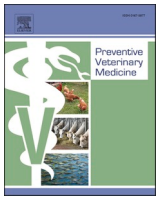
Preventive Veterinary Medicine 203 (2022) 105623

Contents lists available at ScienceDirect

Preventive Veterinary Medicine

journal homepage: www.elsevier.com/locate/prevetmed



Using causal loop analysis to explore pathways for zoonosis control in low-income setting: The case of dog rabies vaccination in Burkina Faso

Madi Savadogo [a,c,d,*], Dimitri Renmans [b], Rianatou Bada Alambedji [c], Zékiba Tarnagda [d], Nicolas Antoine-Moussiaux [a]

[a] Fundamental and Applied Research for Animals and Health (FARAH), Faculty of Veterinary Medicine, University of Liege, Belgium
[b] Institute of Development Policy, University of Antwerp, Belgium
[c] Service de Microbiologie-Immunologie et Pathologie Infectieuse, Département de Santé Publique et Environnement, Ecole Inter-Etats des Sciences et Médecine Vétérinaires, Université Cheikh Anta Diop, Dakar, Senegal
[d] Laboratoire National de Référence-Grippes (LNR-G), Unité des Maladies à potentiel Epidémique-Maladies Emergentes et Zoonoses, Département de Biologie Médicale et Santé Publique, Institut de Recherche en Sciences de la Santé, Ouagadougou, Burkina Faso

ARTICLE INFO

Keywords:
Burkina Faso
Zoonosis
Rabies control
Dog vaccination
Facilitators
Barriers
System dynamics
Causal loop diagraming

ABSTRACT

Dog vaccination is an effective pathway to control rabies if a minimum of 70% dog vaccination coverage is achieved. For more than six decades, dog vaccination has been adopted as part of the rabies control measures in Burkina Faso. However, the required vaccination coverage in canine population remains challenging and rabies endemic. This study describes the use of systems thinking to explore the dynamics arising from dog vaccination complexity and explain the possibles causes of low vaccination coverage in the dog population. In-depth interviews were conducted in three administrative regions and included various stakeholders. A thematic analysis was performed to analyze the obtained narratives. Subsequently, causal loop diagrams (CLDs) were developed, depicting the causes of low dog vaccination coverage. The CLDs were composed of reinforcing loops and balancing loops, visualizing how different variables including social, economic, technical, political and organizational factors that affect the implementation of rabies vaccination in the country are causally interrelated. Overall, the results revealed the importance of community awareness raising, strengthening the vaccination workforce, enhanced governance and leadership in the dynamics of dog vaccination. The study calls for wide consideration of all drivers and factors that may affect dog vaccination coverage, for the development of any rabies control strategy or vaccination program. Beyond the dog vaccination problem, the methods and findings from this study could be applied to other critical rabies-related questions such as postexposure prophylaxis, epidemiological surveillance, dog population management, laboratory diagnosis, and the One Health collaboration issues, to understand and improve rabies control.

1. Introduction

Rabies is a serious global public health threat, with higher impact in low- and middle-income countries in Africa, Asia and Latin America. This preventable but always fatal disease mostly affects poor and rural communities. It is a zoonosis that affects wildlife and domestic animals, and is transmissible to humans, through bite, scratch or licking by a rabid animal. Dogs were reported to be the main cause of human cases in Africa (99%) (Sondo et al., 2015; Minghui et al., 2018). Although rabies remains under-reported, more than 59,000 human cases are estimated to occur in African and Asian countries annually, representing approximatively one human death every nine minutes (Hampson et al., 2015). Every year rabies causes almost 2000 deaths in North Africa, 6000 in Southern Africa, 6000 in West Africa and 7000 in Central Africa (Hampson et al., 2015).

Located in West Africa, Burkina Faso has been endemic to rabies for decades (Dodet and Africa Rabies Bureau (AfroREB), 2008; Savadogo et al., 2020; Minoungou et al., 2021). Indeed, on average 19 human cases and more than 4000 exposures to suspected rabid animals are regularly recorded across the country (Burkina Faso, Ministère de la Santé, 2016; Sondo et al., 2015; Ouermi et al., 2018). Routine laboratory surveillance detected many positive cases in pets, including cats and

* Correspondence to: Fundamental and Applied Research for Animals and Health (FARAH), Faculty of Veterinary Medicine, University of Liege, Quartier Vallée, 2, Avenue de Cureghem, 6, B43, 4000 Liege, Belgium.
E-mail address: savadogo.madi@yahoo.fr (M. Savadogo).

https://doi.org/10.1016/j.prevetmed.2022.105623
Received 16 August 2021; Received in revised form 15 March 2022; Accepted 20 March 2022
Available online 24 March 2022

dogs, but also in wildlife, cattle, and equids (Nitcheman, 1983; Savadogo et al., 2020; Minoungou et al., 2021). From 2001–2013, approximatively 90% of rabies positive samples were from canine species and at least 70% of suspected rabid dog samples were rabies positive (Savadogo et al., 2020; Minoungou et al., 2021). However, rabies is known to be 100% preventable if dogs are appropriately vaccinated and post-exposure prophylaxis is adequately provided to exposed persons (World Health Organization, Food and Agriculture Organization of the United Nations and World Organisation for Animal Health, 2016). It is estimated that rabies can be eliminated if almost 70% of canine population is regularly vaccinated (Cleaveland et al., 2006; Coleman and Dye, 1996; Zinsstag et al., 2017).

Several measures have been initiated in the country to mitigate rabies risk: veterinary public health policies have made rabies a notifiable zoonosis, dog free roaming is prohibited, and rabies vaccination is compulsory for all pets above 3 months of age (Kouldiati, 1989; Burkina Faso, 1989; Burkina Faso, Ministère de la Santé, 2016). Current rabies control actions include awareness campaigns, surveillance, pre- and post-exposure prophylaxis, dog population management, and dog vaccination. The latter has been adopted as a method for rabies control since the 1960s (Nitcheman, 1983). It is provided by private and public veterinary services, the latter being often the sole available in rural areas. In addition, on the yearly World Rabies Day, short vaccination campaigns are often organized, particularly in the main cities, i.e. Ouagadougou, Bobo Dioulasso and Koudougou. Dog vaccination cost ranges between 1.5 euros (during campaings) and 3.8 euros (in veterinary clinics) and is charged to owners (Savadogo et al., 2020, 2021a, 2021b). Despite these measures, owned-dog vaccination coverages in the country remain low: 8.2% in Dédougou (Dahourou et al., 2021), 25.9% in Bobo Dioulasso (Savadogo et al., 2021a, 2021b) and 36.5% in Ouagadougou (Sondo et al., 2015; Savadogo et al., 2020, 2021a, 2021b). Studies investigated the reasons for this poor vaccination coverage using quantitative methods, such as cross tabulation, logistic regression models and principal component analysis (Savadogo et al., 2021a, 2021b). Such methods focus on the main expected drivers through structured questionnaires, leaving aside the in-depth complex dynamics of the issue. However, like any public health intervention, dog vaccination entails a complex setting, the understanding of which requires systemic approaches (Narrod et al., 2012; Peters, 2014; Castillo-Neyra et al., 2017). This study uses causal loop diagraming to analyze the system underlying dog vaccination in Burkina Faso. It aimed to (1) identify barriers and facilitators to dog rabies vaccination as well as the interplay between different stakeholder levels in Burkina Faso, and (2) understand how they causally interact affecting the dog vaccination coverage.

2. Material and methods

2.1. Description of study areas

The study was conducted from February 2019 to February 2021 in three administrative regions of Burkina Faso (Fig. 1): Center (Ouagadougou, the administrative capital), Hauts Bassins (Bobo Dioulasso, the second biggest city) and Center-Ouest (Koudougou). These three areas are the most important urban agglomerations of the country. The local population owns dogs for various purposes, including house or herd guarding, hunting, for sacrifices during traditional meetings, companionship especially for children and for consumption as source of protein (Kouldiati, 1989; Jibat et al., 2015; Savadogo et al., 2020). Ministries, central veterinary and medical offices are located in Ouagadougou. Nevertheless, in each of surveyed locations there are public and private technical services that provide veterinary care and animal rabies vaccination (veterinary clinics, short vaccination campaigns). However, as the interviews were conducted in only three administrative regions, the study did not include rural area. Therefore, factors associated with the vaccination coverage described in this study may not be fully representative for the situation across the whole country.

2.2. Stakeholders identification

The participants were recruited following the process described by Fig. 2. The study started with reviewing existing information (grey literature, theses, publications) to capture the organization of the rabies control system in Burkina Faso (Nana, 2019). In February 2019,

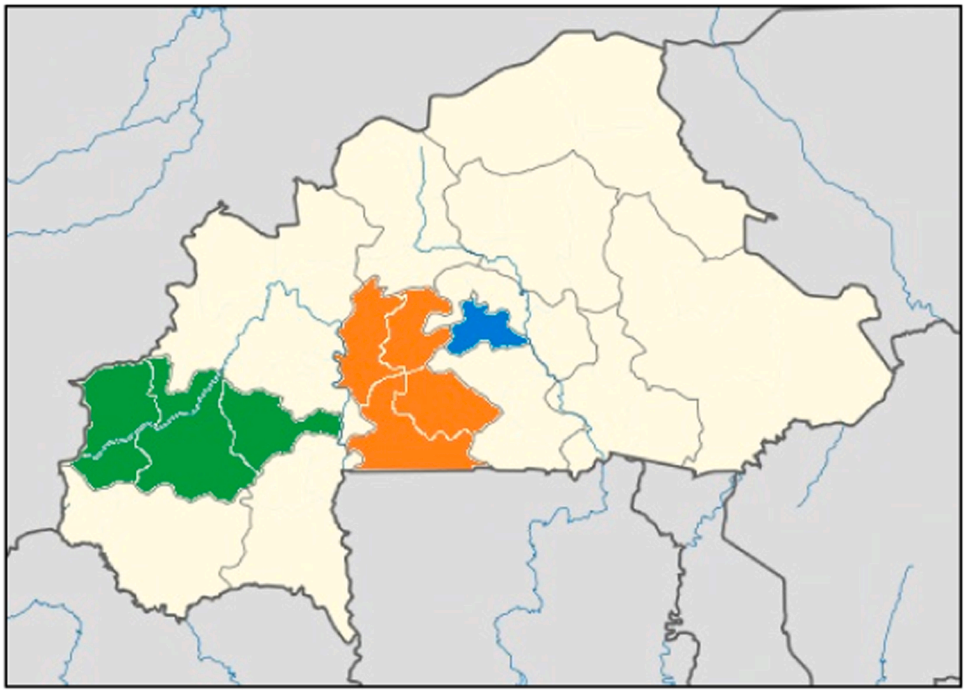


Fig. 1. Geographical location of the three administrative regions where interviews were conducted, Burkina Faso (*Blue: Center region; Green: Hauts Bassins region; and Orange: Center-Ouest region)*. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

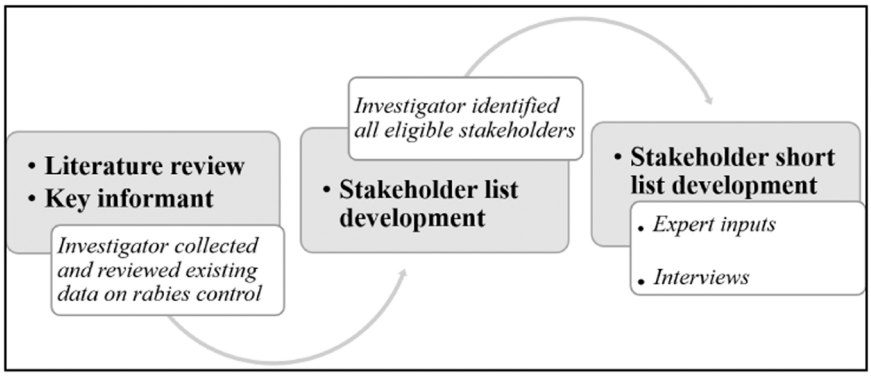


Fig. 2. Mixed methods used for stakeholder recruitment (Literature review, Key informant interviews, inputs from field animal health experts).

interviews with key informants from public and private animal health entities were held during a first field visit in Ouagadougou. These interviews informed a first list of rabies control stakeholders, including entities and actors intervening or affected by the rabies control activities. From this first list, a second list was established including entities and actors playing a direct or indirect role in dog rabies vaccination. Subsequently, a local expert with good knowledge of the issue of dog vaccination helped refine and prioritize a short list of relevant stakeholders to be interviewed. In addition, during the field investigations, interviews also allowed completing the stakeholder short list.

2.3. Sampling methods

Study participants were recruited using a dual sampling approach including purposive and respondent-driven sampling. First, all shortlisted stakeholders were invited to participate in interviews (purposive sampling). Then, these first respondents introduced the researchers to other stakeholders involved in dog rabies vaccination in the study area (respondent-driven sampling). Dog owners were selected from a list of participants established during a short vaccination campaign organized in 2019 by the veterinary services. Victims of dog bite were recruited during field sensitization in the community. Therefore, all included stakeholders were selected on the basis of their involvement or interest in rabies control and, in particular, the dog vaccination issue. The employed sampling method was effective and appropriate for the data collection due to logistic and resource convenience (Taha, 2020). Interviews were conducted until the point of data saturation was reached (Glaser and Strauss, 1967). Thus, inclusion of participants was stopped when, despite the search for various situations, data collected provided enough information, and the capacity to obtain new additional information was reached (Guest et al., 2006; Fusch and Ness, 2015). In total, 62 in-depth interviews were conducted including animal health workers (n = 28), human health workers (n = 16), wildlife workers (n = 4), municipality officers (n = 4), dog owners (n = 8), and victims of dog bite (n = 2) (Table 1). Interview guides were tailored to each category of participants to cover the relevant range of aspects to be discussed.

2.4. Data collection

Data collection included individual and focus group in-depth interviews, conducted both in local language and French by the principal researcher. Participants were invited by email or phone providing them the study background and objectives. Each participant was reminded once every month. In case a participant did not respond or declined the invitation to participate, a replacement was operated from the stakeholder list. An interview guide was used to collect narratives on rabies control, with a focus on the issue of dog vaccination against rabies: known involved stakeholders, roles of each category of stakeholders, challenges, enabling factors, strategies and leverages that may be successful for improving dog rabies vaccination compliance. For each discussion, participants were met in a location convenient to them that ensured confidentiality (e.g. participant office, place of residence). All interviews were conducted by the researcher, audio-recorded and transcribed in a Microsoft Word document. Throughout the data collection process, validity of data was ensured. This started with the used respondent-driven sampling which helped avoiding major biases in participant recruitment. In interviews, participant's own information was crosschecked with opinions of local experts, direct observations of the researcher and with documented information when available. Stated information about context of dog rabies vaccination was crosschecked using independent interviews.

2.5. Qualitative data analysis

Before analysis, transcripts were reviewed and cross-checked with audio-recordings to ensure their quality and completeness. Thematic analysis is a widely used method in qualitative studies to identify patterns of meanings across various interviewees narratives (Olivier de

Table 1
Categories of stakeholders interviewed in the three study locations, Burkina Faso.

Sector	Category	Number of participants		
		Bobo Dioulasso	Koudougou	Ouagadougou
Animal health	Public veterinarians	–	–	6
	Public paraveterinarians	6	5	4
	Private veterinarians	–	–	3
	Private paraveterinarians	2	–	3
Human health	Physicians	1	–	4
	Nurses	2	–	9
Wildlife and environment	Wildlife and environment technicians	–	–	4
Municipality	Hygiene Officers	1	–	3
Community	Dog owners	3		4
	Victims of dog bite	–	–	2
Total		**15**	**5**	**42**

Sardan, 2004; Guest et al., 2006; Xie et al., 2017). Data were obtained using the qualitative reflexive and iterative process developed by Halcomb and Davidson (2006). For the qualitative analysis purposes, themes and sub-themes were defined on the basis of the themes structuring the Stepwise Approach towards Rabies Elimination (SARE) and the Global Framework to eliminate rabies deaths by 2030 (STOP-R framework) (GARC, 2016; Chen et al., 2021). All transcripts were progressively read to explore available data, identify excerpts relevant to the pre-established (sub-)themes and define additionnal sub-themes emerging from the text.

Finally, five themes and nineteen sub-themes were defined as follow: i) socio-economic and cultural context (awareness, dog ownership, accessibility to vaccine and vaccination services, and community engagement), ii) technical factors (logistics, vaccine availability, vaccine effectiveness, training and technical support), iii) organizational factors (governance, synergy, monitoring and evaluation, performance measurement, communication), iv) political factors (political will, policy and framework, partnerships, impact of rabies and vaccination), and v) resources (workforce, budget). Within each sub-theme, the described barriers or facilitators were translated in the form of variables, termed in a concise manner. The stakeholders and their roles, the potential variables that were associated with dog rabies vaccination were then listed using a Microsoft Excel spreadsheet.

2.6. Causal loop diagraming

Causal loop diagraming (CLD) is one of the tools from qualitative system dynamics, used to explore interactions and feedback loops underlying the dynamics at play and specific outputs of a system. As presented in Fig. 3, a CLD is composed of variables (factors) and relationships (influences) (Bowen, 1992). An influence is characterized by an arrow and a polarity: "+" indicates that the two variables change in the same direction and "−" indicates that the two variables change in the opposite direction. According to polarities of arrows that compose a feedback loop, the loop is named reinforcing or balancing loop. A null or even number of negative relationships along the loop indicates a reinforcing dynamic, noted with the letter "R". An uneven number of negative relationships indicates a balancing loop, noted with the letter "B". The direction of a feedback loop is shown by a clockwise or counter-clockwise arrow around the loop-polarity-letters (R or B) (Sterman, 2002).

The Vensim software (*Vensim® PLE for Windows Version 8.2.1 Double Precision x64, 2019 Ventana Systems, Inc, see* https://vensim.com/free-download/) was used to build and generate the CLDs. For each defined sub-theme, all listed variables were displayed in Vensim and linked to each other using arrows. This stage allowed the creation of the first draft of a general CLD. Subsequently, transcripts were read again to ensure that this CLD took into account all topics and ideas collected from participants. The purpose of this process was also to have a revised and better representation of the relationships in the CLD. From the revised general CLD, the most relevant feedback loops were selected according to the following criteria: a selected causal loop should i) best reflect the ideas captured from the participants' narratives, ii) involve as few variables as possible to facilitate interpretation and understanding, and iii) describe a specific dynamic of the dog vaccination. This resulted in 17 feedback loops which were grouped into three distinct diagrams according to the SARE-derived themes.

3. Results

3.1. Stakeholders involved in dog rabies vaccination

Stakeholders were categorized in direct and indirect stakeholders according to their roles in dog vaccination (Table 2). Stakeholders who were directly involved included dog owners, community animal health workers, private veterinarians, public animal health officers, vaccine suppliers, animal health authorities, and illegal field vaccinators. Indirect stakeholders included local authorities, hygiene officers, human health workers, educational actors, media, civil society organizations, NGOs, and international health institutions (FAO, Food and Agriculture Organization; WHO, World Health Organization; OIE, World Animal Health Organization; WAHO, West African Health Organization; and RAHC, Regional Animal Health Center).

3.2. Dynamics involved in dog rabies vaccination: causal loop description

The refined list of 17 causal loops was structured into three categories of dynamics. The socio-economic and cultural dynamics (composed of four reinforcing loops and two balancing loops) describe the factors associated with the community's perceptions of rabies and dog vaccination, the dog husbandry practices, and the social networking in the general public (Fig. 4). The technical and resources dynamics (composed of five reinforcing loops and two balancing loops) capture factors associated with the funding and the effectiveness of the involved animal and public health systems (Fig. 5). The political and organizational dynamics (composed of four reinforcing loops) capture factors associated with the political context of rabies control and the interactions between key stakeholders (Fig. 6). In the description here below, each loop is named by an interpretative term between quotation marks and all variables are highlighted with italic font.

3.2.1. Socio-economic and cultural dynamics for dog vaccination

The "community engagement" reinforcing loop (Fig. 4, R1) is expected to produce a virtuous cycle by which the *accessibility to useful vaccination-related information* by dog owners, their participation in *dog vaccination*, and the *sensitization* of these owners by animal health

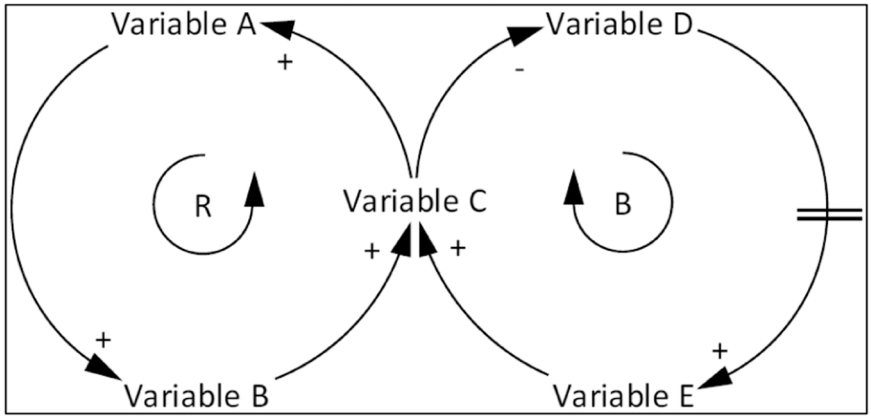


Fig. 3. Example of a causal loop diagram with a balancing loop and a reinforcing loop (Renmans, 2018).

Table 2
Cited stakeholders and their roles associated with dog rabies vaccination.

Category	Stakeholder	Entity	Category of roles
Direct	Dog owners	Local community	Seeking of vaccination, transportation of dogs to vaccination sites, payment for vaccination
	Community Animal Health Workers	Local community	Dog vaccination, community sensitization
	Vaccine suppliers	Veterinary drugs import company	Vaccine supply
	Private technicians and veterinarians	Veterinary clinics	Dog vaccination, data collection and reporting
	Animal health officers	Local and regional animal health offices	Supervising, dog vaccination, data collection and reporting
	Animal health authorities	Ministry of Livestock, National Veterinary Office,	Subsidized vaccine, vaccination planning (resources, logistics), supervising of interventions
	Illegal vaccinators	Local community	Dog vaccination
Indirect	Town criers	Local community	House-to-house information spreading
	Opinion leaders (Traditional chiefs)	Local community	Supporting officers for awareness raising and building of trust
	One Health and rabies associations	Civil society organizations	Education and public awareness raising
	Livestock development projects actors	Ministry of Livestock	Financial and logistic support (cooling equipments)
	Local authorities, Local representatives, Municipal hygiene officers, Public security officers	Ministry of Administration	Awareness raising, control of dog population (roaming), policy popularization, repression against law-breakers, waste management
	Human Health Workers	Ministry of Health	Sensitizing of biting dog owners and victims of bite
	Teachers, Researchers, Students	Ministry of Education and Research	Training, awareness raising, research and evaluation: canine population, vaccination issues, knowledge-attitude-practice assessment, assessment of intervention effectiveness
	Journalists and media actors	Ministry of Communication	Information and communication, community awareness
	Health intervening NGOs	NGOs	Financial support, training of community animal health workers
	FAO, WHO, OIE, WAHO, RAHC	International health institutions	Knowledge and financial resources

workers during vaccination, increase the level of the *awareness* of rabies and dog rabies vaccination. An improved level of *awareness* combined with *policy popularization* (regarding dog ownership and vaccination) leads to a higher *engagement of community* members for dog vaccination. However, the virtuous cycle is presently impaired and the level of awareness about rabies and dog vaccination was reportedly unsatisfactory. The field investigations revealed that the community's knowledge is improved by useful messages provided by animal health workers or shared from a diversity of sources (radio, TV, booklets, banners, flyers, social media, town criers, breeders' networks).

The "vaccination distrust" reinforcing loop (Fig. 4, R2) acts as a vicious cycle mediated by misconceptions and the communities' habits of *killing biting dogs* regardless of their vaccination status. Indeed, in the local practices, in case of bite, the hair of the biting dog should be collected and applied on the wound of the biten victim. Yet, owners make a confusion, thinking that the vaccine should protect their dogs from biting people. Hence, they ascribe the fact that their dog has bitten and was killed to an inefficacy of the vaccine. This loop lowers the *trust of dog owners in the vaccination services*. As participation in *dog vaccination* decreases, level of *awareness* decreases, increasing *misconceptions* and habits of *killing biting dogs*. In addition, trust in dog vaccination is negatively influenced by the occurrence of laboratory results that may declare positive for rabies a dog that has been vaccinated. Owners then preferentially ascribe the discrepancy to a default of the vaccine.

The "health belief" reinforcing loop (Fig. 4, R3) is a vicious cycle whereby the increasing circulation of *misconceptions* is directly defeating the *awareness*-raising actions, which leads to a further increase of popularity of *misconceptions* in the community. Participants reported the low health literacy in the community as a cause of misconceptions (fear of dog vaccination, seeking of traditional treatment such as applying the biting dog hair on the wound). For example, there were socio-cultural barriers to transporting dogs, some owners not wishing to publicly show their affection to a dog. Misconceptions also increase the habits of *killing biting dogs* and the *attitude of indifference* towards rabies in local communities, diminishing *dog vaccination*.

The "social pressure" reinforcing loop (Fig. 4, R4) actually produces a virtuous cycle that improves *dog vaccination*. Indeed, with the rise of *awareness* about rabies, a *social pressure* appears within the community. Dog owners fear being discredited and charged for post-exposure and veterinary observation in case their dog bites a person. Therefore, those owners keep their dog at home, diminishing *dog roaming* in the community. As a result, *dog handling ease* increases, facilitating the owners' participation in *dog vaccination*. Through the *sensitization by animal health workers*, this will further contribute to raising the level of *awareness* and generating higher *social pressure* in the community. Indeed, having vaccinated their dogs (checkable through a vaccination certificate or collar) helps owners reassure neighbors that they care about community health, raising the role of social network in the dynamics.

The "dog roaming" balancing loop (Fig. 4, B1) describes a distinct owner logic that counters the previous loop by reintroducing *dog roaming* in the dynamics. Indeed, with a generally low *awareness* and enforcement of dog management policies, some owners tend to release their vaccinated dogs for free-roaming, believing that the rabies vaccination exempts them from keeping dogs confined. *Dog vaccination* then increases the *dog roaming*, which decreases *dog handling ease* (by owners or vaccinators), then lowering *dog vaccination*.

The "dog killing" balancing loop (Fig. 4, B2) puts a strain on vaccination, being related to the "vaccination distrust" and "dog roaming" loops. This loop points to the increase of *dog roaming* as a result of *dog vaccination*, as described here above (see B1). As the free-roaming dogs increase dog bites and the *killing of biting dogs* by the community members, this decreases the *trust in the vaccination services,* thus *dog vaccination*.

3.2.2. Technical and resources dynamics for dog vaccination

The " workforce allocation " reinforcing loop (Fig. 5, R5) actually produces a vicious cycle whereby the poor *data collection and reporting* about rabies situation (including the incidence and the socio-economic impact) in Burkina Faso weakens the potential for *advocacy*, causing a lack of *budget allocation* and a lack of *staff* and of *staff motivation* that would be needed to produce that knowledge. Indeed, the interviews revealed insufficient staffing, mostly in peri-urban and rural locations, and veterinary officers reported a lack of competencies in frontline animal health officers. As pointed out by interviewees, staff motivation may be raised through continued trainings, incentives and regular free rabies vaccination for the personnel.

The latter dynamic is stressed in a distinct loop, called "staff motivation" reinforcing loop (Fig. 5, R6), which nevertheless acts as a vicious cycle in the present conditions. Indeed, as the *staff motivation* decreases,

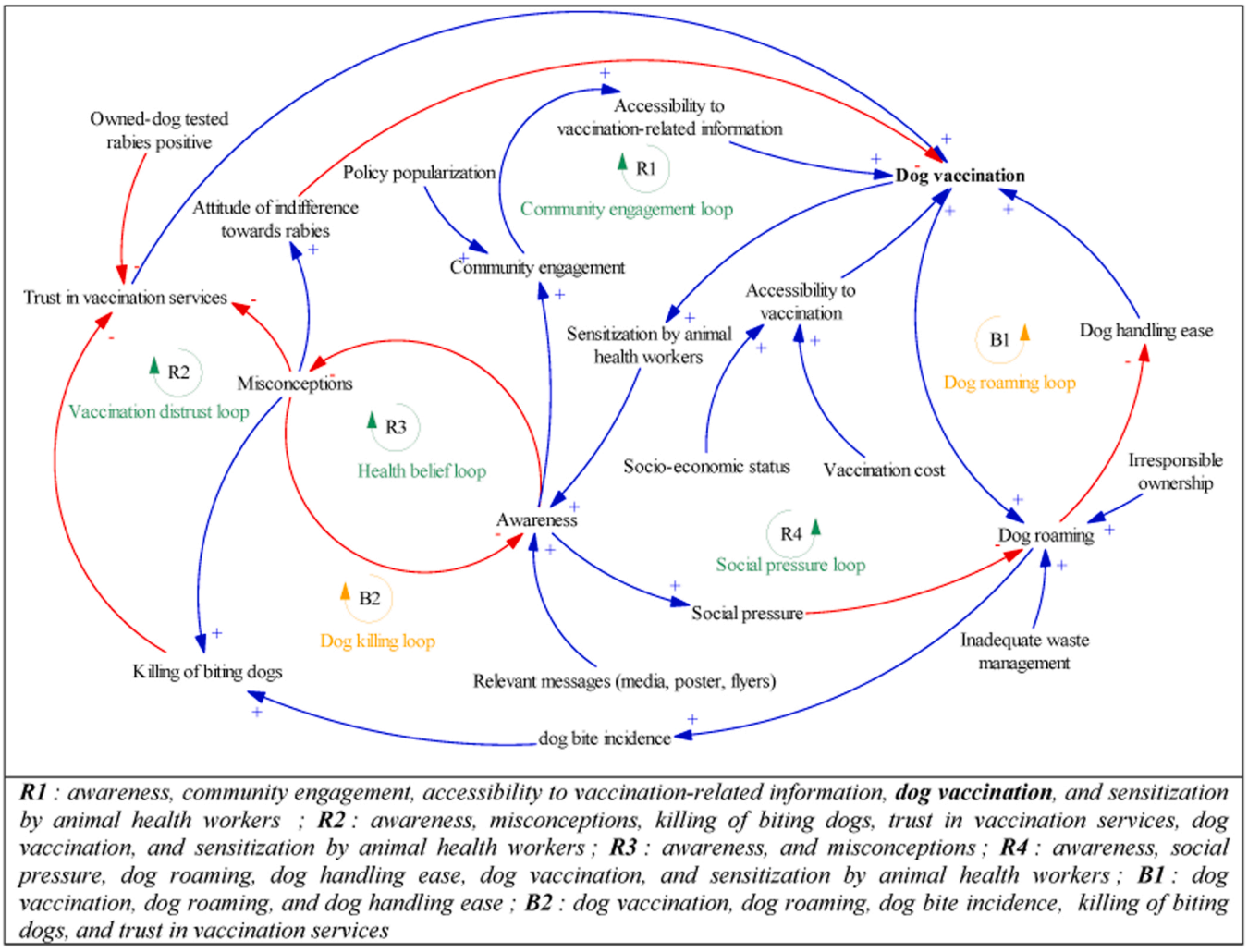


Fig. 4. Socio-economic and cultural causal loop diagram.

the *dog vaccination* delivery decreases, and vice versa. The loop indicates that a satisfactory vaccination delivery requires that the motivation of the workforce be gained and maintained. As highlighted here above (Fig. 5, R5), reported causes of low motivation of the personnel included the insufficient staffing, the lack of continued trainings, and unsatisfactory remuneration, for both public and private vaccinators involved during short vaccination campaigns. Moreover, vaccinators do not themselves benefit of any rabies vaccination, dropping their commitment to dog vaccination.

The "vaccination workload" balancing loop (Fig. 5, B3) limits the ability to benefit from a momentarily improved *vaccine availability* and *staff motivation*. Indeed, the increase in *dog vaccination seeking* from dog owners and subsequently in dog vaccination is reported to rapidly exceed the *workload* limits of staff, in particular during the short vaccination campaings. It is therefore important that technical staff be regularly upgraded to meet higher demand during vaccination campaigns.

The two previous loops combine in a "logistic provision" reinforcing loop (Fig. 5, R7), that shows a vicious cycle whereby low *budget allocation* for rabies control hinders the supply of vaccination *logistics* (cooling material, transportation facilities, infrastructures for dog impounding, dog handling equipments for vaccination purpose, and vaccination personal protective equipments decrease) both in public and private sectors. The lack of logistics hinders vaccination itself then further lowering *staff motivation*, *data collection and reporting*, *knowledge of rabies risk*, and consequently the *political commitment*. The lack of safe handling equipments is a particularly discouraging factor, many dogs being aggressive at vaccination points. In remote rural areas, the lack of transportation facilities constitutes a key barrier to the provision of accessible dog vaccination to communities.

The "vaccine planning" reinforcing loop (Fig. 5, R8) also refers to a same lack of means and *staff motivation* but points to the lack of *data collection* and *knowledge of dog population (size, structure and ecology)*. This gap actually results in inappropriate *vaccine availability*, decreasing the *dog vaccination* delivery, the *staff motivation*, and thus the *data collection and reporting* that would be required for adequate vaccine need assessment. However, inappropriate *vaccine availability* hinders the organization of regular *free vaccination campaigns*. Besides, the vaccination cost was unanimously reported by participants as a significant bottleneck to dog vaccination accessibility. The reported *vaccination cost* (ranging from 1.5 euros to 11.5 euros) was found to be very expensive by interviewed dog owners. Therefore, *vaccination cost* and recurrent vaccine stock-outs impede the *accessibility to vaccine* and the appropriate vaccination of dogs.

The "fraudulent vaccine" reinforcing loop (Fig. 5, R9) represents a vicious cycle that exhibits how the gradual destruction of owners' *trust in the vaccination services* benefits to a *competition by illegal vaccinators*. The *use of fraudulent vaccines* then further destroys the trust in vaccination, affecting indiscriminately fraudulent and official services. The fraudulent practices also produce additionnal side effects resulting from the fact that illegal vaccinators do not issue dog vaccination proofs (vaccination certificate, collar) to owners. This practice makes that more

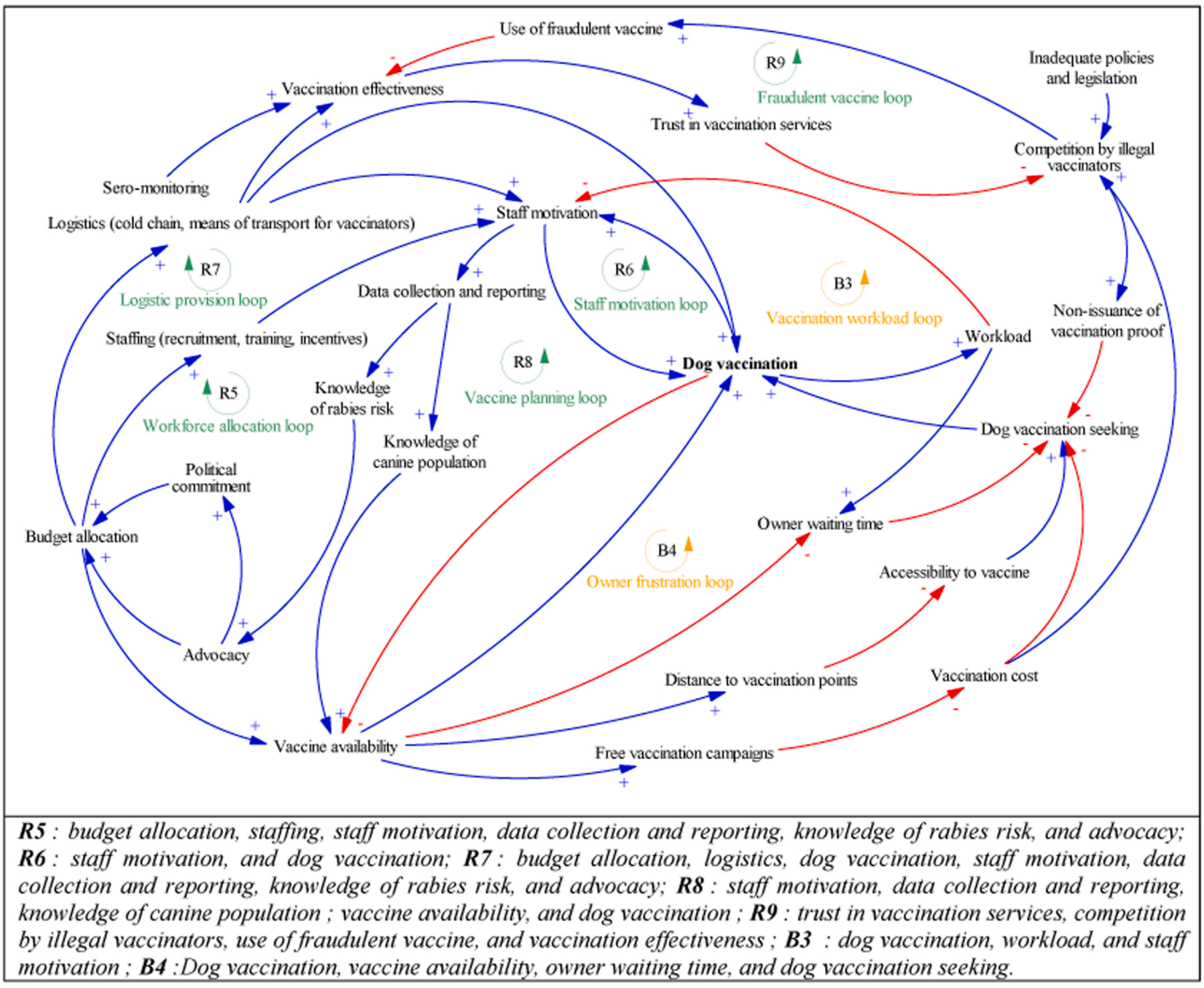


Fig. 5. Technical and resources causal loop diagram.

owners do not expect receiving a proof of vaccination, which lowers their motivation to vaccinate their dogs.

The "owner frustation" balancing loop (Fig. 5, B4) emphasizes the importance of having timely vaccination of owners' dogs. A decrease in *vaccine availability* increases the *waiting time*, sometimes running out of the period of dog vaccination validity. This causes frustration and decreases the *dog vaccination seeking*, and *dog vaccination*.

3.2.3. Political and organizational dynamics for rabies vaccination

The "vaccination governance" reinforcing loop (Fig. 6, R10) acts as a vicious cycle whereby the lack of *supervision* decreases the efforts of *monitoring and evaluation*, the *data collection*, the *knowledge of both rabies burden and vaccination impact*, and therefore the *prioritization of the disease* and the *political commitment*. A lower *political commitment* hinders the *legislation* and *national governance efforts* for rabies control (national rabies control program, proper governance). Reported governance weaknesses included a lack of transparency in the management of vaccines funded by the government, and a lack of regular consultation of stakeholders regarding the roles they could play in dog rabies vaccination.

The "vaccination need assessment" reinforcing loop (Fig. 6, R11) acts presently as a vicious cycle starting from the same problem whereby the low *governance efforts* finally decrease *data collection*. In this case, the poor *data collection* impairs the *need assessment* practices, hence the *governance efforts*. This loop is associated with the level of collaboration between stakeholders and puts a strain on national governance efforts towards dog vaccination improvement, in particular regarding vaccine management.

The "stakeholder synergy" reinforcing loop (Fig. 6 R12) actually produces a vicious cycle. It results in a lower interaction and collaboration between actors along preparation, implementation and evaluation of field interventions, especially municipality, medical and veterinary services. By this loop, the weakness of *policy and legislation* associated with a lack of wide media communication impede the dog vaccination *stakeholders' awareness of policies*. The lack of awareness about legislation by the key stakeholders decreases the *collaboration and coordination*, the *vaccination delivery*, the *knowledge of vaccination impact*, thereby lowering the *prioritization of rabies* and the *political commitment*.

The "supportive partnership" reinforcing loop (Fig. 6, R13) also acts as a vicious cycle whereby the weak *national governance efforts* discourage a diversity of partners from investing in rabies control in the country (in terms of knowledge sharing and financial support). This neglect from diverse partners further weakens *national governance efforts*. Despite the actual key role of public actors (animal health, human health, municipalities), participants mentioned the need of developing stronger partnerships with various stakeholders, including communities,

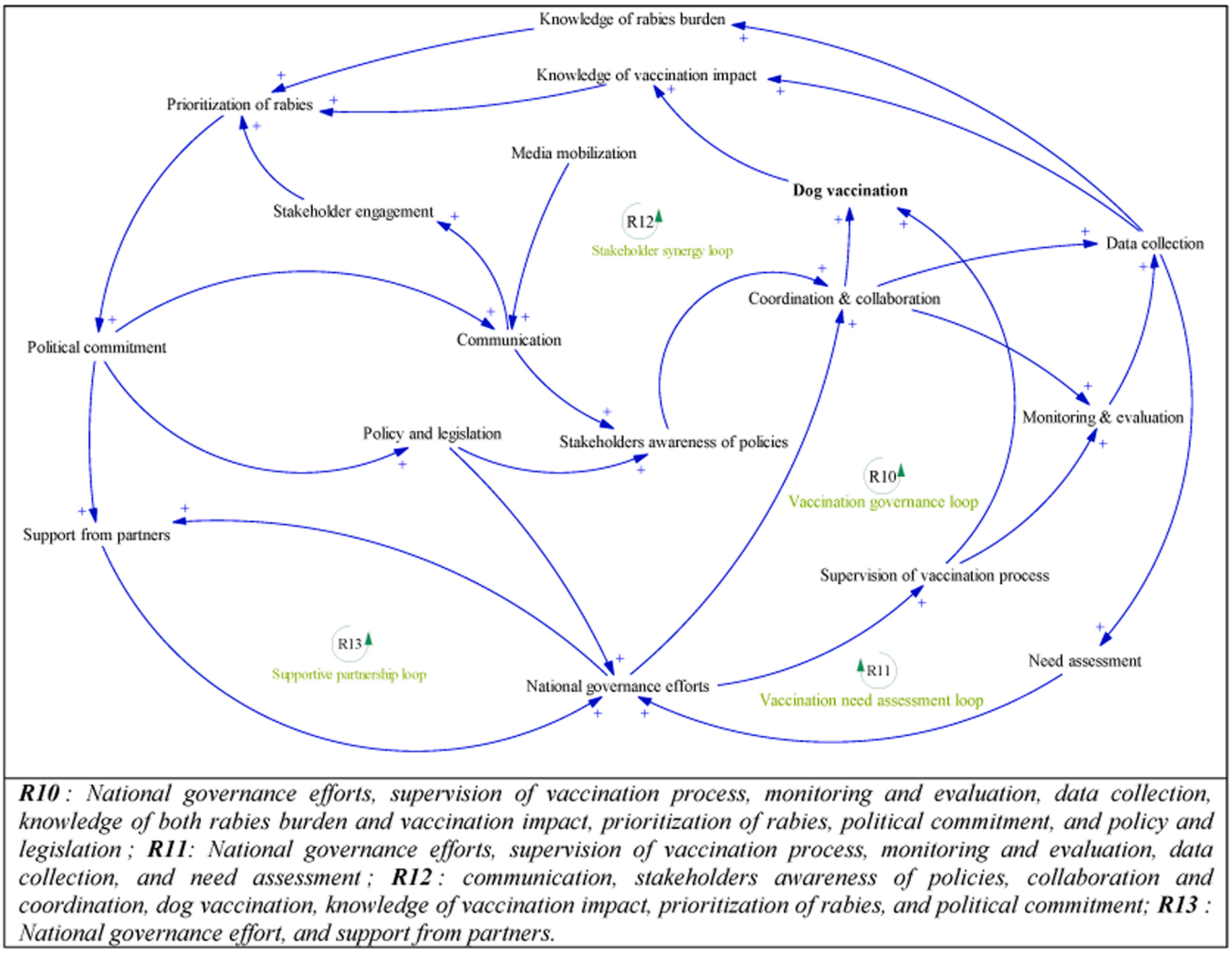


Fig. 6. Political and organizational causal loop diagram.

NGOs and international institutions, especially involved in community engagement.

4. Discussion

Dog rabies vaccination involves various factors, sectors and actors, interacting with each other and having an impact on the final vaccination coverage. According to de Savigny and Adam (2009), health systems have to be considered as complex adaptative systems, subject to continuous change and feedbacks. These systems are thus constantly adapting to internal or external actions or changes, showing a degree of self-organization beside or replacing its planned and expected functioning. Within the approach of systems thinking, several methods have been developed that allow taking into account both the complexity of a vaccination initiative and the whole system within which it operates (Shiell et al., 2008; Peters, 2014; Rüegg et al., 2018). Firstly developed in engineering and management realms (Senge, 1990; Adam and de Savigny, 2012; Peters et al., 2012), systems thinking and its tools/methods are increasingly employed to understand health issues and health systems behavior (de Savigny and Adam, 2009; Xie et al., 2017; Hitziger et al., 2021). From our analysis using the causal loop diagram, we were able to describe the stakeholders involved in rabies vaccination and how multiple categories of factors were interrelated.

4.1. Stakeholders involved in dog vaccination

Stakeholder identification revealed a complex social network in which community members, and several public and private sector stakeholders interact. The established relationships between the multiple stakeholders explain the whole dynamic and the outcomes of the system (Crozier and Friedberg, 1977; Ridde, 2011; Saadi et al., 2021a, 2021b, 2021c). Unfortunately, all previous reflections on the issue of collaboration for rabies control in Burkina Faso have focused on animal health and human health sectors (Coulibaly and Yameogo, 2000; Sondo et al., 2018; Zangré, 2018; Savadogo et al., 2020). The findings showed that beyond animal and human health actors, a successful dog rabies vaccination strategy requires the involvement of multiple direct and indirect stakeholders. By highlighting the diversity of stakeholders involved in dog vaccination, the study exhibited its complexity and the need to consider stakeholders from other involved sectors such as politics, education, environment management and sanitation, security and community, as pointed out for other zoonoses (Saadi et al., 2021a, 2021b, 2021c).

4.2. Socio-economic and cultural dynamics

Concerning the socio-economic and cultural dynamics, the study revealed the positive impact of social networks and social pressure, improving both dog husbandry practices and dog vaccination seeking in

the community. As described by the theories of diffusion of innovations (Balas and Chapman, 2018), of social learning (Parsel and Baranowski, 2013) and of planned behavior (Madden et al., 1992), social norms contribute to involve communities in issues related to their well-being. The use of transectorial approaches that promote community participation along the processes of preparation, implementation and evaluation of interventions can enhance health education and the dog vaccination compliance in owners (Charron, 2012; Buregyeya et al., 2021; Hitziger et al., 2021). However, that social pressure has to be guided by adequate education on rabies prevention measures (dog responsible ownership, vaccination, management of biting dogs and the roles of community members in rabies control). Indeed, if guided by misconceptions, the social pressure can play against vaccination programs. An example from the present case study is that owners vaccinating their dogs may be accused to show undue care for a dog, similarly to what has been reported by Saadi et al. (2021a, 2021b, 2021c) regarding the anthelmintic treatment of dogs against echinococcosis in Morocco. Therefore, in order to take advantage of community interpersonal networks to improve dog vaccination coverage, enhanced communication and education should focus on changing cultural, traditional and social conceptions regarding dog and dog ownership (Akakpo, 1985; Mindekem et al., 2005). As reported in previous studies (Castillo-Neyra et al., 2017; Oyo-Ita et al., 2021), effective community participation and behavioral change requires useful messages provided from trusted sources, like traditional leaders, opinions and religious leaders, or primary school teachers. In addition, networked and influential individuals can be selected in the communities to champion and promote good practices for responsible dog ownership and dog rabies vaccination. The findings showed that local dog husbandry practices characterized by free-roaming were unfavorable to dog vaccination. This is not suprising as no action has ever been taken to educate people on responsible dog ownership in Burkina Faso. In some Latin American countries where dog vaccination coverage has been significantly improved during the last decade, national vaccination strategies included dog social and responsible ownership education programs (Vigilato et al., 2013; González-Roldán et al., 2021). Moreover, the positive feedbacks of community awareness and engagement in the vaccination coverage in children were reported in Burkina Faso (Kagoné et al., 2018), indicating that similar approaches could be employed in the animal health sector to leverage success for zoonosis control (Buregyeya et al., 2021).

4.3. Technical and resources dynamics

Rabies control requires rigorous and integrated planning, with timelines, budgets and mostly accurate performance indicators as recommended by the SARE tool (Coetzer et al., 2016; Chen et al., 2021). Besides these technical requirements, the present analysis of technical and resources dynamics points to the central need for workforce motivation and commitment. If this motivation is present, their efforts to sensitize, collect and report data, and to assess impacts can help to demonstrate the socio-economic importance of rabies, the vaccination impact and to increase the political commitment (Lembo et al., 2010; Tenzin and Ward, 2012). Indeed, in many countries, rabies remains neglected and a low-priority disease due to a lack of evidence on its burden as well as on the control interventions' impact. The number of unreported bite and rabies cases is usually high in sub-Saharan Africa. In Burkina Faso where there is no active surveillance of rabies and, while an average of twenty five human cases is reported per year (Sondo et al., 2014; Burkina Faso, Ministère de la Santé, 2016), no data is available regarding the livestock losses caused by the disease. In addition, its impact in terms of costs (from vaccine purchase, travel to vaccination sites) and losses (children premature death, working time loss) is equally unknown. Therefore, in the absence of such information, such a disease may not be felt as an important public health threat for national policy – makers in comparison with other major animal and human diseases that are highly publicized, like acquired immuno deficiency syndrome (AIDS), highly pathogenic avian influenza (HPAI), Ebola hemorrhagic fever, malaria and the current COVID-19 (Cavaca et al., 2016). In the long run, this contributes to putting a strain on rabies control, reinforcing a kind of "vicious circle of indifference" as termed by Dodet and Africa Rabies Bureau (AfroREB) (2008). We argue that strengthening personnel and efficient use of existing resources can improve the control of rabies in the country. This implies an equitable distribution of veterinary and medical expertize and human resources between urban and rural areas, preventing work overload in areas with low staffing levels (Rwashana et al., 2014; Renmans, 2018). In the long run, work overload reduces the motivation and enthusiasm of the personnel, leading to a loss of initiative and the ability of proposing innovative solutions. In this context, the "lack of financial resources" in countries, regularly presented as the main cause of ineffectiveness of rabies control (Lembo et al., 2010), is highly debatable (Saadi et al., 2021a, 2021b, 2021c). Indeed, rabies is declared as a national priority disease, and while its control seems to be a concern for the technical services (e.g. animal health, public health, municipalities), no integrated control strategy or program has ever been developed in the country.

4.4. Political and organizational dynamics

On the political and organizational side, the lack of a national rabies control program was discussed by most of the stakeholders as the main weakness of dog vaccination governance in Burkina Faso. Human rabies is currently listed as one of the neglected tropical diseases for the national control program developed by the Ministry of Health (Burkina Faso, Ministère de la Santé, 2016). Unfortunately, animal rabies was not considered. Initiating a different national rabies control program for animals would not be cost-effective, creating additional financial support needs from the government and international partners. It would obviously miss the opportunity to take advantage of intersectorial synergies as promoted by the One Health approach (Darkaoui et al., 2017; Lechenne et al., 2017). The direct risk of separate initiatives is that they enter in competition for resources. In contrast, integrated programs allow the pooling of resources and knowledge, which is particularly needed in low-income countries (Narrod et al., 2012; Marcotty et al., 2013; Cleaveland et al., 2014). However, such an integrated initiative requires strong leadership, communication and governance to provide the expected outcomes (Stephen and Stemshorn, 2016; Lechenne et al., 2017; Vesterinen et al., 2019).

The present study describes the cycles by which the vaccination governance plays a central role in dog rabies vaccination and the potential way to leverage those dynamics. The way the key technical services are organized to handle vaccination-related activities (vaccine distribution, short campaign organization, communication) indeed influences the dog owners compliance with vaccination (Varghese et al., 2014; Hitziger et al., 2021; Ozawa et al., 2016). It also impacts the participation of private veterinarians and the interest from other partners, including civil society, NGOs and international institutions (Marks et al., 2010). In turn, the diversity of actors involved in rabies control requires a strong leadership capable of creating synergies among actors and preventing competition for resources (Stephen and Stemshorn, 2016; Emerson, 2017). Therefore, key actions would aim at empowering stakeholders to strengthen ownership of the programs, to ease data sharing and favor transparency and trust between national stakeholders and with their international partners. However, such efforts all remain dependent on the degree of genuine prioritization of rabies on the political agenda but also among the diverse missions of technical services. Besides the lack of data that is highlighted in the present causal loops, we postulate here that the lack of effective prioritization of rabies might depend on socio-professional stakes of involved actors, which would deserve further investigation enlighted by adapted frameworks from sociology of organizations (Crozier and Friedberg, 1977).

4.5. Significance and usefulness of the study

To our knowledge, this study is the first proposing a system view on the possibles causes of low dog vaccination coverage. In line with this objective, the study included a diverse panel of stakeholders, reflecting the complex nature of the intervention. Causal loop diagraming contributed to visualize the issue of dog rabies vaccination in a low-income setting, in a manner of facilitating its understanding by the involved stakeholders. Going beyond a first impression of overwhelming complexity, this conceptualization represents a first step to identify and promote actionable solutions. However, as a research work, the present descriptive approach does not directly offer such actionable recommendations. It provided a visualization of the dog rabies vaccination issue in different perspectives, helping a common understanding as well as the conception of transdisciplinary and actionable solutions. Indeed, these diagrams now need to be mobilized in participatory workshops to reflect with stakeholders on the entry points and leverages that can be mobilized to induce changes in the system. Indeed, the vicious cycles identified may all be turned into virtuous cycles, provided that simultaneous efforts on key leveraging variables are identified and implemented. Balancing cycles appear as points of attention or barriers to be lifted to achieve this turn of events towards a favorable trend. Rather than a desperating set of problems, these causal loop diagrams appear as a set of gearings to be actioned. As suggested here above, further studies will be needed at the various parts of the system to produce a fine-grained understanding of the mechanism at play. For example, the outcome of interrelated causal loops will crucially depend on the distinct time delays of each of these loops. Our interviews did not generate any data on such delays, which remain fully to explore and will influence the prioritization of actions.

Nevertheless, the results already point to main actions for an improvement of rabies control in Burkina Faso. Three areas of action can be pinpointed as first steps:

1. **Awareness raising** – This study pinpoints practical aspects to be included in a renewed communication strategy: the detrimental habit of killing the biting dogs, the need for responsible dog-owning (against free-roaming and in favor of caring owners), and the right of owners to request official vaccination certificates.
2. **Data gathering and advocacy** – The sound functioning of a rabies surveillance and vaccination program would provide for such data and political awareness. However, initial data and awareness has to be produced in order to initiate this virtuous cycle. Action-research may play a role in producing these policy-relevant data. In order to combine this need with the previous point of awareness-raising in the community, pilot studies could target community-based surveillance of rabies, using apps associated with key-messages, in a stimulating collective action providing relevant feedbacks to users and contributors.
3. **Governance improvement** – The multiplicity of stakeholders calls for a clear leadership to take advantage of synergies and counter competition effects. The challenge of rabies appears here common with other zoonoses. Therefore, an integrated rabies strategy for the planning and funding of activities should be taken in charge at the level of the recently instituted national One Health Platform.

4.6. Strenghs and limitations of the study

The strenghs of this study included the fact that interviews were conducted and transcribed by the researcher, reducing translation bias. The study also included a large panel of stakeholders, reflecting the complexity of dog rabies vaccination. In addition, the use of a causal loop based-research allows examining the barriers and facilitators affecting dog vaccination coverage, in the context of the broader rabies vaccination system. To our knowledge, this study is the first of its kind exploring the possible causes of low dog vaccination coverage in Burkina Faso with a focus on complexity. Using causal loop diagraming in this study contributed to capture the complexity involved in dog rabies vaccination in a low-income setting. There are, however, some weaknesses to this study. Indeed, interviews were conducted in only three administrative regions and the study did not include rural areas. Therefore, described factors associated with the vaccination coverage that we found may not be fully representative for the situation across all the locations of the country. In addition, the CLDs described in this study were not built through a participatory process, and therefore may not reflect all the field stakeholder categories' understanding of the dog vaccination challenges. Hence, the study reflects an interpretation of stakeholders' narratives by the research team, and then still needs to be confronted to stakeholder viewpoints and critiques.

5. Conclusion

The study provided a systemic view of social, economic, technical, political and organizational factors that affect the implementation of dog vaccination in Burkina Faso. The causal loop analysis facilitated the understanding and explanation of relationships between different factors and loops that influence the vaccination coverage in the dog population in Burkina Faso. Definitely, the study captures very well the complexity of One Health issues and rabies control in particular and puts in practice systems thinking in research. These findings constitute a starting point for further prioritization of the factors identified and the actions required to improve dog vaccination and rabies control.

Ethical considerations

Ethical approval was obtained from the Research Ethical Committee of Université Cheikh Anta Diop (Protocole-0322/2018/CER/UCAD). In addition, prior to each interview, participants were informed about the background and purpose of the study, highlighting that their participation was voluntary, and information would be kept anonymous. Therefore, only participants who verbally agreed were interviewed.

Funding information

This study received funding from the Academy of Research and Higher Education (ARES) of Belgium.

Declaration of Competing interest

The authors declare no competing interest.

Acknowledgements

The authors are grateful to the participants for their collaboration. They are also grateful to all animal health and human health services for the technical support provided during field investigations. The authors would like to thank sincerely Professor Claude Saegerman, Faculty of Veterinary Medicine, University of Liege, Belgium; Professor Bassirou Bonfoh, Centre Suisse de Recherches Scientifiques en Côte d'Ivoire; Doctor Bernadette Abela-Ridder, World Health Organization, Geneva, Switzerland; Professor Ayayi Justin Akakpo, Ecole Inter-Etats des Sciences et Médecine Vétérinaires de Dakar, Senegal; and Professor Jakob Zinsstag, Swiss Tropical and Public Health Institute, Basel, Switzerland for their scientific advice along the study. For data analysis and causal loop interpretation, we received huge support from Doctor Haitham Jamil Taha from The University of Queensland, Australia.

References

Adam, T., de Savigny, D., 2012. Systems thinking for strengthening health systems in LMICs: need for a paradigm shift. Health Policy Plan. 27 (suppl_4), Siv1–Siv3. https://doi.org/10.1093/heapol/czs084.

Akakpo, A.J., 1985. Le Chien dans la Société Noire Africaine: un réservoir de rage. In: Kuwert, E., Mérieux, C., Koprowski, H., Bögel, K. (Eds.), Rabies in the Tropics. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-70060-6_66.

Balas, E.A., Chapman, W.W., 2018. Road map for diffusion of innovations in health care. Health Aff. 37 (2) https://doi.org/10.1377/hlthaff.2017.1155.

Bowen, M.G., 1992. Feedback thought in social science and systems theory. George P. Richardson. University of Pennsylvania Press, Philadelphia, 1991. Syst. Dyn. Rev.. vol. 8(1), pp. 105–7. ⟨https://doi.org/10.1002/sdr.4260080114⟩.

Buregyeya, E., Atusingwize, E., Nsamba, P., Nalwadda, C., Osuret, J., Kalibala, P., Nuwamanya, R., Okech, S., Ssekamatte, T., Nitumusiima, S., Wakabi, T., Bikaako, W., Yawe, A., Naigaga, I., Kagarama, J., Kabasa, J.D., Bazeyo, W., 2021. Lessons from a community based interdisciplinary learning exposure: benefits for both students and communities in Uganda. BMC Med. Educ. 21 (5) https://doi.org/10.1186/s12909-020-02429-2.

Burkina Faso, Ministère de la Santé, 2016. Plan stratégique de lutte contre les maladies tropicales négligées 2016-2020.

Burkina Faso, 1989. KITI N°AN-VII-113-FP-AGRI-EL portant règlementation de la police zoosanitaire au Burkina Faso.

Castillo-Neyra, R., Brown, J., Borrini, K., Arevalo, C., Levy, M.Z., Buttenheim, A., Hunter, G.C., Becerra, V., Behrman, J., Paz-Soldan, V.A., 2017. Barriers to dog rabies vaccination during an urban rabies outbreak: qualitative findings from Arequipa, Peru. PLoS Negl. Trop. Dis. 11 (3), e0005460 https://doi.org/10.1371/journal.pntd.0005460.

Cavaca, A.G., Emerich, T.B., Vasconcellos-Silva, P.R., Santos-Neto, E.Td, Oliveira, A.E., 2016. Diseases neglected by the media in Espírito Santo, Brazil in 2011–2012. PLoS Negl. Trop. Dis. 10 (4), e0004662 https://doi.org/10.1371/journal.pntd.0004662.

Charron, D.F., 2012. Ecosystem approaches to health for a global sustainability agenda. EcoHealth 9, 256–266. https://doi.org/10.1007/s10393-012-0791-5.

Chen, Q., Ma, X., Rainey, J.J., Li, Y., Mu, D., Tao, X., Feng, Y., Yin, W., Li, Z., Ma, S., Petersen, B., 2021. Findings from the initial stepwise approach to rabies elimination (SARE) assessment in China, 2019. PLoS Negl. Trop. Dis. 15 (3), e0009274 https://doi.org/10.1371/journal.pntd.0009274.

Cleaveland, S., Kaare, M., Knobel, D., Laurenson, M.K., 2006. Canine vaccination providing broder benefits for disease control. Vet. Microbiol. 117, 43–50. https://doi.org/10.1016/j.vetmic.2006.04.009.

Cleaveland, S., Lankester, F., Townsend, S., Lembo, T., Hampson, K., 2014. Rabies control and elimination: a test case for one health. Vet. Rec. 175, 188–193. https://doi.org/10.1136/vr.g4996.

Coetzer, A., Kidane, A.H., Bekele, M., Hundera, A.D., Shiferaw, M.L., Wallace, R., Nel, L. H., 2016. The SARE tool for rabies control: current experience in Ethiopia. Antivir. Res. 135, 74–80. https://doi.org/10.1016/j.antiviral.2016.09.011.

Coleman, P.G., Dye, C., 1996. Immunization coverage required to prevent outbreaks of dog rabies. Vaccine 14 (3), 185–186. ⟨http://www.ncbi.nlm.nih.gov/pubmed/8920697⟩.

Coulibaly, N.D., Yameogo, K.R., 2000. Prevalence and control of zoonotic diseases: collaboration between public health workers and veterinarians in Burkina Faso. Acta Trop. 76, 53–57. https://doi.org/10.1016/S0001-706X(00)00090-5.

Crozier, M., Friedberg, E., 1977. L'acteur et le système, Les contraintes de l'action collective. Editions du Seuil (Ed.), ISBN 978-2-7578-4115-0.

Dahourou, L.D., Savadogo, M., Kaboré, B.A., Konaté, A., Zerbo, M., Guigma, H.V., Ouoba, L.B., Ouandaogo, S.H., Zerbo, L.H., Traoré, A., 2021. Dog ownership, demographics, owners' knowledge of rabies, and factors associated with canine rabies vaccination in urban and rural areas of Dedougou, Burkina Faso. Vet. Anim. Sci. 14, 100205 https://doi.org/10.1016/j.vas.2021.100205.

Darkaoui, S., Cliquet, F., Wasniewski, M., Robardet, E., Aboulfidaa, N., Bouslikhane, M., Fassi-Fihri, O., 2017. A century spent combating rabies in Morocco (1911–2015): how much longer? Front. Vet. Sci. 4, 78. https://doi.org/10.3389/fvets.2017.00078.

de Savigny, D., Adam, T., 2009. Systems Thinking for Health Systems Strengthening. Alliance for Health Policy and Systems Research, World Health Organization,, Geneva.

Dodet, B., Africa Rabies Bureau (AfroREB), 2008. The fight against rabies in Africa: from recognition to action. Vaccine 27, 5027–5032. https://doi.org/10.1016/j.vaccine.2009.06.030.

Emerson, K., 2017. Collaborative governance of public health in low- and middle-income countries: lessons from research in public administration. BMJ Glob. Health 3 (suppl. 4). https://doi.org/10.1136/bmjgh-2017-000381.

Fusch, P.I., Ness, L.R., 2015. Are we there yet ? Data saturation in qualitative research. Qual. Rep. 20, 1408–1416.

GARC (Global Alliance for Rabies Control), 2016. The Global Framework to eliminate rabies deaths by 2030. ⟨https://rabiesalliance.org/news/global-framework-eliminate-rabies-deaths-2030⟩. Retrieved on May 18th, 2021.

Glaser, B., Strauss, A., 1967. The Discovery of Grounded theory: Strategies for Qualitative Research. Aldine Publishing Company, New York.

González-Roldán, J.F., Undurraga, E.A., Meltzer, M.I., Atkins, C., Vargas-Pino, F., Gutiérrez-Cedillo, V., Hernandez-Perea, J.R., 2021. Cost-effectiveness of the national dog rabies prevention and control program in Mexico, 1990–2015. PLoS Negl. Trop. Dis. 15 (3), e0009130 https://doi.org/10.1371/journal.pntd.0009130.

Guest, G., Bunce, A., Johnson, L., 2006. How many interviews are enough?: an experiment with data saturation and variability. Field Methods 18 (1), 59–82. https://doi.org/10.1177/1525822X05279903.

Halcomb, E.J., Davidson, P.M., 2006. Is verbatim transcription of interview data always necessary? Appl. Nurs. Res. ANR 19 (1), 38–42. https://doi.org/10.1016/j.apnr.2005.06.001.

Hampson, K., Coudeville, L., Lembo, T., Sambo, M., Kieffer, A., Attlan, M., Barrat, J., Blanton, J.D., Briggs, D.J., Cleaveland, S., Costa, P., Freuling, C.M., Hiby, E., Knopf, L., Leanes, F., Meslin, F.-X., Metlin, A., Miranda, M.E., Müller, T., Nel, L.H., Recuenco, S., Rupprecht, C.E., Schumacher, C., Taylor, L., Vigilato, M.A.N., Zinsstag, J., Dushoff, J., 2015. Estimating the global burden of endemic canine rabies. PLoS Negl. Trop. Dis. 9 (4), e0003709 https://doi.org/10.1371/journal.pntd.0003709.

Hitziger, M., Berezowski, J., Dürr, S., Falzon, L.C., Léchenne, M., Lushasi, K., Markosyan, T., Mbilo, C., Momanyi, K.N., Özçelik, R., Prejit, N., Zinsstag, J., Rüegg, S.R., 2021. System thinking and citizen participation is still missing in one health initiatives – lessons from fifteen evaluations. Front. Public Health 9, 653398 https://dx.doi.org/10.3389%2Ffpubh.2021.653398.

Jibat, T., Hogeveen, H., Mourits, M.C.M., 2015. Review on dog rabies vaccination coverage in Africa: a question of dog accessibility or cost recovery? PLoS Negl. Trop. Dis. 9 (2), e0003447 https://doi.org/10.1371/journ al.pntd.0003447.

Kagoné, M., Yé, M., Nébié, E., Sié, A., Müller, O., Beiersmann, C., 2018. Community perception regarding childhood vaccinations and its implications for effectiveness: a qualitative study in rural Burkina Faso. BMC Public Health 18, 324. https://doi.org/10.1186/s12889-018-5244-9.

Kouldiati, J., 1989. Contribution à l'étude de la rage canine au Burkina Faso: épidémiologie et prophylaxie (Thèse Médecine Vétérinaire). EISMV, Dakar, Senegal, p. 121.

Lechenne, M., Mindekem, R., Madjadinan, S., Oussiguéré, A., Moto, D.D., Naissengar, K., Zinsstag, J., 2017. The importance of a participatory and integrated one health approach for rabied control: the case of N'Djaména, Chad. Trop. Med. Infect. Dis. 2 (3), 43. https://doi.org/10.3390/tropicalmed2030043.

Lembo, T., Hampson, K., Kaare, M.T., Ernest, E., Knobel, D., Kazwala, R.R., et al., 2010. The feasibility of canine rabies elimination in Africa: dispelling doubts with data. PLoS Negl. Trop. Dis. 4 (2), e626 https://doi.org/10.1371/journal.pntd.0000626.

Madden, T.J., Ellen, P.S., Ajzen, I.A., 1992. Comparison of the theory of planned behavior and the theory of reasoned action. Personal. Soc. Psychol. Bull. 18 (1), 3–9. https://doi.org/10.1177/0146167292181001.

Marcotty, T., Thys, E., Conrad, P., Godfroid, J., Craige, P., Zinsstag, J., Meheus, F., Boukary, A.R., Badé, M.A., Sahibi, H., Filali, H., Hendrickx, S., Pissang, C., Herp, M. V., van der Roost, D., Thys, S., Hendrickx, D., Claes, M., Demeulenaere, T., Dehoux, J.-P., Boelaert, M., 2013. Intersectoral collaboration between the medical and veterinary professions in low-resource societies: The role of research and training institutions. Comp. Immunol. Microbiol. Infect. Dis. 36, 233–239. https://doi.org/10.1016/j.cimid.2012.10.009.

Marks, L., Cave, S., Hunter, D.J., 2010. Governance in public health: the views of stakeholders. Public Health 14 (1), 55–59. https://doi.org/10.1016/j.puhe.2009.11.006.

Mindekem, R., Kayali, U., Yemadji, N., Ndoutamia, A.G., Zinsstag, J., 2005. La démographie canine et son importance pour la transmission de la rage humaine à Ndjamena. Med. Trop. 65 (1), 53–58.

Minghui, R., Stone, M., Semedo, M.H., Nel, L., 2018. New global strategic plan to eliminate dog-mediated rabies by 2030. Lancet Glob. Health 6, e828–e829. https://doi.org/10.1016/S2214-109X(18)30302-4.

Minoungou, G., Dahourou, L.D., Savadogo, M., Tialla, D., Comabari, A.H.B., Kanyala, E., Ouattara, L., Kabore, S.A., Ouedraogo, V., Taboure, Y., Kere, I., 2021. Surveillance of animal rabies in Burkina Faso: a retrospective laboratory data from 2008 to 2012. Int. J. Vet. Sci. 10 (3), 172–176. https://doi.org/10.47278/journal.ijvs/2021.051.

Nana, S.D., 2019. Analyse du dispositif institutionnel sanitaire de lutte contre la rage à Ouagadougou, Burkina Faso (Thèse Médecine Vétérinaire). EISMV, Dakar, Sénégal.

Narrod, C., Zinsstag, J., Tiongco, M., 2012. A one health framework for estimating the economic costs of zoonotic diseases on society. EcoHealth 9, 150–162. https://doi.org/10.1007/s10393-012-0747-9.

Nitcheman, S., 1983. Contribution à l'étude des zoonoses infectieuses majeures en république de Haute-Volta (Thèse Médecine Vétérinaire). EISMV, Dakar, Sénégal, p. 170.

Olivier de Sardan, J.-P., 2004. La rigueur du qualitatif. L'anthropologie comme science empirique. Espace Temps 84–86, 38–50.

Ouermi, A.S., Dravé, A., Sawadogo, N., Barro, M., Sanogo, B., Savadogo, H., 2018. Rabies in children: diagnostic difficulties in an epileptic adolescent at the Regional University Hospital of Ouahigouya, Burkina Faso. Health Sci. Dis. 19 (2), 141–144 (Available online: ⟨http://www.hsd-fmsb.org/index.php/hsd/article/view/1036⟩ (Retrieved on 15-04-2021)).

Oyo-Ita, A., Bosch-Capblanch, X., Ross, A., Oku, A., Esu, E., Ameh, S., et al., 2021. Effects of engaging communities in decision-making and action through traditional and religious leaders on vaccination coverage in Cross River State, Nigeria: a cluster-randomised control trial. PLoS One. https://doi.org/10.1371/journal.pone.0248236.

Ozawa, S., Paina, L., Qiu, M., 2016. Exploring pathways for building trust in vaccination and strengthening health system resilience. BMC Health Serv. Res. 16, 639. https://doi.org/10.1186/s12913-016-1867-7.

Parsel, G.S., Baranowski, T., 2013. Social learning and health education. Health Educ. 12 (3) https://doi.org/10.1080/00970050.1981.10618149.

Peters, D.H., Paina, L., Bennett, S., 2012. Expecting the unexpected: applying the Develop-Distort Dilemma to maximize positive market impacts in health. Health Policy Plan. 27 (Suppl. 4), Siv44–Siv53. https://doi.org/10.1093/heapol/czs085.

Peters, D.H., 2014. The application of systems thinking in health: why use systems thinking? Health Res. Policy Syst. 12, 51. https://doi.org/10.1186/1478-4505-12-51.

Renmans, D., 2018. Opening the 'Black Box' of Performance-based Financing in the Healthcare Sector of Western Uganda (Ph.D. thesis). University of Antwerp, Antwerp, Belgium.

Ridde, V., 2011. Politiques publiques de santé, logiques d'acteurs et ordre négocié au Burkina Faso. Cah. d'études Afr. 2011. https://doi.org/10.4000/etudesafricaines.16603.

Rüegg, S.R., Nielsen, L.R., Buttigieg, S.C., Santa, M., Aragrande, M., Canali, M., Ehlinger, T., Chantziaras, I., Boriani, E., Radeski, M., Bruce, M., Queenan, K., Häsler, B., 2018. A systems approach to evaluate one health initiatives. Front. Vet. Sci. 5, 23. https://doi.org/10.3389/fvets.2018.00023.

Rwashana, A.S., Nakubulwa, S., Nakakeeto-Kijjambu, M., et al., 2014. Advancing the application of systems thinking in health: understanding the dynamics of neonatal mortality in Uganda. Health Res. Policy Syst. 12, 36. https://doi.org/10.1186/1478-4505-12-36.

Saadi, A., Antoine-Moussiaux, N., Marcotty, T., Thys, S., Sahibi, H., 2021a. Using qualitative approaches to explore the challenges of integrated programmes for zoonosis control in developing countries: example of hydatidosis control in Morocco. Zoonoses Public Health 68 (5), 393–401. https://doi.org/10.1111/zph.12814.

Saadi, A., Antoine-Moussiaux, N., Sahibi, H., Filali, H., Marcotty, T., Thys, S., 2021b. Feasibility and acceptability of a new integrated approach to control cystic echinococcosis in Morocco: vaccination of sheep and anthelmintic treatment of dogs. Prev. Vet. Med. 192, 105373 https://doi.org/10.1016/j.prevetmed.2021.105373.

Saadi, A., Sahibi, H., Thys, S., Marcotty, T., Filali, H., Amarir, F., Rhalem, A., Kirschvink, N., Antoine-Moussiaux, N., 2021c. Stakeholder analysis to improve the national control program of cystic echinococcosis in Morocco. Vet. Prev. Med. 186, 105227 https://doi.org/10.1016/j.prevetmed.2020.105227.

Savadogo, M., Koné, P., Dahourou, L.D., Manishimwe, R., Sow, A., Nébié, L., Antoine-Moussiaux, N., Bada- Alambedji, R., 2020. Rabies epidemiology and community knowledge, attitudes and practices in Burkina Faso. Rev. Elev. Med. Vet. Pays Trop. 73 (2), 133–144. https://doi.org/10.19182/remvt.31863.

Savadogo, M., Soré, A., Dahourou, L.D., Ossebi, W., Combari, A.H.B., Bada Alambedji, R., Tarnagda, Z., 2021a. Assessing factors associated with owner's individual decision to vaccinate their dogs against rabies: a house-to-house survey in Ouagadougou, Burkina Faso. Vet. World 14 (4), 1014–1019. https://doi.org/10.14202/vetworld.2021.1014-1019.

Savadogo, M., Tialla, D., Ouattara, B., Dahourou, L.D., Ossebi, W., Ilboudo, S.G., Combari, A.H.B., Tarnagda, Z., Bada-Alambedji, R., 2021b. Factors associated with owned-dogs' vaccination against rabies: a household survey in Bobo Dioulasso, Burkina Faso. Vet. Med. Sci. 21, 1–11. https://doi.org/10.1002/vms3.468.

Senge, P.M., 1990. The Fifth Discipline: The Art and Practice of the Learning Organization. Currency/Doubleday, New York.

Shiell, A., Hawe, P., Gold, L., 2008. Complex interventions or complex systems? Implications for health economic evaluation. BMJ 336, 1281–1283. https://doi.org/10.1136/2Fbmj.39569.510521.AD.

Sondo, K.A., Diallo, I., Savadogo, M., Kaboré, B.E., Ouédraogo, G.A., Zoungrana, J., Diendéré, E.A., Da, L., Bazié, K., Kyelem, N., Basshono, J., Bidima, P., Ouédraogo/Traoré, R., Ouédraogo, M., Ouedraogo, S.M., Drabo, J.Y., 2018. Enquête transversale sur les cas de rage reçus de 2003 à 2014 au Service des Maladies Infectieuses du Centre Hospitalier Universitaire Yalgado Ouédraogo (Burkina Faso). Sci. Tech. Sci. St. 41 (1), 41–51.

Sondo, K.A., Okenga, Y.C., Diop, S.A., Kaboré, B.E., Diallo, I., Kyelem, N., Basshono, J., Thombiano, R., Kam, L., 2015. Rabies in children: report of 24 cases at the Yalgado Ouedraogo University Hospital Center of Ouagadougou in Burkina Faso. J. Trop. Dis. 3 (3), 168. https://doi.org/10.4172/2329-891X.1000168.

Sondo, K.A., Zoungrana, J., Bazié, K., Kyelem, C.G., Diallo, I., Korsaga, N., Basshono, J., Simporé, L., Thiombiano, R., Traoré, A., 2014. Prise en charge post exposition des victimes d'agression par un animal à Ouagadougou. Science et technique, Sciences de la santé 37 (1-2), 27–36. https://www.ajol.info/index.php/stss/article/view/141168.

Stephen, C., Stemshorn, B., 2016. Leadership, governance and partnerships are essential one health competencies. One Health 2, 161–163. https://doi.org/10.1016/j.onehlt.2016.10.002.

Sterman, J.D., 2002. System Dynamics: Systems Thinking and Modeling for A Complex World. Irwin/McGraw-Hill, Boston. ⟨http://hdl.handle.net/1721.1/102741⟩.

Taha, H.J., 2020. Using Systems Thinking to Understand the Drivers of Brucellosis in Jordan (Ph.D. Thesis). The University of Queensland, Australia, 214p.

Tenzin, Ward M.P. 2012. Review of rabies epidemiology and control in south, south east and east Asia: past, present and prospects for elimination. Zoonoses Public Health. vol. 59, pp. 451–7. ⟨https://doi.org/10.1111/j.1863-2378.2012.01489.x⟩.

Varghese, J., Kutty, V.R., Paina, L., et al., 2014. Advancing the application of systems thinking in health: understanding the growing complexity governing immunization services in Kerala, India. Health Res. Policy Syst. 12, 47. https://doi.org/10.1186/1478-4505-12-47.

Vesterinen, H.M., Dutcher, T.V., Errecaborde, K.M., Mahero, M.W., Macy, K.W., Prasarnphanich, O.-O., Kassenborg, H., Yulizar, F., Fauzi, R.P., Budayanti, N.S., Suwandono, A., Artama, W.T., Valeri, L., Pelican, K.M., 2019. Strengthening multi-sectoral collaboration on critical health issues: one health systems mapping and analysis resource toolkit (OH-SMART) for operationalizing one health. PLoS One 14 (7), e0219197. https://doi.org/10.1371/journal.pone.0219197.

Vigilato, M.A.N., Clavijo, A., Knobel, T., Silva, H.M.T., Cosivi, O., Schneider, M.C., et al., 2013. Progress towards eliminating canine rabies: policies and perspectives from Latin America and the Caribbean. Philos. Trans. R. Soc. Lond. B Biol. Sci. 368 (1623), 20120143 https://doi.org/10.1098/rstb.2012.0143 (pmid:23798691).

World Health Organization, Food and Agriculture Organization of the United Nations & World Organisation for Animal Health, ⁋2016⁋. Global elimination of dog-mediated human rabies: report of the rabies global conference, 10–11 December 2015, Geneva, Switzerland. World Health Organization. ⟨https://apps.who.int/iris/handle/10665/204621⟩.

Xie, T., Liu, W., Anderson, B.D., Liu, X., Gray, G.C., 2017. A system dynamics approach to understanding the one health concept. PLoS One 12 (9), e0184430. https://doi.org/10.1371/journal.pone.0184430.

Zangré, H., 2018. Enquête sur l'approche "Une Seule Santé" et son application dans les stratégies de lutte contre la rage au Burkina Faso (Thèse Médecine Vétérinaire). EISMV, Dakar, Senegal, p. 91.

Zinsstag, J., Lechenne, M., Laager, M., Mindekem, R., Naïssengar, S., Oussiguéré, A., Bidjeh, K., Rives, G., Tessier, J., Madjaninan, S., Ouagal, M., Moto, D.D., Alfaroukh, I.O., Muthiani, Y., Traoré, A., Hattendorf, J., Lepelletier, A., Kergoat, L., Bourhy, H., Dacheux, L., Stadler, T., Chitnis, N., 2017. Vaccination of dogs in an African city interrupts rabies transmission and reduces human exposure. Sci. Transl. Med. Am. Assoc. Adv. Sci. 9 (421), eaaf6984. https://doi.org/10.1126/scitranslmed.aaf6984 (2017).