Operational performance and analysis of two rabies vaccination campaigns in N'Djamena, Chad

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ABSTRACT

Transmission of rabies from animals to people continues despite availability of good vaccines for both human and animal use. The only effective strategy to achieve elimination of dog rabies and the related human exposure is to immunize dogs at high coverage levels. We present the analysis of two consecutive parenteral dog mass vaccination campaigns conducted in N'Djamena in 2012 and 2013 to advocate the feasibility and effectiveness for rabies control through proof of concept. The overall coverage reached by the intervention was >70% in both years. Monthly reported rabies cases in dogs decreased by more than 90% within one year. Key points were a cooperative collaboration between the three partner institutions involved in the control program, sufficient information and communication strategy to access local leaders and the public, careful planning of the practical implementation phase and the effective motivation of staff.

The dynamic and semi to non-restricted nature of dog populations in most rabies endemic areas is often considered to be a major obstacle to achieve sufficient vaccination coverage. However, we show that feasibility of dog mass vaccination is highly dependent on human determinants of dog population accessibility and the disease awareness of dog owners. Consequently, prior evaluation of the human cultural and socio-economic context is an important prerequisite for planning dog rabies vaccination campaigns.

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1. Introduction

More than a hundred years after the invention of the first rabies vaccine by Louis Pasteur, this zoonotic disease still claims an estimated 60,000 lives worldwide each year [1]. The onset of rabies in bite victims can be prevented by timely administration of Post Exposure Prophylaxis (PEP), and research regarding new PEP schedules has rendered this intervention in humans less expensive and time consuming in recent years [2]. Because more than half of all rabies victims are children, the costs of PEP alone per death averted calculated on the basis of Years of Life Lost (YLL) are justifiable [3]. But these costs will remain, and potentially rise each year, if transmission between dogs and humans is not interrupted. Vaccination campaigns in dogs are, in the short term, more expensive but will eventually lead to elimination of rabies in the domestic dog population [4] and substantially reduce disease burden, as demonstrated in Latin America [5]. Enhanced advocacy is needed to persuade policy makers and governments to shift the target from trying to minimize the effect of disease in humans to a "one health" approach

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which tackles the problem at its source. In developing countries resources allocated to the health sector are scarce and rabies is one of many other priority diseases, so proof of long term cost-effectiveness is particularly important for advocacy. Short term direct measures of effectiveness are estimated coverage numbers achieved by dog vaccination and the change of rabies incidence dynamics after intervention. Comparable to any other service provision in Health Systems, viability and practical implementation are in the direct causal pathway from the efficiency of a product (in this case rabies vaccine) to the effectiveness outcome in the field (in this case coverage) [6]. Logistical constraints, public participation, performance of vaccination teams and the nature of the dog population are all aspects that have an influence on one or several effectiveness parameters, which are defined as availability, accessibility, affordability, acceptability and adequacy. Without proper attention, these factors directly influence cost and reduce coverage of vaccination campaigns in a multiplicative way [7]. Despite the availability of safe and efficacious rabies vaccines, the ultimate effectiveness in the field is a fraction of the potency under perfect conditions [7,8]. In a specific context, an assessment of all these effectiveness components is complex and difficult but urgently needed. It is especially important in light of the trade-off between targeted maximal accessibility and limited financial resources. Practical examples and careful evaluation help to establish a decision framework to balance cost and performance. Intervention effectiveness research on dog rabies vaccination is scarce, particularly in countries with the highest estimated rabies burden [9]. Since the year 2000 the Swiss Tropical and Public Health Institute (Swiss TPH) works in close research partnership with two Chadian partner Institutions based in N'Djamena, the Institute de Recherche en Elevage pour le Développement (IRED) and the Centre de Support en Santé International (CSSI). Huge progress has since been made in terms of reinforcement of diagnostic capacities and the proof of feasibility of dog vaccination. The description of the dog demography and two pilot vaccination campaigns [10,11] have shown that a high coverage can be achieved through free immunisation by a fixed post approach. The cost-estimation done with the results of the pilot studies [12,13] helped to prepare the citywide campaign and to estimate the cost-effectiveness of such an intervention with a dog to human transmission model [4]. The thorough analysis of the two consecutive interventions presented here helps to prove the outcome of feasibility and cost-effectiveness.

2. Materials and methods

Two campaigns, held in 2012 and 2013, were organized by a coordination committee composed of representatives of IRED, CSSI and Swiss TPH. Finances were shared between IRED (personnel and logistics) and Swiss TPH (vaccine and other material). The operational procedure was based on a Central Point Vaccination (CPV) approach, with the vaccination post installed for the whole vaccination day at a central location, most often in front of a block chief's house. Upon request households with a dog that could not be brought to a post were visited by a mobile vaccinator on a motorbike. Also, in the outskirts of N'Djamena a mobile approach was applied by a vaccination team visiting several villages a day by car. The ten vaccination teams consisted of 3 vaccinators each.

Representatives of the different urban administrative entities participated in preparatory meetings and were actively involved in the organisational planning, in particular regarding public sensitization and location of posts.

The information campaign included use of posters, radio broadcasts, loudspeaker announcements and banners.

Vaccine and materials were procured on the basis of an estimated total dog population of 50,000. Vaccine storage was assured

by IRED. In both years, the campaign ran from October to January on Friday to Sunday (13 weeks; 37 days). One week was defined as a sequence and enumerated from 1 to 13. In addition to dogs, vaccine was also administered to all presented cats and primates. All dogs were collared and marked on the trunk with a livestock marker crayon. The operational plan is further described in the supplementary material.

Vaccination sequences and analysis zones were usually comprised of a district (Fig. 1) and were defined by drawing the circumference around the outermost vaccination posts, with exclusion of peripheral villages. The coverage assessment included a household survey in randomly selected geographical locations within the analysis zone to estimate the proportion of owned vaccinated dogs. In addition, random transect drives were carried out in the same locations to estimate the proportion of free roaming dogs and the fraction of ownerless dogs (Fig. 1). Data from both studies were combined in a Bayesian statistical model (see supplementary file).

Information from vaccination posts and daily team performances as well as data collected during the household and transect study were continuously entered in a Microsoft Access database to analyze in real time the achieved coverage per analysis zone using EpiInfo [14] and Winbugs [15]. For the preliminary estimate, the number of dogs vaccinated before the analysis in the area was used (Table 1). When coverage was <70% and the coordination committee thought that vaccination of more dogs in the area was achievable, teams were sent back to the area. For the final coverage analysis, the sum of dogs vaccinated before and after analysis in a given zone for a given year was taken into account (Table 1). Dogs vaccinated at posts outside of the analysis zone were excluded from the analysis. Due to the lack of long lasting identification of the dogs and the high rate of loss of certificates it was not possible to register the number of dogs that were initially vaccinated in 2012 and revaccinated in 2013. All expenditures prior to and throughout the campaigns were recorded and analyzed.

Incidence data on dog rabies were collected as part of routine diagnostic testing at IRED. Awareness regarding best practice after a dog bite incident and the importance of diagnostic testing was highlighted through a poster campaign in health centers, hospitals and pharmacies prior to the intervention.

Research approval was granted by the Scientific and Technical Research Directorate of the Ministry of Higher Education (Ministère de l'Enseignement Superieur, Direction de la Recherché Scientifique et Technique) in Chad. The study protocol was additionally reviewed by the Ethics Commission of the Cantons of Basel-Stadt and Basel-Land.

3. Results and discussion

In both years, the campaign duration was 37 days within a three month period, with a mean number of dogs per day and post of 53 in 2012 and 70 in 2013. Kayali et al. [12] calculated the daily capacity of one vaccination post to be 100 dogs/day and estimated 15 days to vaccinate an expected 23,000 dogs. This difference is not surprising because the pilot studies were done in densely populated areas with a high dog/human ratio. In our study for the 7th district where the ratio is very high, peak numbers vaccinated were more than 400 animals/day (56/h) in 2013.

Vaccination posts and coverage estimates are shown in Figs. 2 and 3. The number of posts included in the coverage area was 216 in 2012 and 331 in 2013. The increase of over 100 posts more in 2013 was due to quicker relocation when attendance was low with the aim of maximizing accessibility. The overall area for the coverage analysis was calculated as 240 km^2 in 2012 and 285 km^2 in 2013, which corresponds to a mean density of vaccination posts of
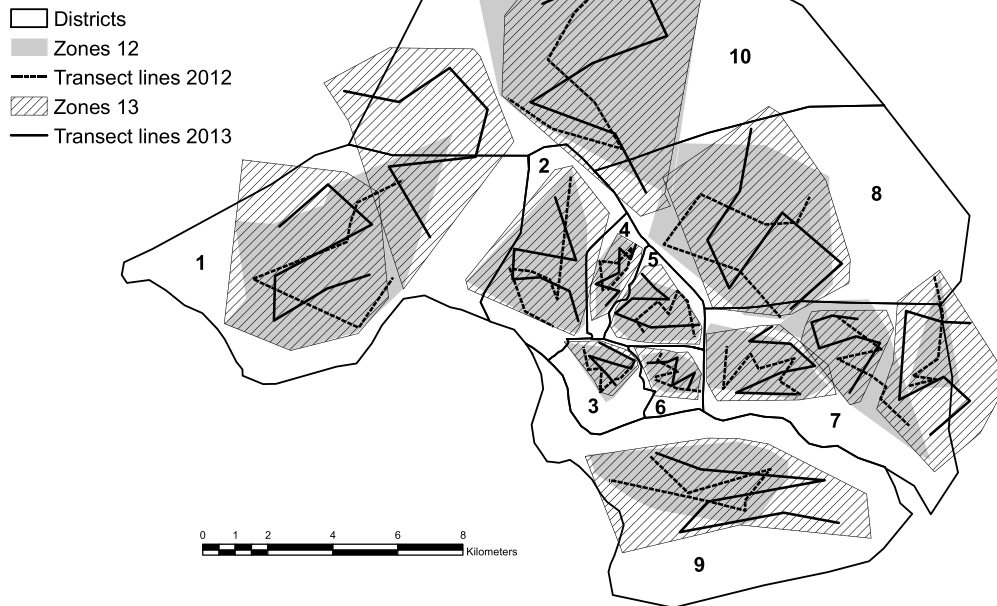
Analysis zones

Fig. 1. Comparison of analysis zones and transects lines for the coverage survey in 2012 and 2013. Changes in analysis area result from varied locations of vaccination posts and the split of the 1st district in two sequences in 2013. These changes were made to achieve higher coverage.

Table 1
Coverage estimates, number of owned dogs, percentage of ownerless dogs and total dog population by district and vaccination sequence.

District	Sequence (intervention week)	Number of owned dogs	% of ownerless dogs	Total dog population	Vaccinated before analysis[a]	Vaccinated total in analysis area[b]	Coverage	Vaccinated out of analysis area
2012								
1	1	1267	2	1289	834	925	72%	26
2	2	130	57	203	64	64	31%	
3	3	497	4	517	376	376	73%	
4	4	48	30	62	24	24	39%	
5	11	474	1	481	311	311	65%	
6	5	1358	30	1762	793	919	52%	
7	6	4724	19	5617	2775	3342	59%	
7	7	7758	0	7783	5893	6683	86%	
7	8	582	24	721	503	503	70%	100
8	12	862	19	1025	361	413	40%	24
9	9, 10	4648	2	4728	3858	3858	82%	429
10	13	296	21	359	120	120	33%	37
Summary 2012	13	22,643	8	24,547	15,912	17,538	71%	590
2013								
1	6	1582	14	1810	1155	1325	73%	113
1	7	73	68	123	52	62	50%	
2	4	208	4	217	123	123	57%	
3	2	646	25	811	468	468	58%	
4	5	95	85	175	49	67	38%	
5	3	530	9	579	330	330	57%	
6	1	1055	45	1535	722	1044	68%	
7	8	6586	15	7606	4850	5507	72%	
7	9	5573	9	6073	4372	4372	72%	
7	10	3111	16	3594	2660	2699	75%	296
8	12	988	42	1399	691	741	53%	35
9	11	5017	13	5672	4314	4402	78%	415
10	13	348	38	482	200	200	41%	107
Summary 2013	13	25,812	14	30,074	19,986	21,340	71%	966

[a] Refers to the number of dogs vaccinated before the coverage survey in a given zone in each year.
[b] Number of dogs vaccinated before the coverage survey plus the number of dogs vaccinated after the coverage survey to achieve the targeted coverage number.

2012

Coverage %
< 50
50 - 70
> 70
Water surface

Vaccination posts
sum of dogs
<=20
21 - 50
51 - 100
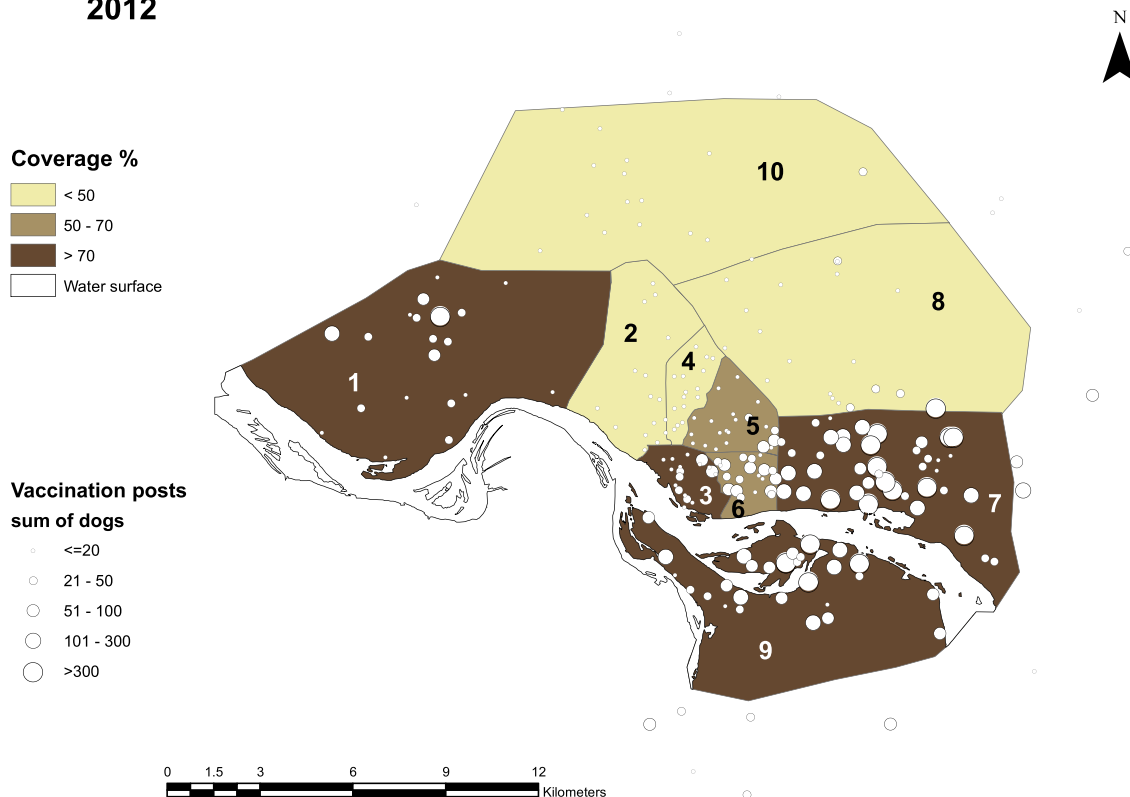101 - 300
>300

0 1.5 3 6 9 12
Kilometers

Fig. 2. Coverage estimates and vaccination posts during the campaign in 2012. The size of the vaccination post bullet indicates the number of dogs vaccinated at the respective post. Vaccination posts outside the borderline of the city include peripheral villages.
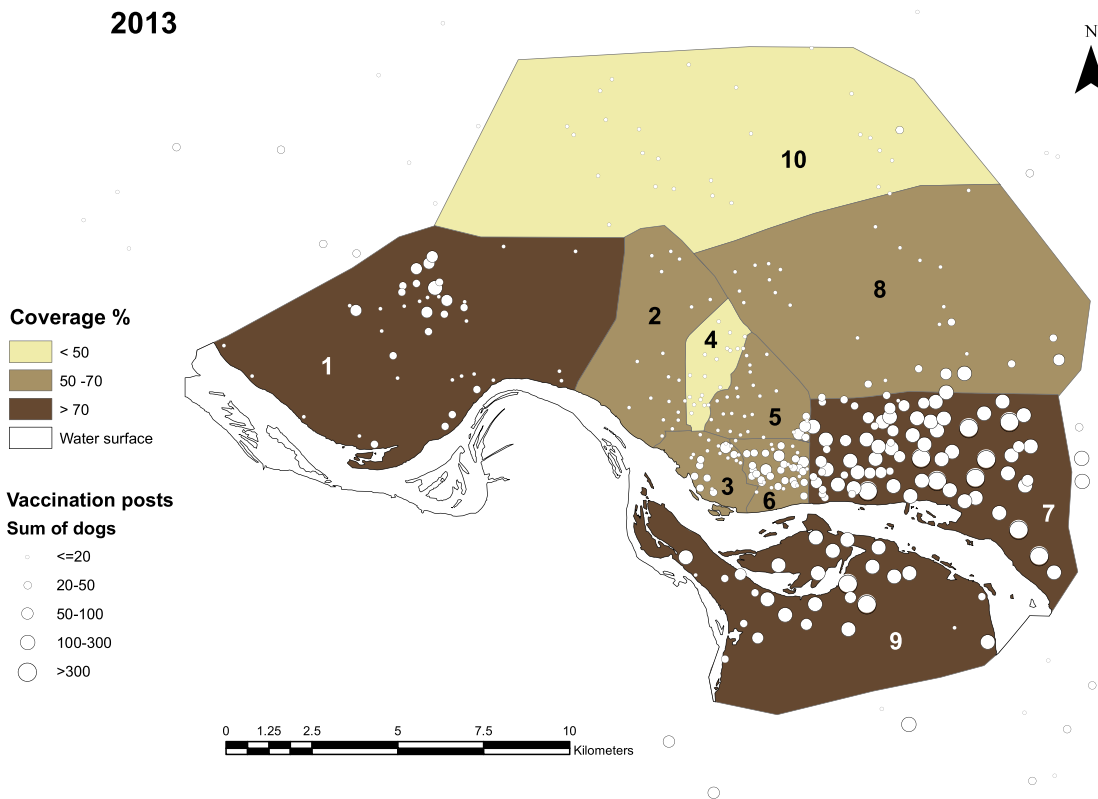
2013

Coverage %
< 50
50 -70
> 70
Water surface

Vaccination posts
Sum of dogs
<=20
20-50
50-100
100-300
>300

0 1.25 2.5 5 7.5 10
Kilometers

Fig. 3. Coverage estimates and vaccination posts during the campaign in 2013. The size of the vaccination post bullet indicates the number of dogs vaccinated at the respective post. Vaccination posts outside the borderline of the city include peripheral villages.

Table 2
Summary of animals vaccinated by district in 2012 and 2013.

District	Vaccinated 2012				Vaccinated 2013			
	Dogs	Cats	Primates	Total district	Dogs	Cats	Primates	Total district
1	951	135	5	1091	1500	410	12	1922
2	64	49	3	116	123	166	1	290
3	376	79	12	467	468	139	10	617
4	24	108	2	134	67	265	0	332
5	311	87	1	399	330	206	0	536
6	919	80	12	1011	1044	154	15	1213
7	10,628	310	41	10,979	12,874	1240	60	14,174
8	437	82	3	522	774	249	8	1031
9	4315	372	24	4711	4828	560	22	5410
10	157	182	1	340	298	212	2	512
Total Ndjamena	18,182	1484	104	19,770	22,306	3601	130	26,037

just under $1/km^2$ and $1.2/km^2$, respectively. A walking distance of roughly 1 km is described as acceptable for good accessibility [16].

Disruption of supply due to logistical challenges regarding traffic only occurred in a few instances and did not greatly impact on the accessibility, because owners were willing to wait at the posts for replenishment. We believe that the cold chain was maintained in the large majority of cases. Preliminary results of follow up vaccination titres show that only 1 of 84 dogs did not have a sufficient titre (>0.5 International Units (IU)) when tested with the FAVN one month after vaccination (Abdelrazakh et al., forthcoming).

The total number of dogs vaccinated was 18,182 in 2012 and 22,306 in 2013 (Table 2). The Bayesian population model applied (see supplementary file) estimated the total number of dogs for the city to be between 24,500 and 30,000 dogs (Table 1), corresponding to a density of about $100\ dogs/km^2$. This population estimated results in a dog to human ratio of between 1:40 and 1:50, which is similar to ratios reported from an urban location in Zambia [17] but much lower than the ratio estimated across Africa reported in Knobel et al. [18] This number is far below the previously estimated total population of 45,000–50,000 dogs. The discrepancy can be explained by the fact that the demographic study in 2003 [19] which served as the basis for the preliminary estimate had a high standard error resulting in a low precision of the dog population estimate. Further extrapolation of the ratio resulted in a high overestimation. In addition, we postulate that the dog population numbers did not grow proportionally to the human population. This finding shows that demographic surveys should not be conducted with a long time lag before intervention and are of limited use for precise coverage estimation. Overestimation of the dog population entails the risk of vaccine wastage. In our case the expiration date of the vials purchased in 2012 and the good storage conditions at IRED allowed the use of the vaccine for the two campaigns.

Our results suggest that between 8 and 14% of the dogs in N'Djamena are actually ownerless (Table 1), which is in line with other studies reporting low ownerless dog numbers [9,20]. However, this estimate of the Bayesian model is sensitive to one model parameter. Details of the sensitivity analysis are provided in the supplementary appendix. Total vaccination coverage was estimated at 71% in both 2012 (CI 0.68–0.76) and 2013 (CI 0.7–0.76). However, this number is a mean over all the districts covered. The districts differ greatly in dog density, participation of owners in the campaign and percentage of stray dogs, so coverage data for each district, and even from quarter to quarter, are diverging (Table 1). Collar loss, immigration and emigration as well as births and deaths did not presumably greatly influence the results because the coverage survey was done 48 h after the vaccination in a given zone (see supplementary file). In the household survey in 2013, only 6.8% of dogs were reported to have lost their collars. When observed in transects, this would likely lead to slight underestimation of coverage as well as overestimation of ownerless dogs.

Accurate coverage assessments are a prerequisite to quantify the effectiveness of vaccination interventions and to predict the impact on disease transmission. Yet in many cases, such surveys are not a part of vaccination campaigns [9], and there is a lack of harmonized, concise methodology.

Cross-sectional assessments estimate vaccination coverage at a given point in time, but actual herd immunity is dynamic [21]. When a vaccination campaign moves to a new zone, coverage in the previous zone starts to decline due to population turnover and immunity loss. The decision regarding timely progression of campaigns must be a balance between overall achievable coverage which increases with speed and accessibility of dog owners which decreases with faster movement. Daily number of animals vaccinated not only impacts time, and consequently coverage, but also has a high impact on the cost per animal vaccinated. Calculated over the two campaigns the incremental cost per vaccinated animal was 2.1 Euros. In 2012, the operational cost of one vaccination team per day was 109 Euros (71,500 FCFA). One-third of this cost was fixed while 2/3 depended on the length of the campaign. The cost for vaccines and collars was 60 cents/animal. Therefore, each animal on the peak day in 2012 (1 animal out of the total of 325 vaccinated) cost only 90 cents. In turn, if only one animal was vaccinated per day at a post, the cost for this animal in 2012 (1 animal out of the total of 1 vaccinated) was 109.5 Euros.

In 2012 the reason for not bringing a dog for vaccination, as stated by owners of encountered unvaccinated dogs during the household survey ($n = 1266$), was most often lack of information (40%). With intensified megaphone mobilization around vaccination posts in 2013, lack of information dropped to 31% ($n = 365$) which would indicate that short term, direct sensitization of the public triggers high response. Preliminary comparison of our campaign with a pilot vaccination in Bamako (coverage <20%) also indicates that baseline awareness in the community has a considerable impact on coverage [22]. Through several years of work on rabies control in N'Djamena people might have been more informed about rabies than in Bamako where intensified control efforts were only recently implemented. A well informed public is likely to exert societal pressure on dog owners to comply with vaccination. The second most reported cause in both years was inability to handle the dog (25% and 28%, respectively). This reduction in accessibility can be addressed by including a mobile approach, by visiting households on request. Some vaccinators used motorbikes to visit dog owners at their home when a dog could not be brought to a post. This should be carefully implemented and communicated to avoid the expectation that vaccinators will go door to door as in polio vaccination campaigns. In 2013 posts were relocated more quickly when utilization was low, contributing, along with intensified mobilization, to higher performance.

In 2012, 5% of owners stated that their dog was too young to be vaccinated. However, it has been shown that the majority of

dogs less than 3 months old still respond positively to vaccination [23,24]. In a setting where population turnover is high and a large number of the population is comprised of young dogs, WHO recommends the vaccination of puppies [25]. After instructing vaccination teams to encourage vaccination of puppies, age as a cause for non-vaccination dropped to 3% in 2013.

Other reasons, including distance to the post, refusal, neglect and age of the dog, did not exceed 3% of all causes for non-vaccination in both years. Refusal due to infectious disease concerns or fighting due to contact with other dogs as observed in studies in Grenada [26] were not specifically stated by owners. However, some people believe that the vaccine may be harmful or cause the dog to be a less effective guardian (author's observation).

Our team performance indicators show that the highest limitation factors are public accessibility and participation rather than the vaccination capacity of a post. Similar observations were made in Sao Paulo city, Brazil [16] where geographical barriers between supply and demand and people's awareness of the benefit of vaccination mostly determined accessibility. The vaccination capacity of more than 200 animals/day and post observed in this study cannot be achieved by a fixed approach in areas where the distance to the post is long, dog population density is low or people are not adequately informed. We found the highest motivation factor for staff is a well visited post, and teams got discouraged when performance was low. Zones with low dog densities, low awareness and accessibility would additionally be impacted by low motivation of vaccinators.

Despite higher overall performance in 2013, the 70% threshold was not achieved in more districts than in 2012 (Figs. 2 and 3). The difference lies mainly in the 2nd and 8th districts, where the 2013 coverage was raised above the threshold of 50%. Districts 4 and 10 were zones that performed weakly (<50%) in both years. The 4th district houses the central market where ownerless dogs gather. The peripheral district 10 is comprised of low-density settlements where accessibility is challenging due to distance and mobilization. Both districts also have a predominantly Muslim population. In some Hadith verses which accompany the Koran the dog is described as an impure animal [27]. Owned dogs are fewer and potentially less accessible in Muslim communities. Similar observations were made in Tanzania [28]. The 2nd district, which has the second lowest dog numbers, is dominated by a relatively affluent neighbourhood, which includes the president's mansion and numerous ministries. In wealthy areas dogs are more likely to be confined, and dog owners are less susceptible to social mobilization [29]. In contrast to Districts 2 and 4, Districts 7 and 9 are dominated by a socio-economically weak, Christian population. Dog density is high and most dwellings are not fenced, so the confinement level is very low. The proportion of ownerless dogs was less than 15% in both years for these districts and coverage was notably high. The performance and background of districts 7 and 9 are comparable to rural agro-pastoralist areas in Tanzania [30]. Our results support the finding of Kaare et al. [30] that there is not one ideal approach for planning dog vaccination campaigns in a diverse context.

After the start of our campaign, the dog rabies incidence calculated based on the population estimates of the campaign dropped from 0.7/1,000 (CI 0.63–0.77) in 2012 to 0.073/1,000 (CI 0.067–0.081) in 2014. We are confident that this decline is not due to a drop in awareness because the rate of negative tested rabies suspicion cases did not change considerably. Since January 2015 cases have risen again in the 9th district which is on the border of the town and thus highly suggestive of reintroduction. Modelling effectiveness of mass vaccination in Bali has shown that even small areas with no or very low coverage can jeopardize the success of a campaign and be the source of continued rabies transmission [21]. Closer investigation through molecular genetic study is currently under way to further detail transmission dynamics.

Whilst financial commitment of Chadian national authorities is lacking for continued citywide vaccination, a small scale containment vaccination in the 9th district and the adjacent villages is funded by donors and planned to take place before end of 2015.

4. Conclusion

Thorough analysis of the vaccination intervention presented demonstrates the feasibility and cost-effectiveness of dog rabies elimination in an African capital city, supporting the vision of achievable elimination across the continent [31]. Identified driving forces of performance are close involvement of local leaders and intense public sensitization. Timely mobilization and adherence of dog owners is crucial to minimize cost and maximize coverage and motivation of vaccinators. Special attention should be given to cultural aspects influencing accessibility of dog populations during the preparation of interventions.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.vaccine.2015.11.033.

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