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Spatio-temporal dynamics of schistosomiasis in Rwanda between 2001 and 2012: impact of the national Neglected Tropical Disease control programme

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Abstract

Schistosomiasis is recognised as a major public health problem in Rwanda. We aimed to identify the spatio-temporal dynamics of its distribution at a fine-scale spatial resolution and to explore the impact of control programme interventions. Incidence data of *Schistosoma mansoni* infection at 367 health facilities were obtained for the period 2001-2012. Disease cluster analyses were conducted using spatial scan statistics and geographic information systems. The impact of control interventions was assessed for three distinct sub-periods. Findings demonstrated persisting, emerging and re-emerging clusters of schistosomiasis infection across space and time. The control programme initially caused an abrupt increase in incidence rates during its implementation phase. However, this was followed by declining and disappearing clusters when the programme was fully in place. The findings presented should contribute to a better understanding of the dynamics of schistosomiasis distribution to be used when implementing future control activities, including prevention and elimination efforts.

Introduction

Reliable updates of the number of people currently infected by schistosomiasis worldwide are difficult to come by as they depend on the level of sensitivity of the diagnostic techniques used. Although the figure of 250 million infected victims given by Hotez *et al*. (2014) is probably an understatement, it is close to figures previously given by the World Health Organization (WHO) and most authors. Mortality is even more difficult to pin down but the figure provided by the Global Burden of Disease (GBD) study in 2010 (Lozano *et al*., 2012) shows that the disease is primarily chronic. Left untreated, schistosomiasis causes damage to the bladder, kidneys, liver, spleen and also other organs depending on which species of the parasite is involved (van der Werf, 2003).

Schistosomiasis is an important neglected tropical disease (NTD) recognised as a major public health problem (TRAC+, 2008). In Rwanda, intestinal schistosomiasis caused by *Schistosoma mansoni* is the only form of the disease, so the morbidity seen does not include the urogenital system. Until 2007, the spatial prevalence pattern within Rwanda remained unidentified. In that year, the Rwandan Ministry of Health (MoH) established an NTD control programme, which started with a nation-wide mapping of NTD prevalence based on a cross-sectional survey of randomly sampled primary schools in each of the country's 30 districts (TRAC+, 2008). School survey outcomes were extrapolated to district-level prevalence maps, which were subsequently used to guide a control initiative (Figure 1). The initiative started with

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a three-year project (2008-2010) with several intervention measures targeting the most endemic districts. The nationwide NTD interventions included mass drugs administration (MDA), training of health workers on diagnosis, treatment and transmission control. Health promotion materials were also distributed.

Figure 1 shows the schistosomiasis prevalence in the 2007-08 period, including the implementation of MDA using praziquantel, while Figure 2 illustrates the achievement of the control initiative. We considered three subsequent periods of the control programme, the first of which shows the period before its establishment (up to in 2007), the second, the implementation period that was surprisingly associated with an abrupt increase (2008-2010). However, this increase was most probably attributed to improved diagnosis that was part of the programme implementation. The third period from 2010 onwards depicts the programme when fully operational, which was characterised by a steep decline in the number of incidence, apparently stabilising to a level comparable to the pre-2007 situation. Thus despite the control effort, the number of confirmed cases of schistosomiasis remains high at the national level. Recent studies by Ruberanziza *et al*. (2010, 2015) also identified changes of focal areas with relatively high prevalence. Some of the recently identified areas with high prevalence are located in districts initially classified as being of low endemicity.

Since schistosomiasis can have a highly localised distribution (Gray *et al*., 2011), a spatio-temporal assessment based on routinely collected incidence data at primary health facilities, can be done using local clustering methods to identify areas with high disease occurrence (Anselin, 1995; Song and Kulldorff, 2003; Bernasco and Elffers, 2010; Quick and Law, 2013). Local clustering methods can be used to identify if cases are geographically concentrated (spatial clusters), tend to be placed closer in time (temporal clus-

ters), or are close both in space and time – spatio-temporal clusters (Tango, 2010). Few studies, however, have aimed at the detection of spatio-temporal schistosomiasis at a detailed spatial scale. A notable exception is Gao *et al*. (2014) who analysed spatio-temporal clustering of schistosomiasis japonica at the village level in Anhui province in China.

The objectives of this study were to explore the spatio-temporal distribution dynamics of schistosomiasis in Rwanda between 2001 and 2012, and to investigate the linkage of this distribution with the NTD control programme interventions. We aimed to analyse these outcomes to assess the impact and effectiveness of the current elimination strategy in Rwanda.

Materials and Methods

The systematic spatio-temporal variation of *Schistosomiasis mansoni* incidence rates at health facility service area (HFSA) was detected with Kulldorff's Spatial Scan Statistics (SaTScan v9.4.2) and results were visualised with GIS software ArcGIS, v. 10.4 (ESRI, Redlands, CA, USA).

Study area

Rwanda, a small, densely populated, landlocked country of 26,338 km² in the Great Lakes region of central-eastern Africa, is administratively divided into five provinces, 30 districts and 416 sectors (MINALOC, 2005). Administrative sectors together are subdivided into 376 primary HFSA, each of which has one Health Centre with one or more health post or dispensary, which routinely reports to the district health department unit. The methodology
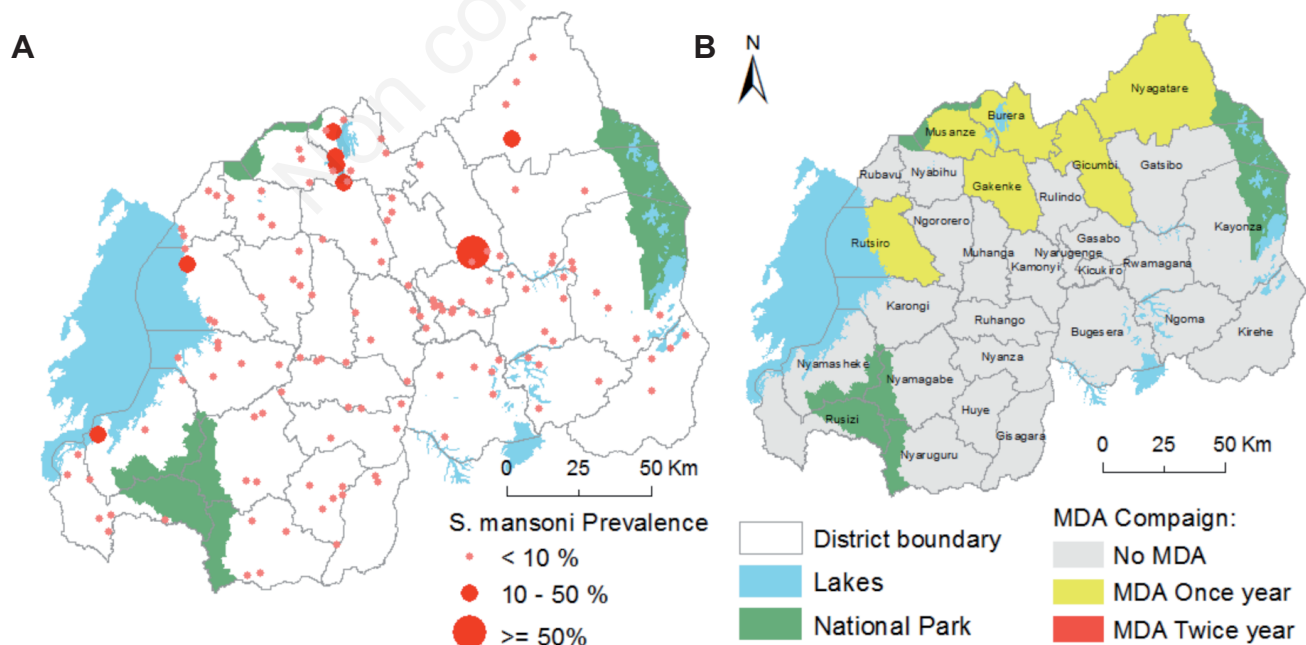
Figure 1. Distribution of schistosomiasis in Rwanda with indication of areas prioritised for control. A) Prevalence map from 2007-08 school-based prevalence survey; B) areas prioritised for mass drugs administration.

developed for demarcation of the HFSA boundaries is documented in our previous study (Nyandwi *et al.*, unpublished material). Rwanda has a relatively dense and dynamic hydrological network with many lakes and rivers and numerous floodplains and wetlands covering 10% of the land surface (Nyandwi *et al.*, 2015). The Government of Rwanda considers marshland as an important resource for the intensification of agriculture (mainly rice cultivation), to achieve the goal of food security in the context of Vision 2020 (http://www.minecofin.gov.rw/index.php?id=148), implemented through a five years economic development and poverty reduction strategy.

Data on schistosomiasis infection and population

Patients suspected to have schistosomiasis are asked and instructed how to collect and submit stool specimen, which were subsequently subjected to testing for eggs of soil transmitted helminths (STH) and *Schistosoma mansoni* using the Kato-Katz technique (Katz *et al.*, 1972). Trained medical laboratory technicians conducted the sample analysis. Two slides per stool specimen were prepared and read separately. The result recorded per patient was the mean of the reading of the two slides (egg count or number of eggs per gram of stool). The number of confirmed schistosomiasis cases per primary health facility were recorded and first reported in an Excel table and later loaded into the Rwandan Health Management Information System (R-HMIS) every month by each primary health facility using a web-based software platform called DHIS 2 (USAID/Rwanda, 2006). The recorded cases, without personal information, were provided by the Malaria and Other Parasitic Diseases Division of the Rwanda Biomedical Centre (RBC/M&OPD). The dataset consisted of laboratory confirmed cases from all public and faith-based primary

health facilities for the period January 2001 to December 2012.

The disease data were felt to be representative for several reasons, such as: i) health service accessibility – primary health facilities are within walking distance for most people (<5 km distance); ii) affordability – health care for most Rwandans is facilitated by the community-based health insurance (patients pay only 10% of the total cost of service and medication); iii) encouragement – community health workers actively stimulate patients to visit the primary health facility in case of suspected health problems; and iv) medication – there is no traditional medicine used for schistosomiasis in Rwanda, patients with symptoms are treated at the primary health facility.

Demographic data were extracted from the 2002 and 2012 Population and Housing Census published by the National Institute of Statistics of Rwanda (NISR). For the years between, population data were estimated using the average national population growth rate of 2.6% (NISR and MINECOFIN, 2014). The resulting population data from 2001 to 2012 for each HFSA was prepared as input for the space-time analysis in SaTScan. In addition, the coordinates file was prepared as X, Y of centroids for each HFSA generated in ArcGIS v. 10.4.

Spatial and space-time clustering analysis

The annual number of confirmed schistosomiasis cases per HFSA were stored in Excel tables. Kulldorff's spatial scan statistic (SaTScan), a widely application in epidemiology (Hanson and Wieczorek, 2002; Read *et al.*, 2011; Yao *et al.*, 2011), was used to identify HFSAs with significantly high incidence rates. Given that we had data of confirmed cases for the period 2001-2012 a retrospective analysis (spatial and space-time) was applied. The analysis was performed using SaTScan 9.4.2 (Kulldorff, 2015).
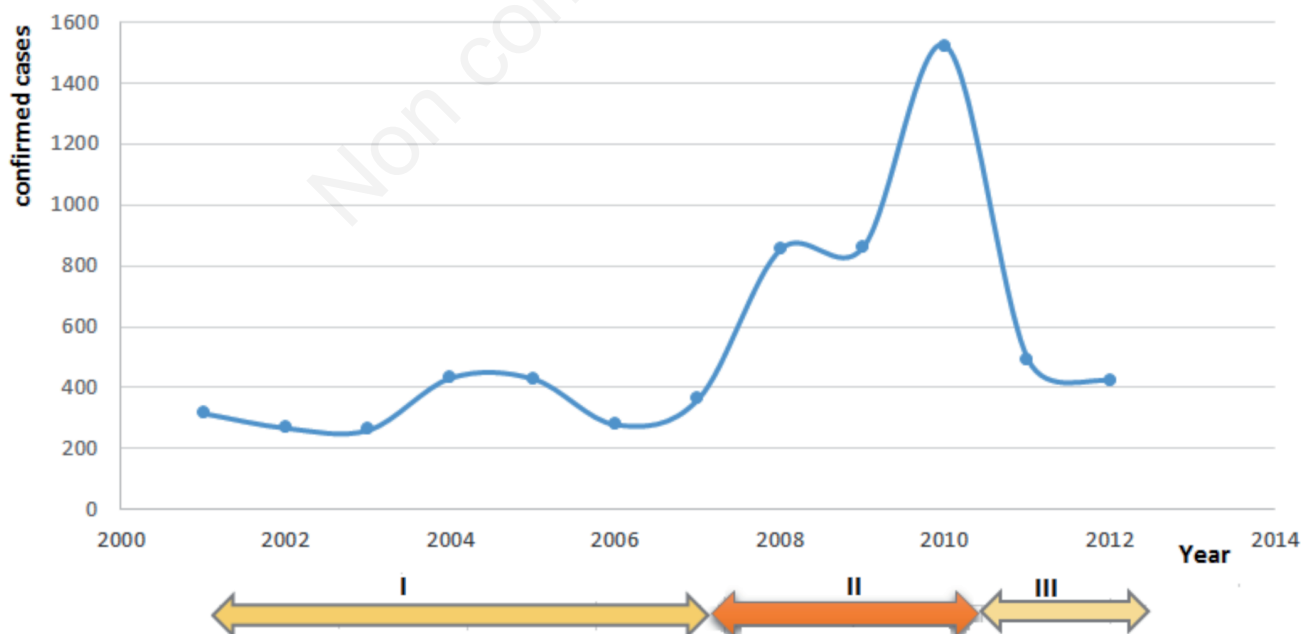
Figure 2. Reported schistosomiasis cases between 2001-2012. The three identified time periods are: I (before the neglected tropical disease control programme), II (during the three years of neglected tropical disease control initiation), and III (the period when the neglected tropical disease programme had become fully functional).

The advantage of the SaTScan over other local cluster analysis methods is that it calculates a likelihood test statistic, avoids multiple testing and has a variable scan window which prevents pre-selection bias (Mather *et al.*, 2006). SaTScan determines statistical significance without specifying the number of areas or location of the clusters before calculating the level of significance; all significant clusters must reject the null hypothesis based on their strength (Almeida, *et al.*, 2011; Kulldorff, 2015). Because of this, any rearrangement of cases outside of the scan window will not change the cluster significance level (Song and Kulldorff, 2003). The level of significance is determined through Monte Carlo hypothesis testing, an estimate of the rank of likelihood of the real data based on randomised versions of the same dataset (Kulldorff, 2015). The likelihood ratio is calculated as:

$$LR(Z) = \frac{L(Z)}{L_0} = \left(\frac{c(Z)}{n(Z)}\right)^{c(Z)} \left(\frac{C - c(Z)}{C - n(Z)}\right)^{C - c(Z)} \qquad \text{Eq. 1}$$

where *LR(Z)* represents the likelihood ratio for scan window *Z* which is calculated as the likelihood of the alternative hypothesis of spatial clustering (*L(Z)*) divided by the likelihood of the null hypothesis of complete spatial randomness (*L_0*). $c(Z)$ is the observed number of cases in scan window *Z*, $n(Z)$ the expected number of cases inside *Z*, and *C* the total number of cases.

After the likelihood ratio (LLR), a P value is estimated by comparing the rank of the maximum LLR from the real data set with the highest LLR from the random datasets using Monte Carlo simulation. We set the number of replications to 999 times. Clusters with P<0.05 indicate raised risk. Relative risk (RR) was calculated for each statistically significant cluster (Kulldorff, *et al.*, 1998) by comparing the risk within the cluster in a particular time and area with the risk outside the cluster.

Spatial clustering analysis

Spatial clusters were detected using SaTScan's circular window that scans the entire study area. The radius of the circle can be varied continuously from zero to a specified maximum spatial window size, corresponding to the maximum percentage of the total population at risk. Since we expected to identify highly localised clusters, we followed the recommendation of Gao *et al.* (2014) and opted for the maximum window size to contain 10% of the population at risk. For each window, the observed cases inside and outside the circle were compared to the number of expected cases, as calculated using the Poisson distribution. The window with the maximum likelihood ratio was identified as the most likely (primary) cluster (Kulldorff, 1997). Subsequent likelihood ratios with significance levels of <0.05 were considered secondary clusters.

Space-time clustering analysis

For detection of space-time clusters, the cylindrical approach was used. Here the window was used as described above, while the temporal aspect was expressed as the height of a cylinder with that window as base. The window started with the minimum radius and height at one location and was then moved throughout the study area with a continuously varying radius and height until reaching the upper limit of the radius. The maximum spatial window was set at 10% of the population at risk, while the height was set at 50% of the total length of the study period.

Cluster detection within sub-periods of study period

Figure 2 identifies three sub-periods that coincide with the time before, during and after the implementation of the NTD control programme. Therefore, the methodology described above was first applied to the entire study period and then repeated for each of the three identified sub-periods. The underlying motivation for this was to facilitate the analysis of the impact of the intervention.

Results

Investigation of spatial schistosomiasis clusters

Transmission of schistosomiasis was found to be concentrated in 32 spatial clusters as shown in Table 1. The most likely cluster found was Ntaruka HFSA situated in Burera District in the Northern Province. The secondary most likely cluster was seen in Jarama HFSA located in Ngoma District in the Eastern Province. The largest cluster consisted of 18 HFSAs located in Rusizi and Nyamasheke Districts in the Western Province.

Investigation of schistosomiasis clusters

As shown in Figure 3 and Table 2, sixteen spatiotemporal clusters were identified between 2001 and 2012. The most likely cluster had a high LLR of 2798.3, and the least likely had an LLR of 28.4 (P<0.001). This demonstrated that a statistically significant clustering pattern of schistosomiasis incidence existed both in time and space. The most likely cluster was Ntaruka HFSA showing high rates for the six-year period of 2003-2008. A similar persistence in time was observed in cluster 4 (2007-2012) and cluster 10 (2005-2010). Many spatio-temporal clusters existed only for one year (in 2008, 2009 and 2010). If we consider geographical distribution, all 16 spatiotemporal clusters were situated near lakes, main rivers and floodplain wetlands, which all are known for schistosomiasis transmission due to the presence of habitats of the intermediate snail host.

Relation to the national neglected tropical disease control programme

Clustering in each sub-period

The results of the spatial scan statistic for each of the three sub-periods is visualised in Figure 4. There were 19, 29 and 11 clusters observed in Rwanda for sub-periods I, II, and III, respectively. While the LLR of the primary cluster remained very much higher compared to the LLR value of the secondary likely cluster 2, the geographical location and size of the identified most likely clusters differed for each of the three sub-periods.

During sub-period I (Figure 4A), the most significant schistosomiasis cluster was in the North, corresponding to the Ntaruka HFSA. During sub-period II the primary cluster was in the Southeast, *i.e.* the Jarame HFSA located in Ngoma district, Eastern Province (Figure 4B). In sub-period III, the most likely cluster, covered very a large area, in the South-West (Figure 4C). In sub-period III all clusters were located in the periphery of the country, with the central parts no longer exhibiting high rates of infection. Cluster number 4 (Kigali City) and 6 (Gisagara District) were, however, exceptions. This meant that hotspots had shifted to peripheral areas, with the most likely cluster in the extreme Southwest and numerous new hotspots in the eastern periphery.

Spatial and temporal cluster dynamics

We distinguish three categories of clusters. The first category consisted of persistent clusters, *i.e.* areas characterised by high rates of schistosomiasis in each of the three sub-periods. There are four such persistent areas (Nkombo Island, Bugarama, Ntaruka-Kinoni and Gikonko) that were seen in the whole study period, and appeared in each sub-period. The second category were emergent clusters, characterised by presence in areas which were originally not highly prevalent but became so after 2007. The third category consisted of disappearing clusters, areas with high rates of schisto-somiasis during sub-period I but not seen during the two later in sub-periods. In these clusters, the rate declined significantly over time.

As can be seen in Figure 1, the prioritised areas target zones with prevalence greater than 10%. The mass MDA was planned at

the district level using prevalence classes as follow: no MDA for district with <10% prevalence; once a year for school children and women of child-bearing age where prevalence was <30% and twice a year all where the prevalence was greater >30%.

Discussion

The focal spatial distribution of schistosomiasis mansoni in Rwanda was confirmed by the spatial scan statistics space-time analysis used in this study. As illustrated in Figure 2, the annual number of confirmed schistosomiasis cases in the period 2001-2012 exhibited considerable variation over time. During the first seven years, the period before the NTD control programme, we observe slightly varying medium-level numbers of infections that

Table 1. Spatial clusters of schistosomiasis (2001-2012).

Cluster identified	HFSAs involved	Name(s) of HFSAs with clusters	LLR	RR	Obs	Exp
1	1	Ntaruka/Kinoni	2828	197	668	4
2	1	Jarama	807	26	356	14
3	2	Cyanika, Kinyababa	597	10	438	47
4	18	Bushenge, Bugarama, Gihundwe, Gisakura, Kibogora, Mashesha, Mibilizi, Nyamasheke, Mushaka, Muyange, Mwezi, Nkombo, Nkungu, Nyabitimbo, Mukoma, Rangiro, Ruharambuga, Rusizi	576	4	1156	374
5	1	Bugarama	517	9	403	47
6	5	Cyabayaga, Karama, Mimuli, Rukomo, Rurenge	443	7	444	73
7	1	Nkombo	432	20	212	11
8	4	Cyondo, Mimuli, Muhambo, Rukomo	354	7	327	48
9	1	Kibogora	254	11	176	17
10	1	Rwesero	200	27	86	3
11	1	Rusoro	188	10	132	13
12	4	Cyabingo, Murandi, Nyundo, Rwaza	181	5	236	51
13	1	Cyimbili	148	10	109	12
14	1	Gikonko	130	10	96	10
15	1	Mwendo	121	14	72	5
16	1	Bisate	85	6	87	14
17	1	Rugarama	80	4	117	28
18	2	Murara, Byahi/Gacuba	79	3	168	53
19	1	Nzige	74	6	84	15
20	2	Ntaruka/Nasho, Gituku	64	7	62	9
21	3	Gasiza, Kinoni-Gahunga, Mucaca	61	3	143	48
22	1	Humure	54	7	53	8
23	4	Gisakura, Mukoma, Muyange, Nyamasheke	49	3	141	54
24	2	Nyagahita-Nyagatare, Rurenge	45	4	83	24
25	1	Busanza	37	3	101	38
26		Mashesha	31	4	47	11
27	1	Rusizi	19	3	61	25
28	4	Mukono, Bushara, Bwisige, Cyondo	18	2	77	35
29	1	Nyamyumba	15	4	25	6
30	1	Nyacyonga	13	3	36	14
31	1	Gatare-Mugonero	12	4	21	6
32	1	Kigufi	9	2	41	19

HFSA, health facility service area; LLR, log likelihood ratio; RR, relative risk; Obs, observed number of cases in the cluster; Exp, expected number of cases in the cluster. All clusters had statistical significance levels P<0.01.
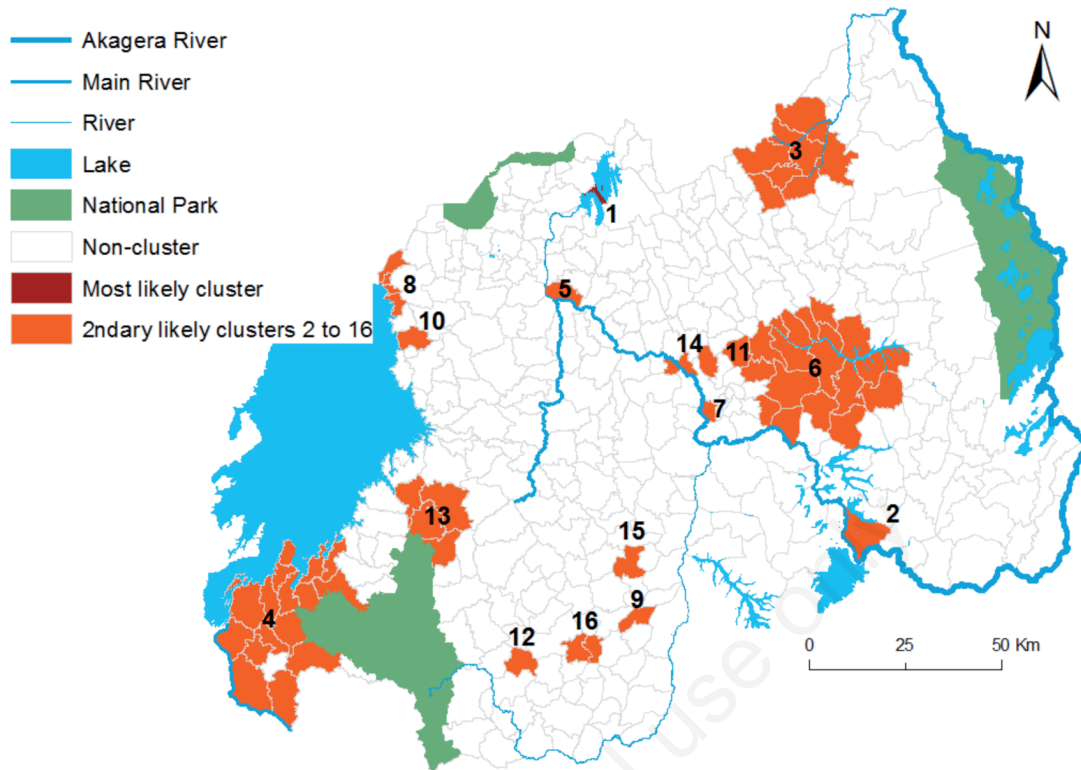
Figure 3. Spatiotemporal schistosomiasis clusters in the period 2001-2012.

Table 2. Spatio-temporal schistosomiasis clusters in order of log likelihood ratio.

Cluster identified	HFSAs involved	Timeframe	Name(s) of HFSAs with clusters	LLR	RR	Obs	Exp
1	1	2003-2008	Ntaruka	2798	348	582	2
2	1	2010	Jarama	1631	283	353	1
3	9	2008-2010	Cyabayaga, Cyondo, Karama, Muhambo, Mimuli, Nyarurema, Rukomo, Rurenge, Tabagwe	763	14	451	34
4	18	2007-2012	Bugarama, Bushenge, Gihundwe, Gisakura, Kibogora, Mashesha, Mukoma, Mibilizi, Mushaka, Muyange, Mwezi, Nkombo, Nkungu, Nyabitimbo, Nyamasheke, Rangiro, Ruharambuga, Rusizi	639	5	869	202
5	1	2010	Rusoro	428	102	118	1
6	18	2008-2010	Busanza, Gikomero, Gishali, Giti, Humure, Kayanga, Kinyinya, Masaka, Muhura, Murambi-Musha-Gahengeri, Muyumbu, Nyagasambu, Nzige, Rubungo, Ruhunda, Rwesero, Rwimitereri, Tanda	2798	348	582	2
7	1	2010-2012	Mwendo	1631	283	353	1
8	4	2010	Byahi-Gacuba II, Gisenyi, Kigufi, Murara	763	14	451	34
9	1	2009-2011	Gikonko	639	5	869	202
10	1	2005-2010	Cyimbili	428	102	118	1
11	1	2009	Nyacyonga	336	5	438	95
12	1	2010	Nyamyumba	205	48	71	1
13	4	2009	Gisovu, Mugonero, Mukungu-Bisesero, Nyarwungo	198	15	111	7
14	3	2008	Jali, Kabuga-Kamonyi, Rutonde	159	25	70	3
15	1	2008	Nyamure	156	15	88	6
16	2	2008	Mbazi and Sovu	87	30	36	1

HFSA, health facility service area; LLR, log likelihood ratio; RR, relative risk; Obs, observed number of cases in the cluster; Exp, expected number of cases in the cluster. All clusters had statistical significance levels P<0.01.

increased sharply during the first three years of control implementation. At first glance, this may come as a surprice, but the explanation is surely a reflection of improved diagnostic coverage. From 2010 onwards, we see a steep decrease in annual incidence, stabilising at the pre-intervention period, which shows the impact of the NTD intervention programme (as the diagnostic coverage remains the same). Taking the annual population growth of 2.6% into account, we can conclude that incidence rates have been dynamic during the study period. Some HFSA were persistently classified as schistosomiasis cluster-related with different levels of significance. Over time, new focal areas emerged, while others disappeared. Overall, 67 HFSA units out of a total of 367 were identified as areas with increased transmission of the disease. Persistent and emergent clusters amounted to 53 HFSA units, while 14 such units became non-endemic towards the end of the study period.

The observed spatio-temporal changes in high-rate schistosomiasis clusters were associated both with changes in environmental risk factors and impacts of the various interventions measures initiated by the NTD programme. In the following, we discuss in more detail the association between these clusters and the interventions. Furthermore, the observed spatio-temporal dynamics may be explained by analogy from the literature. We structure this discussion by presenting possible relations for persistent clusters, emergent clusters, and disappearing clusters.

Starting at the first three years of the NTD control program, resources for schistosomiasis control (awareness raising, diagnostic equipment, medication, training of health personnel) increased tremendously (Ruxin and Negin, 2012). In three years, nearly 100% of the population at high risk was covered by at least two MDAs within the priority districts (Sabin Vaccine Institute, 2011).
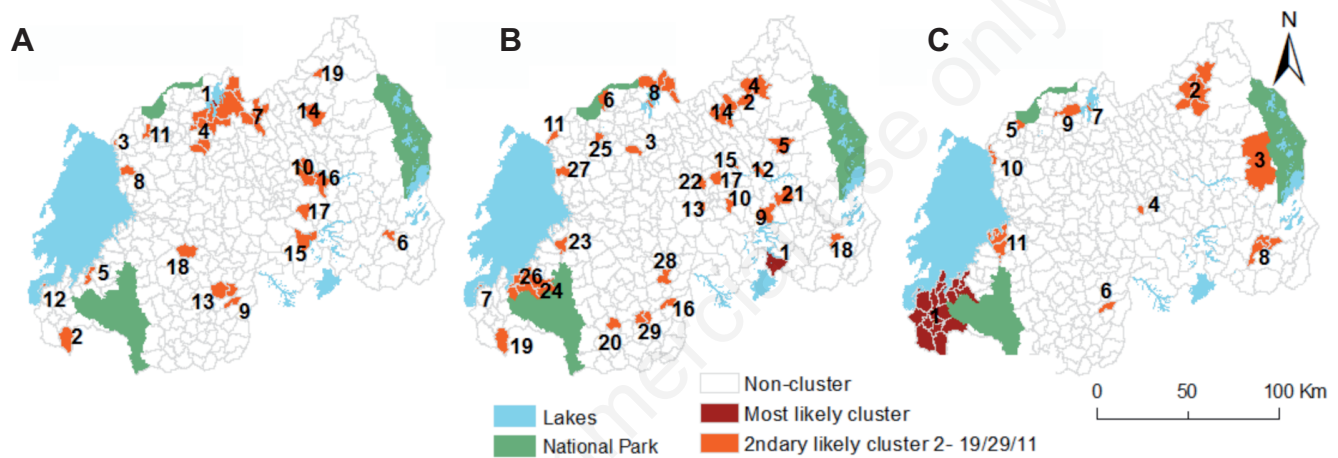

Figure 4. Spatio-temporal schistosomiasis clusters for the three sub-periods. A) Sub-period I (before the neglected tropical disease control programme, 2001-2007); B), sub-period II (during the first neglected tropical disease control intervention, 2008-2010); and C) sub-period III (with the neglected tropical disease control programme in place, 2011-2012).
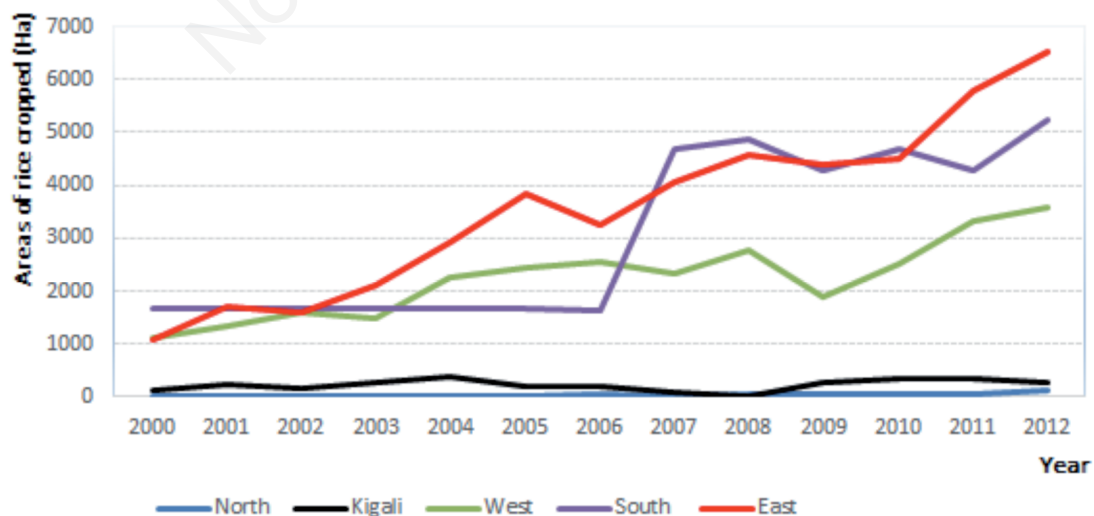

Figure 5. Evolution of rice cultivation areas per province in the period 2000-2012.

The treatments were accompanied by the distribution of informational and educational materials. At the end of the project, 18,825 health staff were trained to identify symptoms and treatment of intestinal schistosomiasis (Ruxin and Negin, 2012). Increased knowledge of, and means for diagnosis and treatment, probably explains the abrupt increase of confirmed cases during the sub-period II of the program implementation and the general strong decrease of confirmed cases since 2011. Our spatio-temporal analysis demonstrates that most of the schistosomiasis clusters disappeared, or that their significance declined over time. In traditional hotspots, *e.g.* Ntaruka-Kinoni HFSA in Burera District, rates have declined consistently. Indeed, this area changed from the most important cluster during sub-period I into a secondary cluster in the following two sub-period. Over the course of three years, the selected areas (Figure 1) were covered by repeated MDA campaigns, guided by the district prevalence map of the nationwide prevalence mapping survey. The approaches initiated by the NTD control programme were also complemented by the great positive impact of improved socio-economic conditions (such as increased number of school attendances, access to improved water for

domestic use, proper sanitation, wearing shoes, *etc.*) (Leuchowius, 2014; MINECOFIN, 2015; United Nations, 2000).

Although the mapping exercise was generally of great help in guiding the NTD control initiatives, it did not capture all high-prevalence locations. The most probable reason for this was that spatial resolution of the district-level baseline map could have been better. The district-based approach was too aggregated, and therefore some high-rate transmission areas were not detected. For example, Nkombo Island and neighbouring areas are located in districts classified as low-endemic, while Ruberanziza *et al.* (2015) identified this area as one of the most important foci in Rwanda. However, this area becomes the most important cluster in sub-period III. Since the districts Rusizi and Nyamasheke were falsely considered among the least endemic districts with prevalence rates of 0.7 and 4.5%, respectively (TRAC+, 2008), they did not benefit from control measures during the first three years of the interventions (Figure 1).

Despite, the substantial impact of the well-managed NTD intervention programme, our analysis revealed that the schistosomiasis rates remain high and that there are also new emerging clus-
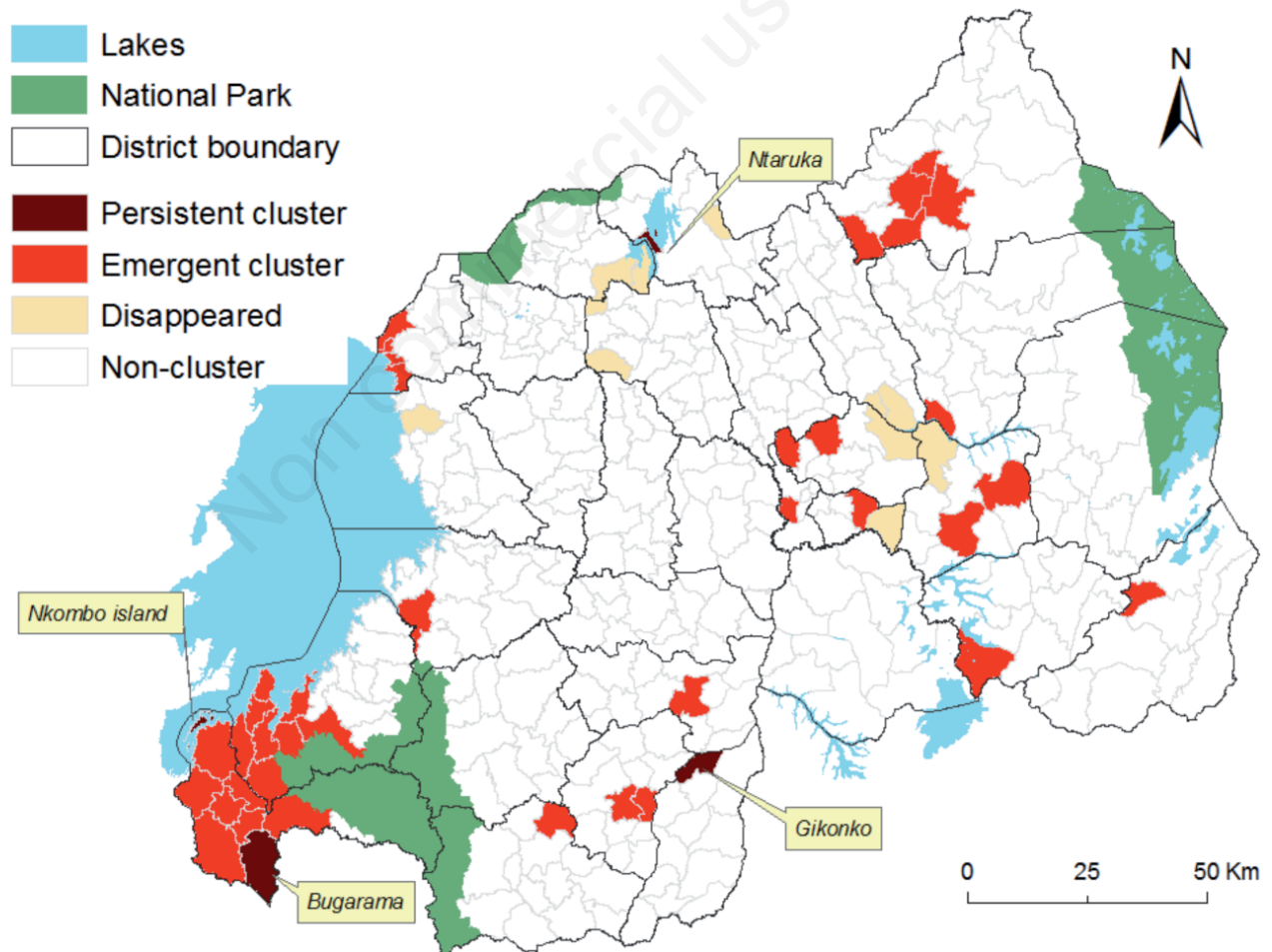
Figure 6. Clusters of high rate schistosomiasis mansoni transmission. Persistent clusters (dark red colour), emerging clusters appearing since 2008 (red colour), clusters that disappeared after control measures had been implemented (sand colour), and non-endemic areas (white).

ters. Thus, the eradication of the disease is difficult since the transmission factors are still there. The persistent and emergent clusters may be associated with various and changing risk factors as discussed by Steinmann *et al*. (2006) in a systematic review of dam projects referring to other African countries that are also endemic for schistosomiasis. In Rwanda, the most important risk factors might be related to the extended and new irrigated areas as a result of the agricultural transformation in Rwanda (Malesu *et al*., 2010). Furthermore, conversion of wetlands for rice cultivation increased from 4000 ha to 13000 ha between 2000 and 210 (Nabahungu and Visser, 2013). Consequently, two of four persistent clusters (Bugarama and Gikonko HFSAs) are both located in areas with the oldest (since the 1980's) and also the largest rice cultivation schemes (Republic of Rwanda, 2010). According to unpublished statistics from Ministry of Agriculture, Rusizi District hosted 20% of the total rice crops in Rwanda by 2012 and Bugarama District counts more than 6000 of about 17,000 households engaged in rice cultivation. Furthermore, rice cultivation in Rwanda involves the most vulnerable community groups, women and children; more than 45% of rice farming workers are women (Nkurikiye, 2016). The number of schistosomiasis infections may double or triple for a relatively small number of peoples in temporal shelters/villages of workers concentrated around such water development projects. Adjacent to most wetlands there are relatively flat areas that are easily settled but which lack hygienic conditions, such as tap water and sewage systems. The expansion of irrigated rice cultivation (Figure 5) may explain the expanding clusters in the Eastern Province, as illustrated throughout by Figures 4 and 6. The Eastern Province totalled 41.5% of rice cultivation areas in Rwanda by 2012. The expansion of rice cultivation in the Eastern Province took place specifically within Nyagatare District, where rice cropping in the wetlands along Muvumba River increased from 180 to 1350 ha between 2000 and 2012. Also, the Eastern Province, a relatively semi-arid region of the country, a lot of dams have been constructed, and hillside irrigation projects initiated (Malesu *et al*., 2010; MINAGRI, 2012).

Other persistent clusters (Ntaruka-Kinoni and Nkombo HFSAs) are situated in close proximity of Kivu Lake and the adjacent lakes of Burera and Ruhondo. Most of the inhabitants in these areas are in permanent contact with the lakes when fetching water for domestic use, swimming, and fishing. This finding is in line with other studies highlighting the link between schistosomiasis and water contact (Tukahebwa *et al*., 2013; Mazigo *et al*., 2014). Likewise, most of the emerging endemic areas are in proximity to water bodies and man-made agricultural schemes, which supports the intermediate snail host and transmission.

Although the spatially structured data recorded at primary health facilities inform us about the distribution of disease transmission, the people tested constitute just the portion representing the seriously infected persons; the total number of infections is surely much greater. We advocate more actively monitoring for all newly emerging clusters using existing routinely collected data, to guide new intervention programmes. Disease-conscious planning of land use in the future could also help to prevent further increase of the disease.

Although the level of aggregation of the data investigated is relatively small (at the HFSA level), they do not represent the exact geographical location of the infected patients for most HFSAs, as unoccupied areas are not excluded (*i.e*., protected areas). Thus, the coordinates linked to the HFSA centroid used may not reflect the reality needed/tracked by the spatial scan window applied. However, earlier comparative studies by Torabi and Rosychuk (2011) and Rashidi *et al*. (2015) show only minor differences between circular and flexible scan statistic methods in cluster analysis.

Conclusions

The analysis presented here has demonstrated that the presence of schistosomiasis in Rwanda varies across space and time. The impact of the NTD national control programme was clearly reflected by localised clusters, which were either persistent, emerging or disappearing over time. The intervention initiative pushed hotpots of schistosomiasis transmission to the periphery but was not able to eradicate the disease. Persistent clusters with high schistosomiasis rates still occur, while emerging clusters show a linkage with new, large-scale agricultural schemes involving irrigation and rice cropping. The results generated should be highly valuable for a spatially structured evaluation of risk factors associated with schistosomiasis and provide vital information for decision-makers and health planners. The methodology presented and outcomes generated contribute to a better understanding of the dynamics of schistosomiasis and are recommended for future prevention, control and elimination interventions.

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