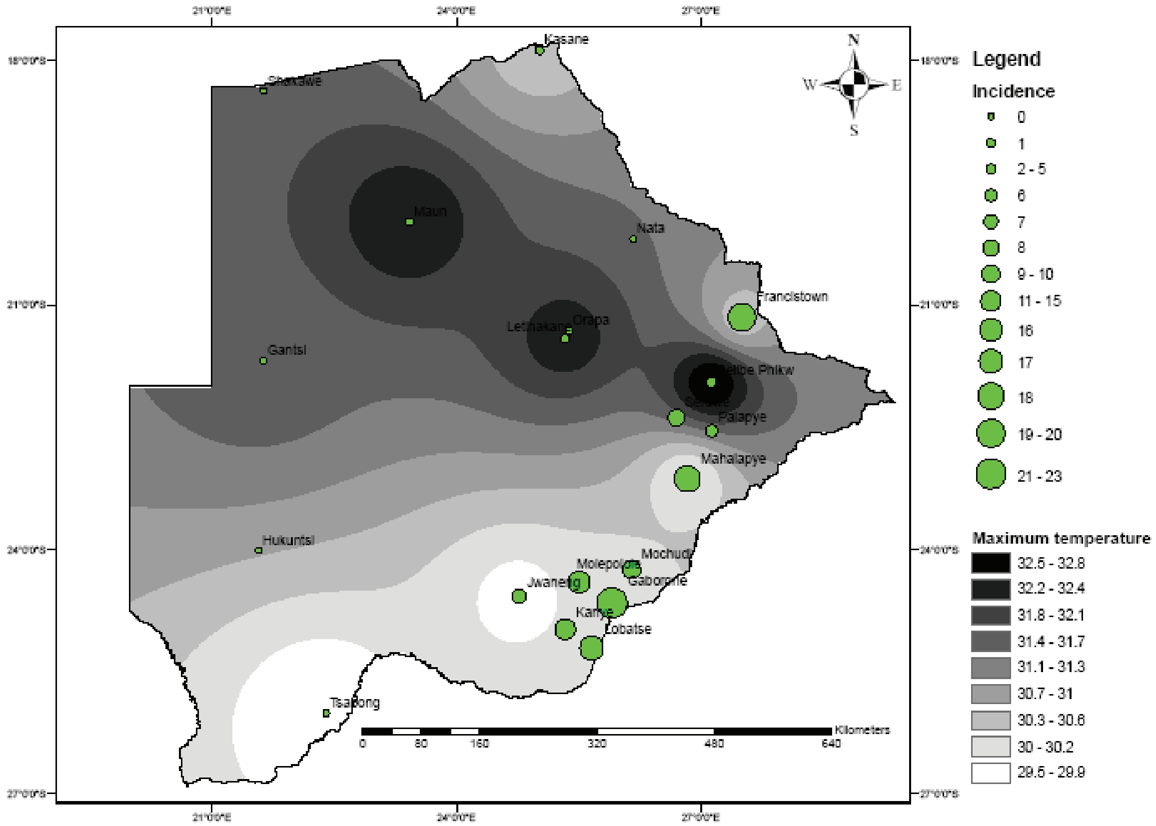

Figure. 8. Spatial relationship between heartwater incidence and maximum temperature

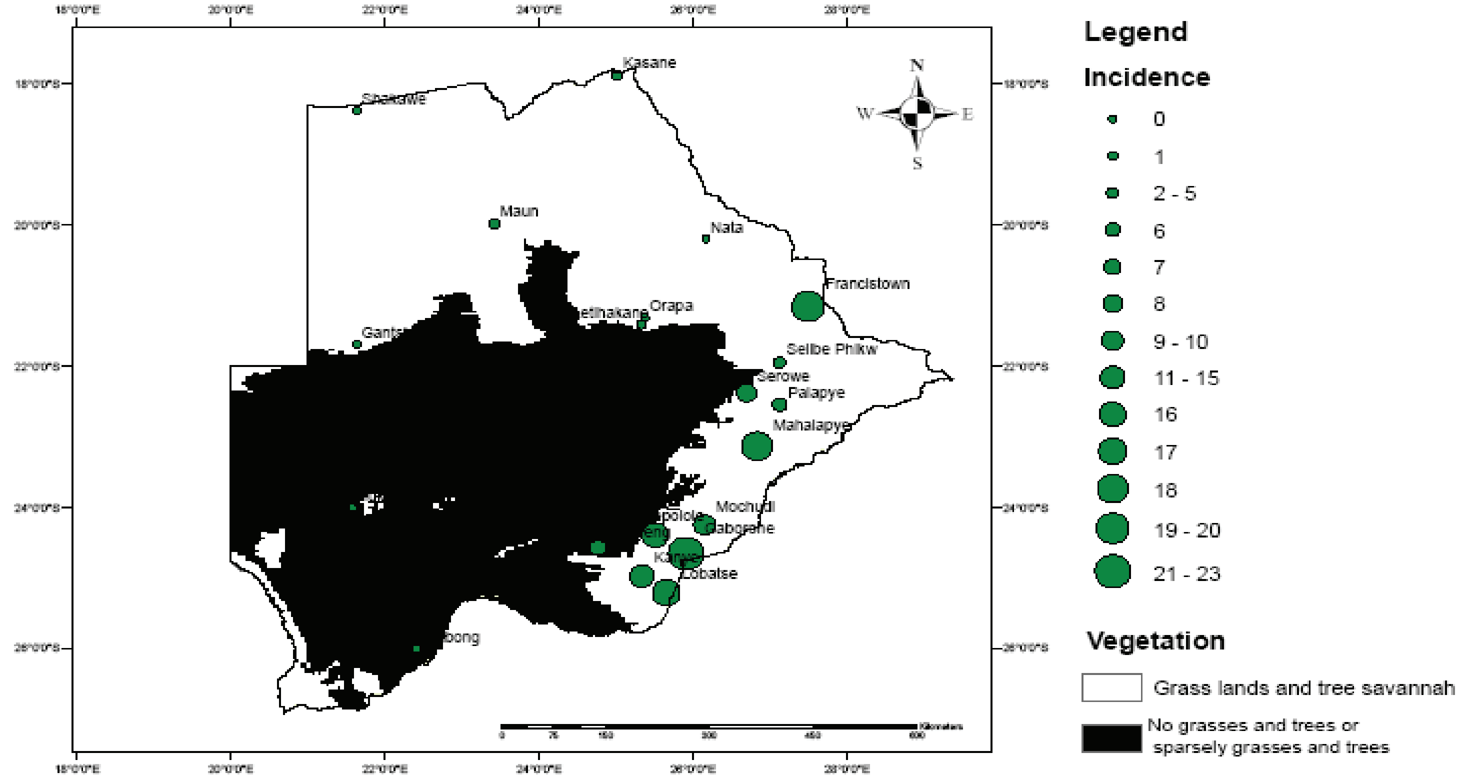

Figure 9. Spatial relationship between and heartwater incidence and vegetation type

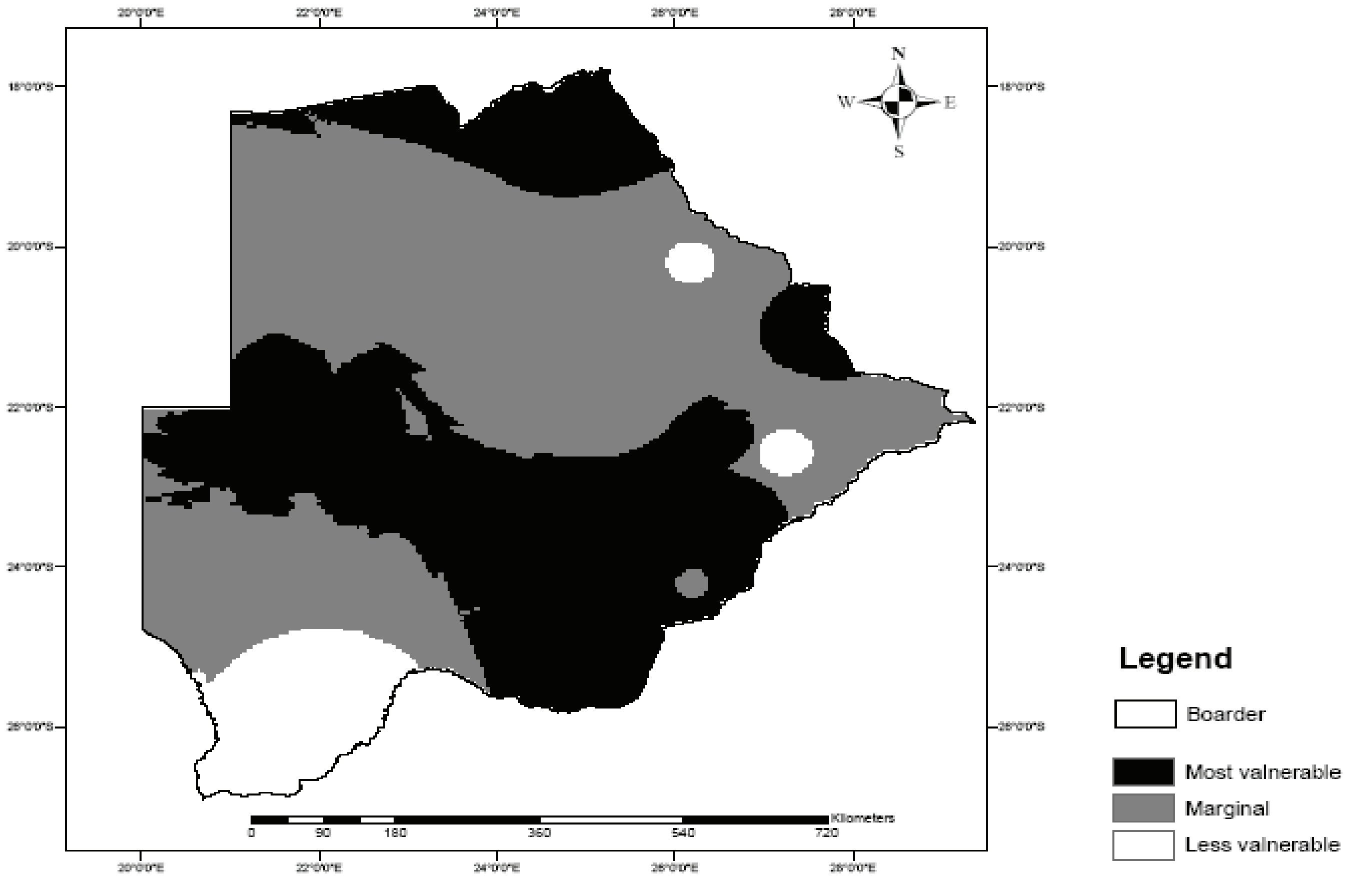

Figure 10. Differential spatial vulnerability to heartwater across the country based on the overlay of Figures (4 to 9).

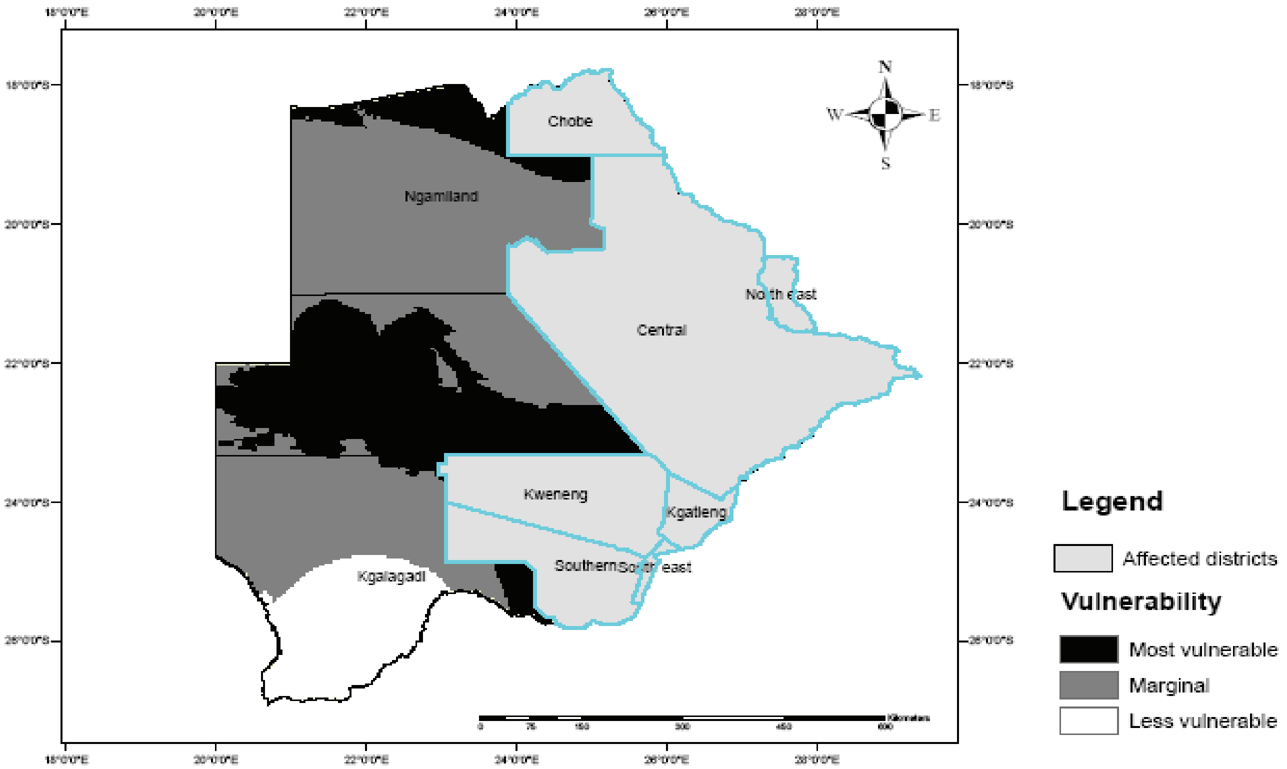

Figure 11. Currently affected and vulnerable districts

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