Rabies intervention in Tanzania: An innovative animal vaccination model to train One Health focused student workforces to control and eliminate rabies

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Abstract

Background: *Every year at least 59,000 people are estimated to die from rabies and more than 10 million are treated with post-exposure prophylaxis (PEP). Over 99% of human rabies deaths occur in developing countries due to bites from domestic dogs. Large-scale mass dog vaccination programs can control dog rabies and, if sustained, can eliminate dog-mediated rabies. However, there has been very little investment in mass dog vaccination against rabies in sub-Saharan Africa, largely due to limited human and financial resources. To overcome this limitation, we piloted the delivery of synchronized dog vaccinations using a temporary workforce of university students. Fifty university students from Sokoine University of Agriculture and Muhimbili University of Health and Allied Sciences were selected to deliver dog vaccinations throughout the Kisarawe district in Tanzania in May 2021. We analysed the vaccination coverage achieved and the cost per dog vaccinated in delivering dog vaccinations using the university students compared to the traditional delivery.*

Results: *A total of 1,457 dogs and 242 cats were vaccinated across 48 villages in the Kisarawe district of Tanzania over the course of five days. The overall cost in delivering mass dog vaccinations was estimated at US$ 28,990 equating to approximately US$19.90 per vaccinated dog. Post-vaccination transects were conducted in all 48 villages where dog vaccinations were implemented, counting 387 dogs. Of these, 54% dogs (N=210) were vaccinated against rabies, 67% (N=258) were free-roaming dogs and 72% of dogs encountered were adult (N=277). The overall district-level mean vaccination coverage was estimated to be 54.3% (CI 49.3% - 59.6).*

Conclusions: *We demonstrated that using university students as a One Health workforce is effective in accelerating the countries' efforts to meet the global target of eliminating dog-mediated human rabies by 2030.*

Background

Rabies is a major global public health challenge that leads to an estimated 59,000 human deaths annually. Furthermore, it causes over 3.7 million disability-adjusted life years and 8.6 billion USD in economic losses annually (1). Over 95% of human rabies deaths occur in Africa and Asia, with approximately 99% of these deaths resulting from infection following bites from rabid domestic dogs (1,2). Human rabies is preventable through prompt administration of post-exposure prophylaxis (PEP) following a bite from a rabid animal (3,4). Application of PEP alone, however, does not interrupt disease transmission within the dog population and does thus not contribute towards disease elimination. In contrast, mass dog vaccination (MDV) is a proven and effective way to prevent the spread of rabies, and when delivered effectively can eliminate the infection (5). International organizations including the World Health Organization (WHO), the World Organization for Animal Health (OIE), the Food and Agriculture Organization of the United Nations (FAO) and the Global Alliance for Rabies Control (GARC) are currently advocating for the global dog-mediated human rabies elimination by 2030 (6,7).

Previous work in rabies control has summarized the metric to be used to measure the effectiveness of vaccination campaigns (8). First, dog vaccination campaigns should aim to reach all dog owning communities, ensuring that no susceptible dogs are unvaccinated (campaign completeness). Patchy coverage has been shown to facilitate rabies persistence, since unvaccinated dogs can be a source of ongoing transmission (9). Second, dog vaccination campaigns should aim to achieve at least 70% coverage of the susceptible dog population to interrupt the transmission cycle of rabies (5,10). The majority of dogs in Africa are free-roaming dogs (family or community-owned dogs) making them particularly susceptible for rabies transmission and they should thus be targeted for mass dog vaccinations (11). Finally, dog vaccination campaigns should be conducted routinely using high-quality vaccine. Vaccination coverage declines rapidly following a campaign as vaccinated may dogs die naturally, susceptible (unvaccinated) dogs may increase in number due to new births or re-introduction of unvaccinated dogs from other areas, and vaccine-induced immunity wanes with time (high-quality vaccines normally provide 2-to-3-year duration of immunity). It is therefore recommended that vaccination campaigns be repeated annually to maintain sufficient herd immunity especially in areas with high dog population turnovers (10).

Dog-mediated rabies has been eliminated from most industrialized countries through mass dog vaccination (12,13), and the continent-wide elimination of canine rabies from the Latin America and the Caribbean (LAC) is now within reach (14). The success of rabies control programmes in LAC countries has been largely attributed to high-intensity MDV campaigns that are conducted annually during national vaccination days (14,15). Additionally, high levels of rabies vaccination coverage have been achieved in LAC countries by mobilizing a larger workforce using volunteers as vaccinators during these synchronized vaccination campaigns (14). Lessons learned from LAC countries show that resource mobilization (human and material resources) and motivation were critical in maintaining short intensive MDV campaigns that effectively interrupted disease transmission (16).

On the African continent, however, most of the countries are still endemic for canine-mediated rabies (1). Tanzania is among such countries where an estimated 345 people die of dog-mediated rabies annually, despite ongoing efforts to eliminate the disease (17). The estimated dog population in Tanzania is approximately 3 million (18), of which 95% are owned dogs that free roam around homesteads and are sometimes used for herding of livestock and hunting of wild animals (19–21). Despite the existence of the Tanzanian Animal Diseases Act of 2003 stipulating that the vaccination of dogs and cats against rabies is mandatory (22), national-wide rabies vaccinations are not implemented in the country. In southeast Tanzania (representing ~20% of the country landmass), where dog vaccination campaigns had been implemented, the average reported dog vaccination coverage was 50%, which was low compared to the recommended coverage of 70% (8). In Tanzania, dog vaccination campaigns are conducted in villages using a central point approach, whereby owners voluntarily take their dogs for vaccination to pre-defined central points within their villages (18).

This traditional practice involves a team of legalised vaccinators (normally Livestock Field Officers or Veterinary Officers) moving from one village to another across the districts (23). Relying on this approach, campaigns last 30 to 60 days depending on available personnel and geography of the district. Although this approach works well, its execution at a scale and intensity required to eliminate rabies is challenging, time-consuming and expensive, with cost for each dog vaccinated being as high as $11.27, with allowances for vaccination teams representing the largest single contributor to the cost (24). Indeed, the workforce capacity to deliver vaccinations in Tanzania is limited (25,26), expensive and unable to reach the vast majority of the population that are most at-risk. It has been reported that if not adequately addressed, the shortage of personnel capacity to conduct large scale dog vaccination could be a setback to achieve the “Zero by 30” target (27).

To overcome the challenges of limited workforce capacity in Tanzania, we investigated the feasibility of using university students to deliver a high-intensity rabies vaccination campaign as a mobilized One Health workforce to control and eventually eliminate dog mediated rabies in the country. To this end, we report on the logistics, costs, and coverage achieved using university students that implemented synchronized disease intervention efforts across the Kisarawe district of Tanzania where rabies is known to be endemic.

Methods

All methods were carried out in accordance with relevant guidelines and regulations as per ARRIVE guidelines.

(https://arriveguidelines.org/)

Study areas

This study was conducted in the Kisarawe district in the Pwani region of Tanzania between 5th and 9th May 2021. The Kisarawe district has a total area of 3,535 square kilometers (km^2) and is located 70 kilometers north-west of Dar es Salaam at 300 meters elevation. The district is inhabited by approximately 101,000 people as per the 2012 National Population Census (28), and an estimated population of 3,700 dogs (18).

Administratively, the Kisarawe district is divided into 16 wards (Figure 1), with each ward containing two to seven villages (median four villages per ward (28)). In this study, four wards (Kisarawe, Kiluvya, Kazimzumbwi and Msimbu) – which are semi-urban areas that are officially categorized as Township Authorities – were regarded as villages for the purpose of the campaign, resulting in campaign sites containing a total of 69 villages. Previous work in the Kisarawe district showed that, between 2011-2015, rabies bite incidence was 40.8 per 100,000 people per year (29). During this period, animal and human bite exposures were declined significantly due to mass dog vaccination interventions (29). However, the support for rabies control interventions ended in 2016 (8), resulting in sporadic cases of animal and human rabies occurring.

Study Logistics

Using the previously tested dog vaccination campaign approach in Moshi Tanzania (30), fifty students were selected from the Sokoine University of Agriculture (SUA) and Muhimbili University of Health and Allied Sciences (MUHAS). Thirty veterinary students (fifth-year students) were selected from SUA and twenty students from MUHAS (10 studying medicine; five studying BSc Laboratory Sciences, and five studying BSc Environmental Health). Students were selected through their Students' One Health Innovation Club (SOHIC) based on membership commitment to the club and gender considerations. SOHIC is a self-organizing student platform that promotes and builds competencies among university students by creating knowledge and awareness on critical One Health issues in the communities. In doing so SOHIC provides students with a critical opportunity for multidisciplinary collaboration designed to develop and strengthen One Health skills, competencies and gain experience in the planning and design of these type of activities. Importantly, SOHICs provide an extracurricular environment for student engagement in One Health outreach activities, and in practical team-based learning exercises, such as case competitions and campaigns to prepare them as One Health champions in their future education and workplace settings. In Tanzania there are currently four SOHIC clubs in four universities meanwhile colleges (non-university) students have also shown initiative to establish

SOHIC clubs in their college. In this study specifically, veterinary students were designated to do the vaccination and the other students were designated to register vaccinated dogs, conduct post-vaccination surveys and other administrative activities. In addition to SOHIC membership, further selection criteria for SUA and MUHAS students were gender, the programme of study (i.e., One Health-related programme of study), active participation in SOHIC activities and general availability during the planned activity.

Vaccination consumables were mobilized from rabies stakeholders, and this was coordinated under the leadership of the Africa One Health University Network (AFROHUN), the One Health Coordination Desk at the Prime Minister's Office (OHCD-PMO) and other strategic stakeholders as summarized in Table 1.

Table 1

List of the vaccination consumables associated values and stakeholders' contributions to the campaigns. The cost for launching the campaign was excluded from the total costs since the launch was designed to engage high-level politicians to endorse students' involvement in dog vaccination campaigns.

Description	Item	Units (cost/unit in US$)	Cost (in US$)	Source (Provided by)
Allowance	*Allowances (food & accommodation) to students*	*50 ($20.22* 6 days)*	*6,066*	*AFROHUN*
	Allowances (accommodation & per diems) to drivers	*7 drives*	*2,496*	*AFROHUN*
	Allowances (accommodation & per diems) to supervisors and Project Investigators	*14 staff*	*3,943*	*AFROHUN, FAO Tanzania*
Subtotal			***12,504***	
Campaign advertisement & awareness	*Posters*	*200 (5.20)*	*1,040*	*AFROHUN*
	T-shirts and caps	*60 (5.20)*	*312*	*WHO Tanzania*
	IEC materials (fliers)	*3000 (0.87)*	*2,600*	*AFROHUN*
	Public address system (loudspeakers)	*3 (86.66)*	*260*	*AFROHUN*
Subtotal			***4,211***	
Campaign set up costs	*Training costs (venue and refreshments)*	*60 (6.50)*	*390*	*AFROHUN*
Subtotal			***390***	
Disposables	*Syringes and needles*	*5000 (0.22)*	*1,083*	*FAO Tanzania*
	Vaccination cards	*4000 (0.39)*	*1,560*	*AFROHUN/ MLF*
	Examination gloves	*20 (6.50)*	*130*	*FAO Tanzania*
	Dog collars	*5000 (0.11)*	*550*	*IHI*
	Sanitizers	*120 (1.52)*	*182*	*FAO, AFROHUN*
	Face covering	*200 (1.08)*	*217*	*AFROHUN*
	Dog registers	*20 (4.33)*	*87*	*AFROHUN*
Subtotal			***3,808***	
Equipment	*Dog restraining materials/equipment*	*20*	*0*	*MLF and SUA*
	Ice packs	*20*	*0*	*Kisarawe Council*

	Chairs and Tables	*1 set per village*	*0*	*Village leaders*
	GARC Data Loggers	*5*	*0*	*GARC*
	GARC App (free to use)	*N/A*	*0*	*GARC*
	Smartphones	*50*	*0*	*Individual phones*
Subtotal			***0***	
Fuel & transport costs	*Fuel provided for free 1 hard top from IHI, 2 hardtops from MUHAS, 2 hardtops from MLF, 1 double cabin from KDC, 1 VX from WHO and 2 hardtops from FAO*	*9 hardtop vehicles (4WD)*	*1,967*	*FAO Tanzania, Additional fuel paid by AFROHUN*
	Hired vehicles (3 four-wheel drive)	*3 ($86.66*6 days)*	*1,560*	*AFROHUN*
Subtotal			***3,527***	
Stationery and miscellaneous	*Notebooks*	*200 (0.87)*	*173*	*AFROHUN*
	Pens	*1000 (0.04)*	*43*	
Subtotal			***217***	
Vaccine	*Dog vaccines*	*5000 (0.87)*	*4,333*	*FAO Tanzania*
Subtotal			***4,333***	
Grand total			***28,990***	

AFROHUN= Africa One Health University Network, IHI=Ifakara Health Institute, MLF=Ministry of Livestock and Fisheries, 4WD=four-wheel drive,

Preliminary trainings

Vaccination teams: Seven teams, each consisting of approximately seven students and one supervisor were formed and trained to undertake the following activities on a daily basis: i) dog vaccinations, ii) recording vaccinated dogs in the dog registers, iii) capturing the vaccination data using either the GARC Data Logger (GDL) device (31,32) or the Rabies Vaccination Tracker (RVT) tool on the GARC App (31), iv) conduct a knowledge, attitude, and practices (KAP) survey, v) conduct post-vaccination transects, and vi) conduct risk communication and community engagement (RCCE) procedures. Each team's supervisor was a university academic staff member with a minimum of master's degree and experience in conducting-one health-related fieldwork.

Prior to implementing the dog vaccination events, all the veterinary students (n = 30) from SUA received instructions on how to capture, handle and vaccinate dogs safely and humanly using the resources provided on the GARC Education Platform (https://rabiesalliance.org/capacity-building/gep) safely and humanely. This training added new skills to their existing formal education and training on the use of these technologies. Again, veterinary students received a one-day in-person training focused on: 1) Rabies education, 2) Community Coordination, 3) Animal Handling and vaccination and 4) Rabies healthcare.

Additionally, all 50 students were trained on data collection using either the GDL device or RVT tool on the GARC App for dog vaccination tracking (32), Open Data Kit (ODK (https://opendatakit.org/)) for post-vaccination transects and KAP surveys, community mobilization of dog owners to bring their dogs to vaccination, ethics in the fields, biosafety & biosecurity, administrative issues, and how to conduct post-vaccination transects. All 50 students received pre-exposure prophylaxis (PrEP) to protect them against accidental rabies as recommended by the WHO.

Mass dog vaccinations

Soon after the campaign launch, which was officiated by the District Commissioner of Kisarawe, Mass dog vaccinations were carried out every day from 8am to 4pm by the teams. Each village had one centrally located vaccination point, with each vaccination point attended by village leaders (logistician), one or two veterinary students as vaccinators, one student to record vaccinated dogs using the vaccination registers, one non-vet student to record vaccinated dogs in the GDL device or GARC App, a medical student for the RCCE and a team supervisor from the universities or the government. Each team was assigned at least three villages to visit for the vaccination campaign depending on the topography and size of the ward. Vaccinated dogs were fitted with collars for easy identification and their owners were given vaccination certificates. Prior to vaccination campaigns, community sensitization about the campaign was undertaken using vehicles fitted with public address systems (a system comprised microphone, amplifier, loudspeaker) and campaign leaflets sensitizing, informing, and urging dog owners to bring their dogs for vaccinations during the campaign days. These materials were displayed in churches/mosques, schools, government offices and other public places.

Cost per dog vaccinated

We collected and documented all administrative costs by keeping logs of all categories of costs incurred in delivering the MDVs. We tracked the number of days over which these vaccinations occurred. These costs were used to estimate the cost per dog vaccinated and compared from previously estimated cost per dog vaccinated in Africa (23,24,33,34). Cost data were adjusted for inflation using Tanzania Shillings (TZS) and subsequently converted to the United States of America dollars (US$) at an average annual exchange rate for 2021 of TZS 2308 per 1 US$.

Post-vaccination evaluations

To assess vaccination coverage, transect surveys were conducted immediately post-vaccination in accordance with the previously established methodology (35). All vaccinated dogs were marked (at the point of vaccination) with temporary plastic collars for identification during transect surveys. In addition, each dogs' confinement status (e.g., roaming or confined), as well as their age (e.g. adult or puppy) were recorded. Transects were conducted in two randomly selected sub-villages in each campaign village, aiming to have a representative sample for assessing vaccination coverage in each village (35). In Tanzania, villages are sub-divided into smaller administrative units (hamlets) which are called sub-villages (ranged 3–5 sub-villages per village (8,26)). Rural villages tend to have dispersed communities and cover large geographical areas making it difficult to survey all sub-villages within two hours. Additionally, vaccination points are normally located at the center of the villages. A practical solution used to avoid dog counting bias was to randomly sample two sub-villages from each village (where each sub-village had an equal chance of being selected). In the first randomly sampled sub-village, enumerators were instructed to start transects at the center of the sub-village heading to the outskirts, while in the other sub-village, transects started from the edge of the sub-village and headed toward the centre.

Data analysis:

Campaign Resource and Cost Comparisons

Dog vaccination data were exported from GDL or GARC app to the Microsoft Excel sheet where they were cleaned for analysis. We calculated vaccination rate by computing number of vaccinated dogs per person per day. We also computed the number of vaccinated dogs per team per day. Additionally, the cost per dog vaccinated was derived from the overall cost for implementing dog vaccinations divided by the total number of dogs vaccinated. Vaccination costs for supplies and consumables were estimated by assigning a monetary value to supplies and consumables based on the 2021 applicable market prices. To analyse the trend of cost per dog vaccinated, we further analysed the cost per dog vaccinated for each day of dog vaccinations. In so doing we were able to calculate the cost per dog vaccinated per each vaccination day by dividing the overall cost for implementing dog vaccinations divided by the number of vaccinated dogs per each day before dividing by the total number of days of vaccinations (n=5).

Vaccination Coverage Estimates

Transect data were exported from ODK to a Microsoft Excel sheet where they were cleaned for analysis. To measure the effectiveness of these campaigns, we used the transect data. The village-level vaccination coverage was calculated by the counts of vaccinated (observed with collars) dogs divided by total dogs (observed either with or without collars). The 95% confidence intervals (CIs) for the village-level vaccination coverage estimates were calculated using the exact binomial distribution using *binom.test* function. Villages without transect data were excluded from our analysis. We further used scatter plots to examine geographical and demographic factors (distance from district headquarters, geographical areas of the village, dog and human population sizes) that have been reported to influence vaccination coverage (8). The mean district coverage and its 95% CIs were based on calculations relying on generalized linear mixed models (GLMMs) with normally distributed (on the logit scale) random intercepts allowing coverage to vary among villages. All data analyses were processed and analysed using R programming language version 3.6.0 (36) using R Studio (37).

Results

Campaign Resource and Cost Comparisons

During the five-day MDV campaign, dog vaccinations were implemented in all 16 wards covering 48 (69.6%) of the villages in the Kisarawe district (Table 2). During this campaign, a total of 1,457 dogs and 242 cats were vaccinated, resulting in a total of 1,699 animals vaccinated over the course of five days. During the first day of vaccination (5th May), dog vaccinations were conducted in only one village where 183 dogs were vaccinated. This day was also used as an official campaign launch that sought to engage the high-level stakeholders (i.e., high-level politicians) in an effort to secure ongoing buy-in and support. During day 2, day 3 and day 4, vaccinations were conducted in 22, 14 and 9 villages respectively, where majority 1,216 (83.0%) of the dogs were vaccinated in these three days. On the last day of the campaign (9th May), vaccinations were only carried out in only two villages where 61 animals (dogs = 58) were vaccinated.

The overall cost in delivering mass dog vaccinations were US$ 28,990, resulting in the average cost per dog vaccinated that equate to US$19.90 per dog. The cost per dog vaccinated was ranged from US$ 7.74 – 99.97 (Table 2). Our data showed that vaccinating larger dog populations decreased the cost per dog vaccinated.

Table 2

The calculations for estimating team and student rate of dog vaccination using central point vaccination strategy.

Date	***Animals vaccinated (dogs)***	***Number of villages with campaigns***	***Dogs vaccinated per team***	***Dogs vaccinated per student***	***Cost per dog (in US$) vaccinated per day***
May 5th	221 (183)	1	26	4	31.68¥
May 6th	875 (749)	22	107	15	7.74
May 7th	344 (302)	14	43	6	19.20
May 8th	198 (165)	9	24	3	35.14
May 9th	61 (58)	2	8	1	99.97
Overall	**1699 (1457)**	**48**	**208**	**29**	**19.90§**

¥Calculated as ($28,990/183 dogs)/5days; §Calculated as $28,990/1457 dogs.

Our estimated cost per dog vaccinated was higher than the previously estimated cost per dog in different settings in Africa (Table 3).

Table 3

The comparison of cost per dog vaccinated using central point vaccination strategy between Kisarawe rural district and other rural and urban areas in Tanzania (23,24,34).

Variable (Year data collected)	*Agro-pastoral communities, Rural-Tanzania (2003)*			*Pastoral communities, Rural-Tanzania (2003)*			*Southeast Tanzania (2010-2017)*	*Urban, Moshi Tanzania (2018)*	*Rural, Kisarawe (2021)*
	Cost	*L95% CI*	*U95% CI*	*Cost*	*L95% CI*	*U95% CI*	*Cost*	*Cost*	*Cost*
Disposables (syringes, needles, certificates, registers, collars)	*0.1*	*0.07*	*0.12*	*0.14*	*0.13*	*0.15*	*2.31*	*NA*	*2.61*
Fuel	*0.17*	*0.14*	*0.2*	*0.79*	*0.7*	*0.86*	*0.50*	*NA*	*1.35*
Allowances for vaccination	*0.26*	*0.23*	*0.3*	*0.9*	*0.78*	*0.99*	*3.63*	*NA*	*4.16*
Stationery and miscellaneous	*0*	*0*	*0*	*0.01*	*0*	*0.01*	*0.00*	*NA*	*0.15*
Vaccine	*0.5*	*0.44*	*0.54*	*0.59*	*0.45*	*0.69*	*0.45*	*NA*	*2.97*
Vehicle maintenance	*0.38*	*0.36*	*0.41*	*1.8*	*1.62*	*1.89*	*0.46*	*NA*	*1.07*[a]
Awareness	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*0.22*	*NA*	*2.89*
Accommodation and supplies	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*0.12*	*NA*	*4.42*[b]
Campaign set-up	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*0.27*
Capital costs/fixes assets (including vehicles and fridge)	*0.32*	*0.27*	*0.35*	*1.32*	*1.08*	*1.56*	*1.13*	*NA*	*0*
Total cost per dog	*1.73*	*1.3*	*2.25*	*5.55*	*5.33*	*5.77*	*8.84*[c]	*1.61*	*19.89*

[a] *Includes vehicles hiring*

[b] *Includes accommodation costs for academic staff (supervisors) and drivers*

[c] *Based on the mean cost per dog vaccinated for three rounds of dog vaccination*

Vaccination Coverage

Post-vaccination transects were conducted in all 48 villages where dog vaccinations were implemented. A total of 387 dogs were counted and recorded in the transect pathway of which 210 (54%) were found to have been vaccinated during the campaign. The transect also found that, 258 (67%) were free roaming while 277 (72%) were adult dogs. The village-level vaccination coverage achieved in the 48 villages is shown in Figure 2.

The scatter plots between the village-level coverage were investigated against distance from district headquarters (most urban), dog population sizes, human population size and geographical areas of the village. Our data showed that village-level coverage slightly decreased as the distance to the district headquarters increased (Figure 3). Using variations of villages level coverages, we estimated the mean district-level coverage of 54.3% (CI 49.3% - 59.6).

Discussion

With the target date of human rabies elimination by 2030 fast approaching, rabies-endemic countries need to step up their efforts to implement dog vaccination campaigns. In so doing, additional resources need to be mobilized to ensure that MDV campaigns are implemented at the scale and intensity that is needed to control and eliminate the disease (27). Here we discussed the first district-wide synchronized MDV campaign in Tanzania that was completed in 5 days using a temporary workforce consisting of animal, human and environmental health university students. In so doing, we demonstrated that using university students provides an excellent opportunity to deliver MDV event that reached almost all villages in a district in five days and achieved an overall mean vaccination coverage of 54%. We further demonstrated that this approach was quicker than the traditional methods applied by the government which takes 30–60 days to complete a vaccination campaign in a district.

In this study, we generated several findings that will be of value in engaging students in delivering interventions to improve human and animal health. First, we demonstrated that using students is not only feasible but can also result in campaigns that reach large communities within a short period of time. These findings suggest that a synchronized campaign enabled the concentration of human resources, expertise and public awareness activities; as well as making use of a government labour force and local media at scale (38).

Second, students were excited about participating in the initiatives as they had made themselves available for work during their academic break as part of their vacations.

Third, we confirmed that mobilizing resources (both human and material) from various stakeholders to host a district-wide synchronized campaign was not difficult as indicated in Table 1. Lesson can be learned that it is possible to mobilise local rabies stakeholders to commit their resources to control rabies. Therefore, this should inspire the government to scale up dog vaccination efforts through similar locally mobilised resources from local stakeholders. Additionally, this study demonstrated the role of engaging international rabies stakeholders such as FAO, WHO, GARC and AFROHUN in controlling rabies. A recent study in Tanzania demonstrated that funding commitment particularly on dog vaccines is crucial in scaling-up dog vaccinations (8). Therefore, engaging international stakeholders to support dog vaccinations is an important move. The tripartite thorough direct support from the OIE has developed opportunities to kickstart vaccination programmes by providing high-quality vaccine supply through the OIE vaccine bank (39). Therefore, we anticipate that this model could be replicated nationally and internationally particularly in Africa and Asia where rabies is still endemic and scaling dog vaccinations as the means to control rabies is slow.

Fourth, we have shown that this model is effective as the temporary workforce of students undertook more than just dog vaccinations during the campaign. In fact, the students also collected animal bites data from local health facilities, conducted KAP surveys and undertook post-vaccination transects. One advantage of this initiative was that the university students were selected from different academic backgrounds (such as human health, animal health, and environmental health). The competencies that students will gain through these opportunities include collaboration in multidisciplinary teams, communicating their science to local communities, and community engagement to address complex health problems using a One Health approach (40, 41).

Our results have shown that the overall cost per dog vaccinated to be approximately $20, which is higher than the previously reported costs from elsewhere in Africa (i.e. $1.7) per dog in agropastoral areas in Tanzania (23), between $1.3 and $1.8 per dog in N'djamena city in Chad (33), between $7.30 to $11.27 per dog in Southeast Tanzania (24), and $1.61 per dog in urban Moshi Tanzania (34).

Our current cost per dog vaccinated was higher due to the following: First, over-purchase of the vaccine and vaccination consumables increase the cost per dog vaccinated. Our experience from implementing dog vaccinations in southeast Tanzania showed that the cost per dog vaccinated ranged from USD 11.27 in the first round of vaccination to USD 7.3 in the third round mainly because of the over purchasing of the vaccine and over purchasing of vaccination consumables (24). In our current study we found that increased number of vaccinated dogs results in decrease of cost per dog vaccinated. Similarly, a 3-years vaccinations program in Kenya reported decreased cost per dog vaccinated across all three years, dropping from US$ 4.76 in 2015 to US$ 2.11 in 2017 as the number of vaccinated increased from 743 in 2015 to 8,332 in 2017 (42).

This was also observed in our study where vaccination consumables were estimated based on an estimated dog population of ~ 5000 dogs (18). Whereas, in reality, only 1,457 dogs were vaccinated during the campaign. However, over-procurement of vaccines and other consumables need not to deter countries starting to scale up dog vaccination campaigns, as vaccine and other consumables could be stored for long periods (normally three years for dog vaccines) for use in future campaigns.

Second, the costs were higher due to restrictions imposed by the COVID-19 pandemic. For example, the vehicle that was supposed to carry 7 to 8 students, was used to carry 3 students to maintain social distance. Furthermore, additional costs were incurred to purchase face covering and sanitizers for each team.

Third, the cost per dog vaccinated was higher because fewer dogs were vaccinated during vaccination campaigns. Our data showed that when the large number of dogs were vaccinated, the cost per vaccinated dog decreased. For example, when 58 dogs were vaccinated, the cost per day was $99.97 but when the number of vaccinated increased to 749 vaccinated dogs per day, the cost per day was reduced to $7.74.

Fourth, the cost per dog vaccinated was higher as students were also involved in other activities (not only vaccination dogs). For example, the students conducted household surveys (KAP studies) in 18 villages and conducted transects in 48 villages. If these activities (i.e. post vaccination activities) could be carried out as separate activities the cost could be higher. The cost to conduct household survey per village was estimated to $155.70 whereas for transect was $12.01 per village (35).

Additionally, the costs per dog were much higher than reported elsewhere in Africa as it included campaign set-up costs. For instance, the students have now been trained, so their involvement in the next campaign will not require training and supervision from university staff. Finally, this study included cost items (such as gloves, t-shirts, face coverings, sanitizers) that were not included in previous studies. As such, if we only considered (vaccines, syringes, needles, and vaccinators ‘allowances) costs associated with implementing the dog vaccination campaign, the cost per dog vaccinated would be reduced to approximately US$7.88.

Our study didn’t demonstrate that the use of students is cost-effective by reducing the cost per dog vaccinated due to the small number of vaccinated dogs. Our focus at the moment was to show the methodology, practicalities and opportunity to engage students as the One Health workforce to complement the shortages of vaccinators. Our study gave us a learning agenda on how we can minimize the cost per dog vaccinated. Minimising the cost per dog vaccinated will facilitate affordability of the campaign which could be a sustainable approach and make this model cost-effective for future campaigns. First, we recommend recruiting students from SOHIC clubs. Livestock Training Institutes (students pursuing Certificate or Diploma in Animal Health who are LFO in training) to supplement veterinary students. This will increase the workforce and positively impact the control of rabies and other diseases. Training Certificate and Diploma in Animal Health students will not only increase the workforce capacity but will reduce the cost per trained student.

Second, we recommend focussing on few activities i.e vaccinating and post-vaccination surveys. This will increase number of vaccination teams which will increase vaccination campaign’s reach. Reaching more communities will increase number of dogs vaccinated and eventually reduce cost per dog vaccinated.

Third, we recommend piloting a single-day vaccination campaign covering whole district (large geographical areas) ensuring that a larger number of dogs are vaccinated. We hypothesize that the single-day vaccination strategy will reduce costs and would benefit massively from a coordinated advertisement before the vaccination day to increase participation in dog vaccinations. These campaigns will further benefit the availability of students during their academic vacation. We anticipate that reduced cost (affordability) of vaccination campaigns will facilitate future sustainability of vaccination campaigns. This is because when dog owners are charged for vaccination, the costs per dog vaccinated increase because fewer owners participate, and coverage falls (43–45).

In some areas, our transect data counted few dogs that caused large confidence intervals which affected our village-level coverage estimates as shown in Fig. 2. Our second limitation of the current study is that we compared the cost per dog vaccinated from different studies that collected data from different years. This variation affected our comparison due to changes in inflation rate. Our third, and final limitation was the different leave schedules between MUHAS and SUA students, which made it difficult for them to work together for an extended time as a result the campaign lasted for five days.

Our study showed that coverage was slightly declined as the distance increased from the district to the headquarters. This negative relationship could be associated with poor penetration of advertisement on the vaccination campaigns. Good advertisement and vaccination campaign launching event at the Kisarawe ward (the district headquarters) probably influenced many dog owners, resulting in more vaccinated dogs as previous research showed that good advertising could increase participation by over 20% (43, 45, 46).

We found that human population sizes were positive relationship with vaccination coverage whereas dog population sizes had negative relationship with coverage. This is because urban areas tend to have more dogs than rural areas. Previous studies on human to dog ratios (HDRs) reported 14 to 27 humans per one dog in urban and 4–7 humans per 1 dog in rural areas (20, 47). We suspect that most of the rural dogs were not brought to vaccination points. This finding is consistent with previous studies conducted in Tanzania that reported low vaccination coverage in rural areas (8, 21, 23).

The main concern of the use of students will be fidelity and acceptability. In this study, we observed fidelity as students were trained and supervised by experienced veterinarians. Whereas the acceptability of engaging students will need to be researched with future studies.

Conclusion

As we approach the global target for the elimination of dog-mediated human rabies by 2030, designing dog vaccination campaigns that will ensure the large number of dogs are vaccinated in a timely manner would be of the utmost importance. As demonstrated in this study, the use of a temporary One Health workforce consisting of university students as vaccinators proved beneficial in controlling rabies. Furthermore, using university students is impactful as it could accelerate countries' efforts to meet the global target of eliminating dog-mediated human rabies by 2030.

Declarations

Ethical approval and consent to participate

Ethical approval for this research was granted by the Institutional Review Board of the Muhimbili University of Health and Allied Science (reference number: MUHAS-REC-08-2021-801). All data collection, except for key informant interviews, was conducted in Swahili (the national language) and translated from and into English. The research participants were recruited to this study after obtaining written informed consent and in accordance with the Declaration of Helsinki. All dog vaccination procedures were performed following good veterinary practices for animal welfare. We confirm that all methods were carried out in accordance with relevant guidelines and regulations.

Consent for publication

All authors read and approved the final manuscript.

Availability of data and materials

The research data generated from this study will be deposited in the University Digital Research Data Repository and made accessible to the research community according to the MUHAS Research Data Sharing Policy and Procedures 2020. Queries and request for datasets and code that used to produce tables and figures should be directed to Maganga Sambo (smaganga@ihi.or.tz)

Competing interests

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Author Contributions

Contributed to the conceptualization and design of the study (MS, NMM, FOF, JK, RM)

Contributed to funding acquisition (JK, RM, FOF)

Responsible for data curation, investigation, analysis (MS, NMM, AC)

Performed analysis and wrote the first draught of the manuscript (MS, FOF, AC)

Contributed to writing and revision of the manuscript (MS, AC, AF, JB, DK, JEK, GM, HM, NMM, AAN, AN, HN, KS, RS, VS, MV, RM, JK, KH, LHN, FOF)

Overall project administration (JK, FOF, HEN)

All authors contributed the writing and have approved the submitted version.

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Figures

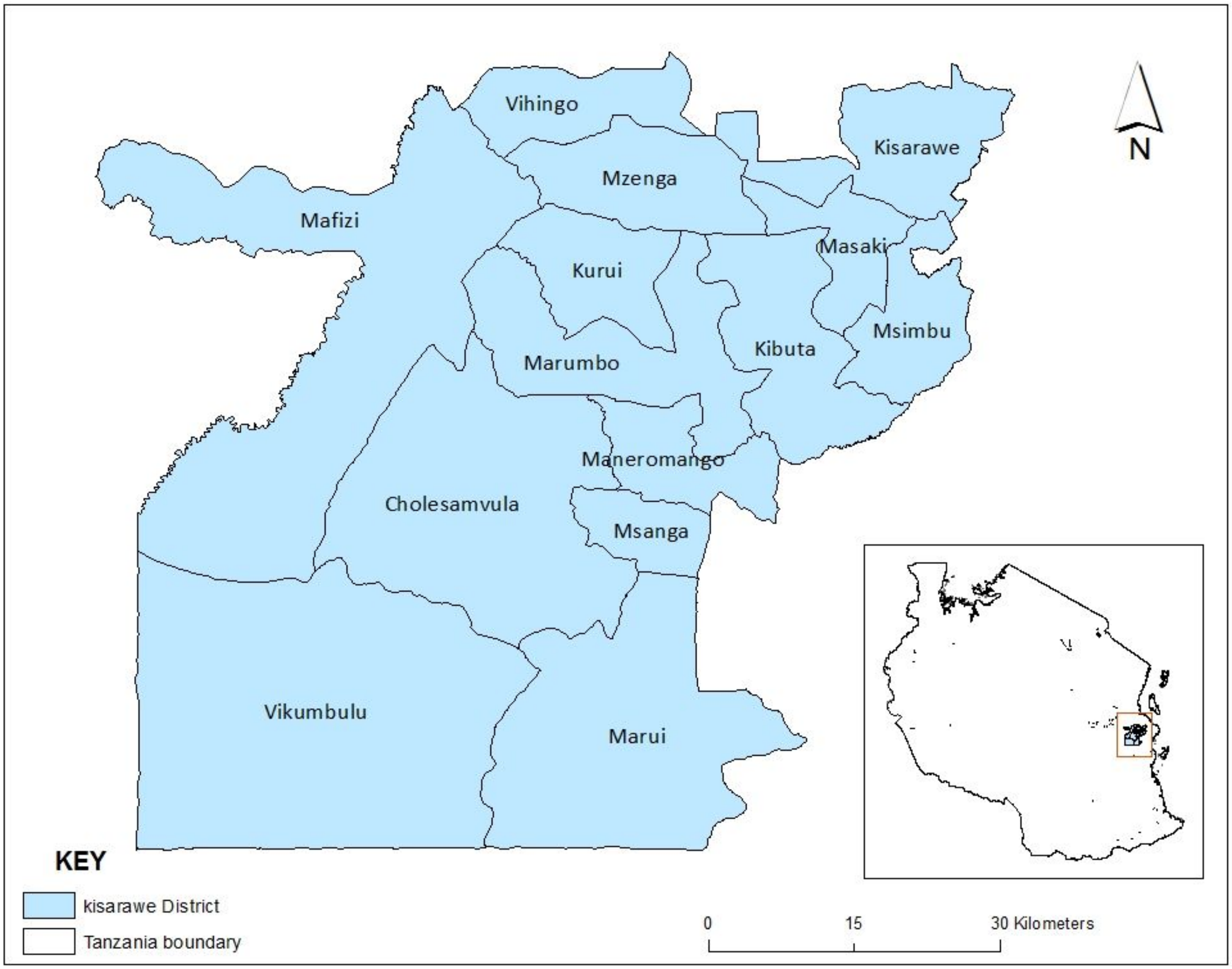

Figure 1

Map of the Kisarawe district showing the location of the wards (insert is the map of Tanzania).

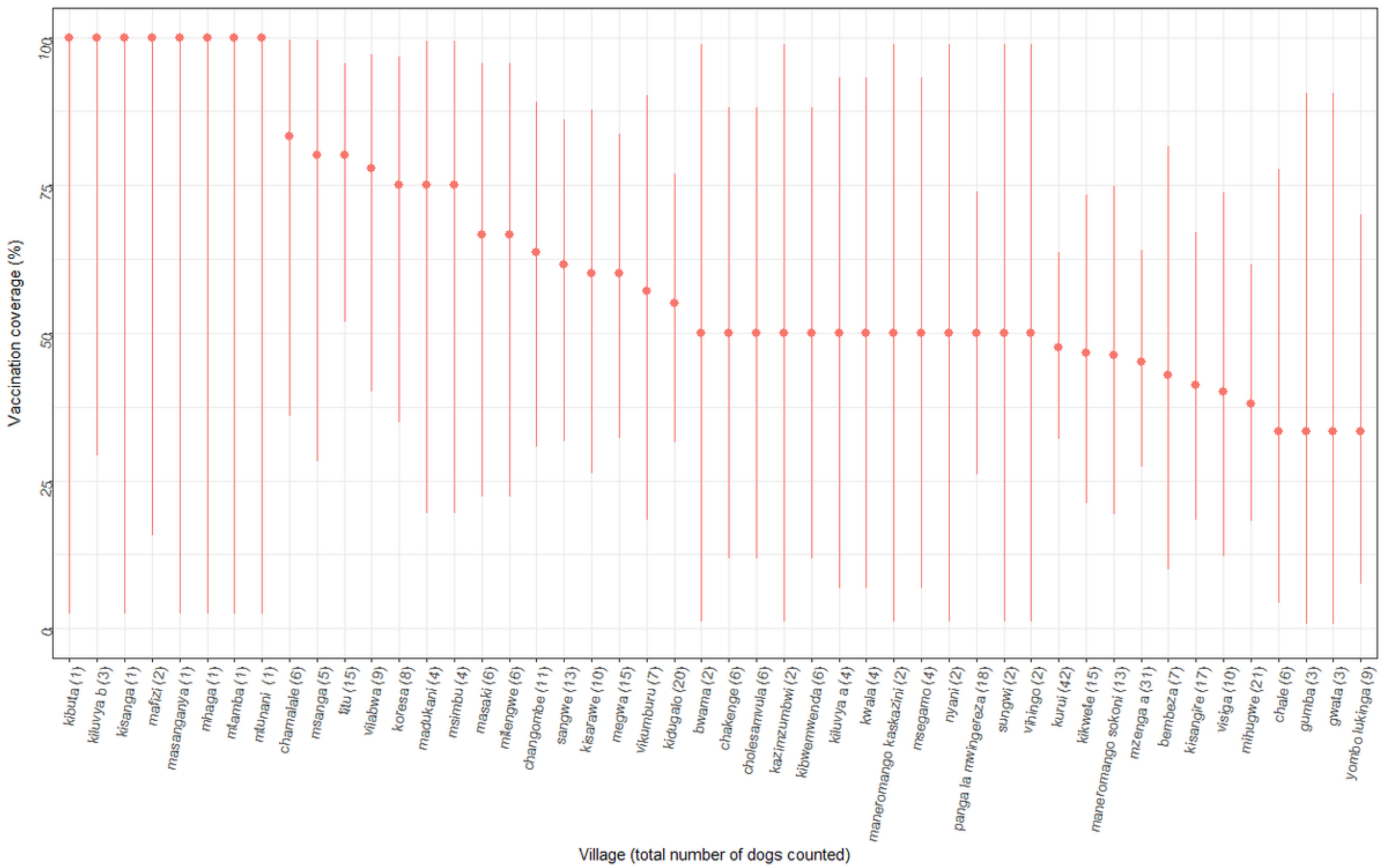

Figure 2

Village-level vaccination coverage (red points) and their ±95% Confidence intervals.

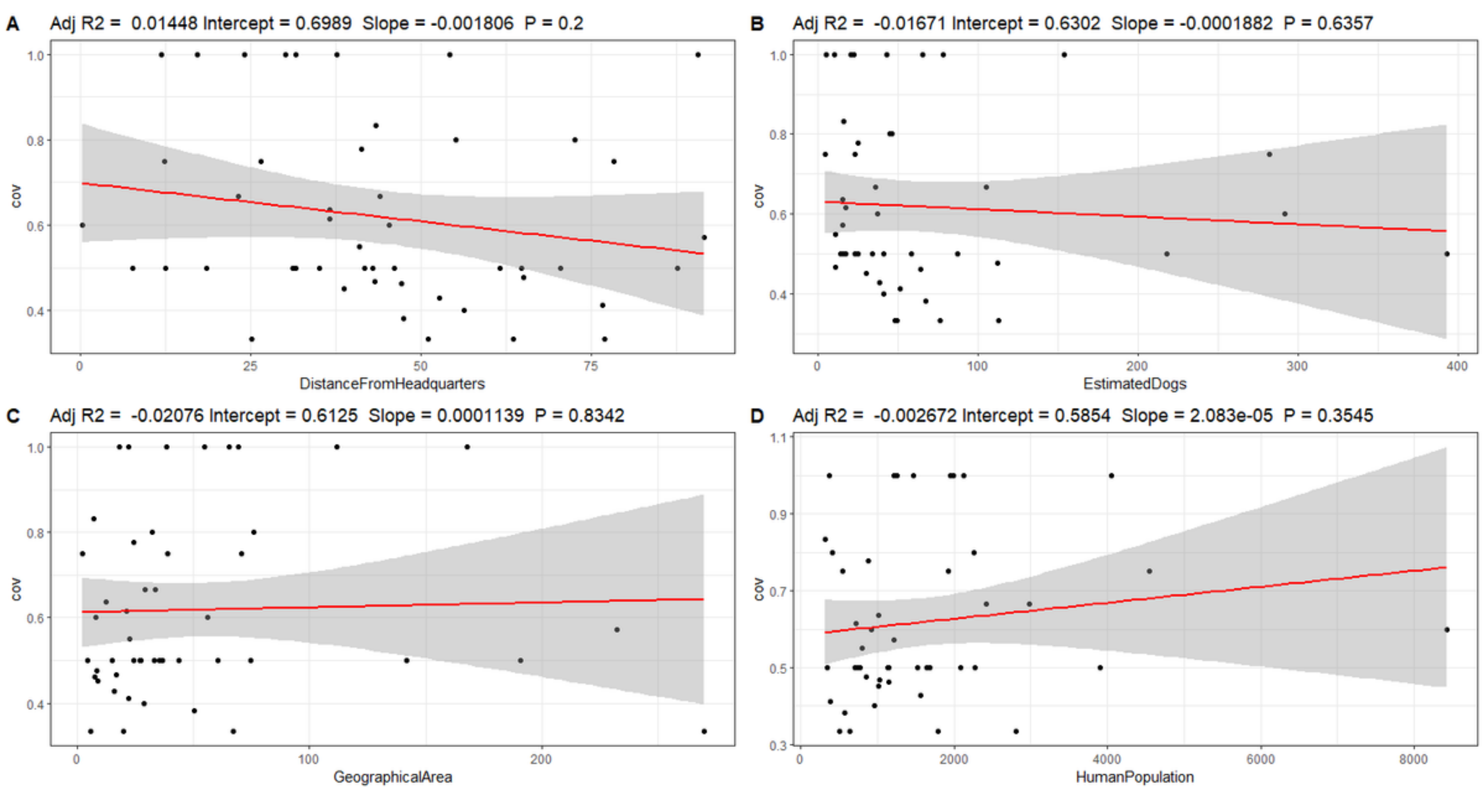

Figure 3

Showing the relationship between coverage versus demographic and geographical factors.