

Creating a framework towards integrated health syndromic surveillance and response in Africa

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À LA MÉMOIRE DE MON COUSIN

ABDOULAYE ABDOURAHMAN, QUI A QUITTÉ PRÉCIPITAMMENT

THIS WORK IS DEDICATED TO MY LATE COUSIN

ABDOULAYE ABDOURAHMAN, WHO LEFT BEFORE TIME!

إلى روح ابن عمي عبدالله عبدالرحمن

الذي رحل قبل الأوان

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TABLE OF ACRONYMS

AHRSP	Alliance for Health Policy and Systems Research
BIA	Budget Impact Analysis
BLV	Swiss Federal Veterinary Office
CBSyS-OH	Community Based Syndromic Surveillance One Health
CHW	Community Health Worker
CONFOFOR	Commission Nationale de Formation de Formateurs
CRASH	Centre de Recherche en Anthropologie et Sciences Humaines
CSSI	Centre de Support en Santé Internationale
CZ	Concentration Zone
FHNW	Fachhochschule Nordwestschweiz Hochschule für Wirtschaft
FoFe	Folic Acid
HAHU	Human and Animal Health Unit
IEC	Information, Education and Communication
INSEED	Institut National des Statistiques et d'Etudes Economiques et Démographiques
IRED	Institut de Recherche en Élevage pour le Développement
MERA	Ministère de l'Élevage et de Ressources Animales
MOH	Ministry of Health
NGO	Non-Governmental Organization
OIE	World Organization for Animal Health
OR	Odds Ratio
PADS	Programme d'Appui aux Districts Sanitaires au Tchad, Yao et Danamadji
PNSN	Programme National de Santé de Nomades
PPR	Pest de Petits Ruminants
R_0	Basic Reproductive ratio
REPIMAT	Réseau d'Epidémiologie-surveillance des Maladies Animales au Tchad
SAGE	Strategic Advisory Group of Experts on Immunization
SCITT	Single Comparative Intradermal Tuberculin Test
SDC	Swiss Agency for Development and Cooperation
SDGs	Sustainable Development Goals
Swiss TPH	Swiss Tropical and Public Health Institute
SWOT	Strengths Weaknesses Opportunities Threats
TD	Transdisciplinarity
UNICEF	United Nations International Children's Emergency Fund
USD	US Dollar
WHO	World Health Organization

I. ACKNOWLEDGEMENT

And... here I am!

Finally, my PhD comes to an end!

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II. SUMMARY

Background:

A substantial part of the population in sub-Saharan Africa live in rural areas characterized by insufficiently equipped health centres and shortages of qualified health workers. These people usually depend on agriculture and livestock but have limited access to social services including health. In Chad, over 78% of the total population lives in rural areas and 3.5% are mobile pastoralists. Previous research has shown that agro-pastoralists suffer from a broad range of diseases of mostly unconfirmed biomedical aetiology. We propose a synergistic approach of integrated “One Health” surveillance-response combining epidemiology, anthropology and advanced biomedical diagnostic with essential complementary elements to anticipate outbreaks of endemic and emerging diseases from perceived illnesses (syndromes). Community-based syndromic surveillance, coupled with mobile technology adapted to the rural agro-pastoralists context, could offer an alternative to existing surveillance systems for humans and animals. Linking such a system with the etiologic confirmation of suspected cases from freshly collected samples would increase the potential of anticipating diseases outbreaks and leads to evidence-based and locally adapted interventions. Such participatory approach to surveillance and intervention could be further used for public and veterinary health service improvement along with zoonosis integration into existing digital and open source health information system application (DHIS2) aiming at their elimination.

Aim and objectives:

The aim of the thesis was to establish the basis of a culturally adapted and integrated community based human and animal health syndromic surveillance and response system among agro-pastoralists in Chad. We addressed intervention effectiveness, joint human and animal health interventions, zoonosis elimination and basic requirements for syndromic surveillance in remote rural communities using modern information and communication technology. The objectives of the thesis were to:

1. Contribute to health interventions effectiveness evaluation methods;
2. Evaluate One Health approaches (e.g. joint human and animal vaccination) among mobile communities and their potential for integration into the public health system;
3. Establish a basic knowledge on syndromic surveillance and response in order to implement a feasibility study of an integrated human and animal health surveillance and response system; and
4. Estimate the potential of zoonosis elimination in developing countries (the case of bovine tuberculosis in Morocco).

Approach:

Effectiveness of health interventions:

Equity effectiveness of maternal health service coverage in rural Chad:

Inequalities and large disparities in the burden of maternal morbidity and mortality still persist within and between different population groups mainly in low income countries. Policies need to be informed by equity sensitive evidence assessing differences in health needs and particularly in the effectiveness of interventions and models of care. The aim of this paper was to assess the community effectiveness of maternal health service coverage for sedentary and mobile populations in two rural districts in Chad. The approach allowed for quantifying the health system’s determinants of effectiveness. Our results provided a baseline to monitor the progress of a health system intervention in these districts focusing on maternal and infant health. Interventions should generally focus in priority on improving community effectiveness through targeting the factors with the highest leverage among specific populations in order to foster effective and equitable health services.

Vaccine hesitancy among mobile communities in Chad:

Demand side barriers for vaccination among rural and mobile populations in Chad are not yet well understood. We hypothesized that these mobile pastoralists' communities face specific demand side barriers to access vaccination services. Understanding the factors that caregivers in these communities could take into account, explicitly or implicitly, in order to decide (or not) to vaccinate a child is an essential element to tailor vaccination programmes towards increasing vaccination acceptance and uptake. Our results showed that mobile pastoralist communities face specific demand side barriers to vaccination. Understanding these barriers is essential to reduce vaccine hesitancy and increase vaccination uptake. Local health systems must plan for periodic presence of pastoralist communities in their zones of responsibility and create more mutual trust.

One Health methods and approaches:

Feasibility and sustainability of joint human and animal vaccination:

Joint human and animal vaccination programmes (JHAVP) such as "One Health" approaches have demonstrated to be feasible; to increase health care access to hard-to-reach communities; and to save resources through sharing transport, equipment and logistics in Chad. The main objective of the study was to give an insight to the feasibility and the sustainability of JHAVP integrated as part of the public health system in Chad. Our results showed that even though its integration as a routine activity at the district level depends on the mobilization of additional financial resources, the district could benefit from JHAVP to maintain a contact network with the nomads in order to promote the use of available immunization services at district level in the long term.

Trends in health surveillance and service delivery for pastoralists in West and Central Africa:

In most sub-Saharan African countries, pastoralism represents an important economic resource and contributes significantly to national growth; however, challenges remain, particularly in providing social services to pastoralists (especially health and education) and in avoiding conflict with local sedentary communities and local authorities. All of this takes place while pastoralists try to maintain their mobile lifestyle within a rapidly changing ecosystem. Although considerable efforts have been made towards integrating mobile pastoralists into social services, obstacles remain to the adoption of a clear, specific and sustainable policy on pastoralism in sub-Saharan Africa.

Transmission dynamics and elimination potential of zoonotic tuberculosis in Morocco:

A simple compartmental deterministic mathematical model for BTB transmission in cattle and humans have been established to provide a general understanding of BTB, in particular regarding transmission to humans. Differential equations were used to model the different pathways between the compartments for cattle and humans. Scenarios of test and slaughter were simulated to determine the effects of varying the proportion of tested animals (p) on the time to elimination of BTB (individual animal prevalence of less than one in a thousand) in cattle and humans and the economic cost due to elimination.

III. RESUME

Contexte :

Une partie importante de la population de l'Afrique subsaharienne vit dans des zones rurales caractérisées par des centres de santé insuffisamment équipés et des pénuries de personnel de santé qualifiés. Ces personnes dépendent généralement de l'agriculture et de l'élevage, mais ont un accès limité aux services sociaux, y compris la santé. Au Tchad, plus de 78% de la population totale vit dans des zones rurales et 3,5% sont des pasteurs nomades. Des recherches antérieures ont montré que les agro-pasteurs souffrent d'un large éventail de maladies dont l'étiologie biomédicale est pour la plupart non confirmée. Nous proposons une approche synergique de la surveillance-réponse intégrée «One Health» combinant l'épidémiologie, l'anthropologie et le diagnostic biomédical avancé avec des éléments complémentaires essentiels pour anticiper les foyers de maladies endémiques et émergentes en se basant sur les syndromes. La surveillance syndromique à base communautaire, couplée à une technologie mobile adaptée au contexte des agro-pasteurs ruraux, pourrait offrir une alternative aux systèmes de surveillance existants pour la santé publique et la santé animale. Lier un tel système à la confirmation étiologique des cas suspects à partir d'échantillons fraîchement collectés augmenterait le potentiel d'anticiper des foyers des maladies et conduirait à des interventions basées sur des preuves et localement adaptées. Une telle approche participative de la surveillance et de l'intervention pourrait être davantage utilisée pour l'amélioration des services de santé publique et vétérinaire ainsi que l'intégration des zoonoses dans l'application du système d'information sanitaire numérique existante (DHIS2) visant leur élimination.

But et objectifs :

Le but de la thèse était d'établir les bases d'un système de surveillance syndromique et de réponse intégré de santé humaine et animale à base communautaire adapté au contexte des agropasteurs au Tchad. Nous avons abordé l'efficacité des interventions, des interventions conjointes en santé publique et animale, des exigences fondamentales pour la surveillance syndromique dans les communautés rurales éloignées en utilisant les technologies modernes de l'information et de la communication et le potentiel de l'élimination des zoonoses. Les objectifs de la thèse étaient les suivants :

1. Contribuer aux méthodes d'évaluation de l'efficacité des interventions sanitaires
2. Évaluer les approches 'One Health' (la vaccination conjointe humaine-animale) parmi les communautés nomades et leur potentiel d'intégration dans le système de santé publique
3. Établir les connaissances de base sur la surveillance syndromique et réponse afin d'établir une étude de faisabilité d'un système de surveillance et d'intervention intégré (santé publique-animale)
4. Estimer le potentiel d'élimination des zoonoses dans les pays en développement (cas de la tuberculose bovine au Maroc)

Approche :**L'efficacité des interventions sanitaires**

Efficacité de la couverture de services de santé maternelle dans les zones rurales du Tchad : Les inégalités et les grandes disparités dans la charge de la morbidité et de la mortalité maternelles persistent encore au sein et entre les différents groupes de population, principalement dans les pays à faible revenu. Les politiques doivent s'appuyer sur des données sensibles à l'équité évaluant les différences dans les besoins de santé et en particulier dans l'efficacité des interventions et des modèles de soins. Le but de cet article était d'évaluer l'efficacité communautaire de la couverture des services de santé maternelle pour les populations sédentaires et nomades dans deux districts ruraux au Tchad.

L'approche a permis de quantifier les déterminants de l'efficacité du système de santé. Nos résultats ont fournis une base de référence pour suivre l'évolution d'une intervention dans le système de santé dans ces districts axée sur la santé maternelle et infantile. Les interventions devraient se concentrer en priorité sur l'amélioration de l'efficacité communautaire en ciblant les facteurs les plus influents parmi des populations spécifiques afin de favoriser des services de santé efficaces et équitables.

L'hésitation aux vaccins parmi les communautés nomades au Tchad : Les barrières de la demande pour la vaccination parmi les populations rurales et nomades au Tchad ne sont pas encore bien comprises. Nous avons émis l'hypothèse que les communautés pastorales nomades au Tchad font face à des obstacles spécifiques à la demande pour accéder aux services de vaccination. Comprendre les facteurs que les communautés pourraient prendre en compte, explicitement ou implicitement, afin de décider (ou non) de vacciner un enfant est un élément essentiel pour adapter les programmes de vaccination en vue d'augmenter l'acceptation et l'adoption de la vaccination. Nos résultats ont montré que les communautés pastorales nomades sont confrontées à des obstacles spécifiques à la demande en matière de vaccination. La compréhension de ces obstacles est essentielle pour réduire l'hésitation envers les vaccins et accroître l'acceptation de la vaccination. Les systèmes de santé locaux doivent être des systèmes flexibles et adaptatifs qui répondent aux besoins des différentes communautés avec des interventions fondées sur des données probantes.

Méthodes et approches d'une seule santé « One health »

Faisabilité et durabilité de la vaccination conjointe humaine et animale : Au Tchad, les approches 'One Health' tels que les programmes de vaccination conjointe humaine et animale (JHAVP) ont démontré être faisables; accroître l'accès aux soins de santé aux populations difficiles d'accès et économiser des ressources en partageant le transport, l'équipement et la logistique. L'objectif principal de l'étude était de donner un aperçu de la faisabilité et de la durabilité du JHAVP intégré dans le cadre du système de santé publique au Tchad. Nos résultats ont montré que même si son intégration en tant qu'activité de routine au niveau du district dépend de la mobilisation de ressources financières supplémentaires, le district pourrait bénéficier du JHAVP pour maintenir un réseau de contact avec les nomades afin de promouvoir l'utilisation des services de vaccination disponibles au niveau du district à long terme.

Tendances de la surveillance sanitaire et de la prestation de services intégrés dans le cadre du pastoralisme en Afrique de l'Ouest et centrale : Bien que le pastoralisme constitue une ressource économique majeure dans la plupart des pays d'Afrique subsaharienne et qu'il contribue significativement à la croissance des économies nationales, il se heurte encore à de nombreuses difficultés liées notamment à l'accès aux services sociaux, en particulier dans les domaines de la santé et de l'éducation, et à la prévention des conflits avec les communautés sédentaires et les autorités locales. Ce constat intervient à un moment où les pasteurs eux-mêmes essaient de préserver leur mode de vie nomade au sein d'un écosystème soumis à de rapides transformations. Bien que des efforts considérables aient été déployés pour faire bénéficier les pasteurs nomades des services sociaux, nombre d'obstacles s'opposent encore à la mise en place d'une politique claire, spécifique et durable en faveur du pastoralisme en Afrique subsaharienne.

Les dynamiques de transmission et les possibilités d'élimination de la tuberculose zoonotique au Maroc : Un modèle mathématique, comportemental et déterministe de la transmission de la tuberculose bovine chez les bovins et l'Homme a été réalisé afin de fournir une compréhension générale de la tuberculose bovine, surtout en ce qui concerne la transmission de la zoonose à l'Homme. Des équations différentielles ont été utilisées afin de modéliser les différents flux entre les compartiments des bovins et des humains. Les scénarios de potentielles interventions de test et abattage ont été simulés afin de déterminer les effets de la variation des proportions d'animaux testés (p) par rapport au temps d'élimination de la tuberculose bovine (prévalence individuelle inférieure à 1 par mille) chez les bovins et l'Homme et le coût économique dû à l'élimination.

IV. ملخص

المضمون:

يعيش جزء هام من سكان منطقة إفريقيا جنوب الصحراء في المناطق الريفية التي تتميز بقلّة المراكز الصحية المجهزة ونقص حاد في عمال الصحة ذوو الكفاءات العالية. يعتمد هؤلاء السكان في الغالب على الزراعة والرعي ولا يحصلون إلا على البسيط من الخدمات الاجتماعية بما فيها الصحة والتعليم. أكثر من 78% من تعداد السكان الإجمالي لدولة تشاد يعيشون في المناطق الريفية و 3,5% من السكان هم من الرعاة الرحل. الدراسات السابقة اشارت الي ان المزارعين والرعاة يعانون من أمراض عديدة معظمها لم يتم تشخيصه. اننا نقترح في هذه الاطروحة رؤية متكاملة لنظام مراقبة الامراض لدى الانسان والحيوان يتكامل فيها علم الأوبئة مع علم الانيروبولوجيا مع التشخيص البيولوجي المتقدم انطلاقا من الأعراض من اجل الرصد المبكر واستباق ظهور الامراض المستوطنة والوبائية. إن مراقبة الامراض بمشاركة الأهالي واستخدام التكنولوجيا الملائمة لبيئتهم يمكن ان يشكل بديلا أفضل لأنظمة المراقبة الصحية الحالية في الصحة العامة والصحة الحيوانية. إن ربط نظام كهذا بالتشخيص الدقيق للعينات المشتبهة المجلوبة حديثا، يؤدي إلي توجيه التدخل الصحي المرتكز على الأدلة المواتية للحالة المحلية ويزيد من قدرة النظام الصحي علي الاكتشاف المبكر للأوبئة والأمراض المنتشرة والمستوطنة. إن مثل هذا النظام يمكن استغلاله أكثر لصالح التوعية واستعمال الخدمات الصحية، والإدارة المتكاملة لحالات الأمراض التي تنتقل من الحيوان إلى الإنسان ودمجها في أنظمة المراقبة الديمغرافية والصحية المتواجدة أصلاً.

أهداف الدراسة:

إن الهدف الهام من هذه الأطروحة هو تهيئة القاعدة لإنشاء نظام مراقبة صحية متكامل لصحة الإنسان والحيوان يعتمد على مشاركة الافراد في الاوساط الرعوية الزراعية في تشاد. وقد تناولنا فعالية البرامج الصحية والبرامج الصحية المشتركة في قطاع الصحة العامة والصحة الحيوانية والقضاء على الامراض المتنقلة بين الانسان والحيوان بالإضافة إلي دراسة الأساسيات المطلوبة من أجل انشاء نظام مراقبة صحي متكامل في الاوساط الريفية باستخدام تكنولوجيا المعلومات والاتصالات. الأهداف الخاصة لهذه الأطروحة هي:

1. المساهمة في طرق ومنهجية تقييم فعالية البرامج الصحية في القطاع الصحي
2. تقييم منهجية (الصحة الواحدة) على سبيل المثال حملات التطعيم المشتركة للإنسان والحيوان
3. تهيئة القاعدة المعرفية من اجل وضع خطة دراسة ذات قابلية للتنفيذ لنظام مراقبة صحية متكامل لمراقبة صحة الإنسان و الحيوان.
4. تقييم امكانية القضاء على الأمراض التي تنتقل من الحيوان إلى الإنسان في البلدان النامية (حالة السل البقري في المغرب)

المنهجية:

فعالية البرامج الصحية

الفعالية والتوزيع العادل لخدمات صحة الأم في الوسط الريفي التشادي: عدم التساوي والاختلاف الواسع في حالات مرض ووفيات الأمهات حاضرة دائما بين السكان خاصة في البلدان ذات الدخل المحدود. وعليه فإن السياسات يجب ان يتم تدعيمها بالدراسات التي تأخذ بعين الاعتبار الفوارق بين مختلف شرائح المجتمع في الاستفادة من الخدمات الصحية. الهدف من هذه الدراسة هو تقييم فعالية تغطية خدمات صحة الأم والطفل في مركزين صحيين ريفيين بتشاد. المنهجية المتبعة ساعدت في التحديد الكمي للعوامل المحددة لفعالية النظام الصحي. وقد أعطت النتائج قاعدة مرجعية من أجل تقييم وتحسين نظام برنامج صحة الأم والطفل في تلك المراكز الصحية.

محدودية التطعيم لدى مجتمعات الرعاة الرحل في تشاد : إن الاسباب التي تحول دون قبول التطعيم لدى المجتمعات الريفية الرعوية للرحل بتشاد لا زالت غير معروفة على وجه الدقة. لقد افترضنا خلال هذه الدراسة أن أفراد المجتمعات الرعوية للرحل في تشاد يواجهون صعوبات خاصة من أجل الحصول على خدمات التطعيم. وقد أشارت نتائجنا إلي ان فهم هذه المعوقات يعتبر ضرورياً من أجل تقليل نسبة التردد في استخدام التطعيم وتوسيع رقعة قبوله لدي الرحل. .

الطرق والمنهجية المتبعة في إطار الصحة الواحدة

إمكانية وقابلية تنظيم حملات التطعيم المشترك (إنسان-حيوان): إن إمكانية وقابلية تنظيم حملات التطعيم المشترك (إنسان-حيوان) قد اثبتت فاعليتها مؤخراً في تشاد وقدمت خدمات وعلاجات صحية للمجتمعات التي كانت في السابق يصعب الوصول إليها، وسمحت بتوفير الموارد المالية وذلك عندما يتشارك الطرفين في تكلفة النقل، والمعدات اللوجستية. إن الهدف الأساسي من هذه الدراسة يتمحور حول تقديم رؤية لإمكانية واستمرارية برامج التطعيم المشتركة ودمجها في النظام الصحي في تشاد. وقد أوضحت نتائجنا بأنه وبالرغم من أن إدماج مثل هذه البرامج في العمل الروتيني للقطاع الصحي يتطلب مصادر مالية إضافية، إلا أن المراكز الصحية يمكنها الاستفادة منها من أجل التواصل مع هذه الشريحة من المجتمع وحثهم على استخدام الموارد الخاصة بالتطعيم على مستوى المركز على المدى البعيد.

التوجهات في المراقبة الصحية وتقديم الخدمات للرعاة في وسط وغرب إفريقيا: في معظم دول إفريقيا جنوب الصحراء يشكل الرعي أحد أهم المصادر الاقتصادية ويساهم بشكل كبير في النمو الوطني. ألا أنه وبالرغم من ذلك فإن هذا القطاع يواجه تحديات تتمثل في توفير الخدمات الاجتماعية خاصة الصحة والتعليم وتجنب النزاعات مع المجتمعات المستوطنة والسلطات المحلية. يحدث كل هذا في وقت يحاول فيه الرعاة الاستمرار في نمط حياتهم المعتمد على الترحال وسط نظام بيئي يتغير بسرعة. وبالرغم من الجهود المقذرة التي تم بذلها من أجل دمج الرعاة الرحل في الخدمات الاجتماعية إلا أن هنالك عراقيل ما زالت تعيق إقرار سياسات واضحة وخاصة ومستدامة تجاه الرعي في إفريقيا جنوب الصحراء.

ديناميكية انتقال وإمكانية القضاء على مرض السل البقري المنتقل من الحيوان إلى الإنسان بالمغرب: تم إعداد نموذج رياضي-حسابي خاص بانتقال مرض السل البقري في الحيوانات و البشر من أجل إعطاء صورة مفهومة بشكل عام عن المرض وبشكل خاص فيما يتعلق بانتقاله إلي البشر. وقد استعملت معادلات تفاضلية من أجل حساب مختلف الطرق للمقارنة بين الحيوانات والبشر. كما تم تمثيل سيناريو لعملية تشخيص وذبح الأبقار المصابة من أجل تحديد آثار التغير في نسب الحيوانات المختبرة على الزمن الكلي اللازم للتخلص من المرض لدى الحيوان والبشر وكذلك التكلفة الاقتصادية الاجمالية.

CHAPTER 1: GENERAL INTRODUCTION

1. COUNTRY PRESENTATION: CHAD

1.1. GEOGRAPHICAL SITUATION, CLIMATE, HYDROGRAPHY AND VEGETATION

Situated in the heart of Africa between the 7th and 24th degrees of latitude north and 13th and 24th degrees of longitude east, Chad is the fourth largest African country after Algeria, DR Congo and Libya with a total surface of 1'284'000 Km². A landlocked country, it has borders with six countries: Libya from the north, Sudan from the east, Niger, Nigeria and Cameroon from the west and Central African Republic from the south (Figure 1.1.).

The Sahara in the north occupies almost 47% of the total surface of the country with almost bare land and dunes except from steppe or pseudo steppe type of vegetation and a mean rainfall of 300mm per year. The Sahelian zone in the centre between the Sahara and the Sudanian zone in the south covers 43% of the total size and the vegetation formation is that of the shrub savanna of the Sahelo-Sudanian type and the rainy season could last up to 3 months with an average rainfall ranges from 400-700 mm per year.



Figure 1.1. Map of Chad (source INSEED)

The remaining 10% of the territory is a Sudanian zone which is constituted by two basins of the main rivers of the country (the Chari and the Logone). The rainfall average is more than 700 mm per year and could reach 1'200-1'300 mm a year.

In terms of water sources and vegetation, Chad has two rivers and five main lakes; 600'000 ha of forests and 400'000 ha of national parks. The river network consists of the Chari which originates from the Central African Republic and flows over 1'200 km to meet in N'Djamena, the capital, with the Logone which has its origin in Cameroon and extends over 1'000 km. They are, in part, navigable four months a year. The main lakes of the country are: Lake Chad, Lake Fitri, Lake Iro, Lake Léré and Lake Tikem. The two most important parks with the most varieties of species are the Zakouma National Park in the Salamat region and the Manda park in the Moyen-Chari region (INSEED et al., 2014-2015).

1.2. HEALTH AND DEMOGRAPHIC SITUATION

Chad is one of the poorest countries in the world with a total population of 14'095'654 in 2016 and 76% among them live in rural areas according to the last national census data projection in 2009 (INSEED, 2014). More than 50% of the total population lives with less than USD 1.3 per day within a highly centralized governance system and limited spaces for political dialogue and citizens' participation. Despite some improvements in the last decade, most of health indicators remain worrying and illustrate the difficulties and weaknesses of the health system (INSEED et al., 2014-2015).

The health system structure in Chad, like in many sub-Saharan African countries, is of a pyramidal type with three (3) levels:

- The **central level** which groups the central departments of the MPH around the ministerial cabinet; It is responsible for developing health policies, coordinating external assistance, supervising, evaluating and monitoring the implementation of national programmes. Reference institutions such as hospitals and treatment centres belong also to this level;
- The **intermediate level** includes the 23 regional health districts; It is in charge of coordinating the implementation of health policy as well as technical support at the peripheral level;
- The **peripheral level** or health district level is the unit of implementation of the health care system; It is composed of two levels: the first level, which is the health centre delivering the minimum package of activities, and the second level represented by the district hospital issuing the supplementary activity package. In 2014, the country has 102 health districts, of which 67 are functional (66%).

In Chad, the health situation is characterized by high morbidity and mortality, mainly among vulnerable groups such as women of childbearing age, young people and children under five years of age. Average life expectancy at birth (52.5 years) is lower than the average for sub-Saharan Africa; Infant and child mortality, as well as the high fertility rate (6.3 children, Demographic and Health Survey, EDST-II (INSEED et al., 2014-2015)), place Chad among the least developed in this field at

the international level. Out of 1,000 live births, 109 die before reaching their first birthday and the risk of death between birth and fifth birthday is estimated at 180 per thousand (Multiple Indicator Cluster Survey, MICS 2010 (INSEED, 2011)).

The maternal mortality rate is very alarming with a trend of aggravation: from 827 maternal deaths per 100,000 live births in 1997 (EDST-I) it has risen to 1,100 maternal deaths per 100,000 live births in 2012 (WHO, 2015b). This high level of mortality is due to haemorrhages, postpartum infections, dystocia, pregnancy hypertension and abortion.

The country faces a very significant qualitative and quantitative shortage of human resources. Health personnel ratios are well below the WHO standards of 2.3 health personnel (doctors, nurses and midwives) per 1 000 population (WHO, 2006) with a total of 0.5 health personnel (doctors and nurses and midwives).

The health infrastructures physical coverage is very poor, i.e. the real coverage of the population per health district is largely below the theoretic coverage due to lack of appropriate plan for health infrastructures development. This leads to inappropriate repartition of health facilities in all levels. For example, the distance between some villages and the nearest health centre could reach 50km, and between some health centres and hospital districts could be more than 100km.

1.3. LIVESTOCK AND ANIMAL HEALTH

Livestock sector represents 53% of the rural GDB and combined with agriculture sector they represent 40% of the national GDP of the country (MERA, 2008). According to 2006 estimates, the livestock population was 7,945,000 cattle, 10,942,500 small ruminants, 1,822,781 dromedaries, 491,440 horses and 520,785 swine (MERA, 2011). Over 80% of ruminants were managed through a pastoral systems characterized by the use of extensive space. Within this system, mobility is a strategy to maximize the use of the available natural resources. Mobile pastoral systems in Chad represent a lifestyle and mean of conservation of livestock (MERA, 2011).

For over three decades, the pastoral activity was subject to many constraints related to weather, animal population growth and expansion of cultivated land that was detrimental pastoral spaces. Therefore, there has been a systematic degradation of natural resources in some regions, particularly in the Sahel area. These changes raised important issues regarding land properties especially with the increased competition between different users of these common resources. Conflicts over access to natural resources mainly between sedentary farmers and nomadic pastoralists have been raising major concerns to the authorities (Reounodji, 2011).

As part of its policy of developing the rural sector, the Government of Chad has elaborated, in collaboration with its partners, a rural development strategy which resulted into action plan for rural development (MERA, 2008).

Animal diseases are still a major constraint to the development of livestock in Chad. Animal health was always an important issue to the Ministry of Livestock. The protection of livestock health was based mainly on fighting against diseases known to be more contagious and spread in the country defined by the law No. 09/PR/04, organizing animal health policy and collective prophylaxis. Among those diseases we could cite: Foot and Mouth Disease (FMD), Peste de Petits Ruminants (PPR), Anthrax, Contagious Bovine Pleuropneumonias (CBPP) and Brucellosis among others (MERA, 2008).

2. RESPONSE AND INTERVENTIONS EFFECTIVENESS

2.1. POOR RESPONSE EFFECTIVENESS

According to the 2013 world urbanization prospect report of the United Nations, the rural population in Sub Saharan Africa is approximately 579 million. In the West and Central African region alone, an estimated 90 million people live in rural areas. They depend on agriculture and livestock, but have limited access to health and other social services, given the unequal distribution of good-quality services between urban and rural areas (United-Nations, 2013). Despite the general health and disease problems faced, and in addition to problems caused by extreme climatic conditions, agro-pastoralists (we refer here to rural mobile and sedentary communities which are pastoralists, crop farmers or both) in the Sahel are largely excluded from health services because the provision of social services adapted to their way of life is challenging (Montavon et al., 2013).

In Chad, a sub-Saharan African country, over 78% of the total population lives in rural areas which are characterized by insufficiently equipped health centres and shortages of qualified health workers. Medical evacuations are extremely difficult to organize, mainly because of deteriorated roads, lack of personnel and vehicles. More so, general health care is difficult to provide because of long distances, poor infrastructure, lack of electricity and water and most prominently the lack of qualified medical and nursing staff. Therefore, they suffer disproportionally from health problems like respiratory disease, malaria and diarrhoea (Daugla et al., 2004). Malnutrition is widespread in the Sahelian belt in Chad among both rural sedentary and nomadic populations. It is linked to socio-economic factors and particularly affected by seasonal variations (Bechir et al., 2010b). Malnutrition and a high prevalence of intestinal parasite are common among women and children. More than 50% of pregnant women among mobile and settled pastoralists near Lake Chad were found to be anaemic (Bechir et al., 2012a). Close contact with livestock and consumption of raw milk and meat could favour zoonotic infections such as anthrax, Q-fever, brucellosis and bovine tuberculosis (Montavon et al., 2013). Pulmonary diseases are more common in children under the age of 5 years. However, during the rainy season, high fever and febrile diarrhoea are more common because access to safe drinking water is lacking and poor hygiene practices prevail (Daugla et al., 2004, Schelling et al., 2005a).

It has been shown that women and children have very low vaccination coverage, and during the dry season, heat and the dust often cause respiratory infections (Bechir et al., 2004). According to data from the last Multiple Indicator Cluster Survey (MICS) conducted in Chad in 2010, polio vaccination coverage (3 doses) was 31.8% and measles vaccination coverage was 36.0% (Ministère du Plan de l'Economie du Tchad et al., 2011). These figures were even lower in rural areas, and extreme examples occurred among mobile pastoralist communities where vaccination coverage among livestock was significantly higher than for children (Zinsstag et al., 2006, Schelling et al., 2007b). In that sense, rural populations in Chad represent a particular case of inequity in access to basic social services including health and education. New ways of social services are needed to provide adequate and locally adapted and accessible health care to mobile pastoralists and remote sedentary populations. One approach could be to joint forces between public health and veterinary services (Schelling et al., 2005c).

2.2. LACK OF METHODS TO ASSESS EFFECTIVENESS

It's well documented that communities in rural sub-Saharan Africa are largely excluded from social services including health and education. However, methods are lacking to assess the effectiveness of interventions mainly in public health. Ensuring access to health care to all citizens of a given country is an issue even though governments declare officially guaranteeing equitably accessed universal health care to all (Obrist et al., 2007). Disparities, however, exist between the poor and the wealthy or between the easiest to reach/to serve and the hard to reach populations and communities within the same country with regard to health care access and therefore health status. Obrist et al. (2017) suggests a livelihood health care access framework combines health service and health seeking approaches and proposes five dimensions that influence the process of health seeking which are: Availability, Accessibility, Affordability, Adequacy and Acceptability of a given health service.

In settings where available resources are limited, it's important to prioritize the most cost effective health interventions while allocating budget to different activities within health sector (Zinsstag et al., 2011a). In fact, the feasibility and the cost which would determine the efficiency of a given health intervention represent a major challenge for health systems. Zinsstag et al. (2011) illustrates the importance of looking behind the average effect of health interventions which could hide significant differences within populations, i.e. different social groups. Here comes the importance of assessing the equity effectiveness of health interventions leading to more equity in health coverage (Tanner, 2005).

To date, few documented examples exist showing how to measure and quantify the effectiveness of a given health intervention. As the effectiveness of a health intervention is the result of interaction between different factors including the determinants of access described by Obrist et al (2007). In this sense, quantifying the contribution of each one of these factors or parameters would help to determine and measure the effectiveness of an intervention. The cumulative effect of different parameters

contributing to the effectiveness of rabies dog mass vaccination, i.e. coverage, was used in Bamako, Mali (Muthiani et al., 2015). Indeed, as the factors are independent, the final effectiveness value is the multiplicative product of the different parameters influencing the mass vaccination coverage in this case. By performing sensitivity analysis, one could determine the most sensitive parameter influencing the effectiveness and could see how much the effectiveness would change or improved if one or more factors were increased by a given percentage.

Mixt methods approach was also used to assess rabies vaccination programmes effectiveness in Bamako (Mosimann et al., 2017). In this case, qualitative and quantitative tools were used to evaluate the effectiveness in two communes in Bamako city with two different vaccination coverages. An intervention effectiveness cycle was proposed aiming at maximizing the effectiveness of the intervention in which quantitative methods (vaccination coverage and household survey) and qualitative methods (interviews and group discussions) were triangulated and compared to effectiveness model findings from Muthiani et al. (2015) and to empirical coverage estimation from Kayali et al. (2003) (Kayali et al., 2003). The interpretation of these mixt methods allowed proposing improved intervention design based on participatory approach (Mosimann et al., 2017).

Globally, through the prioritisation in the Millennium Development Goal 5, the international community has made important strides towards reducing maternal morbidity and mortality. In fact, the global mortality ratio nearly halved between 1990 and 2015 and important increases in maternal health coverage among poor and rural mothers have been achieved (Victora et al., 2017). Despite this progress, inequalities and large disparities in the burden of maternal morbidity and mortality still persist within and between populations. A comprehensive multi-country analysis of health service utilization revealed that inequalities along the socioeconomic gradient are particularly high for skilled care at delivery and antenatal care (ANC) as compared to other health interventions (Gwatkin et al., 2004). Considerable divergences exist in the magnitude of maternal mortality concentrated in vulnerably populations and predominantly in sub-Saharan Africa (Campbell et al., 2006).

A recent household survey in two rural health districts in Chad revealed low health service utilization among agro-pastoralists in general and more particularly among nomads' communities. Only 46% of pastoralist against 79% of sedentary women attended antenatal care (ANC) at least one time. Furthermore, 13% of the sedentary and 8% of the pastoralist mothers had skilled attendants at delivery (SwissTPH, 2016a). This could be effectively used as an indicator to estimate health services coverage effectiveness among these communities. The chapter 1 of the present thesis presents a methodological approach allowing for quantifying the health system's determinants of access to health care which are: accessibility, availability, affordability, adequacy and acceptability. Results should provided a baseline information to monitor the progress of a health system intervention focusing on maternal and infant health in these districts.

3. HEALTH SURVEILLANCE: THE WEAKEST LINK IN THE CHAIN

Emerging disease, among which many are zoonoses keep threatening the health and economy of outbreak countries and other parts of the world (Zinsstag et al., 2007). The 2016 Ebola outbreak in Guinea, Liberia and Sierra Leone is an appalling example of the low sensitivity and slow response causing the death of thousands of patients which could have been prevented (Chertow et al., 2014). The outbreak reveals the persisting vulnerability of local and global surveillance and response capacity to emerging disease. Inadequate surveillance and the lack of diagnostic capacity in the affected countries have further contributed to the late response, pointing to the urgent need for faster, near real-time surveillance.

Today, most of the established syndromic surveillance or early outbreak warning systems in developing countries are based on low technology applications within solid national institutional structures and on a pre-defined time-interval basis (May et al., 2009, Robertson et al., 2010, Brownstein et al., 2008). In such systems various tools including mobile phones, text systems (SMS), Internet, sentinel systems, Health map, etc. are used for the message transfer to the data collecting institutions.

However, syndromic surveillance reporting is often too low, insufficient or even lacking and all this not only because infrastructure limitations impede effective surveillance, other reasons include a poor acceptability among people responsible for the data transfer and/or a lack of properly trained, community-based personnel to fulfil such duties (Jefferson et al., 2008, Calain, 2007, Muula and Maseko, 2006). Furthermore, several authors report on clinical misdiagnosis and empiric treatment, inadequate health care infrastructures and in particular also lack of diagnostic accuracy as indicators for deficient surveillance mechanisms (Bates and Maitland, 2006, Petti et al., 2006, Okeke, 2006, Schroeder and Amukele, 2014, Nkengasong et al., 2010). Specific evaluations also revealed quite some disagreements between syndromic and traditional surveillance data (Jefferson et al., 2008, May et al., 2009) and several authors have thus proposed the syndromic surveillance as complementary to classical surveillance systems (Josseran and Fouillet, 2013).

In the past, the syndromic surveillance has often been applied for individual case studies but not for a large-spectrum disease approach in a One Health context (Ndiaye et al., 2014b, Bourgeois et al., 2006, Perrin et al., 2012). Hence, indispensable medical interventions are often too late, non-targeted or even lacking and as a consequence, potentially new emerging pathogens and diseases from humans and animals may spread undetected for some time (May et al., 2009).

However, the revised International Health regulations by WHO require a timely detection, appropriate reporting and diagnosis followed by a subsequent response to relevant disease outbreaks (Kool et al., 2012), which implies rapid and efficient new surveillance systems and means for an early detection,

appropriate diagnosis and monitoring of disease outbreaks. The use of pre-diagnostic biomedical data including statistical epidemiological approaches aims to detect epidemics earlier than traditional surveillance systems (May et al., 2009). So far, efficient and timely appropriate syndromic surveillance systems in agro-pastoralist populations with their especially close living situation with their animals are deficient or even lacking, but of high public health relevance with a view to rapid and early detection of emerging pathogens and diseases and their targeted treatment and prevention.

A preliminary small-scale pilot study in Chad with a specifically developed mobile phone demographic and health surveillance system has revealed most promising results, in particular by showing a high degree of effective data transfer under such mobile living conditions (Jean-Richard et al., 2014c). The advantage of such a mobile phone-based surveillance system is a rapid and targeted medical response linked with an immediate epidemiological assessment of the ongoing disease outbreak for both, human and animal populations, i. e. in a One Health context.

By using an integrated One Health mobile phone surveillance and response approach from syndromic to etiologic, i.e. the reporting of diseases (data transfer), the etiologic diagnostic approach and targeted responses and interventions including introduction of preventive measures are independent from the patient's locations, can be quantified and compared with the previous reporting and response systems. Therewith associated, epidemiological disease pattern and indicators for prevention will be elucidated by a thorough epidemiological evaluation and comparison with the ongoing surveillance and response system.

The challenge nowadays is to develop culturally adapted, robust, low cost and efficient applications as key element for near real-time community based disease surveillance in remote locations in Africa. Such a system should be functional in settings with high levels of illiteracy and low levels of education and shortage of public health and veterinary staff.

4. ONE HEALTH METHODS AND POTENTIAL OF ZONOSIS ELIMINATION

Although it is well known that human and animal health are inextricably linked, under the increasing influence of specialization, however, human and veterinary medicine have diverged and too often fail to communicate, even when they share interests in the same disease. For example during a recent outbreak of Q-fever in the Netherlands, public health authorities were not informed by veterinary authorities about a wave of abortions in goats (Enserink, 2010a). Similarly, outbreaks of Rift Valley fever in humans in Mauritania were mistakenly identified as Yellow Fever (Digoutte, 1999, Zinsstag et al., 2007).

Such examples could be extended and the collaboration of human and animal health still falls short particularly in low income countries harbouring important reservoirs of emerging diseases. However, in the recent years the collaboration of human and animal health coined One Health (Zinsstag et al.,

2005b), has gained momentum. One Health can be defined as the added value in terms of improved human and animal health or financial savings or environmental services resulting from a closer cooperation of both health sectors (Zinsstag, 2015, Greter et al., 2014). Such approaches have demonstrated that joint human and animal preventive health interventions i.e. vaccination are feasible and provide health care to previously inaccessible communities and save resources in rural Chad (Schelling et al., 2007b).

Engaging with stakeholders as transdisciplinary process of societal problem-solving led to the identification of the main problems in a participatory way, which improved the conception, planning and evaluation of future research and interventions (Wyss et al., 2004, Zinsstag, 2011). By this approach, which served as a case example for the Handbook of Transdisciplinary research (Hirsch Hadorn et al., 2008), for example contamination of the locally produced anthrax vaccine could be detected because herders were asked about their experiences with vaccinating their animals.

Sectorial approaches are inadequate for health interventions especially against zoonotic diseases. Bovine tuberculosis (BTB) could serve a good example to apply One Health methods on controlling aiming at eliminating the disease.

BTB is a zoonotic cattle disease caused by a slow growing bacteria *M. bovis* belonging to mycobacterium tuberculosis complex (MTBC) maintained and transmitted between animals mainly by respiratory routes. This way of transmission plays an important role in the cycle of reinfection by introducing infected animals to non-infected herds (Neill et al., 2001). It could be transmitted to humans through consumption of raw milk and inhalation of aerosols during contact with infected animals (Thoen et al., 2006).

BTB is endemic in animals in almost all developing countries mainly in Africa due to economic constraints related to its elimination which based on test and culling of infected cows and farmers compensation (Zinsstag et al., 2007). Although, wildlife appear to be a concern for a potential risk of emergence in developed countries, still in sub-Saharan Africa, neither direct spill over from wildlife to humans, nor BTB case spillback from wildlife to animals has been confirmed and documented so far (De Garine-Wichatitsky et al., 2013).

Detecting human BTB cases is challenging because pulmonary tuberculosis caused by *M. tuberculosis* and BTB cases are not distinguishable on the basis of clinical symptoms, radiography or histopathology (de la Rua-Domenech et al., 2006). The standard Gold Standard test for TB, Glycerol-containing Löwenstein-Jensen medium, inhibits the growth of *M. bovis*, thereby increasing the number of undetected cases (Grange et al., 1996). Although, new molecular diagnostic tools, for example spoligotyping, and even whole genome sequencing have been developed for *M. bovis* detection (Robbe-Austerman and Turcotte, 2014, Kao et al., 2016), they require enhanced laboratory infrastructure and qualified personnel which are lacking in some developing countries. Hence, knowledge on human cases from BTB infection in Africa remains largely unknown. The lack of

control and diagnostic measures in these countries could lead to increased risk of BTB human infections particularly within a high HIV prevalence context (Etter et al., 2006). A recent meta-analysis estimated the median proportion of human BTB among all TB cases in 13 African countries at 2.8%, with a range of 0-37.7% (Muller et al., 2013a). National prevalence data from a range of countries worldwide were summarized in a 2014 review; in Mexico up to 13% of all TB cases are reportedly due to BTB, while in the United States it is only 1.4% (Perez-Lago et al., 2014). In Morocco, Bendadda et al. reported *M. bovis* prevalence of 17.8% among drug resistant TB isolates from 200 human sputum samples (Bendadda, 2003).

Studies in Chad confirmed the presence of BTB in cattle in different regions in the country based on skin tuberculin-positive tests (Delafosse et al., 2002, Schelling et al., 2000). It's also known that BTB is an important cause of condemnation while meat inspection in abattoirs in Chad because the whole carcasses were destroyed in these cases (Maho et al., 1999). The first molecular characterization and confirmation of *M. bovis* was done after conducting slaughterhouse study and showed similarities with strains found in Cameroun and Nigeria suggesting an ongoing cross boarder transmission of BTB between cattle (Diguimbaye-Djaibe, 2006). An epidemiologically important clonal complex of *M. bovis* named Afl has been identified in Cameroun, Mali, Niger and Chad (Müller et al., 2009).

The epidemiological situation of BTB in North African countries is not an exception. In Morocco, BTB is an endemic zoonosis in livestock. The most recent national survey, conducted in 2004, showed an individual cattle prevalence of 18% and a herd prevalence of 33% (Fao, 2011b). This prevalence remained similar in the individual level (20%), while the herd prevalence increased (58%) in a 2012 pilot study of 1'200 cattle using the tuberculin skin test (Yahyaoui Azami H., 2006). Since 2000, the health risk of tuberculosis in Morocco has been addressed through a national TB programme funded by the Ministry of Health in collaboration with the World Health Organization (WHO). In 2014, TB caused 2'800 deaths in Morocco (World Health Organization, 2015), and human tuberculosis had a relatively high incidence, with 36'000 new cases (106 cases per 100'000 inhabitants) (WHO, 2015a). These data do not appear to differentiate between *M. tuberculosis* and *M. bovis* infection.

One of the challenges facing health interventions in limited resources countries is mobilizing funds necessary to cover interventions' costs. The so-called "Development Impact Bonds (DIB)" or social impact bonds could be nowadays considered one of the means that could help to overcome this issue. Indeed, DIB is an attracting way of investment for donors which encourages private sector to put upfront money to fund social interventions and payed back by donors with benefit upon achievement of pre-set outcomes and goals (Warner, 2013, Group, 2013). It has a great potential of success because it transfers the risk of failure to the investors which bring them to focus more on the implementation and delivery of successful results.

A DIB was proposed as a way of investment for human and animal trypanosomiasis elimination programme in Uganda to tackle the disease at scale as the country lacking necessary funds for that (Welburn and Coleman, Chapter 18 in (Zinsstag et al., 2015)). A first study of cost estimation of

canine rabies elimination in Chad based on a DIB was presented by Anyiam et al. (2016). A cash flow scenario were developed and a cumulative cost was presented to be shared by the government, private investors and donors based on shared risk principle (Anyiam et al., 2016). This could help to make funds available for rabies elimination in Chad.

We have estimated the associated costs of an intervention based on test and slaughter to eliminate BTB in cattle and humans in Morocco with a model. Our findings suggested that BTB might be eliminated in cattle within 13 years if 90% of cattle population is tested with a total cost of 1.48 billion euros (Abakar et al., 2017) (Chapter 4 of the present thesis). Such intervention could be foreseen only if enough resources are available, which make DIB a promising option to the way forward.

5. GAP OF KNOWLEDGE

It's well known that early detection and confirmation of diseases is a key element in health interventions aiming at controlling outbreaks and diseases spread. Modern technologies, especially mobile communication technology, are rapidly growing and increasing the people's connectivity mainly in LMICs with a great potential for health system improvement in different fields such as improving routine immunization, diet and physical activity, client education and supply chain management, improving quality by increasing adherence to guidelines and improving diseases surveillance among others (Kazi et al., 2017, Afshin et al., 2016, Kazi, 2017, Gibson et al., 2017, Hall et al., 2014, Chaudhry et al., 2006). Mobile communication supporting health care, known as mHealth, is influencing public health system especially surveillance methods. For example, in Sierra Leone during the 2014-2016 Ebola outbreak, free text messages reporting suspected cases has been used with the collaboration of local mobile service providers to inform the authorities (O'Donovan and Bersin, 2015).

In settings like in rural Chad, where the main population is rural sedentary and mobile agro-pastoralists, a better understanding of mobile communication on the potential of disease surveillance is needed. As mentioned earlier, the pilot study done by Jean-Richard et al. 2014 demonstrated that mobile phones can facilitate the communication between mobile pastoralists and health professionals (Jean-Richard et al., 2014c) which may shorten the time span between recognition of illness or symptoms at the community level and the etiological confirmation by biomedical health professionals. Although, mobile communication help to connect people, some categories may be excluded mainly those who have less power, wealth or technical capabilities (Seli, 2013). Therefore, more needs to be known on mobile phone use in connection to health and illness.

Indeed, mobile phone and emerging technology based surveillance systems use for infectious disease must be carefully examined in real life situations because of the associated challenges such as the specific technical requirements and its acceptability by health staff and most importantly by policymakers (Velasco et al., 2014). A framework for integrated surveillance and response requires

appropriate social mechanism to identify perceived priorities among communities and health professionals for a well-functioning surveillance and response system in order to develop applications which are culturally appropriate. In a given settings, research on public health practice has to account for dynamic interpretations of symptoms and causes of illness and associated preventive and curative action which are created in social interaction between the patient, caregivers, relatives, local healers (such as marabouts), itinerant drug sellers and health facility staff (Hampshire, 2002b).

Among the recognized weaknesses of public health surveillance systems is the lack of direct benefits and adequate responses and interventions linked to surveillance and timely reported health information (Halliday et al., 2012). Therefore, appropriate planning to couple reporting with intervention is a key element to overcome this handicap. Adequate response must be as equitable as possible in settings with high inequalities like in rural Chad. The needs of disadvantaged and marginalized populations must be included in benefits of the interventions which requires methods to measure access to health care and hence, the community effectiveness of health intervention. An in-depth understanding of effectiveness includes qualitative and quantitative knowledge on the parameters of access to interventions. Methods of intervention effectiveness allow identifying inequities between different population groups and therefore, providing a baseline to monitor the progress of a given health intervention (Tanner, 2005, Tugwell et al., 2006a, Zinsstag et al., 2011a, Obrist et al., 2007).

Control and elimination of infectious diseases, in particular zoonoses, are non-linear dynamic processes and therefore, they require mathematical models for their simulation. The implication of different sectors at different levels is essential to achieve such objective. Simulations of disease transmission using mathematical models should be connected to economic assessments to assess their profitability in a local context (Zinsstag, 2007, Zinsstag et al., 2009, Zinsstag et al., 2007, Palatnik-de-Sousa et al., 2004, Quinnell and Courtenay, 2009, Narrod et al., 2012).

Hence we propose the following aims and objectives.

6. AIM AND OBJECTIVES

6.1. AIM

The aim of the present thesis is to establish the basis of a culturally adapted and integrated community based human and animal health syndromic surveillance and response system among agro-pastoralists in Chad. We explore sequentially different steps with specific case studies from the portfolio of activities of the Human and Animal Health research unit at Swiss Tropical and Public Health Institute (Swiss TPH). Hence, we address intervention effectiveness, joint human and animal health interventions, zoonoses elimination and basic requirements for syndromic surveillance in remote rural communities using modern information and communication technology.

6.2. OBJECTIVES

The objectives of the thesis are thus to:

- Contribute to health interventions effectiveness evaluation methods
- Evaluate One Health approaches among hard to reach communities (i.e. joint human and animal vaccination) and their potential for their integration to the public health system
- Establish a basic knowledge on syndromic surveillance and response in order to implement a feasibility study of an integrated human and animal health surveillance and response system
- Estimate the potential of zoonosis elimination in developing countries (case of BTB in Morocco)

7. COLLABORATION AND SUPPORT

This thesis has largely benefited from the basic tripartite collaboration agreement between Swiss TPH, IRED and CSSI which illustrate the longstanding relationship and collaboration in research development activities between these institutions. The local public health and veterinary services officials at the regional and district levels have shown a great two health districts (Yao and Danamadji).

The Swiss Development and Cooperation agency (DDC) funded project PADS has contributed through the baseline study on health systems capacity and the utilization of maternal health in the two districts of the study area (Yao and Danamdji are the intervention sites of PADS). The project is also involved in the planning of the implementation of the syndromic surveillance and response system in the two districts.

The Alliance for Health Policy and Systems Research funded project at IRED contributed to the vaccine hesitancy study and the evaluation of joint human and animal vaccination programme with close collaboration with PADS (Swiss TPH and CSSI).

**CHAPTER 2: TOWARDS EQUITY EFFECTIVENESS OF
MATERNAL HEALTH SERVICE COVERAGE: RURAL SEDENTARY
AND MOBILE POPULATION IN CHAD**

Towards equity effectiveness of maternal health service coverage: rural sedentary and mobile population in Chad

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Abstract

Inequalities and large disparities in the burden of maternal morbidity and mortality still persist within and between different population groups mainly in low income countries. Policies need to be informed by equity sensitive evidence assessing differences in health needs and particularly in the effectiveness of interventions and models of care. The aim of the current paper was to assess the community effectiveness of maternal health service coverage for sedentary and mobile populations in two rural districts in Chad.

The methodological approach is based on two parts: in a first step, the maternal health service utilisation rates have been empirically estimated based on a random household survey in both districts. In a second step, using different data sources (household survey, health facility and qualitative data), determinants of the effectiveness of maternal health services coverage using the example of antenatal care (ANC) have been quantified using a multiplicative specification of different coverage factors. The model allowed for quantifying and interpreting the health system's determinants of health care effectiveness building on five main access factors: accessibility, availability, affordability, adequacy and acceptability. Sensitivity analysis has been applied to account for uncertainty around the estimated factors.

Empirical estimates showed that the utilisation rate for ANC decreased with the number of required visits: among mobile pastoralists, only 20% of pregnant women attended ANC at least three times compared to 63% of sedentary women. Whereas utilisation rates of health services were systematically lower for mobile pastoralists, statistical associations revealed that maternal service utilisation rates were primarily driven by economic and geographical factors. Looking at the health system's determinants as quantified by the effectiveness model, availability, accessibility, affordability and acceptability contributed to the reduction of the service's coverage for both populations. For mobile pastoralists the acceptability dimension clearly stood out as the most important factor.

Utilisation of mother and child health services was low in rural areas of Chad and particularly low for mobile pastoralists. For both sedentary and mobile populations, the dominant drivers for low health service utilisation seemed to be economic and geographical factors. In general, maternal health service's effectiveness was reduced by its availability, accessibility, affordability and acceptability. Acceptability was the parameter with the highest leverage on the final effectiveness among mobile pastoralists and mainly explained the prevailing difference between the two population groups. Interventions should generally focus in priority on improving community effectiveness through targeting the factors with the highest leverage among specific populations in order to foster effective and equitable health services. Hence, an in-depth socio-cultural assessment among mobile pastoralist women on their perceptions may contribute to improve their acceptance and lead towards a higher equity effectiveness of antenatal care.

Keywords

Equity, effectiveness, maternal health, rural populations, Chad

Background

Maternal health is a global concern for securing future economic and social development: worldwide, around 210 million women become pregnant annually. In 2015, 216 women died of maternal causes per 100'000 live births (WHO, 2015b). Through the prioritisation of maternal health in the Millennium Development Goals, the international community has made important strides towards reducing maternal morbidity and mortality. In fact, the global mortality ratio nearly halved between 1990 and 2015 and important increases in maternal health coverage among poor and rural mothers have been achieved (Victora et al., 2017). Despite this progress, inequalities and large disparities in the burden of maternal morbidity and mortality still persist within and between populations.

A comprehensive multi-country analysis of health service utilization revealed that inequalities along the socioeconomic gradient are particularly high for skilled care at delivery and antenatal care (ANC) as compared to other health interventions (Gwatkin et al., 2004). Considerable divergences exist in the magnitude of maternal mortality concentrated in vulnerably populations and predominantly in sub-Saharan Africa (Campbell et al., 2006). A women's lifetime risk of dying as a result of pregnancy and childbirth is more than 100 times higher in sub-Saharan Africa than in high-income countries (WHO, 2015b). Reducing maternal health inequities is a vital step in the process of realising the vision of the Global Strategy for Women's, Children's and Adolescent's Health and the Sustainable Development Goals (SDGs).

Modern health policies must ensure that the needs of disadvantaged and marginalized populations are included in benefits of the interventions, which requires equity sensitive evidence that assesses differences in health needs and particularly in the effectiveness of interventions and models of care (Tugwell et al., 2006a). (Zinsstag et al., 2011a) illustrates the importance of looking behind the average effect of health interventions which could hide significant differences within populations. This highlights the importance of assessing the equity effectiveness of health interventions leading to more equity in health service coverage (Tanner, 2005).

In Chad over 78% of the total population lives in rural areas which are characterized by insufficiently equipped health centres and shortages of qualified health workers. General health care is difficult to provide because of long distances, poor infrastructure, lack of electricity and clean water and most prominently the lack of qualified medical and nursing staff. Chad represents a particular case of inequality: maternal mortality rate is one of the highest in the world at 1099 per 100,000 live births with only 30 per cent of women being assisted by a qualified personnel while giving birth in 2010 (INSEED, 2011). This figure is expected to be even lower in remote areas and especially for mobile pastoralists (they represent 3.5% of the population) as they are particularly affected by low access to and provision of health services (Zinsstag et al., 2011a).

With regard to immunisation, extreme examples occurred among mobile pastoralist communities where vaccination coverage among livestock was significantly higher than for children (Zinsstag et al., 2006, Schelling et al., 2007b). Equitable progress is required to reduce the disproportionate burden of poor maternal health in Chad and to close potential gaps between population groups.

Effective maternal health interventions and models of care are associated with improved maternal and neonatal health outcomes (Campbell et al., 2006). As for maternal health services, the progress in the provision of these services through the health system implies that the service must meet a variety of demand- and supply-side requirements (i.e. availability, affordability, adequacy etc.) which in turn reduce the number of beneficiaries reached, leading eventually to the community effectiveness of the service (Vlassoff and Tanner, 1992). Although different studies explore the effectiveness of maternal health interventions (Hill et al., 2013, Dellicour et al., 2016), little is known on the specific requirements for socioeconomically disadvantaged and vulnerable groups (Hollowell et al., 2011) such as mobile pastoralists.

To date, few documented examples exist showing how to measure and quantify the health system's determinants of a given health service's effectiveness. An analytical framework has been presented by Obrist et al. (2007) which identifies five relevant dimensions of access: availability, accessibility, affordability, adequacy and acceptability (Obrist et al., 2007). Based on this framework, Zinsstag et al. (2011) developed an effectiveness model for health interventions, where effectiveness is quantitatively determined as the product of the interventions efficacy and coverage, which in turn is reduced by the five determinants described above. The model has been applied to assess and optimize the effectiveness of a rabies dog mass vaccination, in Bamako, Mali (Muthiani et al., 2015, Mosimann et al., 2017).

Building on this approach, the aim of the current paper was to assess the community effectiveness of maternal health service coverage and according equity issues in two rural districts in Chad. The approach allowed for quantifying the health system's determinants of effectiveness. Results will provide a baseline to monitor the progress of a health system intervention in these districts and to optimise its future intervention design. This paper contributes to the existing literature by extending the methodological framework described in Zinsstag et al. (2011) by two elements: first, the target population has been divided in rural sedentary and mobile populations in order to highlight equity issues inherent in the effectiveness of maternal health services and to ensure that interventions will be tailored to different population needs. Second, probabilistic sensitivity analysis was introduced to test for uncertainty around the estimated effectiveness parameters. The assessment included the following steps: in order to explore the actual service coverage, maternal health service utilisation rates have been empirically estimated based on a random household survey in both districts including 1144 respondents. Then, using different data sources (household survey, and health facility data),

determinants of the effectiveness of maternal health service coverage using the example of ANC have been quantified. The according results have been compared with estimated utilisation rates and assessed against qualitative findings in order to validate the results.

Methods

Study area

The study has been conducted in Yao (region of Batha) and Danamadji (region of Moyen-Chari) health districts. The first is located in the centre and the latter in the south of Chad along the border with the Central African Republic. Together, the two districts cover 31 functional health zones providing health services for a total of approximately 270'000 inhabitants (INSEED, 2014). Both districts are populated by a substantial number of pastoralist communities (mainly camel and cattle breeders from Arab and Fulbe ethnic groups) with transhumance routes and areas of concentration during the dry season.

The two health districts have been selected by the Swiss Development Cooperation to be provided technical assistance for improving the organisation and performance of health services with a particular focus on marginalized population.

Survey design

The current analysis is based on data gathered from two cross-sectional surveys in the study area. In a first step, a health facility survey has been conducted in January 2015 in both districts including the full number of facilities (29) in order to collect data on structural and process-related attributes of maternal health service quality (Donabedian, 1988).

In second step, a representative household survey has been conducted in April and May 2015. A structured questionnaire was developed covering among others the utilisation of maternal and infant health services and socio-demographic characteristics. The design of the survey and sample size calculation has been guided by a focus on collecting the minimal essential data required to obtain a given precision of ANC utilisation rates.

A stratified two-stage sampling procedure has been adapted to the prevailing socio-epidemiological characteristics of rural sedentary and mobile populations. The sampling frame for nomadic populations has been developed beforehand based on participatory mapping approach. A total number of 1'144 observations (mothers with child) have been realised including 358 mothers from nomadic communities. In parallel to the described quantitative data collection, two focus group discussions and key informant interviews have been conducted in both districts aiming mainly at understanding access to maternal and infant health services (SwissTPH, 2016b). The according results enabled a secondary assessment and discussion of the quantitative results.

Utilisation of maternal health services

Utilisation rates of maternal health services have been empirically estimated in order to describe and explore current service contact of rural sedentary and mobile populations in the study districts. The obtained contact coverage (proportion of the target population that receive the service) estimated through reported service utilisation has been subsequently used to compare and validate outcomes of the effectiveness model.

Utilisation rates related to ANC visits and skilled attendant delivery have been estimated using a generalised linear model with household being integrated as a random effect to account for the clustered random sample. Multivariate regressions have been applied to explore socio-economic factors that best predict these outcomes.

To group respondents by socio-economic status, an asset index has been created applying principal component analysis to participants' responses on possession of assets (Filmer and Pritchett, 2001). This data reduction technique produces linear combinations of the variables (components) with the first component typically explaining a high proportion of the variation.

Based on the asset index, households have then been assigned to three socio-economic categories which have been created (the bottom 40%, the middle 40%, and the top 20%). Different assets have been proposed for sedentary populations and mobile pastoralists in order to account for different life styles between the two sub-groups.

Assessment of effectiveness parameters

ANC services have been used as an indicator to assess the effectiveness of maternal health service coverage in the two districts in Chad. An effectiveness model based on Zinsstag et al. (2011) has been used to quantify the magnitudes by which the health service coverage is reduced as it progresses through different stages of the health system. In particular, the process of actually obtaining the health service must meet a pre-defined cascade of requirements: first of all, it must be available. Then, the service can only be used if it is accessible and affordable for the population. The organization of the service must further meet the clients' expectations (adequacy) and, finally, the characteristics of providers must match with those of the clients including the social and cultural values (acceptability) (Obrist et al., 2007). The potential coverage of the service is expected to be reduced along this process as it must meet more requirements when progressing through these stages.

In algebraic terms, the effectiveness of the service can be considered as a product of the intervention efficacy, α , multiplied by the coverage which is typically reduced by different factors $\beta_{(i)}$ that relate to the five dimensions described above (availability, accessibility, affordability, adequacy and

acceptability). Assuming the coverage factors to be mutually exclusive, effectiveness can be specified as a multiplicative term:

$$effectiveness = \alpha \prod_{i=1}^n \beta_{(i)}.$$

For the case of ANC services, we will focus on the assessment of coverage assuming that efficacy is 100% ($\alpha = 1$).

Values for the coverage factors $\beta_{(i)}$ (henceforth effectiveness parameters) have been primarily derived from the random household survey described above. In particular, survey participants that did not attend ANC were asked for a reason. The possible structured answers proposed to the interviewees are presented in Table 2.1. The according answer possibilities have been matched to the five effectiveness dimensions in order to derive proportions of interviewees pertaining to a specific category (see Table 2.2.)

Table 2.1. Reasons for not attending ANC (answer possibilities in the questionnaire)

Answer possibilities	Short description
Hospital or health centre is distant	Distance
Waiting time is too long	Waiting
I do not have enough money to pay for health care	Money
There are usually no medicaments available at the health facility	Medicaments
Bad reception (health staff unpleasant)	Health staff
Quality of the service is bad	Quality
I didn't have time	Time
It is not our custom	Habits
It was advised to me	Disadvised
I don't know	
Other (open answer allowed)	

The availability parameter has been approximated based on the health facility survey through the average availability of folic acid (FeFo) for anaemia prophylaxis, typically provided to women attending ANC.

The quantification of the single parameters in the effectiveness model only provides information on the magnitude of possible determinants but do not pinpoint to the actual determinant that drives the actual coverage. Results of the effectiveness model have been therefore contextualized and verified in the discussion part based on results from the qualitative study described above.

Table 2.2. Assessment of the effectiveness parameters

Parameter	Description	Primary quantitative assessment	Secondary mixed-methods assessment
A1 Availability	Service meets clients' needs in terms of <ul style="list-style-type: none"> - quality of care - availability of medicaments 	<i>Health facility survey:</i> Availability of folic acid (FeFo) for anaemia prophylaxis, provided to women attending ANC	<i>Qualitative survey:</i> Focus group discussions and in-depth interviews with caregivers and mothers about the availability of health services and wishes for better availability of health services. <i>Household survey:</i> proportion of interviewees who consider quality of care and availability of medicaments a reason for not attending ANC (quality, medicaments).
A2 Accessibility	Locations of service points are in line with the location of pregnant women	<i>Household survey:</i> proportion of interviewees who consider the location of the service point as reason for not attending ANC (distance).	<i>Qualitative survey:</i> Focus group discussions and in-depth interviews with caregivers and mothers about barriers to access health services
A3 Affordability	Willingness and possibility to pay for the service	<i>Household survey:</i> proportion of interviewees who consider direct and indirect costs (lack of time) of the service as reason for not attending ANC (money, time).	<i>Qualitative survey:</i> Focus group discussions and in-depth interviews with caregivers and mothers about affordability and cost of maternal health services
A4 Adequacy	The organization of the service meets the clients expectations	<i>Household survey:</i> proportion of interviewees who consider the long waiting time and reception at the service point (unpleasant behaviour of health staff) as reason for not attending ANC (waiting, health staff).	<i>Qualitative survey:</i> Focus group discussions and in-depth interviews with caregivers about barriers to access health services
A5 Acceptability	Characteristics of providers match with those of the clients (including appropriate information and consideration of cultural and social values)	<i>Household survey:</i> proportion of interviewees who report that visiting ANC is not their habit, that they are not sufficiently informed and that they don't have the husbands permission (habits, misadvised).	<i>Qualitative survey:</i> Focus group discussions and in-depth interviews with caregivers about barriers to access health services

For the multiplicative model to be accurate, individual factors are assumed to be mutually exclusive and uncorrelated. As factors, $\beta_{(i)}$, are principally calculated based on proportions of reported reasons for not attending ANC, the denominator for calculating these proportions has been adjusted using the term $(N_{tot} - \sum_{j=1}^{i-1} N_j)$ for $i = 2, \dots, n$. N_{tot} denotes the total number of participants (mothers with child) and N_j the number of responses with reason related to an antecedent effectiveness factors. Each reason was converted into effectiveness factors by calculating 1 minus the proportion. Robustness of the assumption related to the independence of the factor has been scrutinized by examining the distribution of answers given by participants. Identification of the parameters with highest leverage was calculated by comparing changes in the overall effectiveness by increasing a single parameter by 5% (Muthiani et al., 2015). The parameters derived from participants' responses have been subject to probabilistic sensitivity analysis. Normal distributions were constructed for the number of participants' responses with the estimates of the survey being the most likely value (mean), and the standard deviation being 5% of the actual responses. Latin hypercube sampling was applied to allow for uncertainty around the estimated effectiveness parameter and to investigate partial correlation between the single parameters and the effectiveness outcome.

Ethical approval

Ethical approval was given by the Ministry of Health, Chad. Participation was voluntary. All data were treated confidentially. Informed consent by all study participants has been obtained and signed (or a fingerprint in the case of illiterate individuals). All interviews, discussions and questionnaires were conducted in participants' local languages (specifically Chadian Arabic in Yao health district and Sara in addition to Chadian Arabic in the Danamadji district).

Results

Utilisation of maternal health services

Table 2.3. shows utilization rates for ANC as well as the rate of home delivery stratified for sedentary and mobile populations. ANC has been differentiated according to the number of visits: at least one visit (ANC), at least three visits (ANC3) and at least four visits (ANC4). Utilisation rate were systematically higher for sedentary populations. The utilisation rates for ANC decreased with the number of required visits ranging from 70% to 29%. For mobile pastoralists, only 46% of pregnant women attended ANC at least one time, 20% at least 3 times and 9% at least 4 times. 13% of the sedentary and 8% of the pastoralist mothers had skilled attendants at the health facility during delivery.

Table 2.3. Utilisation of maternal health services

	Any visit to ANC (95% IC)	At least 3 ANC visits (95% IC)	At least 4 ANC visits (95% IC)	Homebirth (95% IC)
Sedentary population (n=786)	79% (71%-85%)	63% (55%-71%)	29% (23%-36%)	87% (77%-93%)
Mobile pastoralists (n=358)	46% (40%-53%)	20% (12%-32%)	9% (3%-23%)	92% (81%-97%)

Utilisation of maternal health services (ANC visits and skilled attendance at the health facility during delivery) was significantly associated with a higher socio-economic status of the household and with being in the district of Danamadji (Table 2.4.). Whereas utilisation rates of health services were systematically lower for mobile pastoralists in Table 2.3. the dominant drivers for low maternal health service utilisation were economic and geographical factors. Noticing that, based on the proportion of respondents, at this stage the regression takes into account only the quantitatively measurable aspects.

Table 2.4. Association between the utilisation of maternal health services, and socio- demographic and geographical variables

	ANC1		Homebirth	
	OR (95% CI)	p value	OR (95% CI)	p value
Belonging to the intermediate socio-economic category	1.48 (0.66-3.34)	0.34	0.66 (0.30-1.47)	0.31
Belonging to the rich socio-economic category	2.86 (1.01-8.05)	0.04	0.29 (0.10-0.86)	0.02
Living in the Danamadji district	7.01 (3.34-14.70)	<0.01	0.11 (0.03-0.49)	<0.01
Belonging to the sedentary population	1.03 (0.28-3.82)	0.97	0.93 (0.14-6.18)	0.94
Secondary school completed	1.54 (0.59-4.02)	0.38	0.28 (0.11-0.76)	0.01

Assessment of effectiveness parameters

Effectiveness parameters were principally derived from the study participants' reported reason for non-participation in a simultaneous way allowing for multiple answers. Thus, individual factors are not a priori mutually exclusive and can therefore not be assumed to be uncorrelated.

To better understand the distribution of the reported answers, the relative frequencies of answers and answer combinations have been mapped to the five access dimensions presented in Figure 2.1. Answers for "I don't know" and "others" were dropped.ⁱ It can be seen that the majority of answers can be matched to a single dimension, which generally supports the independence assumption and, thus, the application of the multiplicative model. In particular, 59% of answers can be categorized as single dimension for sedentary populations and 72% for mobile pastoralists. It can be noted that acceptability, accessibility and affordability were the most frequent dimensions. For mobile pastoralists the acceptability parameter clearly stood out as the most frequently reported reason.

ⁱ "I don't know" was reported as reason for not attending ANC by 7% of sedentary populations that didn't attend ANC (4% for mobile pastoralists). 4% of sedentary populations and 3% of mobile pastoralists reported other reasons which could not be matched.

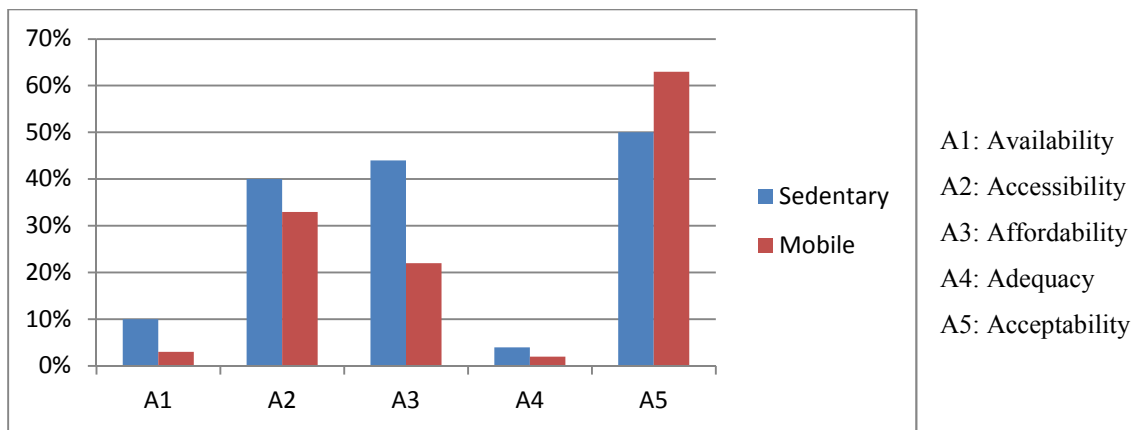


Figure 2.1. Distribution of combined answers mapped to the 5 coverage dimensions as percentage of study participants that not attended ANC (cutting point 3%)

Figure 2.2. and Figure 2.3. depict the multiplicative relation as specified by the effectiveness model differentiating between the single parameters ($\beta_{(i)}$) and its cumulative effect. In both communities, nomads and sedentary, the availability factor had the same effect as it was calculated based on the availability of folic acid in the health facilities (it contributes up 82% to the effectiveness). A substantial number of respondents from both communities considered long distances a reason for not attending ANC. Translated into a coverage factor in the effectiveness model, accessibility contributed almost equally to the effectiveness of ANC coverage in both populations (82% in sedentary and 80% in mobile pastoralists).

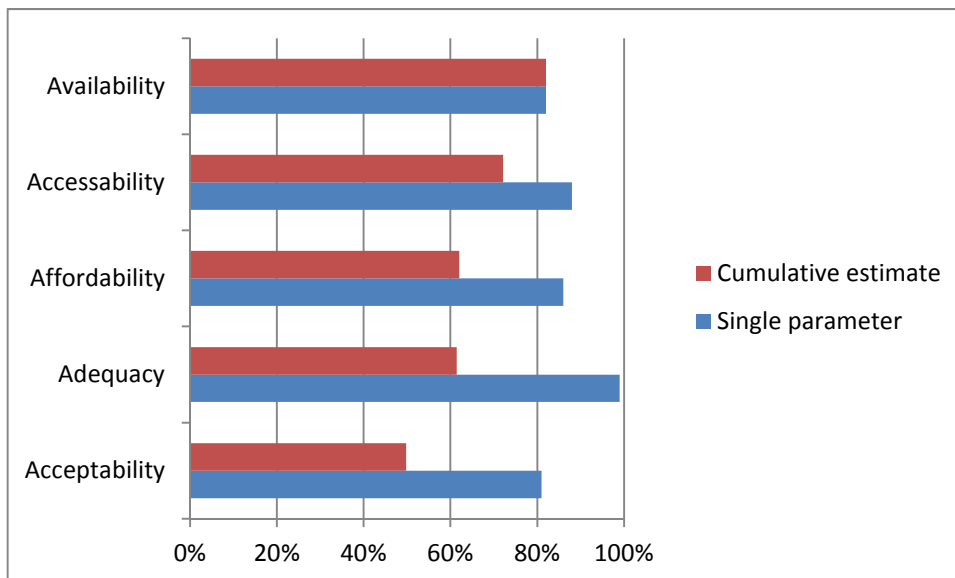


Figure 2.2. Contribution of parameters determining the effectiveness of ANC services among sedentary populations

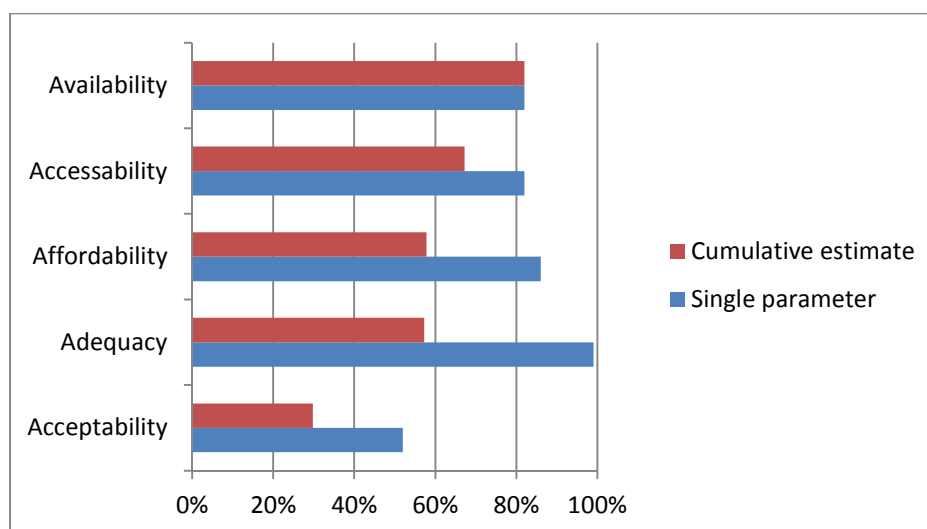


Figure 2.2. Contribution of parameters determining the effectiveness of ANC services among mobile pastoralists

As it has been shown from the regression analysis results (Table 2.4.), health service utilisation was closely associated with the socio-economic status of the population. In the effectiveness model, willingness and ability to pay for health service together with time spent as an indirect cost were expressed as affordability parameter that reduces the service's coverage. In terms of coverage factors, affordability contributed equally to effectiveness by 86% for both communities.

The way that health services are organized in terms of reception, hospitalisation and care provision (adequacy) is expected to contribute to the effectiveness of a given health intervention or health service. When these elements meet clients' expectations, then the service's coverage is not expected to be considerably reduced by the adequacy parameter. In fact, adequacy represents the parameter with the highest value among all factors for both populations (it contributes up to 99% to the effectiveness).

The acceptability parameter revealed the lowest value as compared to the remaining factors and was particularly low for mobile pastoralists (81% among sedentary and only 52% among mobile pastoralists) contributing considerably to the final effectiveness. Acceptability implies that participants have enough and appropriate information about ANC services and that they corresponds with their socio-cultural values. In fact, "not in our habits", "not having husband's permission" or lack of information were often reported by participants as reasons for not attending ANC. For mobile pastoralists, acceptability clearly stood alone as a major reported reason among participants that have not attended ANC.

Final effectiveness of ANC coverage is 50% for sedentary populations and 30% for mobile populations. For the latter group, the calculated effectiveness ratio falls within the 95%-confidence band for estimated ANC3 service utilisation presented in Table 2.3.. For sedentary population, the calculated ratio is slightly below this confidence interval.

Sensitivity analysis

Table 2.5. identifies the different leverages of the single parameters based on a deterministic one-way sensitivity analysis. Generally, the most important parameters were availability, accessibility, affordability and acceptability for both sedentary populations and mobile pastoralists. Acceptability appeared to be the parameter with the highest leverage among mobile pastoralists whereas for sedentary population the four parameters seem to be equally important.

Table 2.5. Sensitivity of overall effectiveness with respect to a 5% increase in single factors for sedentary populations and mobile pastoralists

	Sedentary population		Mobile pastoralists	
	Parameter	Sensitivity in %-points	Parameter	Sensitivity in %-points
Availability	0.82	3.0%	0.82	1.8%
Accessibility	0.88	2.8%	0.82	1.8%
Affordability	0.86	2.9%	0.86	1.7%
Adequacy	0.99	0.5%	0.99	0.3%
Acceptability	0.81	3.0%	0.52	2.8%

Probabilistic sensitivity analysis showed that results are robust to inclusion of uncertainty. Looking the empirical density functions in Figure 2.4., it can be noted that the final effectiveness was with high probability between 0.47 and 0.51 for sedentary and between 0.25 and 0.33 for mobile populations. The according functions did not overlap, suggesting that the difference of final effectiveness of maternal health services between sedentary and mobile populations persist also when accounting for parameters uncertainty

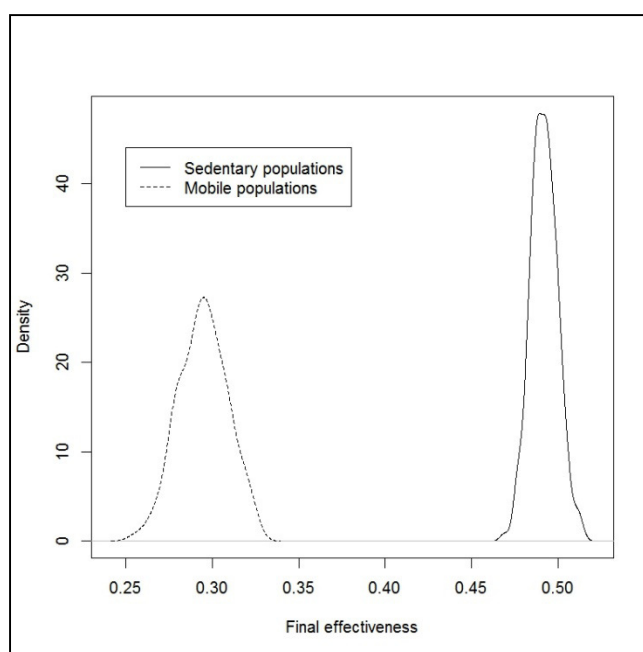


Figure 2.4. Empirical density function of the model result (effectiveness of ANC coverage)

The partial correlations presented in Figure 2.5. measure how strong the linear associations are between the effectiveness and each input parameter, after removing the effect of the other parameters. Results are in line with the one-way sensitivity analysis: For both populations adequacy was weakly related to the final effectiveness. On the other hand, final effectiveness is considerably sensitive to availability, affordability and acceptability. For nomadic populations, acceptability was the most sensitive parameter, whereas the three appeared to be equally important for sedentary populations.

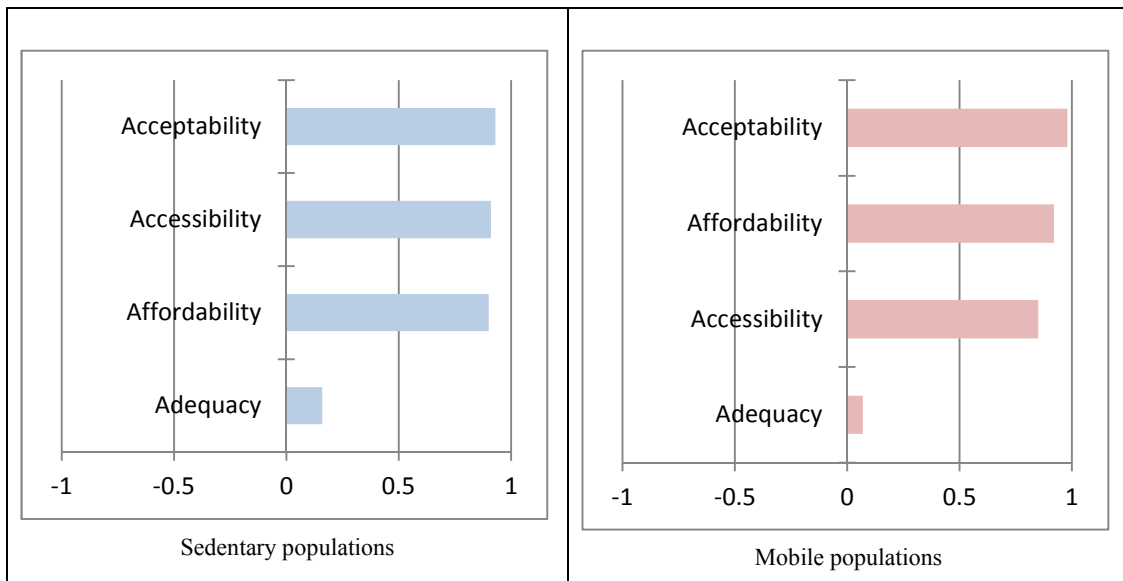


Figure 2.5. Partial correlation coefficients between the model result (effectiveness of ANC coverage) and each parameter

Discussion

ANC is considered one of the most effective health interventions in improving pregnancies outcomes and was therefore suggested as an overwhelming priority to policymakers aiming at reducing maternal mortality (Bullough et al., 2005, Hollowell et al., 2011, Campbell et al., 2006, Carroli et al., 2001). Even though large inequalities exist (Bullough et al., 2005, Hollowell et al., 2011, Campbell et al., 2006, Carroli et al., 2001), evidence to recommend implementation of maternal health interventions for improving health outcomes for disadvantaged and vulnerable women is insufficient (Bullough et al., 2005, Hollowell et al., 2011, Campbell et al., 2006, Carroli et al., 2001).

In general, the empirical estimates from this study showed that utilisation rates of maternal and infant health services were systematically lower among mobile pastoralists when compared to rural sedentary populations. The rate of respondents who attended at least one ANC visit among sedentary populations was 79%, while among nomads it was only 46%. Although this rate decreased in both populations with the increasing number of required ANC visits, the difference between the two groups persisted. According to the national DHS survey conducted in 2014, 59% of rural mothers between 15

and 49 years in Chad have attended at least one ANC during pregnancy, which lies between the utilisation rate estimated for sedentary and mobile populations in the present study. Consistent with our findings, the national estimates for rural areas decreased with the number of required visits: 54.3% attended ANC at least 3 times and 26% at least 4 times (the national health system policy in Chad requires a minimum of 4 antenatal visits). These figures are well above the utilisation rate of mobile pastoralists in the study districts (20% attended ANC at least 3 times and 9% at least 4 times) and are roughly covered by the 95% confidence interval of the according rates for sedentary populations (63% attended ANC at least 3 times and 29% at least 4 times). Both communities in the two study districts had high rates of home birth attendance (87% of sedentary and 92% of mobile populations) which means only very few mothers attended skilled assisted delivery at a health facility. This corresponds with the latest DHS estimates that indicate that in rural Chad, 85.3% of the mothers gave birth at home. In general, compared to sedentary populations, mobile pastoralists in the study district revealed larger deviations from national (rural) averages of ANC utilisation and facility-based delivery, which confirms the inherent inequality of maternal health service contact.

The maternal and infant health service utilisation was found to be significantly associated with high socio-economic status of respondents and geographical factors. Indeed, maternal health service utilisation is known to be associated with high socio-economic status of women. For example, analysis of data issued from health and demographic surveys conducted in 31 countries revealed that for the poorest women (those in the poorest wealth quintile) the odds of having skilled attendant at delivery are 94% lower than those in the highest wealth quintile (Ahmed et al., 2010). Similar patterns linking maternal health utilization and more generally health service utilization with high socio-economic status were documented in low income countries aiming at addressing the inequity in health service delivery between and within countries (Whitehead, 1991, Peters et al., 2008, Wagstaff, 2002). With regard to the geographic factor, in line with our findings, the latest DHS survey confirms a large difference in ANC attendance between the two regions where the study districts are situated: only 26% of the mothers have attended at least one ANC in Batha (Yao region) as compared to 81% of the mothers in Moyen Chari (Danamadji region). The latter district is generally known to be better equipped in terms of infrastructure including health services, which might be an explanation of the low utilisation rate. In fact, the quality of services is found to be higher in the Danamadji health district than in Yao in terms of structural attributes (SwissTPH, 2016c).

The presented utilisation estimates suggest that, to foster more equal benefits of maternal health services, interventions must be increasingly targeted towards marginalized populations, poor households, and neglected geographical regions. To better understand the health system's determinants of these differences in service coverage and enable the design and optimisation of according interventions, an effectiveness model of ANC has been calibrated to household and health

facility data. The model gave a final community ANC effectiveness of 50% for sedentary population and 30% for mobile pastoralists mirroring the differences of the empirical utilisation rates between the two populations groups. The final effectiveness lies below the estimated rate of mothers attending ANC at least one time and corresponds roughly with the percentage of mothers attending ANC at least three times. The lower effectiveness derived from the model as compared to the empirical estimates is consistent with the fact that coverage factors were estimated based on study participants' reported reasons for not attending ANC and that multiple answers were allowed. Even though most respondents mentioned only one reason, justifying the independence assumption in the multiplicative specification of the effectiveness model, the remaining multiple answers shifted the final ANC effectiveness below the empirical utilisation rate due to double counting a part of the responses. Nonetheless, probabilistic sensitivity analysis showed that the difference in effectiveness between the two groups of population is robust to the inclusion of uncertainty in participants' responses.

Five dimensions of access have been used to quantify the health system's determinants of ANC effectiveness: availability, affordability, accessibility, adequacy and acceptability. Deterministic and probabilistic sensitivity analysis has been used to show which of the parameters provides the highest leverage for increasing final effectiveness. For sedentary populations, availability, accessibility, affordability, and acceptability were equally important, whereas sensitivity of the effectiveness outcome for mobile populations was highest with respect to acceptability. In order to increase maternal and infant health service effectiveness for both populations, an in-depth understanding of the results attributed to the five dimensions is required. In the following, these dimensions are discussed against the background of a qualitative study conducted in the study districts on access to maternal and infant health services (SwissTPH, 2016b).

Although, availability was calculated primarily based on the folic acid (FeFo) availability at health facilities, other factors should be considered such as the availability of qualified health personnel for ANC. Qualitative data showed that mothers mentioned concerns with the availability of qualified personnel in health centres mirroring the fact that maternal health services are usually provided by matrons. Furthermore, quality/efficiency of care as well as the availability of medications and prescriptions were considered as barriers to access maternal health services (SwissTPH, 2016b).

Accessibility contributed equally to effectiveness among both study populations by up to 82%, which is relatively high. Nonetheless, attention should be paid to long distances to health centres which are often mentioned as reasons for non-attending ANC at health facilities especially in rural areas in developing countries. Considering the deteriorated roads conditions especially during rainy season and the distance between health facilities and households (villages and camps), transportation for pregnant women to health facilities is challenging (Simkhada et al., 2008, Say and Raine, 2007, Mrisho et al.,

2009, Gabrysch and Campbell, 2009). This is also line with the results of the FGDs where sedentary and nomadic mothers raised concerns about the distance to health facilities (SwissTPH, 2016b).

Affordability contributed to the final effectiveness with 86% for both sedentary and nomadic populations which is comparable to the accessibility dimensions. Issues with ability to pay for ANC services are related to transport, waiting time and sometimes bribes in exchange for better services. Mothers from sedentary populations generally showed more concerns about the costs related to ANC attendance and assisted delivery at a health facility. This could be partially explained by the fact that nomads have more possibilities to cover costs related to health services as they rely on their livestock while the majority of sedentary populations depend only on agricultural activities.

Although adequacy clearly represented the least important effectiveness parameter, findings from the qualitative study revealed that poor reception, such as health personnel being unpleasant, and long waiting time were considered as reasons for not attending ANC for both sedentary and mobile populations. Despite all this, only very few respondents have not attended ANC due to a lack of adequacy for both communities (4% among sedentary and 2% among nomads).

Acceptability was the key factor providing the main contribution to the final effectiveness by reducing ANC coverage by 81% for sedentary populations and 52% for mobile pastoralists. It is also the parameter revealing the largest difference between the two population groups, which suggests a large potential for improving equality of maternal health outcomes. The specific reasons of low acceptability of maternal health services are likely to be found in inadequate information and cultural issues. The cultural distance between the provision of maternal health services and the target communities appeared to be particularly large for mobile populations. For example, it was found that sedentary and nomadic women rely on the husband's approval for visiting a health facility which turned out to be challenging in nomadic communities where men are frequently absent due to mobile pastoralism (SwissTPH, 2016b). Furthermore, appropriate information on ANC services and their importance for pregnant women and children's health was lacking. Being confused about ANC services and not being aware of the importance of delivery in a health facility were among the reasons preventing child and maternal health service utilization for mothers from sedentary and mobile populations. Nomadic women appeared to be particularly ill-informed which led to a biased perception on ANC, considering the services only necessary in case of severe illness (SwissTPH, 2016b). In line with these findings, results from a recent study on vaccine hesitancy among mobile populations conducted in one of the two concerned health districts (Danamadji) revealed that the lack of appropriate information and cultural issues were respectively cited as the main factors preventing the nomads from accessing vaccination services (IRED-SwissTPH, 2016). These are all reasons that are captured under the acceptability factor in the present study.

Furthermore, rural populations typically prefer the utilisation of alternative health services such as traditional birth attendants, traditional healers and the “marabouts” services, and only come to health facilities when it gets complicated (Anderson et al., 2003, Peltzer, 2009), which is also confirmed by the results of the qualitative study (SwissTPH, 2016b).

Following the logic of the iterative cycle of action (Mosimann et al., 2017), in a subsequent step, health service intervention in the two districts need to be improved through a participatory approach, based on the outcome of the current study. Considering the fact that the five dimensions to access health care are related to each other, a holistic view must be considered when trying to improve the community effectiveness. In particular, interventions must seek to target not only the provision and quality of services (availability) but also demand side barriers related to costs, transportation and cultural values.

To foster more equal access between sedentary and mobile populations, particular attention must be paid to acceptability of maternal health services among nomadic communities. Adapted information campaigns for illiterate men and women targeting specific cultural barriers of nomadic populations as well as sedentary populations are required in order to increase acceptability in these communities. Furthermore, next to improving quality of care, appropriate health financing schemes for poor households need to be considered. A participatory process bringing together all relevant stakeholders and communities representatives would contribute not only to increase acceptability but also to help prioritizing the actions towards more effectiveness. Encouraging and accompanying the community health workers current strategy of the Chadian Ministry of Health would be an appropriate option for increasing effectiveness and reduce inequalities.

Conclusion

Utilisation and effectiveness of mother and child health services was low in rural Chad. Whereas utilisation rates of health services were systematically lower for mobile pastoralists, the dominant drivers for low health service utilisation seem to be economic and geographical factors. Acceptability of maternal health services resulted as the most sensitive factor for increasing effectiveness especially for mobile pastoralists. Intervention must generally focus on improving community effectiveness through targeting the factors with the highest leverage among specific populations in order to foster effective and equitable health services. Improved equity-effectiveness of antenatal care can be achieved by entering an effectiveness optimization cycle.

**CHAPTER 3: VACCINE HESITANCY AMONG MOBILE
PASTORALISTS IN CHAD: A QUALITATIVE STUDY**

Vaccine hesitancy among mobile pastoralists in Chad: a qualitative study

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Abstract

Demand side barriers for vaccination among rural and hard-to-reach populations in Chad are not yet well understood. Although, innovative approaches such as linking human and animal vaccination have been shown to increase vaccination uptake among mobile pastoralist communities, vaccination coverage in these communities is still lower than for sedentary populations. We hypothesize that mobile pastoralists' communities in Chad face specific demand side barriers to access vaccination services. Understanding the factors that caregivers in these communities could take into account, explicitly or implicitly, in order to decide (or not) to vaccinate a child is an essential element to tailor vaccination programmes towards increasing vaccination acceptance and uptake. At the same time, we better need to understand the providers' perspectives to get a fuller picture.

We have conducted a qualitative study with key 12 informant in-depth interviews (KII) and four focus group discussions (FGD) with 35 male and female participants. Participants in the study included caregivers, traditional chiefs, local and religious leaders from mobile pastoralist communities, and health officials and staff in Danamadji District in Southern Chad.

The most frequent group of demand side barriers reported in FGDs was mistrust on the expanded programme on immunization (EPI) and polio vaccination outreach services (53%, n = 94), followed by health system issues (34%, n = 94), and finally concerns related to potential harm of vaccines (13%, n = 94). Concerns identified by caregivers, health professionals and community leaders followed a similar distribution with issues with programme mistrust being the most frequently reported and issues with harm the least frequent. None of the health professionals reported concerns about vaccinations being potentially harmful.

Mobile pastoralist communities face specific demand side barriers to vaccination. Understanding these barriers is essential to reduce vaccine hesitancy and increase vaccination uptake. Local health systems must plan for periodic presence of pastoralist communities in their zones of responsibility and create more mutual trust.

Keywords

Immunization, vaccination, barriers, mobile pastoralists, Chad

Background

Vaccination is one of the most successful and cost-effective interventions in public health (Ozawa et al., 2012). The World Health Organization in 2015 estimated that 2-3 million deaths from vaccine preventable diseases (VPD) were averted yearly due to vaccination. However, vaccination provision and uptake remains low in diverse settings with substantial gradients across population groups (Restrepo-Mendez et al., 2016, Hosseinpoor et al., 2016). Globally, the international community has made important strides towards improved vaccination coverage (WHO, 2014), but in most low and middle income countries, full immunization coverage of children and women is distributed unevenly according to socio-economic status (Restrepo-Mendez et al., 2016).

Whereas increasing access to vaccination has been the main strategy to improve vaccination coverage for the last three decades, there is an increased focus of policy makers and international institutions on what has been called ‘vaccine hesitancy’ (demand side barriers to vaccination) (Larson et al., 2014). Vaccine hesitancy exists “when vaccine acceptance in a specific setting is lower than what would be expected, given the availability of vaccine services” (SAGE working group, 2014). Vaccine hesitancy could lead to suboptimal compliance with vaccination schedules in children, low vaccine uptake or even vaccine refusal (Brown et al., 2010, Falagas and Zarkadoulia, 2008). A recent systematic review of the literature found that despite concerns spread across most of the settings, e.g. the fear that vaccines could produce serious negative effects on children’s health, these were highly influenced by cultural, religious or social beliefs (Cobos et al., 2015).

According to data from the last Multiple Indicator Cluster Survey (MICS) conducted in Chad in 2010, polio vaccination coverage (3 doses) was 32% and measles vaccination coverage was 36% (INSEED, 2011). These figures were even in rural areas. Among mobile pastoralist communities, vaccination coverage among livestock was significantly higher than for children (Zinsstag et al., 2006, Schelling et al., 2007b). Hence, mobile pastoralists in Chad represent a particular case of inequity in access to vaccination services.

Demand side barriers for vaccination among rural and hard-to-reach populations in Chad are not yet well understood. Based on anecdotal and non-structured analysis of people’s beliefs and attitudes towards vaccination, managers of the Expanded Programme on Immunization (EPI) have focused their efforts on providing information on the benefits of vaccines as a means to increase vaccination uptake. However, evidence from other West and Central African countries suggests that there can be other relevant factors that prevent caregivers from vaccinating their children, for instance, concerns about the potential harm of vaccines in Benin (Fourn et al., 2009), fear of being sterile after vaccination in Nigeria (Babalola, 2011) or worry about health staff being unpleasant in Burkina Faso (Sia et al., 2011). Lack of transportation, language barriers and health staff being unpleasant were among constraints preventing pastoralists women to access health services in Chad, beside Muslim women

need to ask husbands for permission or being accompanied by a relative (Hampshire, 2002b). One should also add women's difficulties to call their husbands, who might not be around, to ask for permission while mobile phone network is sometimes weak (Corradi and Schurr, 2011).

The Sustainable Development Goals (SDGs) target in an interdisciplinary manner the reduction of inequities with universal policies considering the needs of disadvantaged and marginalized populations. Although, innovative approaches such as linking human and animal vaccination with interdisciplinary teams have been shown to increase vaccination uptake among mobile pastoralist communities (Ndiaye et al., 2014a, Kamadjeu et al., 2015, Belmaker et al., 2006, Schelling et al., 2007c), vaccination coverage in these communities is still lower than for sedentary populations.

Thus, we hypothesize that mobile pastoralist communities in Chad face specific demand side barriers to access vaccination services. Understanding the factors that caregivers in these communities could take into account, explicitly or implicitly, in order to decide (or not) to vaccinate a child is an essential element to tailor vaccination programmes towards increasing vaccination acceptance and uptake.

Methods

This study aims to identify demand side barriers that hinder the access to vaccination services among mobile pastoralist communities in Chad. We use inter-exchangeably the term nomadic communities when referring to the same communities despite not all mobile pastoralists are necessarily nomads. We have conducted a qualitative study with key informant in-depth interviews (KII) and focus group discussions (FGDs). Participants in the study included caregivers, traditional chiefs, local and religious leaders from mobile pastoralist communities as well as local health official and staff in Danamadji district in Southern Chad.

Study setting

Danamadji district is located in the southern part of Chad along the border with the Central African Republic. The district covers 18 functional and 7 non-functional health zones (SwissTPH, 2016a), that provide health services for a total of 128,369 inhabitants (INSEED, 2014). This district has a substantial number of pastoralist communities (mainly from the Arab and Fulbe ethnic groups and important pastoral areas as transhumance routes and resting areas. During the study period the transhumance to the Republic of Central Africa (RCA) was virtually blocked which led to a higher concentration of Fulani pastoralists who have long transhumance routes between RCA and Chad. The findings from a recent random household survey in the district showed that health service utilization rates were relatively low on average and were systematically lower for mobile pastoralists as compared to sedentary populations. In total, 39% of the sedentary populations and only 12% of the pastoralist mothers had experienced skilled birth delivery. With regards to vaccination, 7% of the children in pastoralist communities were vaccinated against BCG compared to 79% of the children in

the sedentary population. Poliomyelitis vaccination coverages were 11.6% among mobile pastoralist communities and 80% among sedentary children (SwissTPH, 2016a).

Data collection & participants

Researchers with experience in qualitative data collection and analysis have conducted the interviews and have facilitated the FGDs. The study design and planning of field work was done jointly between scientists in Chad and Switzerland. All interviews and FGDs were done in April 2016.

Qualitative methods allowed exploring the underlying issues of vaccination hesitancy beyond the observed low utilization rates of vaccination services among mobile pastoralist communities. FGDs were conducted in order to provide insight regarding experiences and beliefs that may not have been revealed in one-to-one interviews but were only observable through participation in a social gathering and interaction.

Semi-structured interviews were conducted with key informants within the nomadic communities, civil and traditional authorities and health staff. In particular, the study participants included primary caregivers (mothers with at least one child under 5 years old), heads of families who are decision makers and resource controllers, local health authorities as well as civil and religious leaders (Table 3.1.). Key informant interviews (KII) took on average 45-60 minutes to complete.

Table 3.1. Summary of data collection

Method	Target group	Sex	Location	Number
Individual interviews	Civil authority	Male	Danamadji	1
	Responsible for vaccination services	Male	Danamadji	1
	Head of family	Male	Ridina, Konoko, Daranaïm, Djanatanaïm	5
	Caregiver (mother with child < 5 years)	Female	Ridina, Konoko	4
	Religious leader	Male	Daranaïm	1
Total interviews				12
FGD	Caregiver (mothers with child < 5 years)	Female	Ridina, Daranaïm	2
	Head of family	Male	Darbarid, Alqaba	2
Total FGD				4

The participants in each two FGDs were mothers and heads of family (Table 3.1.). The duration of the FGDs was on average one hour. FGDs were conducted in nomadic camps, in a quiet, private place away from distraction. Each FGD was facilitated by at least two people of the same sex as the participants.

The first draft of the KII and FGD guidelines were elaborated based upon literature review and discussions with experts of the Chadian context. Care was taken to include questions related to all categories of preliminary vaccination concerns as outlined in Table 3.2.

Table 3.2. Categories of concerns about vaccination adapted from the literature (Mills, 2005; Cobos, 2015)

<p>1. Issues with harmful effects of vaccination</p> <ul style="list-style-type: none"> a. Concerns that immuno-compromising b. Concerns that cause diseases / general harm / adverse effects c. Concerns that is harmful if the child is sick d. Concerns with side-effects after vaccination (including pain) e. Parents remember their own or other adverse experiences f. Exposed to pathogens in clinics g. Fear of needles h. Vaccines are provided at too young age / too many vaccines and doses
<p>2. Issues with programme mistrust</p> <ul style="list-style-type: none"> a. Rumours / distrust of medical community b. Lack of confidence in vaccines effectiveness c. Religious reasons d. Not enough information to make the decision
<p>3. Health system issues</p> <ul style="list-style-type: none"> a. Concern with cost / access to the health facility b. Concern with time / working hours c. Health staff are unpleasant / untrained d. Concern with not been able to get the vaccine e. Concern with quality of the vaccine
<p>4. Other issues</p>

The draft was field tested and further refined in a participatory process involving local experts in human and animal health as well as representatives of the nomadic communities to compare and contrast views and opinions. The interview guide was piloted among the different target groups in the study district before being implemented. The interviews and FGDs were audiotaped, transcribed and translated from Chadian Arabic into French. The analysis was conducted with the French translation.

Analysis

We have conducted a thematic content analysis of the transcripts of KII and FGD. We adapted an existing framework to understand concerns about vaccinations (Cobos et al., 2015, Mills et al., 2005, Schelling, 2002) to code and then categorize the themes. The main categories were: (i) issues with harmful effects of vaccination, (ii) issues with programme mistrust (we mean by programme here all vaccination activities carried out [e.g. EPI and polio vaccination days]), (iii) health system issues, and (iv) other issues raised were elaborated (Table 3.2.).

Each transcript was analysed systematically and responses were “cross-coded” to the category where they fitted thematically.

Ethical considerations

The study received ethical clearance from the Nation bioethics committee in Chad “Comité National de Bioéthique du Tchad (CNBT)” and the WHO Research Ethics Committee Review (WHO ERC) (decision N°186/PR/PM/MESRS/SG/CNBT/2016, 12/04/2016; Protocol ID: ERC.0002684, 18/03/2016).

The study participants were given detailed information about the purpose of the study and extent of their involvement. Informed consent was obtained from all study participants before starting the interviews and FGDs. It was explained that participation is voluntary, without compensation and individuals may withdraw from the study at any time, no tracing back of statements to individuals would be possible and participation was without negative consequences for them, their family or their community. All participants were adults and either signed or fingerprinted the consent form.

Results

A total of 94 quotes were extracted from 12 KII and 4 FGD reported concerns about hesitancy or barriers to access vaccination in Danamadji. In total, 35 men and women participated in the four FGDs.

The quotes were retrieved as follows: 73 from KII, 15 from FGDs with male participants and 12 from FGDs with female participants. Most quotes were from caregivers, followed by health staff and community leaders.

Demand side barriers to vaccination in Danamadji

The most frequent reported demand side barrier were related to issues with programme mistrust (53%), followed by health system issues (34%), and finally concerns related to potential harm of vaccines (13%). The five most frequently reported demand side barriers to vaccination are shown in Table 3.3.

Table 3.3. Five most frequently reported demand side barriers to vaccination in Danamadji district

Category	Issue/concern	Number of quotes
Trust/mistrust	Not enough information to make the decision	34
Health system	Health staff are unpleasant / untrained	22
Trust/mistrust	Religious reasons	10
Harm	Concerns that causes diseases / general harm / adverse effects	9
Health system	Concern with time / working hours	6

Concerns identified by caregivers, health professionals and community leaders followed a similar distribution with issues of trust/mistrust being the most frequently reported and issues with harm the least frequent (Figure 3.1.). None of the health professionals reported concerns about vaccination being harmful.

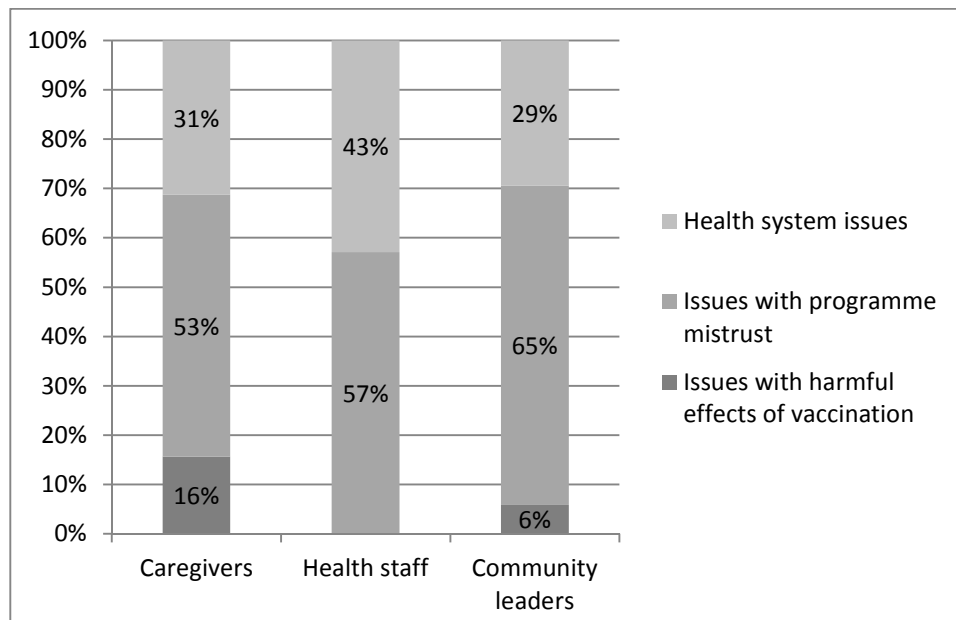


Figure 3.1. Distribution of concerns about vaccination reported in Danamadji per type of participant (n=95)

Issues with harmful effects of vaccination

Concerns related to the potential harmful effects of vaccines or their side effects were the least reported category of demand side barriers to vaccination among mobile pastoralist communities in Danamadji. Among concerns reported the risk of sterility, fever, diarrhoea, inflammation of the throat and even death, were some of the reported potential adverse effects.

For some individuals, a disease was an opportunity for the body to get stronger and, since vaccines prevented that process, they subsequently weakened the child's (immune) system. One father pointed out:

“In general, diseases are part of human daily life. It is not all the time that when a child is sick, then we should go immediately to a hospital. Diseases for children are somehow a necessary bad thing. By falling ill, they become immune. So we do not go to the hospital or health centre immediately for a given disease of the child” (Man, Alqaba).

This thinking seems to be wider than for vaccinations: *“Certainly the disease is a very bad thing, especially malaria and colds in children. In general, we do not want the children to get sick. But when that happens, we do not get too concerned. For myself, I have bad experience with healthy children. When the child falls sick from time to time, this is a good sign that it will survive because it gets stronger. But when the child is still in good health, there is fear the day it falls ill. I have in all 7*

children 2 of them died. One died unexpectedly because he was always healthy. One day he fell ill and the third day of his illness, he could not conquer the disease and died. Therefore, diseases in children are a sign of longevity. Do not regret too much that children fall ill” (Woman, Konoko).

Issues of mistrust of vaccination programmes/services

The most frequently reported demand side barrier to vaccination was that caregivers did not have enough information to understand the benefits of vaccination, to know the process to get their children vaccinated or to trust the health workers coming to the camps during polio outreach vaccination days. It was widely acknowledged by most participants that nomadic communities received too little information about vaccines and their benefits:

“We cannot comment on the pros and cons of a thing until you know the thing. In the case of vaccination, we cannot say, because no one came to us to tell us against which disease the vaccination is. So we cannot know whether vaccination is a solution as described by the State or a problem as the rumours say” (Male, Alqaba).

Mobile pastoralist communities are usually less reached with information than other communities, and they do not have regular contact with health facilities or authorities. There are only few opportunities when individuals have some regular contact with conventional health services (e.g. antenatal care visits or delivery), and they only make use of health services during illness or in emergencies. A participant in a FGD was surprised that they could use health services for vaccination when they are healthy: *“Here we do not know that when a child is healthy, we can get him to the hospital to take the vaccine which protects him against a number of diseases that are disturbing and even killing our children” (Male, Darbarid).*

Even the most basic information about vaccinations did not reach some nomadic communities: *“Vaccination, I heard about it in street talks from people who do not know more than me. So nobody really told me what it is?” (Male, Darannaïm).* Seemingly, there is no channel that brings pro-vaccination messages to nomadic communities. Some caregivers complained that instead of receiving more information they were intimidated by health authorities forcing them to vaccinate their children. A camp leader reported: *“There are no communication channels between nomads and health professionals. In our camp here as elsewhere, we do not have a person who acts as an intermediary to convey information between us and the immunization services. There is a total lack of dialogue between us and the health services. They do not even have the phone number of the camp chief to call and deliver information. We are not informed of what is happening in the hospital. Even when the drugs arrive at the hospital, we have no one to inform us of the arrival of new products. I have no contact with people from the hospital and so I play no role in the health of neither children nor adults.” (Male).*

A mother complained: *"What we deplore is that when the vaccinators come here, they do not explain what they came to do. They only call the children and put the drops in their mouths. They are always in a hurry"* (Female, Daranaïm).

Some participants pointed out that it is understandable that parents do not trust something they do not know or have not been informed about. The way in which vaccination days are organized, with teams moving during one day from camp to camp to vaccinate children, was inadequate to provide sufficient information and convince caregivers to vaccinate their children. A religious leader reported: *"It's true that I am the imam (religious leader) having a great influence on the community, but no one came to explain to me what the vaccination is about so that I may have the possibility to widely inform my congregation during the Friday prayer and when people meet. General health services and those related to vaccination in particular lack a method to inform or convey their message. For example in the case of polio, instead of explaining us the merits and inform us of the arrival of the team of vaccinators in our camps, we suddenly see them arriving and catching children within their reach and administering the drops of vaccines. We parents only accept this method against our will. Some prefer to hide their children and sometimes colour their fingers as if to show that the children were already vaccinated so that they would not swallow anything. All of this is the lack of information about polio"* (Religious leader)

There was some confusion about the difference between vaccination days for polio vaccination and routine vaccination. Several participants referred only to polio vaccination when raising their arguments. They usually talked about "drops" when they referred to vaccination in general. Benefits of vaccination were not clear (neither for polio vaccination) and there was some reluctance to believe that vaccines are effective: *"Yes we heard about the vaccination about polio. But also for this vaccination issue, we have not seen drugs that can cure or protect our children"* (Female, Konoko). Some participants even felt that vaccination is not effective and vaccination campaigns are only conducted in the interest of district officials and health workers who receive per diem payments for the vaccination days: *"For me, polio is an organized business from the high hierarchy to the last vaccinators who administers the drops. Everyone finds his interest and that's it. This practice makes me doubt about the efficacy of poliomyelitis vaccine"* (Male, Darannaïm).

Religious and cultural beliefs also played a role in the decision making process of whether to vaccinate infants living in nomadic camps. Some communities believed that diseases are *"(...) a plan of God to train the child for the difficult moments"* (Woman, Daranaïm), and they should not fight them. For others, diseases had a religious/divine origin and they must be handled by traditional healers such as the Marabout. The services provided by traditional healers were considered to be more affordable, despite that vaccination is free of charge in Chad. They were also considered more effective as compared with western medicine (including vaccination): *"There are many kinds of illnesses in children, varicella, measles, etc. When the children here become sick, I intervene in the first place to*

use religious incantations. And it is only when the disease persists that the child is brought to the hospital. There are also cases where the child is sent home from the hospital without being cured, and at this level too I am the last resort to pray for God to cure the sick child. I intervene, I use incantations for all kinds of diseases”. (Male [Marabout], Ridina).

Issues with the health system

Concerns about vaccination providers in health facilities being unpleasant were widely reported by participants in KII and FGDs. Some participants considered health workers authoritarian and bad tempered. One informant pointed out: *“When we go to the health centre for care of our sick children, we are very poorly received. In some situations, we are expelled by health workers. Hoping that a child would never be ill so that one would not have to wait at the hospital saying that we want to have medication, imagine what treatments can be reserved for us? We pastoralists, don’t we have rights? Health workers consider us like our animals.”* (Male, Konoko).

Nomadic communities have a very poor opinion of health care workers in the district and this is a major barrier to vaccination. Even acknowledging that vaccination is free of charge and could have some benefits for children, parents decide not to vaccinate because they do not trust the system that provides them: *“The vaccination we know here is limited to polio. It is free, which is good, but the fact that there is no doctor or a serious health worker to come and administer the drops makes us sceptical about these drugs. You see filthy agents who come to do this work. Some of them are drunkards, which we know. This does not inspire confidence. You end up saying this vaccination business is a way to get work for some, to make money for others and all this at the expense of the health of our children. Finally, I have a negative perception of the entire vaccination operation”*, (Male, Ridina).

It was frequently reported that health professionals working in vaccination campaigns were not trained doctors or nurses and this raised concerns about their capacity to deliver vaccination activities. Some interviewees even saw this situation as a form of disrespect to nomadic communities: *“They send us the dirty young people from the neighbourhood to come and vaccinate our children against poliomyelitis. They are young people who only seek money without further concerns. They do not know anything about health (.....) People treat us like our animals and have no consideration for us. We have never seen a trained health worker or a doctor coming to vaccinate our children”* (Man, Ridina).

The fact that the messages about vaccination (essentially polio) or the interventions themselves are not provided by staff considered as peers in terms of religious and cultural background prevented some parents from vaccinating their children. In addition to the language barrier between health professionals and nomadic communities, health workers seemed to ignore the basic cultural and religious norms in the camps and there were only few Muslim health workers. One camp chief criticised: *“We want people to send us staff who know the health field. We prefer people close to our*

realities, who know our problems and who can transmit them to higher authorities to react. We want reliable people, who can educate us on vaccination” (Camp leader, Male).

Other examples of health system issues are the lack of cultural appropriateness of vaccination services and the timing of teams from the health centre for visits of camps. The timing for the visits significantly interfered with daily activities and obligations for both men and women in the camps. As one of the administrative authorities in Danamadji recognised: *“The reality is that the vaccinators cannot make the trip to the camps at any time, when the head of household is absent following his herds, for example. This is a serious cultural breach in pastoral communities as a wife has to seek opinion of her husband to decide on certain issues; such as exposing a child to strangers. This is also valid for the vaccination of children.”* (Male, Danamadji).

Discussion

We have identified demand side barriers to vaccination among nomadic communities in Danamadji District in Chad. There is a significant amount of literature which endeavours to understand barriers to vaccination services (Larson et al., 2014, Falagas and Zarkadoulia, 2008, Mills et al., 2005); however, nomadic communities faced specific barriers to vaccination that must be known in order to adapt the provision of services at the local level. Indeed, our study reveals more specific barriers for mobile pastoralist communities, particularly the mistrust to and bad reception at health centres, than time and distance that several other studies have reported earlier. One of the most frequent demand side barriers of vaccination is worry about the harmful effects of vaccination (Cobos et al., 2015).

Although the questions were designed to capture the perception on vaccination of women and children in general, most participants referred solely to the polio vaccination outreach days.

Issues related to lack of trust in the vaccination outreach days against polio and health system issues were the most frequently reported. Nomadic communities are reluctant to vaccinate their children because they did not have enough information about the benefit of vaccines or the location of vaccination services in their district. A substantial number of participants in our study complained that health staff was unpleasant or that they felt neglected or humiliated because they were nomads. They raised concerns about the qualification of vaccinators and their cultural distance from them as one of the most important disincentives to get their children vaccinated. Indeed, they sought interlocutors with knowledge on the daily life and culture between them and the health services.

Comparing to previous studies about vaccine hesitancy in low and middle income countries LMIC (Cobos et al., 2015), it is surprising that nomadic communities did not raise many concerns about vaccines being harmful for children or causing dangerous adverse effects. A recent literature review synthesized concerns about vaccination in LMIC and found that issues with harmfulness were the most frequently reported in both qualitative and quantitative studies across all continents (Cobos et al.,

2015). In this study however, the experiences reported on vaccination of children were virtually exclusively for polio vaccination. Other vaccines such as the *pentavalent vaccine* are more prone to cause side effects than the polio vaccine. Another interesting finding is that the Muslim nomadic communities did not report concerns about vaccines being part of a (Western) conspiracy to harm or sterilize Muslim communities. These concerns have been widely reported in Muslim countries (Chaturvedi et al., 2009) and were a major barrier to vaccination (Olufowote, 2011).

Communication channels between nomadic communities and the local health system seem to be non-existent. It is well known that communication and social mobilization is associated with high vaccination coverage and allows reaching “the sparsely covered groups” when included as a key component of immunization programmes, e.g. polio (Waisbord et al., 2010, Obregon and Waisbord, 2010). Although standard communication programmes exist, participants in our study stated that there was essentially no communication taking place between mobile pastoralist communities and the local health system, in general and specifically for vaccination. In addition the information channels were not adapted to the pastoralist context where illiteracy rates were much higher than among settled communities, and did not address the real concerns of nomadic communities’ caregivers in the Danamadji health district. Therefore, advocacy could be directed towards exploring new channels of communication with nomadic communities in the Danamadji health district by involving the community more through local social mobilisation teams and maintenance of a permanent contact network, e.g. using mobile phones with camp and group leaders. Importantly, interlocutors between them and the services need to be established.

The health system in Danamadji and elsewhere in Chad and the Sahel fails to provide vaccination services to nomadic communities, which translates into substantial immunisation inequities when compared to sedentary populations in the same district. To reduce health inequities in light of the sustainable development goals (SDGs), modern health system interventions must ensure that all population strata benefit of new policies. Barriers to existing vaccination services among mobile communities in the Danamadji could be substantially reduced by improving the information exchanges between the provider (health district) and the population. It has been previously shown that outreach campaigns combining veterinary and human health services are a promising and feasible strategy for increasing vaccination uptake among mobile communities (Schelling et al. 2007a). These campaigns were also successful because there was and is ongoing investment in appropriate information campaigns based on perceptions of human and animal vaccination. Indeed, adapted information material and routine (Expanded Programme on Immunization) vaccination campaigns using interlocutors for dissemination are now ongoing in Danamadji.

Less cost-intensive solutions must be explored in order to enable regular communication and information activities aimed at enhancing service utilisation of vaccination services at the health facility. Furthermore, cultural distance between vaccination providers and communities can be reduced by involving the representatives of the pastoralist communities in service delivery and communication activities.

In the past, we have good experience with transdisciplinary (TD) stakeholder meetings (Schelling et al, 2007) between communities, authorities and health workers. Such meetings can be foreseen in the study in the future to feedback these results and plan for Information, Education and Communication (IEC) training sessions for future campaigns, training for empathy and cultural sensitivity of health workers.

Conclusions

Nomadic pastoralist communities face specific demand side barriers to vaccination. Understanding these barriers is essential to reduce vaccine hesitancy and increase vaccination uptake. Local health systems must be sensitive to and act upon these specific needs particularly the mistrust based on bad experiences of mobile pastoralist communities.

Declarations

Ethics approval and consent to participate

The study participants were given detailed information about the purpose of the study and extent of their involvement, as appropriate. Informed consent was obtained from all study participants before starting the interviews and FGDs. It was pointed out that participation is voluntary, without compensation and that individuals may withdraw from the study at any time, without negative consequences for them, their family or their community.

Competing interests

The authors declare that they have no competing interests.

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**CHAPTER 4: EVALUATION OF THE FEASIBILITY AND
SUSTAINABILITY OF JOINT HUMAN AND ANIMAL
VACCINATION AND ITS INTEGRATION TO THE PUBLIC HEALTH
SYSTEM IN CHAD**

Evaluation of the feasibility and sustainability of the joint human and animal vaccination and its integration to the public health system in Chad

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Abstract

“One Health” approaches have demonstrated that joint human and animal vaccination programmes (JHAVP) are feasible and provide health care to previously inaccessible communities and save resources through sharing transport, equipment and logistics in Chad. The main objective of the study was to give an insight to the feasibility and the sustainability of JHAVP integrated as part of the public health system in Chad.

We have conducted a mixed methods research design with qualitative and quantitative methods including semi-structured key informant interviews, focus group discussions, and a budget impact analysis (BIA) of the implementation of JHAVP. In order to better understand the feasibility of this health programme, basic questions of feasibility study were asked to address the issues of acceptability, implementation and adaptation.

The acceptability of this approach has always been the subject of ongoing assessments by the Immunization campaigns team. Meetings were regularly held to evaluate the JHAVP activities to which the representatives of the nomads were invited. The presence of authorities during the lunches of the programme had an incentive effect, since they represent a mark of consideration which the nomadic populations generally declared to be lacking. The coordination between the public health and veterinary services at central and decentralized level and bringing nomads together to a great reunion mass seemed to be key elements in the success of the implementation of JHAVP. Involving social mobilization teams issued from the nomadic communities and providing additional package of services were among the strategies used to adapt the JHAVP to the socio-cultural and health context of these communities. The total incremental budget impact was 27% slightly decreasing to 26% in 5 years horizon meaning that the realization of one JHAVP would use up almost one third of the districts available funds. Thus, with the share of fixed costs being relatively low, efficiency gains from scale effects over time were limited.

Although its integration as a routine activity at the district level depends on the mobilization of additional financial resources, the district could benefit from joint immunization to maintain a contact network with the nomads in order to promote the use of available immunization services at district level.

Keywords

Joint vaccination, feasibility, sustainability, mobile pastoralists, one health

Background

According to the last national census in Chad, over 78% of the total population is rural and lives as sedentary or mobile agro-pastoralists and around 3.5% are mobile pastoralists depending mostly on livestock and agriculture for living (INSEED, 2014). However, rural and mobile pastoralists in Chad, like almost in all Sahelian African countries, are rarely considered as beneficiaries of national health and development interventions because of their location in remote areas and their mobile lifestyle that take them across multiple countries in some cases (Zinsstag et al., 2006). Quality of health services is perceived as poor by nomadic communities (IRED-SwissTPH, 2016). Even countries that have health policies specific for mobile pastoralist communities neglect to address essential elements such as gender disparities, high maternal mortality rates or child health care (Abakar et al., 2016).

Despite the general health and disease problems being faced in addition to problems caused by extreme climatic conditions, mobile pastoralists in the Sahel are virtually excluded from health services in part due to the challenges to adapt the provision of social services to their way of life (Montavon et al., 2013). Earlier studies in rural areas in Chad mainly among mobile communities have showed high frequencies of fever-related illness, anaemia, respiratory and gastro-intestinal illnesses, which still mainly without etiologic diagnosis and confirmation (Daugla et al., 2004, Bechir et al., 2010d, Bechir et al., 2012a). Access to health services is more difficult for mobile pastoralists' communities. However, because of their mobility in arid and semi-arid zones, providing access to primary social services including health to pastoralists in Chad is extremely difficult and challenging (Schelling et al., 2008, Montavon et al., 2013). Unpublished data from a recent survey among nomads conducted in May 2015 show that Polio 1 and Polio 3 coverages are 11.6% and 2.7% respectively and Penta1 coverage is 0% among pastoralist communities in the Danamadji district, which is considerably lower than for the sedentary populations (SwissTPH, 2016a).

There have been examples of interventions tailored to meet the need of mobile pastoralist communities. Collaboration of human and animal health still falls short particularly in low income countries, however, in the recent years the collaboration of human and animal health coined One Health (Zinsstag et al., 2005b), has gained momentum. "One Health" can be defined as the added value in terms of improved human and animal health or financial savings or environmental services resulting from a closer cooperation of both health sectors (Zinsstag et al., 2005c, Greter et al., 2015b). Such approaches have demonstrated that joint human and animal preventive health interventions (i.e. vaccination) are feasible and provide health care to previously inaccessible communities and save resources through sharing transport, equipment and logistics in Chad (Schelling et al., 2007b).

There are, however, circumstances where an intervention or a programme offers good value for money, while the implementation itself is not affordable. In this sense, there is a general need to better understand whether cost-effective interventions also translate into affordability, considering especially

the low health budget allocations in low- and middle-income countries (Gelband et al., 2016, Levin and Chisholm, 2016). The integration of these joint programmes as a routine activity into existing infrastructure and programmes that are funded by the district health system could require substantial level of financial reallocations putting a strain on the delivery of other essential health services.

The benefits of the integration of vertical programmes in local health systems such as primary health care are well documented and vaccination programs are one example of that (Briggs and Garner, 2006). Although there is some debate about the definition and scope of integration of health services exists (Shigayeva et al., 2010), there is a substantial body of knowledge supporting the integration of services to improve health system performance (Atun et al., 2010). The operational arrangements and users perspectives about the integration of vertical interventions are not well understood.

The objective of the present study is thus to give an insight to the feasibility and the sustainability of joint human and animal vaccination programme (JHAVP) integrated as part of the public health system in Chad.

Methods

We have conducted a mixed methods research design with qualitative and quantitative methods including semi-structured key informant interviews, focus group discussions, and a budget impact analysis (BIA) of the implementation of JHAVP campaigns. Our main research questions were:

- What are the main strengths and weaknesses of the JHAVP, how was it coordinated and what are provided services and was it adapted to the nomads' context?
- What are the main lessons learned from the JHAVP, and how was it perceived by the local population?
- What are the main financial and implementation challenges facing the JHAVP and does it have a future?

Study settings

Our study took place in Sarh, Moyen-Chari region, in the southern part of Chad bordering the Central African Republic. The Danamadji health district on which focuses our study is one of the 3 health districts of this Region. Its population is 128'369 inhabitants according to the last national census (INSEED, 2014), 3.5% among them are nomads mainly Arabs and Peuls cattle breeders. The district has 18 functional health zones, 17 health centres and 1 district hospital. According to a recent household survey, health service utilization especially vaccination is significantly lower among nomads communities when compared to sedentary populations. For example, Polio 1 coverage was 11.6% among nomads compared to 80% among local sedentary populations (SwissTPH, 2016a).

Qualitative methods

Data collection methods

Experienced researchers in qualitative methods were recruited and supervised by IREDⁱⁱ and CRASHⁱⁱⁱ to conduct KII and facilitate FGD among relevant stakeholders involved in the design, implementation or management of JHAVP. Both, the KII and the FGD were conducted in French or in Arabic. All of them were recorded, transcribed and finally translated into French.

Semi-structured key Informant Interviews (KII) were conducted with 10 participants from public and veterinary health authorities in the Moyen-Chari and the Danamadji health district involved in the programmes, and representatives of the nomadic communities.

We have conducted one FGD-SWOT among the same 10 participants gathered in 2 days workshop during which SWOT analysis have been realized (see table 4.1.).

Table 4.1. study participants (KII and FGD-SWOT)

Target population	Number of KII
Public health delegate for the Moyen-Chari region	1
Livestock delegate for the Moyen-Chari region	1
Medical chief of Danamadji health district	1
Research coordinator at CSSI ^{iv}	1
Chief of health zone responsibility of Danamadji	1
Chief of veterinary post of Danamadji	1
Chief of veterinary post of Roro	1
Responsible of the expanded immunization programme, Moyen-Chari region	1
Nomads representative	1
Responsible of the national programme of health of nomads PNSN ^v	1
Total	10

Data analysis

We have used 2 different frameworks or tools in the analysis of the data collected in the KII and the FGDs: the framework develop by Bowen et al. to assess the feasibility of the JHAVP (Bowen et al., 2009). complemented with the framework proposed by Schell et al. (Schell et al., 2013); and a SWOT analysis to identify strengths, weaknesses, opportunities and threats with regards to the feasibility and sustainability of JHAVP (Pahl and Richter, 2007, Gibis et al., 2001, van Wijngaarden et al., 2012).

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ⁱⁱⁱ Centre de Recherche en Anthropologie et Sciences Humaines (CRASH)

^{iv} Centre de Support en Santé International (CSSI)

^v Programme National de Santé de Nomades (PNSN)

Bowen et al. recognized that there are no ready-made criteria to understand the feasibility of health programmes; nevertheless they suggested 8 areas that could be examined when assessing the feasibility of a programme. We have used 3 domains to assess the feasibility of the JHAVP (acceptability, implementation and adaptation) as we considered them as the most relevant in this specific setting. First, we wanted to explore the JHAVP acceptance among nomadic communities and whether it is accepted voluntarily or not. Second, we were interested in the implementation of the programme among nomads who live in an environment dominated by a mobility lifestyle and limited access to basic social services. Specifically, we explored whether the operational implementation of the JHAVP took these realities into account in order to meet the needs of nomads. Finally, we investigated whether the programme was adapted to the socio-cultural context of the nomadic populations of Danamadji district.

Key messages were identified and then codified in order to be classified according to the themes to which they relate. Depending on each case, the themes were regrouped or pinned separately to form expressive answers to the initial research questions. The SWOT analysis session provided complementary data to the KII information which allowed drawing more precise conclusions regarding the feasibility and sustainability of the JHAVP.

Budget impact analysis (BIA)

Data sources

Data on resource use and local prices are gathered from the health district accounting system in Danamadji as well as from project reports that resulted from a mixed vaccination campaign realized in 2016 in the same district. Taking the perspective of the district health system, the purchase costs of human vaccines were not included as these costs are typically borne by the expanded programme on immunization. Meanwhile, livestock vaccines purchase costs were covered through direct payment by animal owners on a cost recovery basis. Furthermore, all costs related to higher functional levels (region, nation) such as expenditures for administrative and managerial support as well as costs assigned to the veterinary sector were not considered for the BIA. Base salaries for field personnel are not included (only allowances) as this expenditure is typically handled at the national level and assuming that the campaign will draw on the already salaried health workers in the district.

Data analysis

The design of the BIA approach in this study builds on a costing model that describes the implementation of JHAVP and which is based on detailed data from local accounting systems. An overview on the basic assumptions and most essential elements of the study design is given in Table 4.2.

The analysis takes the perspective of the human health-care provider at district level using the case of Danamadji. The target population of JHAVP were children below 60 months which are part of hard-to-reach communities, typically mobile pastoralists. As sizes of the pastoralist communities were largely unknown, we derived the initial total population size of mobile pastoralists that are present in Danamadji based on the number of children reached through a joint vaccination campaign supported by Swiss TPH and implemented in 2016 in the same district (n=1'684). Assuming that most children below 60 months from pastoralist communities in the district have been attended during the campaign, we derived the total initial population in the district applying the proportion of children below 60 months derived from routine statistical indicators for sedentary populations living in the district (16.5%).

Table 4.2. BIA design and assumptions

	Design and assumptions
Perspective	Human health care provider at local level (health district): costs borne at higher levels or related to the veterinary sector are not taken into account.
Time horizon	5 years, capital costs are not annualized
Target population	Children from mobile pastoralist communities < 60 months
Initial population	The initial population is unknown. Derivation based on the number of nomadic children reached during a mixed vaccination campaign in 2016 assuming that the intervention covered the total population at that time.
Population growth rate	3%
Cost of the intervention	Derived from project reports and budget of a mixed vaccination campaign realized in Danamadji in November 2016.
Current cost of interventions aimed at reaching mobile pastoralist communities for vaccination	As recent studies show that vaccination coverage is very low among mobile pastoralists in Danamadji, we assume that no resources are currently employed for vaccination delivery to remote populations.
Economic impact	Economic consequences stemming from improved health outcomes through increased vaccination coverage among mobile pastoralists are not taken into account.
Health district budget	Derived from the official budget 2016

Regarding the low vaccination coverage among nomads in the Danamadji health district, we assume that, there is currently no employment of resources (and no costs) for delivering vaccination services to mobile pastoralists. This implies that total budget impact of implementing a combined vaccination programme corresponds to the incremental budget impact.

Possible financial consequences stemming from improved health outcomes through increased vaccination coverage among mobile pastoralists are not taken into account. Building on a provider perspective, private costs incurred by households to participate in the vaccination campaign were not included. A five year time horizon has been chosen to examine possible scale effects over time.

Ethical considerations

The study has been given ethical clearance from the Nation bioethics committee in Chad (CNBT) and the WHO Research Ethics Committee Review (WHO ERC) (See Annexes section). Interview sessions always begin with reading the survey information sheet and asking the respondent if he/she has any questions before signing the consent form. Participants in the survey were given the choice to decide whether interviews should be recorded or not.

Respondents were free to interrupt or stop interviews at any time, or choose not to answer some specific questions. The confidentiality of the interview and the anonymity of the respondent were assured. Interviews take about 30-45 minutes. They were held in Sarh, capital of Moyen-Chari region during a workshop where all the above targeted people were invited.

Results

Qualitative methods

In order to better understand the feasibility of this health programme, basic questions of feasibility study were asked to address the issues of acceptability, implementation and adaptation (Bowen et al., 2009).

Acceptability

The acceptability of this approach has always been the subject of ongoing assessments by the Immunization campaigns team. Meetings were regularly held to evaluate the JHAVP activities to which the representatives of the nomads were invited.

"Indeed, during the implementation of the JHAVP, we did an evaluation meeting of the activities we had to organize and the reaction of this community is that this kind of activities should be repeated more often, because they think it's good to bring an additional package of services that is often goes beyond vaccination". (Head of an NGO)

This tendency among nomads to prefer the JHAVP is confirmed by a regional health official in the Moyen-Chari region.

"I think this programme was much appreciated by the nomads, because after the activities we tried to hold meetings with the various actors to determine the bottleneck that prevents the children of the nomads to come to vaccination. And they (nomads) have spoken in favour of joint vaccination which is an opportunity for them to benefit from its activities. "

Unlike other vaccination campaigns (outreach strategy and routine immunization), the JHAVP is marked by an official launch of a large scale in which participated high authorities, namely the Minister of Public Health and the Ministry of Livestock. The presence of these authorities has an incentive effect, since they represent a mark of consideration which the nomadic populations generally declare to be lacking.

The acceptance of the JHAVP by nomadic populations is confirmed by officials and nomads representatives.

"The joint vaccination approach has paid off, as long as it has mobilized resources. Seeing the results, we have never reached this coverage level in our routine immunization activities. I do not have the number in mind, but the approach has allowed us to reach nomadic children who have never been vaccinated since they were born until the age of five". (Delegate, Moyen-Chari region)

A representative of the nomads present at the workshop agrees in the same direction confirming that:

"On the side of the nomads where I am the representative, everyone is on the same wavelength as this joint vaccination operation is beneficial and everyone wants it to happen every year."

Implementation

The coordination between the public health and veterinary services at central and decentralized level seems to be a key element in the success of the implementation of the JHAVP.

"There are many consultations between the two ministries during the implementation of this approach. I wanted to say that when it comes to a disease that is common between humans and animals, the two ministries always meet to think about the strategies to adopt". (Delegate, Moyen-Chari region)

Among the strategies adopted is to bringing nomads together to a great reunion mass between themselves, which was often lacking for the nomads and which they often wanted, as noted by a health service worker who took part in the JHAVP held in 2013 in the Danamadji health district.

"It was a great joy, a great reunion. Breeders who have separated from each other for a long time have found themselves together again. (...), nomads often like these kinds of opportunities because it allowed them to access health services to their children, their pregnant women (...)".

Adaptation

Involving social mobilization teams issued from the nomadic communities is one of the strategies used to adapt the JHAVP to the socio-cultural and health context of these communities. The report of the last JHAVP stated that a total 36 social mobilizers have been identified among nomads' representatives and trained in the Danamadji and Kyabe health districts.

It's known that one of the basic realities that characterize nomadic communities in the Danamadji health district is the low access to health services in general and immunization in particular (SwissTPH, 2016a). However, with the seriousness of some diseases, nomads are still tempted to go to health facilities for care. But very quickly, they are discouraged either by the distance, by the cost of care, or again by a so-called discrimination of which they would be victims (IRED-SwissTPH, 2016).

Therefore, providing a package of health services beyond vaccination is one of the means to adapt the JHAVP to the specific needs of nomads.

"We intervened by bringing a joint package of human and animal vaccination and also taking care of the mothers at the camps level. Our teams have nurses within them to make rapid consultations for the sick people. Also, our teams have some drug supply to take care of the minor health problems". (An NGO representative)

This is also confirmed by a delegate of Moyen Chari regional who goes further and adds that:

"The joint vaccination strategy is not just about vaccination. We take advantage of this approach to do primary prevention against malaria, deworming of nomadic children and also vitamin A supplementation. We also do pre-natal consultation. In short, we were able to reach these communities with activities that, without this approach, would be difficult to achieve".

SWOT analysis

The Table 4.3. summarizes the main findings of the SWOT analysis realized during our study.

Table 4.3. SWOT analysis summary

	Opportunities <ul style="list-style-type: none"> - Political stability - Political good willingness with regard to JHAVP - Funders adherence to the approach 	Threats <ul style="list-style-type: none"> - Security - Scarcity of funds - Natural catastrophes - Breeders agricultures conflict
Strengths <ul style="list-style-type: none"> - Existence of framework - Availability of personnel - Coordination at all levels 	SO strategies <ul style="list-style-type: none"> - Establishment of inter-sectoral dialogue framework - Holding donors meetings for mobilization of additional funding 	ST strategies <ul style="list-style-type: none"> - Establishment of inter-sectoral platform for collecting and analysing information needed to anticipate potential threats - Promotion of dialogue between communities (sedentary and nomads)
Weaknesses <ul style="list-style-type: none"> - Absence of legal basis - Insufficient funds - Absence of additional health intervention (rabies, CBPP, etc.) 	WO strategies <ul style="list-style-type: none"> - Establishment of inter-ministerial entity for the implementation of JHAVP - Advocacy for resources mobilization 	WT strategies <ul style="list-style-type: none"> - Establishment of a legal basis to the JHAVP - Advocacy for resources mobilization

Strengths

Although JHAVP is implemented in an "informal" way, as it does not yet have a formal institutional framework that can guarantee its sustainability, it still has strengths that allow it to survive and to continue to provide a number of services to nomadic populations and their livestock.

Existence of financial support from donors

One of the conditions for the sustainability of any health programme, such as the JHAVP, is the availability of financial resources. Indeed, such health programme requires substantial financial resources. *"Yes, there is funding"*. A delegate from the Moyen-Chari region said. The delegate further added *"When there is a strong political will, it means that the finances will follow as well"*. Even that there is not yet a substantial governmental funding for the programme, as there is not yet a special service for this purpose, there are some NGOs which are working in this field for more than a decade in addition to other NGOs and UN agencies that can always provide financial support for the JHAVP, although this may not be enough to ensure its regularity.

"(...) Because I know that there is now in Moyen-Chari, many projects like PADS, there is also the project led by IRED (AHPSR) and the health project of the mobile pastoralists in Central Africa lodges at the CSSI. There is also the MSF who is intervening". (An NGO representative)

Existence of a reference framework document

To well strengthen the JHAVP among nomadic populations, the strategy was to develop a holistic programme of integrated health activities. This programme goes beyond the health aspect and also includes education, safety, pastoral wells and so on. A milestone was reached with the creation of the Governmental Nomadic and Islander Community Health programme (PNSN): Decision No. 227 MSPASSN/SE/SG/DGRP/2014 (Abakar et al., 2016).

Although the various objectives and recommendations contained in this document are not yet translated into practice, this document constitutes a reference framework to which the various actors working in support of nomadic populations can refer for the implementation of health approaches and other integrated activities for the benefit of nomadic populations and their livestock.

Existence of the programme of health of nomads (PNSN)

Until recently, the joint human and animal vaccinations of the nomadic populations are the result of initiatives of the NGOs, without a real institutional base, till the establishment of a national institutional framework responsible for nomadic populations, i.e. PNSN (National Programme for Nomadic Health) in 2014. This institution is created to serve as a framework for reflection, orientation and planning of health activities for nomadic populations and, in a broad sense, hard to reach populations.

"Well, if I have one last thing to add, it may be a suggestion. It is to advocate with the Ministry of Health so that all actors involved in the nomadic health sector can get around this programme, work in synergy. The interventions of certain partners, notably the NGOs, must not be allowed to escape the national coordination of the PNSN, which is today the nomadic health programme which is for us a key partner and which already shows the good will of the government to appropriate the thing. (...)". (An NGO representative).

Availability of qualified vaccinators and supervisors

Indeed, although the logistics and per diem has always been financed by NGOs, the management of these vaccines is largely the responsibility of the health and veterinary officers. Apart from the few people recruited as community health workers responsible mainly for communication, most vaccinating agents are qualified government personnel.

"At the level of the health districts, there is the District Medical Officer who coordinates activities at the district level. When we go out here and we go for the vaccination, he knows that in such a place it is such person who goes to vaccinate. There is an implementation plan. At the regional level, the delegate coordinates. I remember when I was in Danamadji, it was the MCD who was in charge of coordinating our activities at Danamadji level. "

Weaknesses

Although its regularity is not assured (since its first implementation in 2000, it has only been executed two or three times till today), the JHAVP has benefited from a number of favours guaranteed its survival since then. However, it has some weaknesses such as lack of a proper institutional framework, insufficient financial support, lack of implementation infrastructure and lack of socio-anthropological study among nomads to improve the performance of this approach.

The non-institutionalization of JHAVP

Although JHAVP seems to be well appreciated by nomadic populations, however, this initiative suffers from a number of disabilities which could undermine its regularity and sustainability. One of these weaknesses is the non-institutionalization of the programme. Indeed, the programme is transversal health operation between the Ministry of Health and the Ministry of Livestock, however, it must be noted that there is a lack of a transversal institution with legal bases capable of managing the integrated health of nomads and their livestock, as a regional delegate rightly observed:

"There is no proper framework for managing this integrated human and animal health operation. Until then, now the things worked on the basis of the good relationships between the human and animal health authorities that we are"

This concern is widely shared by the relevant service officers, namely those of human health and animal health, such as a regional delegate who is concerned and suggests something in these terms

"And here I think it is necessary to think about creating a formal framework of consultation in order to manage this issue of human health and animal health, for example an inter-ministerial decree"

Insufficient financial resources

As there is not yet an institutional service within the districts that in charge of implementing JHAVP, there is no sufficient financial resources neither a budget line from the government. Most of the operational costs are covered by external donors' contributions.

"Now, the weaknesses are insufficient funding especially from the government. It is an activity that should be regularly applied, because interrupting it for a year or two is an handicap".
(Regional delegate, Moyen-Chari region)

Because this programme is implemented in the nomadic environment, which is highly mobile, therefore, any delay in the execution of a scheduled could have consequences in its success.

Construction of fences for livestock vaccination is a bottleneck

The nomadic populations in Chad in general and those of Danamadji in particular are much attached to their livestock, to which they give sometimes even a little more importance than their own children, as confirmed by a vaccination programme officer in the region: *"Yes indeed, the statement of nomadic communities better vaccinates their cattle than their children is true. This can be justified by the absence of nomads in the immunization service. Everywhere in the health centres, we do not notice the presence of the nomads."*

Therefore, the success of JHAVP depends on the success of animal vaccination, as one NGO official states. Animal vaccination is actually set up as gate of entrance to the nomadic populations who are looking for the least initiative for the health of their livestock. Thus, it was thought that by making them come to massively vaccinate their cattle, we can benefit to vaccinate their children. Meanwhile, the success of animal vaccination depends on the availability of vaccination fence (park or enclosure) which creates few problems:

"Among the challenges, there is the question of the enclosure (...). You know at the bush there, if you want to make an enclosure with the woods, you will have problems with the agents of waters and forests. Not long ago, the Livestock Delegate told me to do an enclosure and as soon as it was done with the woods, we had problems with water and forest agents. (...) and I ended up paying something to solve problem". (A nomads' representative)

Lack of qualitative investigation

While assessing the acceptability of the JHAVP among nomads, we have mentioned the ongoing meetings to assess the implementation of all activities related to the programme to which representatives of the nomads were invited. Nevertheless, the presence of nomads' representatives during a meeting cannot in fact reflect deeply the view of nomadic populations in general. In order to better understand the perception of the nomads, their preferences and their suggestions for improving this approach, it would be important to conduct qualitative socio-anthropological studies among the nomads in their great diversity which is lacking in this programme.

Budget impact analysis (BIA)

The main budget characteristics of the mixed campaign is represented in Table in USD (1 USD = 616 FCFA, January 2017). The total costs of the intervention are 17'328.3 USD with 1684 children being vaccinated. Transportation is the budget category with the greatest weight followed by personnel and logistics (e.g. basic equipment including chairs, tents, and refreshments for participants etc.). Considering costs incurring only at the district level, the total costs are 14'384.2 USD. The allocation of the costs of resources used to the veterinary and public health sector is based on equally divided shares for the transportation and the logistics category assuming comparable utilization of these basic inputs. Personnel costs have been distributed proportionally to the according health workers present during the campaign with 79% being allocated to the public health sector. The share of fixed costs is rather low and only applicable to costs related to logistics (57%), which is the budget category with the lowest share on total costs (see Table 4.4.).

Accordingly, it can be noted that, apart from the logistics category, marginal costs correspond to average costs which indicates little room for economies of scale. All in all, average costs per fully vaccinated child (without costs of vaccines) correspond roughly with the calculation presented by Schelling et al. (2007).

Table 4.4. Cost characteristics of a joint vaccination campaign in Danamadji

	Total costs (USD)	Total costs district (USD)	Share public health sector	% fixed	Average costs per FIC (public health sector, USD)	Marginal costs per FIC (public health sector, USD)
Transportation	8028.5	8028.5	50%	0%	2.38	2.38
Logistics	1416.8	1416.8	50%	57%	0.42	0.16
Personnel	7883	2944	79%	0%	1.28	1.28
Total	17'328.3	14'384.3			5.55	5.29

Table shows the budget impact of realizing one intervention over one year time horizon. The total incremental budget impact is 27% meaning that the realization of one JHAV campaign would use up almost one third of the districts available funds. Assigning the different types of expenditures to their according budget category, it can be noted that the burden will be especially high with respect to human resources were costs for personnel are expected to exceed the according budget line by almost half (153%).

Table 4.5. Incremental budget impact of combined vaccination campaigns for the public health sector at district level

	Incremental costs at district level (USD)	Incremental budget impact	Incremental budget impact per budget category
Transportation	4172.6	15%	23%
Logistics	1154.1	4%	51%
Personnel	2236.3	8%	153%
Total	7562.0	27%	

Figure 4.1. examines the financial consequences over time under the scenario that a combined vaccination campaign is realized every year assuming a constant population growth rate of 3%. The budget impact of logistic expenditures decreases considerably over time due to the reuse of inputs over the course of time. However, as it can be seen from Table 4.5., transportation and personnel expenditures are fully variable and therefore increase over time stemming from higher workloads due to an increasing target population. In total, the impact of the intervention on the district budget decreases slightly from 27% to 26%. Thus, with the share of fixed costs being relatively low, efficiency gains from scale effects over time are limited.

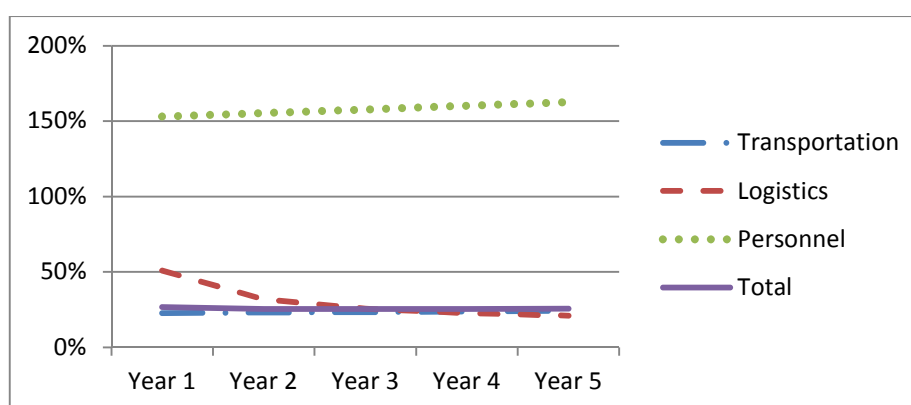


Figure 4.1. Incremental budget impact for the public health sector at district level over a 5 years' time horizon

Discussion

In general, the feasibility of the JHAVP is ensured on its three dimensions analysed, which are acceptability, implementation and its adaptation to the context of nomads. It has been demonstrated that the joint delivery of human and animal health services, including joint immunization, is well appreciated by nomadic communities (Schelling et al., 2005c). According to Schelling et al., in addition to sensitization on vaccination in these campaigns, nomads appreciated the quality and potential of health services and began to trust health service providers. Indeed, this tendency among nomads to prefer joint vaccination was confirmed by several interviewees in our study. The magnitude of the event, marked by a large-scale official launch, played an important role in the acceptability and awareness of immunization in the nomadic community in Danamadji. The presence of the authorities during these events had an incentive effect, since they represented a mark of consideration which the nomadic populations generally declared to be lacking.

The implementation of JHAVP has been a great success mainly because of ongoing coordination and exchanges between the public health and livestock sectors. This resulted in several strategies to increase the success rate of implementation. Among these strategies is the organization of preparatory missions composed of the agents of two ministries for the mobilization as well as the involvement of the administrative, religious and traditional authorities as facilitators. Also the choice to resemble the

nomads in a locality that will give a mass of reunion which will not only facilitate the operations but also will have a mobilizing media effect.

The lack of trust towards local health systems is one of the factors limiting access to vaccination among nomads (IRED-SwissTPH, 2016). Another factor was using social mobilizers from nomads themselves and offering, besides vaccination, an additional package of health services such as prenatal consultations, distribution of impregnated bed-nets, vitamin A supplementation and many others (Report of the Joint Immunization Campaign, 2013).

The sustainability of JHAVP has several strengths, namely the existence of a document framework "*Programme d'appui intersectoriel aux communautés nomades au Tchad* " and the existence of the nomads' health programme (PNSN) in the ministry in charge of public health. To this could be added the current willingness of some donors to support this vaccination strategy to reach nomads.

It should be noted here that all joint immunization campaigns organized in the past have been supported by partners and implemented by central structures. This has led us to examine its sustainability from the point of view of the possibility of its integration into the local health system at the district level through a budget impact analysis. Considering the affordability of the intervention at the district level through the lens of a BIA, this study shows that the financial burden on the local health system would be relatively high if the current funding scheme for the Danamadji health district is maintained in the coming years. With no external funds available, the implementation of a yearly campaign would use up around one third of the district's health budget. This implies substantial consequences with regard to budget reallocation which applies particularly to the most constraint budget categories as for example human resources. Combined vaccination campaigns, being an outreach activity, do not rely on substantial infrastructural investments such as buildings and fixed equipment. Interpreted from a costing perspective, this implies only minor shares of fixed cost with little room for economies of scale. As a consequence, increasing the target population through geographical expansion of the intervention to other districts will only bring minimal efficiency gains.

Building on these findings, we conclude that for mixed campaigns to be delivered as a part of the routine district health system, a considerable increase in financial resources would be required. If external funding is available, local health systems shall continue to implement mixed campaigns in order to establish contact between nomadic communities and the health district to catch up with vaccination coverage. However, since the approach does not appear to be financially feasible at the local level over the longer run, health districts need to enable less cost-intensive regular communication and information activities aimed at enhancing service utilization of vaccination services at the health facility.

In fact, as it has been pointed out in the vaccine hesitancy manuscript (chapter 3), lack of information is one of the principle demand-side barriers for vaccination among these communities, whereas geographical barriers do not appear to be a major concern (IREC-SwissTPH, 2016).

A current representative survey in the Danamadji district has shown that 57% of mobile pastoralist households own a mobile phone (Swiss TPH, 2016). Efforts to sustain regular communication and exchange of vaccination-related information with the pastoralist communities between the sporadic realizations of the campaigns in a less cost intensive way could be managed through the systematic application of mobile phone technology.

Conclusions

In general, the operational feasibility and sustainability of the JHAVP among nomads' communities in the Danamadji health district do not have major problems even if improvements can be still made. However, while its feasibility is not problematic, its sustainability raises concerns about a few lines of weakness and threats to this health programme. These weaknesses, which influencing the regularity of the programme, could constitute serious long-term handicaps for its survival.

Although its integration as a routine activity at the district level depends on the mobilization of additional financial resources, the district could benefit from joint immunization to maintain a contact network with the nomads in order to promote the use of available immunization services at district level.

Declarations

Competing interests

The authors declare that they have no competing interests.

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CHAPTER 5: TRENDS IN HEALTH SURVEILLANCE AND JOINT SERVICE DELIVERY FOR PASTORALISTS IN WEST AND CENTRAL AFRICA

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Trends in health surveillance and joint service delivery for pastoralists in West and Central Africa

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Trends in health surveillance and joint service delivery for pastoralists in West and Central Africa

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Summary

In most sub-Saharan African countries, pastoralism represents an important economic resource and contributes significantly to national growth; however, challenges remain, particularly in providing social services to pastoralists (especially health and education) and in avoiding conflict with local sedentary communities and local authorities. All of this takes place while pastoralists try to maintain their mobile lifestyle within a rapidly changing ecosystem. Transdisciplinary approaches, such as ‘One Health’, which covers both human and animal health, have proven effective in delivering services and reaching mobile pastoralists in remote areas. The pastoralist way of life could be described as being linked to both their livestock and their environment, which makes social science an important element when researching the delivery and adaptation of social services to pastoralists.

Early or pre-diagnostic detection of emerging and endemic infectious disease remains a vital aspect of health surveillance targeted at preventing further transmission and spread. Community-based syndromic surveillance, coupled with visual mobile phone technology, adapted to the high levels of illiteracy among nomads, could offer an alternative to existing health surveillance systems. Such an approach could contribute to accelerated reporting, which could in turn lead to targeted intervention among mobile pastoralists in sub-Saharan Africa.

Although considerable efforts have been made towards integrating mobile pastoralists into social services, obstacles remain to the adoption of a clear, specific and sustainable policy on pastoralism in sub-Saharan Africa.

Keywords

Central Africa – Health surveillance – One Health – Pastoralism – Public engagement – Service delivery – Sub-Saharan Africa – Syndromic surveillance – West Africa.

Background

Pastoralism is an extensive farming method based on the exploitation of natural vegetation and often dependent on mobility. It is the dominant economic activity in arid and semi-arid regions of Africa. Pastoral and agro-pastoral systems account for over 80% of the supply of animal products in the Sahel and West Africa, where – in countries that include Mali, Chad, Uganda, Ethiopia and Kenya – animals represent up to 70% of the agricultural gross domestic product (GDP)(Hatfield and Davies, 2006).

According to World Bank estimates, the rural population in sub-Saharan Africa is approximately 587 million (WorldBank, 2013). In the West and Central African regions alone, an estimated 90 million people live in rural areas. They depend on agriculture and livestock, but have limited access to health and other social services, given the unequal distribution of good-quality services between urban and rural areas (Nations, 2013). Earlier studies in rural areas of Africa have shown high frequencies of fever-related illness, anaemia, and respiratory and gastro-intestinal illness, which still have no etiologic diagnosis and confirmation (Daugla et al., 2004, Bechir et al., 2010d, Bechir et al., 2012a). Small-scale studies among pastoralists, who may be the most vulnerable to exclusion from social services, such as health and education, have demonstrated the feasibility of mobile communication for health and demographic surveillance (Jean-Richard et al., 2014c).

The main objective of this paper is to illustrate and discuss integrated services delivery of human and animal health to pastoralists, and its added value. Moreover, the paper emphasizes the potential of integrated syndromic surveillance among rural populations; notably pastoralists, who tend to have even higher levels of illiteracy and be harder to reach than other communities in rural areas of sub-Saharan Africa. The authors wish to present ways in which appropriate integrated surveillance systems, combined with mobile technology, could improve early detection of both human and animal health abnormalities and thus enable prompt corrective measures. Such an early syndromic surveillance system could also lead to more timely etiologic diagnosis and a targeted response. In addition, the paper highlights the importance of public engagement and discusses how transdisciplinary participatory decision-making could have a huge impact on the well-being and health of these communities.

One health and transdisciplinary approaches

Although it is well known that human and animal health are inextricably linked, under the increasing influence of specialization, human and veterinary medicine have diverged, often failing to communicate, despite a shared interest in the same zoonotic diseases. For example, during a recent outbreak of Q-fever in the Netherlands, public health authorities were not informed by veterinary authorities about a wave of abortions in goats (Enserink, 2010a). Similarly, outbreaks of Rift Valley fever in humans in Mauritania were mistakenly identified as yellow fever (Digoutte, 1999, Zinsstag et al., 2007).

Such examples could be extended, and collaboration between the human and animal health sectors still falls short, particularly in low-income countries, which harbour important reservoirs of potentially emerging zoonotic diseases. In recent years the collaboration of human and animal health services, under the coined phrase ‘One Health’ (Zinsstag et al., 2005c), has gained momentum. Closer cooperation between the two health services was fostered during the recent avian influenza pandemic with new partnerships being developed at the political, institutional and technical levels (Enserink, 2010a). The One Health approach can be defined as the added value – in terms of improved human and animal health, financial savings or environmental services – resulting from the closer cooperation of both health sectors (Zinsstag et al., 2005c, Greter et al., 2014). It is also the inter-sectoral, collaborative approach to preventing, detecting and controlling diseases among animals and humans, and includes collaboration among the institutions and systems that support such prevention, detection and control (Glynn and Brink, 2014). Engaging communities and authorities in all research and actions through iterative participatory stakeholder processes has demonstrated that joint human and animal preventive health interventions are feasible. Moreover, they can provide health care to previously hard-to-reach communities while also saving resources, in countries such as Chad (Schelling et al., 2007b).

Health service delivery to pastoralists

Pastoralists have difficulty in accessing health services. But we should not forget that many of these difficulties and barriers are shared with remote rural populations in general. Mobility, the quality of health services, gender disparities, high maternal mortality rates and child health care are particularly poorly addressed in health policies for pastoral people. Barriers to health services can be classified as geographical, economic, cultural, technical, social or political (Wiese, 2004). In pastoral and remote rural zones there is hardly any institutional framework adapted to pastoral needs (Fokou et al., 2004). Mobility and a lack of conflict management are sometimes regarded as major barriers. For mobile populations, the geographical dispersion of groups and their distance from each other and from health services interact with other factors linked to everyday constraints.

Studies show that, rather than taking a traditional approach – i.e. initially serving those who are easiest to reach – approaches designed to first increase coverage among disadvantaged groups provide the most progress towards universal health coverage (Gwatkin and Ergo, 2011). However, better access to the governmental health system alone, without any political improvement in the situation of a marginalized population, may not have the expected positive impact on health. Even with efficient fixed or mobile clinics in pastoral zones, significant barriers to service delivery may still exist. Pastoralists have had contact with modern (Western or international) medicine for many decades, including through the Veterinary Services, but information on good performance at health facilities must spread more efficiently along their communication networks. The pastoralist way of life is

closely related to their livestock and their environment. Research on adapted social services (e.g. health and education) requires the recruitment of social scientists.

The ability of health and veterinary systems to deliver services is constrained by a number of factors: declining public-sector budgets; loss of confidence by the community as a result of unmet demand; a severe shortage of human resources, especially qualified personnel; inadequate infrastructure and equipment; and weak monitoring and information systems (Schelling et al., 2007d). Because they occupy remote areas with difficult access, pastoral communities are also at risk from criminal, contraband and terrorist activities. For example, the village and commune (administrative district) of Ber in North Mali and along the southern shores of Lake Chad is exposed to Islamist terrorist groups.

Veterinarians are not allowed to treat human patients, and para-professionals are often not allowed to handle certain human and animal drugs or to perform simple interventions. These restrictions also apply in remote areas, where neither physicians nor veterinarians are available. With a proper legal framework and appropriate training, however, certain selected public health activities could be shared – for instance, surveillance. Patient care would, of course, remain the sole responsibility of the human health agents (Catley et al., 2004, Kahn et al., 2007). While the animal health sector lacks institutional focus – for example, the establishment of long-term community animal health systems – the human health sector lacks participatory rural appraisal methods to increase community involvement (Riviere-Cinnamond, 2005).

Pastoralist communities often demand more health information. How to communicate health matters effectively and conduct social marketing campaigns to influence behaviour is understood (Maibach et al., 2007), but is often not done because of poor resourcing or concerns about how to provide understandable concepts to low-literacy populations. Anthropological studies on diseases that occur in general livestock-keeping and specifically in pastoralist communities are still scarce and tend to be limited to better targeting of good health messages. Community health and community animal health workers (CAHWs) can provide primary health care in remote zones. After initial training, the key activities for the long-term provision of both human and animal health community services include continued exchanges concerning quality services and supervision by the health systems, as well as patient referral systems (Catley et al., 2004, Jaskiewicz and Tulenko, 2012). The advantage of community workers is that they are more accessible to pastoralist community members who may face difficulties in accessing services that are further away. In addition, strong producer organizations or farmer cooperatives can sometimes deliver human and animal health services, although care is needed since mixing marketing and services may lead to an undesirable confusion of the functions and responsibilities of the public versus the private sector. The authors believe that all stakeholders, including non-governmental organizations, should be included in the discussion to identify opportunities for closer cooperation, which may lead to synergies in health service delivery.

In pastoralist communities in developing countries, livestock often contribute to multiple livelihood objectives and are not kept solely for food production, so focusing on Western technology to maximize individual animal production is a solution that is too often and inappropriately put in the foreground (Randolph et al., 2007). McCorkle (McCorkle, 1996) argues that, especially for remote or rural people in developing countries, an inter-sectoral approach, partly modelled along the lines of traditional models for joint human and animal health service delivery, would be more feasible than attempting to impose a dual Western-style structure. Formal and informal and traditional and modern medical sectors could be combined if traditional/local practitioners are included. Effective ethno-medical practices and traditional healthcare networks could be an integral part of such a delivery system (Last, 1990).

However, the issue of how to integrate the two systems of medicine without the complete structural and cultural subordination of traditional medicines remains unresolved (McCorkle, 1996). Public health and veterinary programmes should more widely share their knowledge and their different approaches – and explore local priorities and perceived needs. They can then develop joint arrangements to implement and improve services to remote and rural communities. Different authors have proposed combining veterinary and public health services to increase the level of coverage to communities in remote zones (reviewed in Swift et al. (1990))(Swift et al., 1990). When pastoral and other livestock-keeping families in remote zones can be reached, maximum use should be made of each visit (Majok and Schwabe, 1996). In conflict situations, animal health services are sometimes still active when health services have already broken down (B. Peterhans, personal communication).

Organizations such as the International Committee of the Red Cross have – in situations of humanitarian crisis, such as drought or armed conflict – implemented joint human and livestock vaccinations. However, such approaches are rarely documented. Based on findings from a simultaneous assessment of human and animal health needs in Chad, broad agreement was reached with the national and local authorities, as well as local communities, to test joint human and animal vaccination services. Sharing transport and equipment between physicians and veterinarians reduced total costs (saving 15% of the public health sector budget) (Schelling et al., 2007b, Schelling et al., 2015).

In its Expanded Programme on Immunization, Chad's Ministry of Health, together with the country's Veterinary Services, continues to implement such joint vaccination campaigns in priority zones, particularly in regions with frequent cross-border pastoralist movements, representing ~20% of all pastoralist zones in Chad.

Integrated syndromic surveillance and the use of mobile phones to spread public health information

Early detection of emerging disease, in particular infectious disease, is a key element in health surveillance and is aimed at a rapid response to prevent further spread, thereby reducing morbidity and mortality. Different terms have been used to describe public health surveillance systems for the early detection of outbreaks. ‘Syndromic surveillance’ is the term that has persisted for humans and animals (Henning, 2004). It can be defined as the regular collection, analysis and interpretation of real-time and near real-time indicators of disease and outbreaks by public health organisations (Fricker et al., 2008). Syndromic surveillance methods have been developed as a complement to traditional health data analyses to allow the early detection of unusual health events with clearly identifiable syndromes (Warns-Petit et al., 2010b). In the animal health sector, syndromic surveillance has been used in Europe mainly for cattle (Hyder et al., 2011), goats and wildlife (Warns-Petit et al., 2010b).

Syndromic surveillance in Africa is in its infancy. A systematic review, released in 2014, revealed that mobile-phone-based surveillance projects in sub-Saharan African countries are on a small scale, fragmented and not well documented (Brinkel et al., 2014). It has been applied in Sierra Leone for Peste des Petits Ruminants. Health and demographic surveillance networks, such as the INDEPTH consortium, are still underused for surveillance of emerging diseases (www.indepth-network.org), but they spearhead the use of mobile communication technologies for health surveillance. Mobile phones offer a useful tool for consistent demographic and health surveillance of mobile pastoralists and their animals (Jean-Richard et al., 2014c). Mobile devices and Web-based applications have revolutionized disease surveillance and health interventions (mHealth) in low- and middle-income countries. They cover, among other things: client education and changing behaviour, sensors and point-of-care diagnostics, data collection and reporting, and supply chain management (Hall et al., 2014). Collecting integrated human and animal health data through mobile phones in two health districts in Tanzania for a period of more than five months has shown an improvement from 50% to 89% for data completeness and timeliness (Luba PASCOE, 2012).

However, while mobile communication coverage rapidly expands into remote areas, local communities still have low rates of literacy and require visual supports for education and communication for syndromic surveillance. In fact, the high illiteracy rate among pastoralists in sub-Saharan Africa is a motivation for finding other ways to include them within a community-based surveillance system, as is the value of their local observations and perceptions of most human and animal diseases. Therefore, appropriate syndromic surveillance among pastoralists, using the potential of mobile communication and visual technology, is a better alternative in trying to reach these hard-to-reach populations and including them in national health services.

Public engagement and its impact on the future of pastoralism: Chad case study

In most African countries, pastoralist communities live in vulnerable situations with limited access to social services. In general, national policies do not propose adapted solutions and the scarce existing legislation is either narrowed to specific conditions or not updated. In Chad, for example, a pastoralist legal framework (pastoralist code) and customary law were published in 1959 and 1967, respectively (Law No. 4, 31 October 1959 and Law No. 24 in July 1967). Both are now outdated (Bechir et al., 2013). More recently, at the beginning of 2014, a pastoralist code was adopted by Parliament and sent to the government for endorsement. Between adoption and promulgation, the code was subject to huge political debate and polemics until its rejection by the President in December of the same year. This step back shows the complexity of the pastoralist issue, especially with regard to the continuous conflict between mobile pastoralists and farmers which, most of the time, is exacerbated to serve local political interests.

Moreover, some other decisions of the Chad government have had negative impacts on pastoralist communities and their livestock. The recent decision to close the borders with the Central African Republic, due to a political crisis, led to a high concentration of pastoralists on the Chad side of the border. Elsewhere, the low level of information in rural areas provided on the government's policy of decentralization meant that pastoralists were unable to participate effectively in the decision-making process to protect their interests.

Non-governmental organizations, such as the Centre de Support en Santé Internationale and the Swiss Tropical and Public Health Institute, have supported the Chad government since 1998 in undertaking research and interventions to provide specific services, using a combined 'One Health' approach. It is important to go beyond these programmes and develop such joint interventions in remote and mobile pastoralist areas, to reach vulnerable communities (Montavon et al., 2013, Schelling et al., 2007e).

Much reflection and advocacy have taken place, with the aim of ensuring that the health issues of remote and mobile communities are taken into account by government policy (Bechir et al., 2012c). (41). A milestone was reached with the creation of the Governmental Nomadic and Islander Community Health programme: Decision No. 227 MSPASSN/SE/SG/DGRP/2014. More sharing of information with neighbouring countries is envisaged to establish cross-border vaccination campaigns, such as the continuing project, 'Reaching the hard-to-reach mobile pastoralists with the most appropriate vaccination scheme in Central Africa', funded by Pfizer.

Conclusion

To date, few documented studies exist that illustrate the feasibility, acceptability and potential savings (through sharing resources and personnel) of health and surveillance systems adapted to the pastoralist way of life. The inclusion of various stakeholders in the conceptual and planning phase is crucial, as it increases a feeling of ownership among the populations and authorities concerned (Schelling and Zinsstag, 2015). As far as possible, we must avoid establishing parallel structures and instead make use of existing health systems, infrastructure and human resources that are well integrated into the service provision systems of the countries involved. Moreover, any integrated service should try to meet the health priorities of the communities that it serves.

An increasing use of mobile technology may be a way forward. Even though signal strength is highly variable, and the platforms, hardware and operating systems available change rapidly, the rate of mobile communication use is rapidly increasing in Africa and mobile technology is reaching remote areas. The main challenge is how to develop culturally adapted, robust, low-cost and efficient phone-based applications as a key element for near-real-time disease surveillance in remote locations. Such a system needs to be able to function in settings with high levels of illiteracy in communities and low levels of education among health and veterinary staff.

To ensure that a surveillance system remains effective, it must be coupled with the capacity to respond, whether via individual emergency referral or with rapid mass interventions, such as ring vaccination around outbreaks. Like surveillance systems, responses to disease will benefit from new technologies if such technologies are well embedded in the prevailing socio-cultural context.

**CHAPTER 6: WORKING PAPER ON INTEGRATED SYNDROMIC
SURVEILLANCE AND RESPONSE AMONG RURAL SEDENTARY
AND MOBILE AGRO-PASTORALISTS IN CHAD**

Working paper on integrated syndromic surveillance and response among rural sedentary and mobile agro-pastoralists in Chad

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Background

Early detection of emerging disease is a key element in health surveillance aimed at a rapid response to prevent further spread and impact of diseases. Syndromic surveillance (SyS) can be defined as the regular collection, analysis, and interpretation of real-time pre-diagnostic indicators of diseases, such as syndromes or symptoms, by public health organizations (Fricker et al., 2008). SyS methods have been developed as a complement to traditional health data analyses to allow the early detection of unusual health events (Warns-Petit et al., 2010a). It was emerged following 2001 during the phase of bioterrorism in the USA (Reingold, 2003). However, its current goals go beyond detecting bioterrorism threats and aim to identify illness clusters early, before diagnoses are confirmed and reported to public health agencies. The European Union recently released its first guidelines for the use of SyS in humans and animals in order to increase the capacity for near real-time surveillance and monitoring of health related events in both health sectors. According to the TRIPLE S project (Syndromic Surveillance System in Europe), different forms of SyS systems exist in many European countries (www.syndromicsurveillance.eu). These include ambulance dispatches, outbreak detection, mathematical algorithms, cluster identification and generation of maps.

The revised International Health regulations by WHO request a timely detection, appropriate reporting and diagnosis followed by a subsequent response to relevant disease outbreaks (Kool et al., 2012). This implies rapid and efficient new surveillance systems and means for an early detection, appropriate diagnosis and monitoring of disease outbreaks. The use of pre-diagnostic biomedical data including statistical epidemiological approaches aims to detect epidemics earlier than traditional surveillance systems (May et al., 2009).

Syndromic surveillance in Africa is just beginning. Today, most of the established SyS and early outbreak warning systems in developing countries are based on low technology applications within solid national institutional structures and operate on a pre-defined time-interval basis (May et al., 2009, Robertson et al., 2010, Brownstein et al., 2008). However, SyS reporting is often insufficient or even lacking because infrastructure limitations impede effective surveillance. Also, there is poor acceptability among people responsible for the data transfer and/or a lack of properly trained personnel to fulfil such duties (Jefferson et al., 2008, Muula and Maseko, 2006, Calain, 2007). Several authors report on clinical misdiagnosis and empirical treatment, inadequate health care infrastructures and also lack of diagnostic accuracy as indicators for deficient surveillance mechanisms (Bates and Maitland, 2006, Schroeder and Amukele, 2014). Hence, indispensable medical interventions are often too late, non-targeted or even lacking and as a consequence, potentially new emerging pathogens and diseases from humans and animals may spread undetected for some time (May et al., 2009).

So far, efficient and timely appropriate SyS systems are deficient or lacking for populations living in remote areas, particularly for mobile, pastoral populations. However, such systems would be of high

public health relevance with a view to rapid and early detection of emerging diseases and their targeted treatment and prevention (Ndiaye et al., 2014b). A preliminary small-scale pilot study in Chad with a specifically developed mobile phone surveillance system has revealed promising results, in particular by showing a high degree of effective data transfer under such mobile living conditions (Jean-Richard et al., 2014c). Mobile devices and web-based applications have revolutionized disease surveillance and health interventions in low and middle income countries (Hall et al., 2014). However, while mobile communication coverage rapidly expands in remote areas, local communities still have low rates of literacy and require visual supports for education and communication for SyS. Also, signal strength is highly variable, and the available platforms, hardware and operating systems change rapidly, which are additional challenges.

The concept of "One Health" – collaboration of human and animal health sectors – introduces a new dimension of integrated disease surveillance. One Health can be defined as the added value in terms of improved human and animal health and financial savings resulting from a closer cooperation of both health sectors (Zinsstag et al., 2005c). Although it is well known that human and animal health are inextricably linked, under the increasing influence of specialization, human and veterinary medicine have diverged, often failing to communicate despite shared interests in the same disease. For example during an outbreak of Q-fever in the Netherlands in 2009, public health authorities were not informed by veterinary authorities about a wave of abortions in goats (Enserink, 2010b). Similarly, outbreaks of Rift Valley fever in humans in Mauritania were mistakenly identified as yellow fever (Zinsstag et al., 2007). Joint human and animal health interventions were highly appreciated, leading to improved understanding of the general morbidity patterns and nutritional status, as for example in agro-pastoralists and their animals in Chad (Schelling et al., 2005c, Bechir et al., 2012a). Agro-pastoral populations have especially close living situation with their animals. It has been demonstrated that more cattle were regularly vaccinated than children (Schelling et al., 2007a). This provided the basis for joint human and animal preventive health interventions and facilitated health care to previously inaccessible pastoralist communities, and save financial resources.

In Chad, over 78% of the total population lives in rural areas which are characterized by insufficiently equipped health centres and shortages of qualified health workers. Despite the general health and disease problems faced, and in addition to problems caused by extreme climatic conditions, agro-pastoralists (we refer here to rural mobile and sedentary communities which are pastoralists, crop farmers or both) in the Sahel are largely excluded from social services including health because the provision of social services adapted to their way of life is challenging (Montavon et al., 2013). Therefore, they suffer disproportionately from health problems like respiratory disease, malaria and diarrhoea (Schelling et al., 2005b). Malnutrition is widespread in the Sahelian band in Chad among both rural sedentary and nomadic populations. It is linked to socio-economic factors and particularly affected by seasonal variations (Bechir et al., 2010a). Malnutrition and a high prevalence of intestinal

parasite are common among women and children. More than 50% of pregnant women among mobile and settled pastoralists near Lake Chad were found to be anaemic (Bechir et al., 2012a). Close contact with livestock and consumption of raw milk and meat could favour zoonotic infections such as anthrax, Q-fever, brucellosis and bovine tuberculosis (Montavon et al., 2013). Poliomyelitis reemerged among Chadian pastoralists due to low vaccination coverage (Ndiaye et al., 2014b), which could contribute to its re-emergence, and there is also the consideration of previously undetected pathogens. During the rainy season, high fever and febrile diarrhoea are more common because access to safe drinking water is challenging (Schelling et al., 2007a).

This project aims to develop a culturally adapted, robust, low cost and efficient reporting system as a key element for near real-time community based syndromic surveillance applied in an integrated One Health approach (CBSyS-OH) in remote locations. The aim of such a system is to increase the timeliness and sensitivity of disease surveillance in humans and animals and to accelerate targeted response. It should be functional in settings with high levels of illiteracy and low levels of education of health and veterinary staff. Through the engagement of communities and authorities in all steps of this project via iterative participatory stakeholder processes, sustainability of the projects aims will be enhanced. We propose to develop this study in Chad because of the highly dynamic social-ecological system with mobile and interactive communities along a changing agro-pastoral continuum, the ongoing dynamics of disease transmission and the potential for detecting new genetic lineages or even emerging pathogens, as previously demonstrated (Maho et al., 2006a, Müller et al., 2009). In addition, the longstanding existing partnership makes Chad well suited for realizing this project, which may end up as a pilot to establish CBSyS-OH in other countries. Researchers integrated in this project successfully validated earlier the use of mobile phones for consistent demographic and health surveillance of mobile pastoralists and their animals (Jean-Richard et al., 2014c).

The project is stand-alone, however is planned to be implemented in conjunction with other syndromic and health related project in Chad ("*Projet d'Appui aux districts sanitaires de Yao et Danamadji au Tchad* (PADS)", funded by the Swiss Agency for Development) and in Switzerland (submitted to the research fund of the Bundesamt für Lebensmittelsicherheit und Veterinärwesen BLV), which will have similar aims of using stakeholder based syndromic surveillance for early detection and response.

Aims and objectives

The overall project aims at rapid detection of emerging and endemic diseases for targeted health interventions among agro-pastoralists and their animals in Africa as a contribution to human and animal health and wealth. At the same time, the project contributes in reducing the risk of regional spread of endemic and emerging diseases.

The objectives of the project are:

1. Evaluation and analysis of the sensitivity and timelines (time to detection) of the existing health surveillance and response systems in human and animal sectors and their potential close collaboration;
2. Development, implementation and evaluation of a near real-time CBSyS-OH system using mobile phones; we hypothesize that the CBSyS-OH will reduce time to detection and accelerates etiologic confirmation and targeted medical response when compared to the existing surveillance systems;
3. Establishment of etiologic disease diagnosis capacity based on timely enabled collection of fresh field samples;
4. Development of responses adapted to local needs (evacuation, field sample collection, treatment, vaccination, etc.). This part will be led by the PADS.

Expected results

This project will firstly contribute to near real-time anticipation of emerging and endemic diseases in remote African locations, which are considered to be important disease reservoirs. The following outcomes are expected:

1. A locally validated mobile phone based CBSyS-OH system for effective near real-time disease surveillance in humans and animals; this tool will be flexible for adaptations in other regions and will open a pathway to novel disease surveillance and response;
2. Time to detection of a disease reduced to 48h through the direct CBSyS-OH reporting system and the collection of fresh samples readily after reporting;
3. Biomedical clinical diagnostic and molecular characterization of emerging and endemic diseases in humans and animals which improves epidemiological knowledge and identification of potential unknown reservoirs;
4. In-depth understanding of local One Health practice and mutual information between public health and veterinary health services;
5. Culturally adapted, adequate and near real-time response interventions tested on small scale;
6. Capacity building in public and veterinary health, diagnostics and technology and in research on postdoc level.

Methods

Study site and target population

The planned project integrates two regions west and southwest of the Lake Chad Basin: Yao in the Lake Fitri Basin in the Sahel and Danamadji in the middle Chari River valley in the sub-humid zone (Figure 6.1). They are also interventions zones of the project PADS, with whom synergies are foreseen and build. The two sites represent different climate, geographic and population lifestyle settings and livestock management systems.

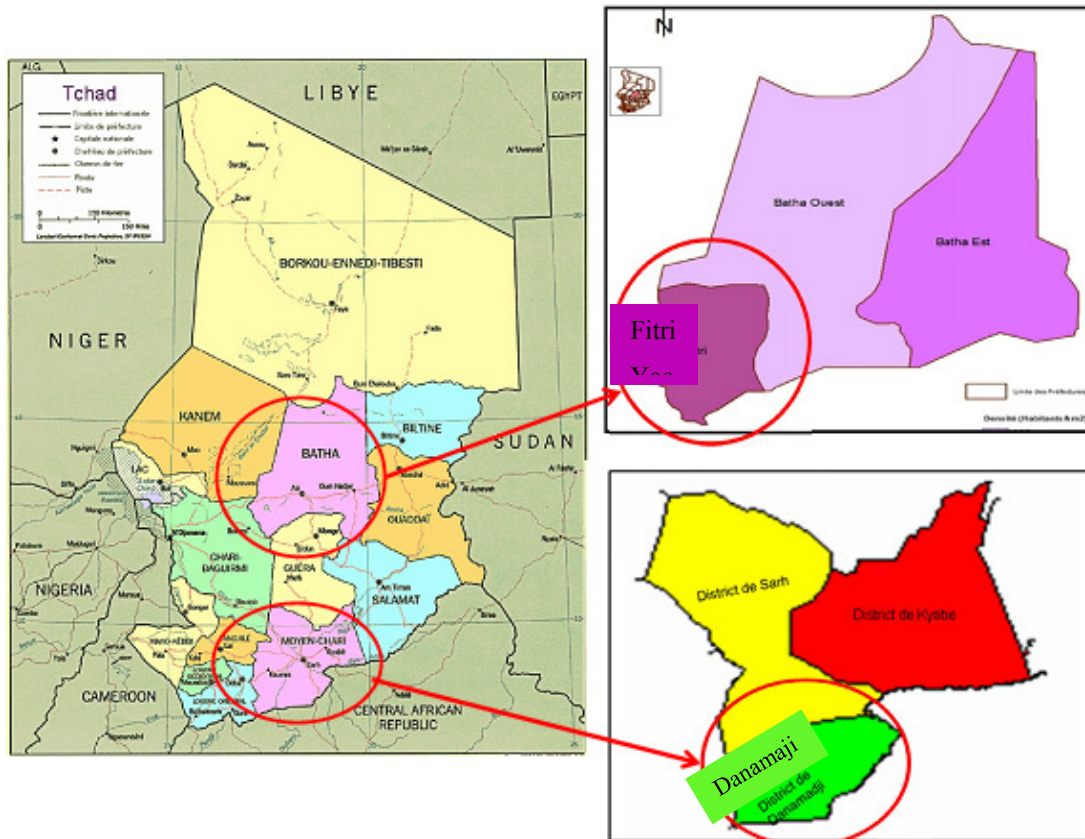


Figure 6.1. Proposed study areas in Chad. Source: PADS

The main ethnic groups in these regions are Fulani, Goranes and Arabs, in addition to other more local populations. In the Yao district, Arabs and Goranes are the two major ethnic groups of nomads. People from other ethnic groups, mainly fishers, could also be found in fishing camps in some islands in the lake Fitri in addition to the indigenous population (mainly Boulala). In the Danamadji area, the local populations (mainly Sara) are agriculturalists, while the pastoralists are Arabs and Fulani. Since many agriculturalists also keep livestock and some pastoralists cultivate food crops, it seems accurate to speak of an agro-pastoral continuum or “agro-pastoralists” when referring to all the ethnic groups in the study districts.

The project will undergo ethical review by the local Ethics Review Committee in Chad (CNB-Tchad) and the Ethik Kommission der Nordwest- und Zentralschweiz (EKNZ.)

Objective 1: Evaluation of the existing health surveillance and response system

The aim of this objective is to provide a benchmark for the project regarding the disease pattern and spread in humans and animals and the performance of the existing surveillance systems through a) the establishment of a baseline human and animal health survey with regard to the most important diseases and b) a retrospective analysis of human and animal health surveillance data.

To determine the current prevalence and the spatio-temporal distribution of diseases, a cross-sectional study using cluster sampling proportional to size, with villages and camps as cluster units, will be conducted and sampling of humans and animals will be undertaken analogous to Bonfoh et al. (Bonfoh et al., 2012). Within selected villages or camps, households and families, respectively, will be randomly selected. In humans, all individuals from selected households and families will be included. In animals, randomly selected domestic animals will be sampled. Those include ruminants (cattle, camels, goats and sheep), mono-gastrics (horses, pigs) or poultry (chicken and ducks). Samples collected will be diagnosed at the One Health diagnostic unit that will be established at the Institut de Recherche en Elevage pour le Développement (IREDE) in N'Djamena.

A retrospective analysis study of the human and animal health surveillance and response system using existing data will be carried out. The data will be sourced from the epidemiological surveillance service of the Ministry of Health and the national animal health surveillance network (called REPIMAT). The data is mostly in paper-based format, although the recent data are recorded in electronic format as well. Data collected during the last ten years will be included in the study in order to analyse time to detection (Figure 2), the cost per reported case, the sensitivity, specificity and timeliness of the existing system as a bench mark, using existing analytical frameworks (Andersson et al., 2014).

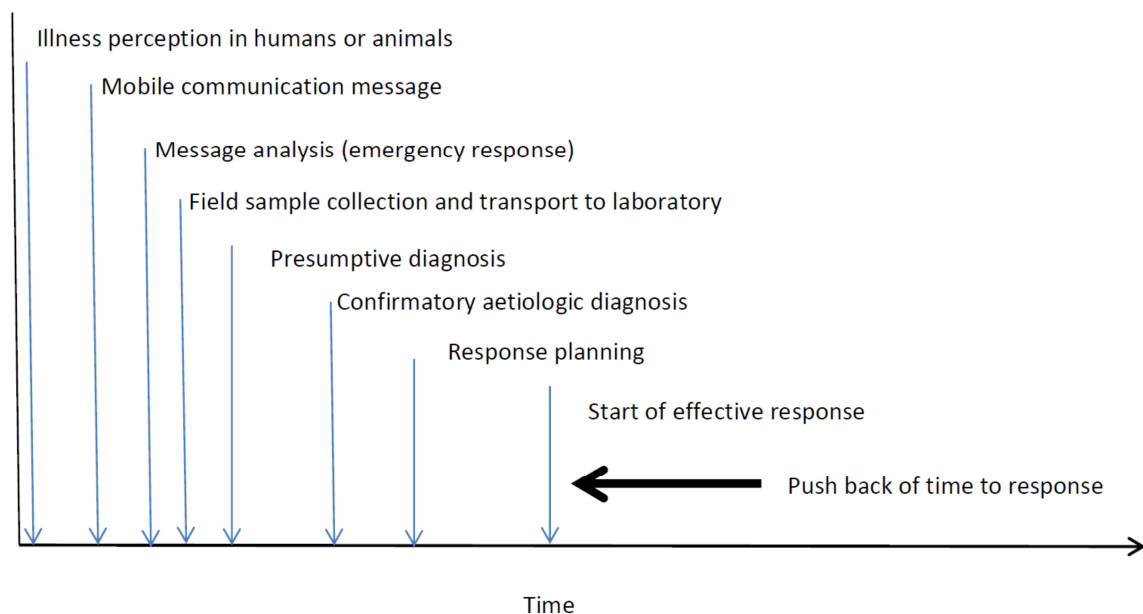


Figure 6.2. Framework and time to intervention of the existing mobile surveillance and response system

Objective 2: Development, implementation and evaluation of near real-time CBSyS-OH using mobile phones

The CBSyS-OH system will be used for continuous syndromic surveillance in the human and animal sector. The herewith collected data will be compared with the existing surveillance system in respect to the sensitivity, specificity and timeliness for detection of diseases. This objective will be implemented in close collaboration with PADS and the IT service at CSSI.

Development of the mobile phone system for CBSyS-OH

The CBSyS-OH system will support the existing human and animal health surveillance systems and will not create a parallel system or structure. Syndromes/diseases and appropriate interventions will be identified during a participatory workshop involving all stakeholders. Further monitoring and evaluation workshops will be organized regularly during the implementation of the project. Goal, objectives and planned activities for each workshop will be detailed in a specific terms of references. Figure 6.3. summarizes the mechanism (the decision tree) of the CBSyS-OH.

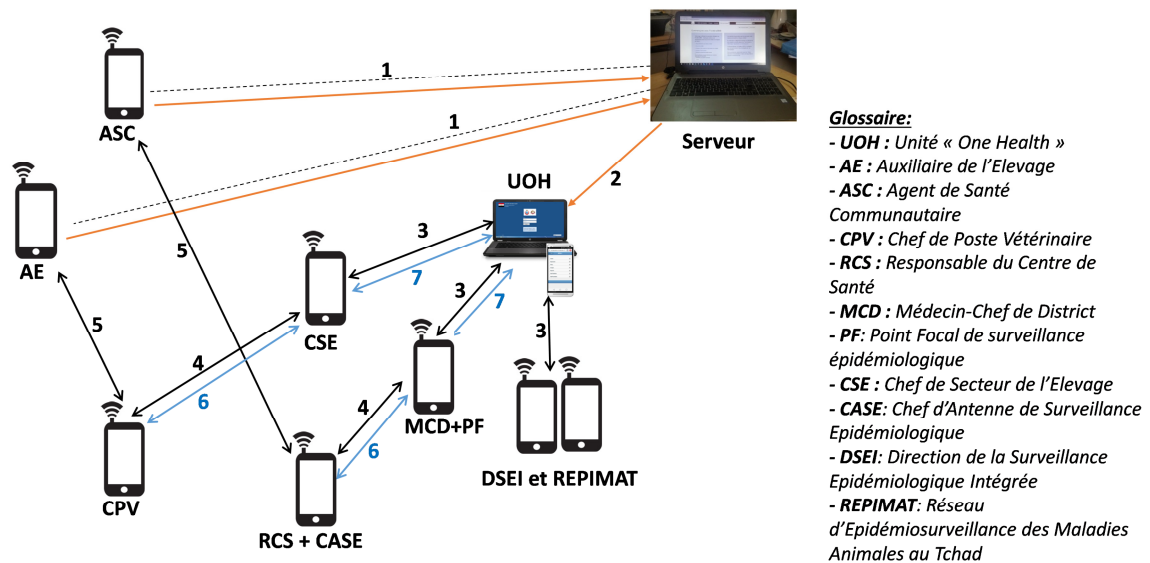


Figure 6.3. Operating mechanism of CBSyS-OH

Implementation of the CBSyS-OH system

The CBSyS-OH system will be implemented using a cluster randomized (two-arm) controlled trial with groups of people (clusters) are randomly allocated to either the control (arm 1) or intervention (arm 2) group. This will be conducted to compare the new (CBSyS-OH) with the existing surveillance system. Interventions will be undertaken in villages for sedentary populations and concentration zones (CZs) for nomadic population during the dry season, when populations' mobility is relatively low.

Control group (arm 1): 8-10 villages for the sedentary population and the same number of CZs for nomads with two camps in each CZ will keep standard surveillance and response activities as done in the past for humans and animals.

Intervention group (arm 2): 8-10 villages for the sedentary population and the same number of CZs for nomads with one camp in each CZ will keep standard surveillance and response activities as done in the past for humans and animals. In addition, mobile phones for the use of the CBSyS-OH system will be distributed to the most appropriate households in order to be able to assess the impact of this tool. With five mobile phones distributed per village and CZ camp, 100 mobile phones are required in this project.

In the intervention group, workshops will be organized within the villages and CZs to introduce the study, distribute the smart phones and explain the use of the CBSyS-OH reporting system. The identification number of the mobile phone will be linked with the user so that the identification of the data provider is guaranteed. A total of four additional workshops (one per year and region) will be organized during the period of data collection for feedback from the communities and dissemination of the results to stakeholders and partners. They also serve to evaluate the project's implementation and provide ongoing guidance and suggestions.

Evaluation of the CBSyS-OH system

Over a period of at least one year, data will be generated via the CBSyS-OH system. The data will not only be used to provide direct and timely response, but also to analyse and compare the data generated by this new system with those collected by the existing surveillance system.

Two sets of comparative data will be available to evaluate the CBSyS-OH system: First, the human and animal surveillance data that will be gathered and analysed under objective 1b and second the data generated contemporaneously by the control group (arm 1 in objective 2b). Through the much more direct reporting and follow-up sample collection using the CBSyS-OH system, diseases can be located more efficiently, which should contribute critically to the reduction of time to detection. For this purpose the database of the CBSyS-OH system will be analysed relating time of reporting to diagnosis for specific diseases and compare this time with the one needed by the existing surveillance system. In this way the respective time intervals depicted in Figure 2 can be analysed for the most sensitive intervals. We expect that the time from reporting to diagnosis can be minimized, aiming at an interval of 48-72 hours.

In addition to the time to disease detection, the cost per responded case, sensitivity and specificity of the surveillance system will also be evaluated. Using a Bayesian surveillance sensitivity framework (Andersson et al., 2014, Cameron, 2012), that will be extended to One Health surveillance, sensitivity and specificity of the existing and new system will be quantified and compared.

Objective 3 and 4: Establishment of etiologic disease diagnosis capacity and development of responses adapted to local needs

To generate an inter- and transdisciplinary dialogue for the development and implementation of the CBSyS-OH system, a One Health unit (the local project leading team) will be created, including a mixed team of physicians and veterinarians. The One Health unit will stimulate and facilitate a participatory process, involving all stakeholders including agro-pastoral communities, local and national health providers and policy makers as well as scientists. The One Health unit will be scientifically and technically supported by the project partners in Chad and in Switzerland.

The study population equipped with the mobile phones (intervention group) will record health problems via the CBSyS-OH reporting system. This information will be validated by the One Health unit through a phone call. It will further be communicated directly to official surveillance systems in human and animal health services at the central level and to the health centres and veterinary posts at the decentralized level.

A joint field intervention team (with a four-wheel drive car) will be organized to collect fresh diagnostic samples from humans and animals in the field. This team will be constituted by professionals from the decentralized health centres and veterinary posts and coordinated by the principle investigator in Chad. Biomedical analysis will be performed at IRED to diagnose reported diseases and to enable targeted health interventions. The One Health unit will process the data, react accordingly and will ensure follow up of cases. This direct targeted response will be the most meaningful and effective incentive for people in Chad to contribute to the study.

The development of targeted responses will be led by the project PADS. Both projects aim to investigate effectiveness of interventions in terms of general access to care. For example, it could happen that cases of meningococcal meningitis are reported for which a vaccination campaign would have to be organized by the ministry of public health (Daugla et al., 2014). The project could then assess the time from reporting to confirmation and to intervention (the vaccination). It could further assess the access to vaccination and assist with a vaccination coverage study. Such case examples will contribute to validate the overall response capacity and timeliness of CBSyS-OH approach.

Dissemination of results

Dissemination of results will take place at the districts level in Yao and in Danamadji, regional level in Moyen-Chari region and in Batha region and at national level in N'Djamena. Results from the different steps will also be shared with representatives of targeted communities. The principal investigator in Chad will be responsible for these activities with the support of the local and international research institutions. A draft for an integrated human and animal diseases surveillance policy for agro-pastoralists in an African context will be written.

The overall CBSyS-OH system will be further assessed for its connectivity between the public and animal health systems, for example in the case of the management of dog rabies. The validated CBSyS-OH system will be discussed with the national public and animal health authorities in view of establishing a national Chadian integrated surveillance and response system.

Scientific publications planned:

- Current state of the human and animal health surveillance systems: capacity of detection and intervention
- Syndromic surveillance and response using mobile phone reporting system within agro-pastoral communities in Chad: feasibility, adequacy and perspectives
- Impact of a synergetic participatory approach in public health: anthropology, human and animal health combined with technology

Time schedule

The project would be executed over three years (36 months). It is planned to start in April 2017. Close collaboration with other research projects are planned or foreseen. These are the PADS project "Appui aux districts sanitaires de Yao et Danamadji au Tchad" funded by the Swiss Agency for Development (ongoing project, first phase 2014-2018) and a community based surveillance project in Swiss animal owners (, 2017-2019) and the Afrique One ASPIRE project on surveillance and response of zoonotic diseases (2017-2019). Also, experience exchange with a similar project in Guatemala (2017-2019) is planned.

Table 6.1. Time schedule of the project's execution

Activities	2017		2018		2019		2010
Staff recruitment & training (One Health unit, diagnostic laboratories)							
Diagnostic capacity building (objective 3)							
Evaluation of existing surveillance system, analysis of existing data and baseline survey (objective 1)							
Development and pre-testing of the CBSyS-OH system (objective 2a)							
Implementation of the CBSyS-OH system, mobile phone reporting and data collection (objective 2b and objective 3)							
Evaluation of the CBSyS-OH system in respect to disease detection (objective 2c) and response and intervention (objective 4)							
Ongoing intervention (objective 4)							
Dissemination of results (report and publication writing, meetings with national and regional public and animal health authorities)							

CHAPTER 7: TRANSMISSION DYNAMICS AND ELIMINATION POTENTIAL OF ZONOTIC TUBERCULOSIS IN MOROCCO



RESEARCH ARTICLE

Transmission dynamics and elimination potential of zoonotic tuberculosis in morocco

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Transmission dynamics and elimination potential of zoonotic tuberculosis in Morocco

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Abstract

Bovine tuberculosis (BTB) is an endemic zoonosis in Morocco caused by *Mycobacterium bovis*, which infects many domestic animals and is transmitted to humans through consumption of raw milk or from contact with infected animals. The prevalence of BTB in Moroccan cattle is estimated at 18%, and 33% at the individual and the herd level respectively, but the human *M. bovis* burden needs further clarification. The current control strategy based on test and slaughter should be improved through local context adaptation taking into account a suitable compensation in order to reduce BTB prevalence in Morocco and decrease the disease burden in humans and animals.

We established a simple compartmental deterministic mathematical model for BTB transmission in cattle and humans to provide a general understanding of BTB, in particular regarding transmission to humans. Differential equations were used to model the different pathways between the compartments for cattle and humans. Scenarios of test and slaughter were simulated to determine the effects of varying the proportion of tested animals (p) on the time to elimination of BTB (individual animal prevalence of less than one in a thousand) in cattle and humans. The time to freedom from disease ranged from 75 years for $p = 20\%$ to 12 years for $p = 100\%$. For $p > 60\%$ the time to elimination was less than 20 years. The cumulated cost was largely stable: for p values higher than 40%, cost ranged from 1.47 to 1.60 billion euros with a time frame of 12 to 32 years to reach freedom from disease. The model simulations also suggest that using a 2mm cut off instead of a 4mm cut off in the Single Intradermal Comparative Cervical Tuberculin skin test (SICCT) would result in cheaper and quicker elimination programmes.

This analysis informs Moroccan bovine tuberculosis control policy regarding time frame, range of cost and levels of intervention. However, further research is needed to clarify the national human-bovine tuberculosis ratio in Morocco.

Key words

Bovine tuberculosis, *Mycobacterium bovis*, transmission modelling, Morocco, disease elimination, cattle

Author summary

Tuberculosis is a disease of humans and animals which mainly affects the lungs but can also manifest in other organs. A variety of tuberculosis bacteria cause the disease and are usually transmitted through air, i.e. inhalation of aerosols. Bovine tuberculosis (BTB) occurs predominantly among domestic cattle, although wild animals are an important reservoir for transmission. Humans are usually infected with BTB through contaminated dairy products or close contact with cattle.

While BTB has been eliminated in cattle and human populations of most high-income countries, it is still a major health threat in low- and middle-income countries. In Morocco, the disease frequently occurs in cattle and poses a health risk for humans. An effective intervention to reduce BTB among domestic cattle and reduce the risk to humans is slaughter of cattle which test positive for the disease.

We simulated BTB in the Moroccan cattle and human populations using a disease transmission model. We assessed effects of test and slaughter in regard to elimination of disease in cattle and humans and estimated the associated costs with the model. The time to elimination of disease depended on the number of cattle tested.

Our model suggests that the disease might be eliminated in cattle within 32 years if 40% of Moroccan cattle are tested annually and infected individuals are slaughtered or within 13 years if at least 90% of the cattle populations are tested. The estimated total costs for the time periods until elimination ranged from 1.55 billion euros for testing and slaughter at 50% to 1.48 billion euros at 90%. These results can be used as a guide for planning BTB control policy in Morocco with regard to time frames and associated costs.

Introduction

Bovine tuberculosis (BTB) is a zoonotic bacterial infection caused by *Mycobacterium bovis*. It belongs to a group of well-known and newer mycobacteria, together with *Mycobacterium tuberculosis*, all of which derive from a common ancestor forming the *Mycobacterium tuberculosis* complex (MTBC) (Wirth et al., 2008, Langer and LoBue, 2014, Clarke et al., 2016, Alexander et al., 2016). *M. bovis* is capable of infecting a broad range of hosts, including ruminants (predominantly domestic cattle), humans and other primates (Cosivi et al., 1995, O'Reilly and Daborn, 1995, De Vos et al., 2001, Drewe, 2010, Humblet et al., 2009, Palmer, 2013). The wide host range makes BTB highly relevant to conservation projects and difficult to eliminate where wildlife reservoirs are involved, for instance, badgers (*Meles meles*) in the United Kingdom (Michel et al., 2006, Kaneene et al., 2014).

Bovine tuberculosis infection in cattle is a chronic disease which first affects the lymph nodes and from weeks to decades later can affect lungs. The disease can also be manifested in other organs such as, mammary tissue, and the gastrointestinal or urinary tract. Since transmission between cattle occurs predominantly through aerosol inhalation (Kaneene et al., 2006, Pollock and Neill, 2002, Neill et al., 2001, Behr and Waters, 2014, Cousins, 2004), the transmission rate is increased by risk factors such as high herd density and intensive breeding (Elias K, 2008). Pseudo-vertical transmission from cows to suckling calves through infected milk has been described (Drewe et al., 2014). Factors like a long survival period for the microbes in manure and soil and close contact between animals, for example around water sources, also contribute to an increased risk of infection (Wray, 1975, Ayele et al., 2004).

In humans, contaminated dairy products are considered to be the main source of BTB infection, usually resulting in extra-pulmonary infection such as lymphadenitis (Torgerson and Torgerson, 2010, Kazwala et al., 2001, Oloya et al., 2008). These patients are missed by thoracic radiographic screening and the resulting diagnostic cascade (Allix-Béguet C, 2010). Aerosol cattle-to-human transmission can occur during close contact with infected animals, posing an occupational risk, especially for pastoralists and farmers (Langer and LoBue, 2014, Fetene et al., 2011). Infection risks linked to local cultural practices, for instance consumption of fresh blood, are reviewed by Daborn et al. 1996 (Daborn et al., 1996). There is evidence that human patients can transmit BTB to animals, and human to human transmission occurs (Fritsche et al., 2004, Evans et al., 2007).

There is a bottleneck in detecting human BTB cases because the routine diagnostic protocols were developed for patients with pulmonary tuberculosis, as caused by *M. tuberculosis*. Tuberculosis (TB) and BTB cannot be distinguished on the basis of clinical symptoms, radiography or histopathology (de la Rua-Domenech et al., 2006). Glycerol-containing Löwenstein-Jensen medium, the long-time gold standard for TB culture, inhibits the growth of *M. bovis*, thereby increasing the number of undetected cases (Grange et al., 1996). New molecular diagnostic tools, for example spoligotyping, and even

whole genome sequencing have been developed for *M. bovis* detection (Robbe-Austerman and Turcotte, 2014, Kao et al., 2016). Although they require enhanced laboratory infrastructure and personnel training which are not currently available in some developing countries, these new techniques offer promise for epidemiological research, control and adequate treatment, particularly since *M. bovis* is resistant to pyrazinamide, one of the first-line antibiotics for TB treatment (Zinsstag et al., 2011b).

Morocco is transitioning from extensive pastoralist livestock and dairy production to more intensified production due to increasing demands for dietary protein by a growing human population (FAO, 2011a). The shift in agricultural practice and increased use of high-producing Holstein cattle in place of local breeds may have an impact on BTB epidemiology and contribute to a higher prevalence (Ameni et al., 2007). The official national control programme in Morocco is currently based on a test and slaughter scheme. However, large-scale application remains challenging because testing is not mandatory, and the proposed compensation, ranging from 470 euros for local breeds to 980 euros for improved breeds, is considered lower than market value.

In Morocco, BTB is an endemic zoonosis in livestock. Even though the predominant livestock species in Morocco are sheep and goats, cattle remain of major importance. The most recent national survey, conducted in 2004, showed an individual cattle prevalence of 18% and a herd prevalence of 33% (Fao, 2011b). This prevalence remained similar in the individual level (20%), while the herd prevalence increased (58%) in a 2012 pilot study of 1,200 cattle using the tuberculin skin test (Yahyaoui Azami H., 2006). Since 2000, the health risk of tuberculosis in Morocco has been addressed through a national TB programme funded by the Ministry of Health in collaboration with the World Health Organization (WHO). In 2014, TB caused 2'800 deaths in Morocco (World Health Organization, 2015), and human tuberculosis had a relatively high incidence, with 36'000 new cases (106 cases per 100,000 inhabitants) (WHO, 2015a). These data do not appear to differentiate between *M. tuberculosis* and *M. bovis* infection. A recent meta-analysis estimated the median proportion of human BTB among all TB cases in 13 African countries at 2.8%, with a range of 0-37.7% (Muller et al., 2013a). National prevalence data from a range of countries worldwide were summarized in a 2014 review; in Mexico up to 13% of all TB cases are reportedly due to BTB, while in the United States it is only 1.4% (Perez-Lago et al., 2014). In Morocco, Bendadda et al. reported *M. bovis* prevalence of 17.8% among drug resistant TB isolates from 200 human sputum samples (Bendadda, 2003).

In the early 20th century, the prevalence in German cattle herds was 90% (Meissner, 1974), with 25-80% in other European states and only 2-10% in the US (Olmstead and Rhode, 2012). In most industrialised countries, the health risk and economic loss from *M. bovis* were considerably reduced or eliminated through strict test-and-slaughter and meat inspection protocols for cattle, along with the implementation of milk pasteurization and financial compensation of farmers (Olmstead and Rhode, 2012). Using a similar control strategy, Switzerland eradicated BTB in 1960 (Schiller et al., 2011). In

most developing countries where the disease is endemic, such measures are not feasible due to financial constraints, particularly for farmer compensation, and inadequate veterinary services (Zinnstag et al., 2007). Alternatives for BTB endemic countries to reduce the health and economic risk related to the disease must be sought.

Although cost estimation is difficult due to immense local variability in production parameters and prices (Tschopp et al., 2013), the global economic loss due to BTB is thought to be about 3 billion USD annually (Schiller et al., 2010). In cattle, the disease has a significant economic impact, through an increased death rate and decreased milk and meat production, draft power and fertility (Thoen et al., 2014). Modelling approaches have been used, mainly for developing countries, to estimate different parameters and factors related to BTB. Previous publications on the economics of BTB focus mainly on the cost of disease and control efforts. Analyses of the profitability of control efforts are very scarce (Zinnstag et al., 2006). A study on the economics of BTB in Africa showed higher losses in intensive dairy systems in peri-urban areas of Ethiopia when compared to extensive pastoral production systems in rural areas but did not include the cost to public health (Tschopp et al., 2013). Zinnstag et al presented a simplified framework for a model of animal to human transmission in which transmission between cattle and from cattle to humans is considered (Zinnstag et al., 2006). This model allows the simulation of different scenarios over 5-10 years, with and without intervention, where the measurable outcome is prevalence in humans and in cattle. The economic analysis further delineates broader issues such as inter-sectorial contributions from agricultural and public health or private households affected by BTB.

Interventions to reduce health and economic risks, such as those related to BTB, are non-linear processes. Although, statistical analyses of data have been used for many years to analyse different types of health interventions, mathematical modelling represents an alternative approach which provides a broader understanding, especially regarding disease transmission to humans.

Several mathematical BTB models have been developed to study the transmission dynamics and to assess the effectiveness of control measures mostly for wildlife (badgers and possums) but also for cattle (Alvarez et al., 2014). In Italy, a compartmental stochastic model of within and between-farm BTB dynamics in cattle was developed using a monte-Carlo simulation of BTB epidemics following the random introduction of infected individuals in the network. Consequently, slaughterhouse inspection has been found to be the most effective surveillance component (Rossi et al., 2015). The same methodology was used in Great Britain in order to study BTB transmission dynamics and to assess the currently used control measures (Brooks-Pollock et al., 2014). A model composed of two sub-models for buffalo and cattle populations in South Africa showed that BTB infection is only sustained in cattle and buffaloes when all transmission routes are involved (Phepa et al., 2016). In France, a compartmental stochastic model was used to assess within-herd spread of BTB operating in discrete time in order to design, calibrate and validate a model of spread of *M. bovis* within a cattle

herd. Various herd management practices as well as control programmes were parameterized into the model. Therefore, the median effective reproductive ratio was estimated to be 2.2 and 1.7 respectively in beef and dairy herds (Bekara et al., 2014). This paper presents an ordinary differential equation (ODE) mathematical model of BTB transmission from cattle to humans in order to estimate the disease cost and simulate potential interventions in Moroccan cattle.

Materials and methods

Epidemiological data collection

Annual data on cattle numbers are estimated using data routinely collected by the Ministry of Agriculture and reported to veterinary services. Our model considered these data from 1995 to 2013. In the transmission model, the cattle population was not stratified by age and sex. We used a tuberculin prevalence of 18% for cattle, as reported in the most recent national survey (2003) [33]. A similar prevalence was noted in a smaller study performed in 2012 in Sidi Kacem, Morocco (Yahyaoui Azami H., 2006).

Model

A schematic diagram of the model is depicted in Figure 7.1. and the variables and parameters are described in Table 7.1. and Table 7.2., respectively. The cattle population is divided into three mutually exclusive compartments consisting of susceptible cattle (S_C), exposed cattle with latent BTB which are positive to the tuberculin test, without showing gross visible lesions (E_C) and infected cattle with active BTB showing tuberculosis lesions (I_C). Those parameters were estimated based on Ngandolo et al 2009 (Ngandolo et al., 2009). The total cattle population (N_C) at time t is:

$$N_C(t) = S_C(t) + E_C(t) + I_C(t) \quad (1)$$

The human population consists of four mutually exclusive compartments: susceptible humans (S_H), exposed humans with latent BTB reacting to the Mantoux test (E_H), infected humans with active BTB (I_H) and humans recovered from BTB with temporary immunity (R_H). The total human population (N_H) at time t is:

$$N_H(t) = S_H(t) + E_H(t) + I_H(t) + R_H(t) \quad (2)$$

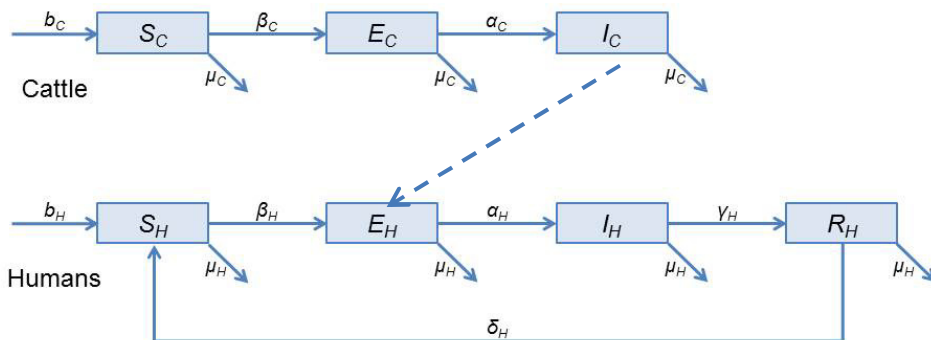


Figure 7.1. Schematic diagram of the BTB cattle-human transmission model for Morocco

The susceptible cattle population ($S_C(t)$) increases through birth (at a rate b_C) and decreases through exposure to BTB (at a rate β_C) and mortality (at a rate μ_C). Exposure to BTB is assumed to be frequency dependent. According to Bernues (Bernues et al., 1997a), the rate b_C decreases by 5% for exposed cattle with latent BTB ($E_C(t)$) and for infected cattle with active BTB ($I_C(t)$), such that:

$$\frac{dS_C}{dt} = b_C S_C + (0.95 \times b_C (E_C + I_C)) - \beta_C \frac{I_C S_C}{N_C} - \mu_C S_C - (1 - sp)pSc \quad (3)$$

The population of exposed cattle with latent BTB ($E_C(t)$) is generated through infection of susceptible cattle with BTB (at a rate β_C) and decreased through the development of active BTB (at a rate α_C) and through mortality (at a rate μ_C). Consequently:

$$\frac{dE_C}{dt} = \beta_C \frac{I_C S_C}{N_C} - \alpha_C E_C - \mu_C E_C - se * pEc \quad (4)$$

Similarly, the infected cattle population with active BTB ($I_C(t)$) is generated through the development of active BTB among exposed cattle with latent BTB (at a rate α_C) and decreased through mortality (at a rate μ_C):

$$\frac{dI_C}{dt} = \alpha_C E_C - \mu_C I_C - se * pIc \quad (5)$$

For simplicity, no additional mortality rate due to BTB is assumed for the cattle and human populations in the model.

Table 7.1. Description of the variables of the BTB model for Morocco

Variable	Interpretation
S_C	Population of susceptible cattle
E_C	Population of exposed cattle with latent BTB
I_C	Population of infected cattle with active BTB
S_H	Population of susceptible humans
E_H	Population of exposed humans with latent BTB
I_H	Population of infected humans with active BTB
R_H	Population of humans temporarily immune to BTB

The susceptible human population ($S_H(t)$) increases through birth (at a rate b_H) and through recovered humans becoming susceptible again (at a rate δ_C). The population decreases through exposure to BTB from cattle with active BTB (at a rate β_H) and through natural mortality (at a rate μ_H). For the susceptible human population, the exposure (both direct (aerosol) and indirect (milk) transmission) to BTB from cattle with active BTB is assumed to be frequency dependent and proportional to the number of infected cattle (I_C):

$$\frac{dS_H}{dt} = b_H S_H - \beta_H \frac{I_C S_H}{N_C} - \mu_H S_H \quad (6)$$

Human to human transmission is assumed to be negligible. The population of exposed humans with latent BTB ($E_H(t)$) is generated through infection of susceptible humans with BTB (at a rate β_H) and decreased through the development of active BTB (at a rate α_H) and through natural mortality (at a rate μ_H):

$$\frac{dE_H}{dt} = \beta_C \frac{I_C S_H}{N_C} - \alpha_H E_H - \mu_H E_H \quad (7)$$

The infected human population with active BTB ($I_H(t)$) is generated by the development of active BTB among exposed humans with latent BTB (at a rate α_H) and decreased by recovery of humans with active BTB due to treatment (at a rate γ_H) and by natural mortality (at a rate μ_H):

$$\frac{dI_H}{dt} = \alpha_H E_H - \gamma_H I_H - \mu_H I_H \quad (8)$$

The population of humans recovered from BTB and temporarily immune due to treatment is generated through the recovery of humans with active BTB (at a rate γ_H) and decreased through humans becoming susceptible to BTB again after the end of the prophylactic period of the drugs (at a rate δ_H) and through natural mortality (at a rate μ_H), so that:

$$\frac{dR_H}{dt} = \gamma_H I_H - \delta_H R_H - \mu_H R_H \quad (9)$$

Table 7.2. Description of the parameters of the BTB model for Morocco

Parameter	Interpretation
b_C	Birth rate of cattle
β_C	Cattle to cattle transmission rate
μ_C	Mortality rate of cattle
α_C	Inverse of cattle incubation period
b_H	Birth rate of humans
β_H	Cattle to human transmission rate
μ_H	Natural mortality rate of humans
α_H	Inverse of human incubation period
γ_H	Treatment success rate of humans
δ_H	Loss of immunity in humans

Values for variables and parameters of the model

Variable starting values

The most recent estimate (2013) for the cattle population in Morocco is 3,173,000 (N_C), of which 18% [95% CI: 16.5%-20.3%] are tuberculin skin test positive. The initial values of the three compartments

I_C , E_C and S_C were calculated such that the pre-intervention endemic equilibrium of the model equals the prevalence of 18% (Supporting information 1). This yield:

$$I_C = \frac{\alpha_C \varphi_C}{\alpha_C + b_C - (b_C - r_b b_C) \varphi} N_C \quad (10)$$

$$E_C = \left(\varphi_C - \frac{I_C}{N_C} \right) N_C \quad (11)$$

$$S_C = N_C - E_C - I_C \quad (12)$$

The human population of Morocco in 2013 is estimated to be 33,008,150 individuals (United-Nations, 2013). The estimated number of people with active TB is 43,000 (prevalent cases) (WHO, 2015a). In Africa, a median of 2.8% of all human TB cases are caused by BTB (Muller et al., 2013a). Between 5 and 10% (mean 7.5%) of TB-exposed people will develop active TB during their lifetime (Centers for Disease Control and Prevention and Division of Tuberculosis Elimination (DTBE), 2011). The starting values of the variables are listed in Table 7.3. Based on these estimates the starting values of I_H , E_H , R_H and S_H are calculated as:

$$I_H = \frac{\alpha_H \varphi_H}{\alpha_H + \delta_H + b_H} N_H \quad (13)$$

$$E_H = \left(\varphi - \frac{I_H}{N_H} \right) N_H \quad (14)$$

$$S_H = N_H - E_H - I_H \quad (15)$$

$$R_H = 0 \quad (16)$$

Table 7.3. Initial values for the BTB cattle-human transmission model (supporting information 3)

Variable	Starting value
S_C	2,601,860
E_C	79,610
I_C	491,529
S_H	33,006,946
E_H	784
I_H	420
R_H	0

Parameter values

The average lifespan of the Moroccan cattle is 6 years which yields a death rate of $\mu_C = 0.167$. From data on cattle populations (Supporting information 3) using least squares the birth rate was estimated as $b_C = 0.177$.

From the UN World Population Prospects we calculated the birth rate b_H and death rate μ_H in humans (United-Nations, 2013). Although BTB bacteria are not completely eliminated from treated humans

(Lay et al., 2007, van den Driessche et al., 2007) it is nevertheless assumed, for the sake of simplicity, that all successfully treated humans are recovered and become susceptible again within a period of 6 months.

The cattle to cattle transmission rate, β_C , and the cattle to human transmission rate, β_H , were estimated from the pre-intervention endemic equilibrium (Supporting Information 2). The model was implemented using MATLAB (MathWorks, Natick, MA). Table 7.4. shows the baseline values of the parameters with the respective source.

Table 7.4. Parameters of the BTB cattle-human transmission model assuming a stable prevalence (endemic stability)

Parameter	Baseline value		Source
$b_C(\text{year}^{-1})$	0.177	[0.121 - 0.274]	Supporting information 3
$\beta_C(\text{year}^{-1})$	0.249	[10.244 - 0.255]	Estimated from the endemic prevalence in cattle
$\mu_C(\text{year}^{-1})$	0.167	[0.111 - 0.333]	(Tijani and Amechtal, 2012)
$\alpha_C(\text{year}^{-1})$	1.083	[0.5 – 1.667]	(Wirth et al., 2008)
se	0.438	[0.057 – 0.819]	(Ngandolo et al., 2009)
sp	0.894	[0.842 – 0.946]	(Ngandolo et al., 2009)
$b_H(\text{year}^{-1})$	0.0229		(United-Nations, 2013)
$\beta_H(\text{year}^{-1})$	0.00015		Estimated from the endemic prevalence in humans
$\mu_H(\text{year}^{-1})$	0.0063		(United-Nations, 2013)
$\alpha_H(\text{year}^{-1})$	1.083		
$\delta_H(\text{year}^{-1})$	2		(WHO, 2010)

The reproductive number of the transmission between cattle R_0 was computed as:

$$R_0 = \frac{\alpha * \beta}{(\alpha + \mu)\mu} \quad (17)$$

Sensitivity analysis of model

A sensitivity analysis of the model recalculated the change of prevalence if individual parameters varied from baseline over 30 years.

Simulation and cost of interventions

Although Morocco has a test and slaughter policy for the control of BTB, it is currently not effectively implemented. The BTB transmission model was used to estimate the effect of the proportion of tested

and slaughtered tuberculin positive animals on the duration to reach freedom from disease, achieving an individual animal prevalence of less than one in a thousand tested animals ($<1/1000$) according to the standards of the World Organization for Animal Health (OIE) (Health, 2004). The proportion of tested and slaughtered animals was simulated by removing 10-100 % of the exposed (E_c) and infectious cattle (I_c) per year from the herd. The control reproductive number R_c including the test and slaughter intervention as proportion p with a test of sensitivity se was computed as:

$$R_c = \frac{\alpha * \beta}{(\alpha + \mu + se * p)(\mu + se * p)} \quad (18)$$

The associated costs were estimated in a summaric way, assuming an incremental cost of comparative intradermal or interferon gamma (BOVIGAM) testing of 3 euros per animal. The cost of compensation at 80% of the market value varies from 470 euros for local breeds to 970 euros for improved breeds (Ministère Marocain de l'agriculture, 2001). For the current estimation of the cost of BTB elimination in Morocco, we used a single value of 500 euros of compensation per slaughtered animal. Models run with and without interventions were simulated using data from 2013 onwards.

The OIE recommended cut-off for SICCT interpretation is 4 mm, however, many studies showed that a severe cut-off of 2mm increased the sensitivity of the test (Awah-Ndukum et al., 2016, Karolemeas et al., 2012), without affecting the specificity compared to the recommended cut-off (Ameni et al., 2008). Consequently, we decided to consider both 2mm and 4mm cut-offs in the model, and to compare the respective results. The present model considered both options of SICTT cut-off at 2mm and 4mm.

Results

Model properties

The reproductive ratio of the cattle to cattle transmission of bovine tuberculosis without intervention was 1.325. For the total cost, the birth rate of cattle b_c was the most sensitive parameter influencing the dynamics of BTB transmission (Figure 7.2.). High birth rate values lead to an increased cattle population yielding higher costs for elimination. For the time to elimination, the sensitivity of the test was the most sensitive parameter. Low test sensitivity (i.e. with cut-off at 4mm) leads to low detection of infected animals and therefore less culling of infectious cattle, which leads to a longer time to elimination.

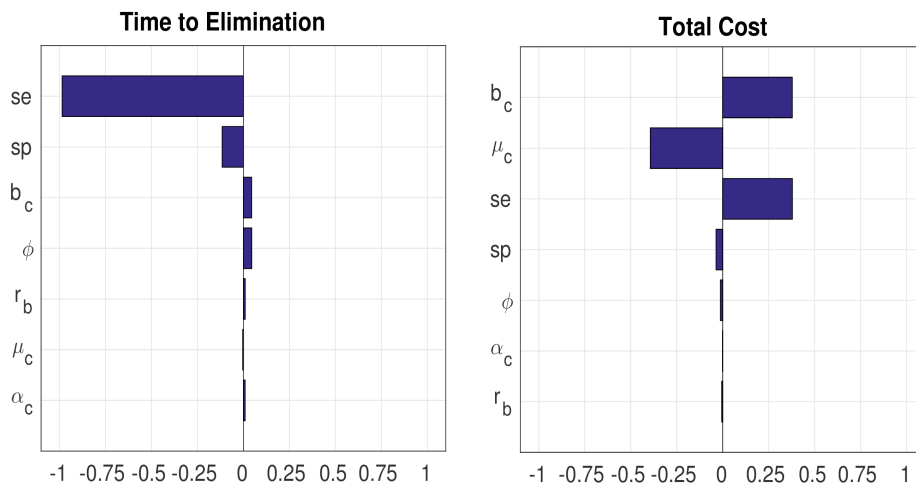


Figure 7.2. Partial rank correlation coefficients (PRCC) sensitivity analysis of time to elimination (right) and total cost (left) on parameter values

The simulation of a test and slaughter intervention led to a decline in BTB prevalence depending on the proportion p of testing (Figure 7.3.). The time to elimination, i.e. the time to reach an individual animal prevalence of less than one in a thousand, ranged from 75 years for $p = 20\%$ to 12 years for $p = 100\%$. For values of $p > 60\%$, the time to elimination was below 20 years (Figure 7.3.).

The reproductive number decreased rapidly below one with an increasing proportion test and slaughter p (Figure 7.4.). With 60% testing and culling, the prevalence of exposed and active human BTB cases decreased from 3.5 per 1,000,000 to less than 1 in 1,000,000 at the time of freedom from disease after 20 years (Figure 7.5.).

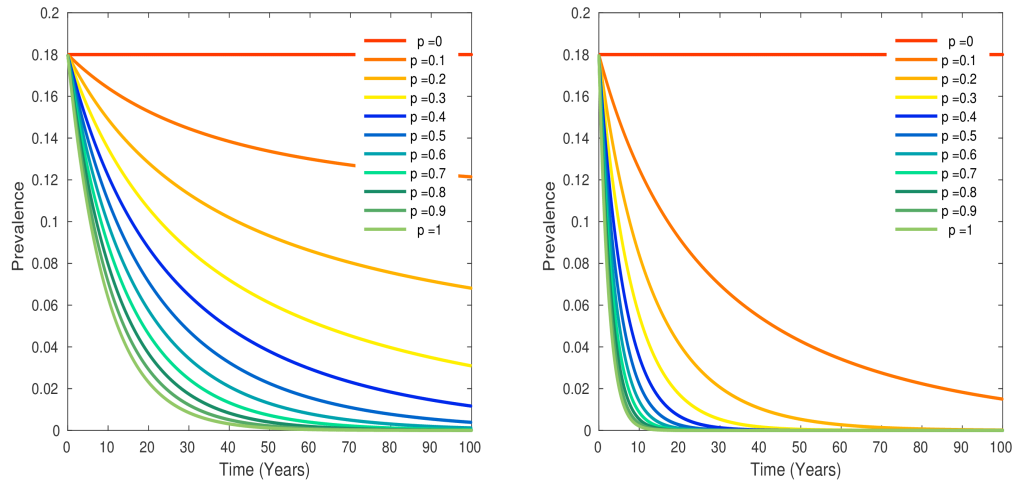


Figure 7.3. Prevalence of tuberculin positive cattle depending on the proportion of test and slaughter between 0 and 1 (in steps of 0.1) with sensitivity and specificity of the 4mm cut-off test (left) and the 2mm cut-off test (right).

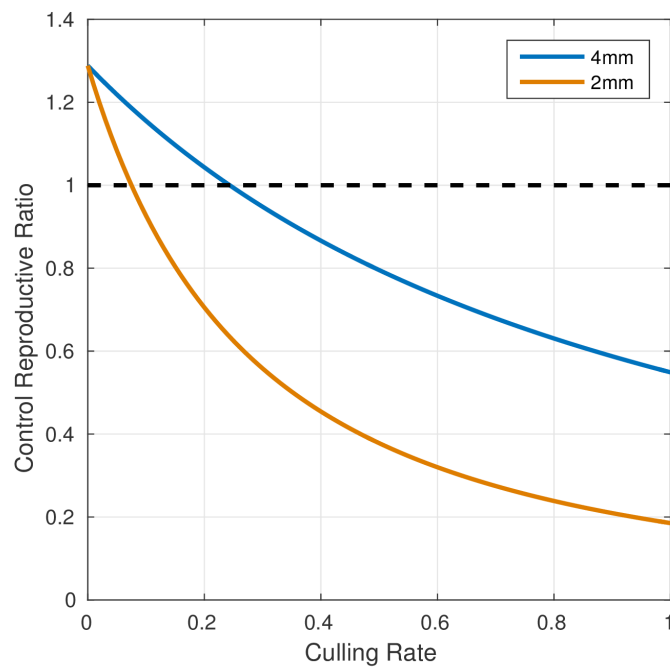


Figure 7.4. Relationship between reproductive number and proportion of test and slaughter for the 4mm cut-off test and the 2 mm cut-off test

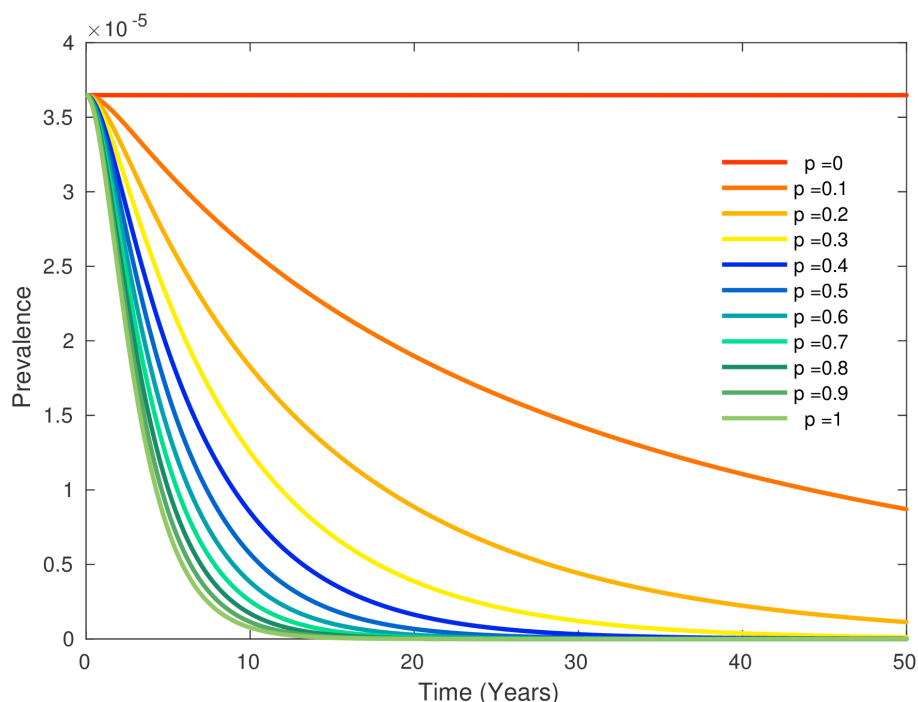


Figure 7.5. Relationship between human prevalence and proportion of test and slaughter using 4mm cut-off test

Cost of test and slaughter intervention

The cost of test and slaughter depends on the percentage p of test and slaughter (Table 7.5.). Lower p results in lower cumulated costs but longer time until elimination. The cumulated cost is remarkably stable for p values higher than 0.2, ranging between 1.47 to 1.87 billion Euros within a time range of 12 to 75 years to reach freedom from disease. The cumulated cost of BTB test and slaughter intervention and the time to elimination were lower using 2mm cut-off of SICTT compared to the 4mm cut-off (Figure 7.6.).

Table 7.5. Relationship of proportion of animals included in test and slaughter and the cumulated cost and time freedom from disease (Individual animal prevalence $<1/1000$).

Proportion of test and slaughter p	Cumulated cost of control in billions of euros* (4mm Test)	Time to reach freedom from disease in years (4mm Test)	Cumulated cost of control in billions of euros* (2mm Test)	Time to reach freedom from disease in years (2mm Test)
0		> 100		> 100
0.1		> 100		> 100
0.2		> 100	1.87	75
0.3		> 100	1.68	44
0.4		> 100	1.60	32
0.5		> 100	1.55	25
0.6		> 100	1.53	20
0.7	1.99	82	1.51	17
0.8	1.94	69	1.49	15
0.9	1.90	59	1.48	13
1	1.84	51	1.47	12

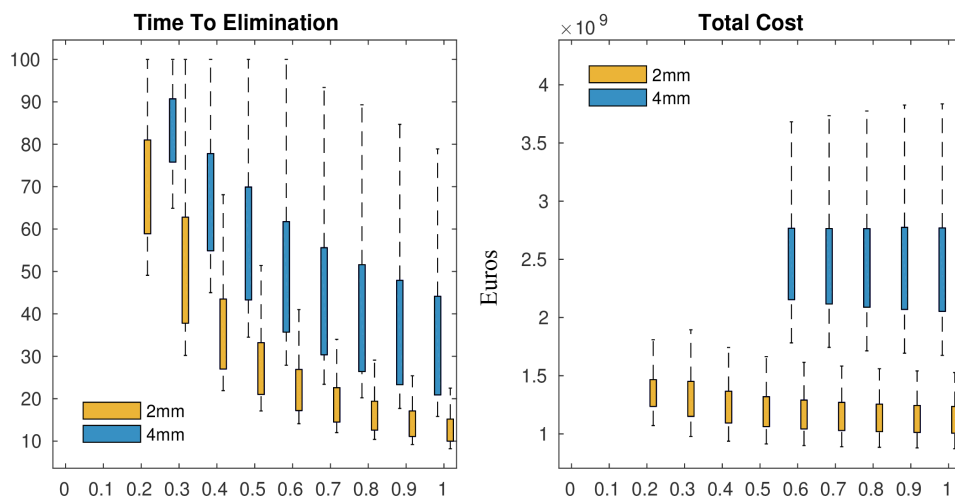


Figure 7.6 Total Cost of the interventions that reach elimination for different proportions of tested animals and 2mm cutoff test (yellow) and 4mm cut off test (blue)

Discussion and Conclusions

This manuscript presents the first cattle to cattle and cattle to human compartmental deterministic mathematical model. Differential equations were used to describe different pathways within and between compartments at human and animal level. Sensitivity analysis of the model has been used to determine the most sensitive parameter. Additionally, different scenarios of test and culling interventions were simulated by considering different proportions of tested population per year (p).

Model properties

To our knowledge this is the first model describing cattle to cattle and cattle to human transmission of BTB in Morocco, although an African buffalo-human model has been published (Hassan et al., 2014). Time series data similar to those for brucellosis in Mongolia (Zinnstag et al., 2005) are unfortunately not available, but the available data allows for a parameterization under the assumption of endemic stability similar to Ethiopia (Tschopp et al., 2010b). The estimated reproductive number of 1.325 is in the range for both low risk areas ($R_0 = 0.6-1.4$) and high risk areas ($R_0 = 1.3-1.9$) reported for the United Kingdom (O'Hare et al., 2014) but is lower than the 1.7-2.2 reported by Bekara et al. for France (Bekara et al., 2014). Using a sensitivity analysis, the birth rate of cattle (b_c) was determined to be the most sensitive parameter of the model.

A key challenge in this model was to distinguish between exposed and infected cattle because the diagnostic test utilized was the intradermal tuberculin test. We used the proportion of cattle with active TB (13.5%) among cattle tested positive by tuberculin skin test, as reported by Ngandolo et al (Ngandolo et al., 2009), to calculate the number of infected cattle. Further microbiological data is required to better describe BTB prevalence in humans in Morocco. Patients treated for active BTB do not completely clear all organisms from their body, with some bacteria persisting in bone marrow (Lay et al., 2007).

Therefore, in contrast to our model, humans do not become completely susceptible again but technically are subject to re-infection (van den Driessche et al., 2007). We argue that this has only a minor impact on total human BTB prevalence, but re-infection should be considered to refine the model.

Our model contains many simplifications. The primary simplification is that of homogeneity: all cattle are not the same. Risk exposure of animals and humans to BTB could change according to sex and age, and we have ignored these differences. Contact between cattle is also not random and is far more likely within herds than between cattle in different herds. Many models have included this heterogeneity in contact patterns within and between herds (Alvarez et al., 2014, Rossi et al., 2015, Brooks-Pollock et al., 2014), but we ignore it here because of a lack of data on within herd BTB transmission in Moroccan husbandry systems. Furthermore, although deterministic models provide reasonable estimates of mean behaviour in large populations, they cannot provide expected distributions of rare events. Therefore, they may not be appropriate for analysing very low transmission settings (that are necessary before elimination can occur). We circumvent this issue with a rather generous definition of elimination as prevalence of less than 1 in 1000.

Test and slaughter intervention

BTB prevalence was found to reach less than one per thousand in less than 20 years when the proportion of tested cattle was above 60%. The annual cost for this potential intervention was nearly 77 million euros. Intervention in cattle was found to impact the prevalence of human TB due to *M. bovis*, which decreased from 5 per 10,000 to 1 per 10,000 after 17 years.

The economic assessment presented here is preliminary, and a detailed cost and cost-effectiveness analysis will be published separately. However, our analysis informs Moroccan bovine tuberculosis control policy on the time horizon, range of cost and optimal levels of intervention. An effective control programme will depend on the human resources and technical and logistical capacity of the veterinary services to implement testing and slaughtering of animals. If the proportion of cattle subjected to test and slaughter was greater than 60%, freedom from disease would be reached in less than 20 years. The simulation results suggest that switching from a 4mm cut off to a 2mm cut off would be likely to result in significantly shorter durations of elimination programmes and much cheaper elimination campaigns.

Our model simulates the removal of individual animals rather than whole herds. Past experience in Europe has shown that whole herd removal is critical for effective elimination in low prevalence situations (Schiller et al., 2011). In addition, a herd based model of the Moroccan cattle population could potentially lead to a lower intervention cost, as it is more realistic.

A recalculation of the intervention cost taking into account stratification by breed, sex and age should be undertaken, as it could lead to a different cost estimation of BTB control strategy. Shortage of human resources should be considered for intervention planning, a maximum of 40% cull rate might be feasible; however, it would be costly in view of current Moroccan economic situation. One may think that test and slaughter implementation would lead to a reduction in cattle population and its by-product. But on the other hand, the increased import of cattle from other countries, with enhanced control measures, could maintain the current population density. In the meantime, as dairy products are provided mostly from highly controlled farms where BTB has a very low prevalence, we could argue that milk production would not be significantly affected.

Towards One Health

The WHO includes BTB amongst the seven neglected zoonoses which are perceived to be severe threats to public health (Wirth et al., 2008). Further molecular epidemiology investigations in Morocco are needed in order to clarify local and national human BTB/TB ratios. To reach this goal, closer collaboration, at the national and international level, between the human and animal health sectors through a One Health approach is highly recommended. Operations in these two sectors remain largely independent in Morocco. Communication must be enhanced to establish a One Health approach, which has proven efficacy in health service delivery and potential for economic savings in zoonosis control (Zinnstag et al., 2011, Zinnstag, 2015).

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CHAPTER 8: COST EFFECTIVE CONTROL STRATEGIES FOR ANIMAL AND ZOO NOTIC DISEASES IN PASTORALIST POPULATIONS

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Cost-effective control strategies for animal and zoonotic diseases in pastoralist populations

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Cost effective strategies for animal and zoonotic diseases in pastoralist populations

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Abstract

Animal diseases and zoonoses abound among pastoralist livestock, which is composed of cattle, sheep, goat, yak, camels, llamas, reindeer, horses and donkeys. There is endemic and periodically epidemic transmission of highly contagious viral and bacterial diseases in Africa, Asia and Latin America. Pastoralist livestock is often multiparasitised with endo- and ectoparasites, as well as vector borne viral and protozoal diseases. Pastoral livestock can be a reservoir of such diseases and can also conversely be exposed to wildlife reservoirs. Public and private animal health services currently underperform in almost all pastoral areas due to structural reforms and lack of income as indicated in assessments of veterinary services by the World Organization for Animal Health. Control of infectious disease in industrialized countries has been achieved through large-scale public funding of control measures and compensation for culled stock. Such means are not available in pastoralist areas of most low and middle income countries (LMICs). While knowledge of the cost-effectiveness and profitability of the control of animal diseases and zoonoses seems less important in industrialized countries, in the experience of the authors it is a prerequisite for successful attempts to improve animal health in low and middle income countries. Incremental cost of animal disease control can potentially be shared using cross-sector assessments, integrated control and regional coordination of mitigating transboundary disease risks. In this paper, we discuss cost-effective animal disease and zoonoses control in LMICs. It illustrates frameworks and examples of integrated control and cross-sector economics showing conditions under which these diseases could be controlled in a cost-effective way.

The burden of animal disease in pastoralist areas and measures for disease control

Livestock, mainly cattle, sheep, goats, llamas, camels, dromedaries, reindeer, horses and donkeys are plainly livelihood for several hundred million pastoralists worldwide. These livestock populations suffer from many contagious diseases and malnutrition (Molla and Delil, 2015), including infectious viral (Staeuber et al., 1993, Molla and Delil, 2015, Gustafson et al., 2015) and bacterial (Maho et al., 2006b, Kasymbekov et al., 2013, Gumi et al., 2013a, Gumi et al., 2012a) diseases and multiparasitism with gastrointestinal nematodes, trematodes (Zinsstag et al., 1998, Jean-Richard et al., 2014a) and ectoparasites. Mobile pastoralists avoid periodic exposure to ticks and thus tick-borne diseases like East Coast Fever (EVF) and arthropod-borne infections like trypanosomiasis. Priority diseases in Asian, African and selected Latin American pastoralist areas continue to be highly contagious diseases like foot and mouth disease (FMD) and peste des petits ruminants (PPR), followed by contagious bovine and caprine pleuropneumonia (CBPP, CCPP), pasteurellosis, blackleg, Rift Valley Fever (RVF) (Abakar et al., 2014), brucellosis (Racloz et al., 2013), sheep pox, bovine tuberculosis (Gumi et al., 2012b) and, locally, East Coast Fever (ECF) and anthrax (Maho et al., 2006b). For certain diseases, like brucellosis and bovine tuberculosis, wildlife reservoirs exist, while others are related to dogs or rodents, for example, echinococcosis and leptospirosis. Since dogs are kept for herding or protection, dog rabies is also important. Extensive pastoral and specifically mobile husbandry systems may reduce exposure risks because they can move away from a risk area. Infectious disease transmission is also reduced by lower animal densities, for example for bovine tuberculosis or brucellosis (Racloz et al., 2013).

Despite high animal disease burdens, pastoralists, and especially mobile pastoralists, are poorly served by animal health services (Onono et al., 2013), relying heavily on traditional and informal animal health care workers (Hilou et al., 2015) and self-medication (Healy Profitós et al., 2013). With the privatization of veterinary services following the structural reforms advocated by the World Bank (Leonard, 2008), public animal health services were further reduced in pastoralist areas, especially in sub-Saharan Africa. In those countries, some governments attempted to motivate private veterinarians to serve pastoralist areas using sanitary mandates, but high coverage did not result due to the high logistic costs. The high cost of disease control in pastoralist areas remains an obstacle for effective control of transboundary and endemic diseases in pastoralist populations and indirectly also for the global community. Finding solutions for more effective control of animal diseases in pastoralist areas is a priority for the World Organization for Animal Health (OIE). The OIE developed a tool to evaluate the performance of veterinary services (PVS) (OIE, 2013) on a voluntary basis but has not yet established a mechanism that enhances animal health delivery in remote pastoralist areas. This brief discussion paper addresses options for cost-effective control of animal disease and zoonoses in pastoral areas, disease surveillance and animal health service financing. Many aspects are not specific to pastoralist areas but are inclusive for pastoralist livestock production in LMICs, which are the most underserved areas by public services.

Frameworks of economic efficiency of animal disease control

From the perspective of pastoralism as a livelihood, animal disease control should be profitable in terms of benefits in livestock production against the cost of disease control (benefit-cost ratio above 1) (McDermott et al., 2013, Rich and Perry, 2011). In the public health sector, the cost-effectiveness of an intervention is expressed as the cost per life year saved. Specifically, the term cost per averted disability adjusted life year (DALY) is used. For example, it costs about 25 USD to save one year of life for a person suffering from tuberculosis. Similarly one can consider cost-effectiveness in animal health as cost per animal life saved or added value in productivity, but we do not further propose to adapt the DALY concept to livestock (Babo Martins and Rushton, 2014).

Animal diseases cause losses in terms of animal numbers (asset value), income from animal products like meat, milk, hides and other products and expenditure in reaction to the disease (McInerney, 1992). The cost of disease control should be less than the losses from animal disease to justify animal disease control interventions. Understanding the cost of disease requires an understanding of the effect of diseases on the demographic composition, i.e. through increased abortion or mortality rates or by reduced off-take in terms of lower milk and meat production and cost of treatment. Standard packages like the Livestock Development Planning System (Jahnke, 1982) or generic demographic matrix models using Monte Carlo simulations which consider uncertainty of productivity parameters and price variability are suitable tools to estimate the losses due to livestock disease (Tschopp et al., 2012b, Chengula et al., 2013). However, such assessments are limited by knowledge of how diseases reduce productivity parameters (Bernues et al., 1997b) or even knowledge on normal herd composition. In many cases, we must rely on very old estimates since no current data exist, e.g. for bovine tuberculosis (Meisinger, 1970). Through the control of disease, some losses can be avoided. Economic analyses contribute to evaluate whether the extra resources needed for disease control are outweighed by the avoided losses from a disease. In most cases, effects of disease control are dynamic non-linear processes requiring mathematical models of disease transmission to simulate interventions. Such models allow for simulation of disease frequency with and without interventions and translation into analyses of economic efficiency of interventions (Zinsstag et al., 2005a, Roth et al., 2003). In addition there may be other production-related direct and indirect costs to the food chain, environmental services or trade restrictions or costs to other sectors such as tourism.

In the case of zoonoses, costs of disease in human health also arise for which cross-sectoral methods have been generated (Narrod, 2012). Such cross-sectoral analyses assess the societal cost of disease and show under which conditions interventions in human and/or animal health are cost-effective. For example for dog rabies control in N'Djaména, Chad, it can be shown that the mass vaccination of dogs is less costly than the post-exposure prophylaxis of humans after 10-15 years (Zinsstag et al., 2009).

Mass vaccination of pastoral livestock against brucellosis in Mongolia is not profitable for the public health sector alone. However, if benefits for livestock production and human health are pooled as societal benefits, mass vaccination of livestock becomes largely profitable to Mongolian society (Roth et al., 2003). Examples from joint human and animal health service provision to mobile pastoralists are described by Schelling et al. (Schelling, 2016).

Consequently, disease control efforts resulting in benefits from closer cooperation between human and animal health, known as One Health approaches, have a high potential for provision of cost-effective interventions in pastoralist areas (Okello et al., 2014). While bovine tuberculosis (BTB) has been eliminated in some industrialized countries, it persists worldwide, particularly in Africa. In Ethiopia, BTB is prevalent in pastoral livestock (Gumi et al., 2011, Gumi et al., 2012c) but has not been demonstrated in wildlife (Tschopp et al., 2010a), with only very few cases found in humans (Berg et al., 2015b, Gumi et al., 2012a). Control of bovine tuberculosis in pastoral areas requires a better understanding of the cost of disease. A recent study on the cost of BTB to urban and rural cattle production in Ethiopia estimated an average annual loss of one USD per cow per year, which is lower than the tuberculin testing cost. In the case of BTB in pastoral areas of Ethiopia, we cannot currently demonstrate a measurable loss in asset value or cost of disease, but control of BTB may also be justified on other than economic grounds (Tschopp et al., 2012b).

Integrated approaches to animal disease control

In pastoral areas of LMICs, available resources are so limited that any effort to reduce the incremental cost of control in order to increase the benefit-cost ratio of interventions is attractive. This increasingly includes integrated efforts to prevent a set of prevailing livestock diseases rather than only single diseases. It is important to note that efficacy and safety for new combinations of vaccinations against several diseases, such as FMD combined with brucellosis, are not documented and industrialized countries could make a contribution in this area. In pastoral areas near the south-eastern shores of Lake Chad, cattle vaccination against anthrax (Maho et al., 2006b) could be combined with deworming against *Fasciola gigantica* (Jean-Richard et al., 2014a). At the same time dogs could be vaccinated against rabies. In areas with concurrent bovine tuberculosis in cattle, echinococcosis and brucellosis in small ruminants and rabies and leishmaniosis in dogs, such as Sidi Kacem in Morocco (Ducrotoy et al., 2015), an integrated control package could be applied. An animal health worker visiting a household would vaccinate dogs against rabies, deworm them for adult *Echinococcus granulosus*, and put on a repellent collar against sand-flies. The sheep would be vaccinated against brucellosis, and cattle would be tested for bovine tuberculosis.

Such integrated control strategies require advanced knowledge about the epidemiology of the prevailing diseases. Such multi-disease intervention shaping and planning require the involvement of authorities, disease control experts and communities in a participatory way to achieve local ownership

and avoid negative effects on minorities (Schelling et al., 2007e, Okello et al., 2014, McGahey, 2011, Schelling, 2015). Published economic analyses of such integrated control packages are not known to the authors, but it seems reasonable to assume that the incremental cost of control for several diseases at once would be lower and the overall profitability higher compared to control programmes against single diseases. In public health the Expanded Programme on Immunization (EPI) already uses several vaccines to immunize children during the same session. However, in animal health such approaches require a high level of expertise and contextual adaptation. Fixed costs to enhance public services levels and maintain supportive health services infrastructure require higher level planning. Integrated disease control packages may be of particular interest for diseases that are not considered as a priority, i.e. like dog rabies in pastoral areas. In such cases, rabies mass vaccination of dogs could be piggybacked on priority interventions like FMD vaccination of cattle (Zinsstag, 2013, Hasler et al., 2014) or with conservation activities (Ferguson et al., 2013). To ensure pastoralists' adherence to such integrated approaches, additional services could be offered during the same operation, such as delivery of official birth certificates for children. An important issue is the need for comprehensive decision making regarding willingness to pay for such integrated interventions in areas where animal ownership may be diverse, for instance either within the family or community.

Similarly, One Health service provision to pastoralist communities might provide vaccination services to children and women simultaneously with mass vaccination of livestock (Schelling et al., 2007a) as further described by Abakar et al. (Abakar, 2016). In addition to integrated control approaches, regional coordination between countries is essential for transboundary diseases, including major zoonoses. Hampson et al. describe synchronous cycles of dog rabies transmission across East African countries (Hampson et al., 2007), also highlighting the importance of regional control efforts in Latin American countries for elimination of dog rabies. A classic example for the effectiveness of regionally coordinated livestock disease control efforts is the successful elimination of rinderpest in Africa (Klepac et al., 2013, FAO, 2012). Regional governance bodies like the African Union-Interafrican Bureau for Animal Resources (AU-IBAR), the Pan American Foot and Mouth Disease Centre (PANAPHTOSA) in Latin America and the Association of Southeast Asian Nations (ASEAN) would play a very important role in animal health diplomacy.

Disease surveillance and animal health education

Effective disease control efforts require functional, timely monitoring and surveillance systems. The global community's slow response during the Ebola epidemic in West Africa in 2014-15 is a warning that ineffective health systems and surveillance, late understanding of the social context and global response mechanisms delay detection of emerging pathogens and cause unnecessary suffering and loss of life, possibly also wasting limited resources (Moon et al., 2015). In most pastoralist areas of LMICs, animal disease surveillance is too slow for rapid detection of emerging outbreaks. Sentinel herds in high risk areas are frequently not maintained due to costs and routine data are not available in

a timely manner or are of poor quality. Most often, before the information reaches decision makers, biological samples are no longer viable for processing. Future disease surveillance in pastoralist areas should make use of mobile communication and other modern technologies. A proof of concept for integrated health and demographic surveillance of humans and animals in mobile pastoralist communities has already been published by Jean-Richard et al. (Jean-Richard et al., 2014c). Such systems could be refined to develop a near real-time community-based syndromic surveillance and response using mobile communication combined with geographical positioning systems and the use of drones or possibly integrated into the existing INDEPTH network. The field for technical and disease control innovation is currently wide open in thus far hard to reach pastoral areas. Beyond all technical improvements, it is investments in information, education and communication for pastoralists, across all ages and genders, which are the foundation of community based surveillance, creating a first line of attention for poor health of animals and humans in pastoral areas (Ban-Bo et al., 2014, Chengula et al., 2013, Gustafson et al., 2015). The basis of better surveillance coupled with response in terms of herd level interventions (e.g. ring vaccination) provides an important strengthening for general health systems, but its cost should also be factored into the overall economics of disease control.

Animal health financing and global solidarity

Animal disease control in pastoralist areas is hindered by lack of sensitive disease surveillance, diagnostic capacity and inadequate service provision and, importantly, also by financing. Institutional donors are reluctant to invest in high risk interventions without a stringent framework for monitoring success (Hughes, 2014). A new concept using Development Impact Bonds (DIBs) has evolved from initiatives in social financing (Hughes, 2014), which shares investment risks between private investors and institutional donors within a “payment on result” framework. However, the modalities of purchase and refunding of such bonds are still a matter of debate for animal disease control. Currently, one of the first DIBs for animal disease control aims to eliminate *Trypanosoma brucei rhodesiense*, zoonotic sleeping sickness, in Uganda (Welburn and Coleman, 2015).

Additionally, the financing of the above mentioned successful Panafrican Rinderpest Control campaign (PARC) is an example of international solidarity in animal disease control. International animal disease control efforts should also learn from the Global Fund to control Tuberculosis, HIV/AIDS and Malaria, which builds on the principle of making diagnosis, essential drugs and management strategies for these diseases available to eligible countries through international donations (Zinsstag et al., 2007). Infectious disease risks like avian influenza, FMD, PPR, African horse sickness and African swine fever justify a global solidarity principle advocating freedom from transboundary diseases as a global public good.

A globally coordinated control effort, especially in pastoral areas, should be much more cost-beneficial than limiting disease surveillance and control within national governments. The improved cooperation of OIE, the Food and Agricultural Organization of the United Nations (FAO) and the World Health Organization (WHO) is encouraging and crucial for such globally coordinated efforts.

Concluding remarks

Cost-beneficial animal disease control in pastoralist areas requires information, education and communication efforts in order to develop locally adapted community based disease surveillance that can identify the causative agents of outbreaks and disease burden in near real-time. Knowledge about the cost of disease and, ideally, the profitability of disease control should be assessed prior to undertaking mass interventions and herd level decision making. For zoonoses, the societal benefits, across all involved sectors, should be assessed and costs of intervention assigned proportionally to sectors – and if possible, the human health benefits should be expressed as averted DALYs. Based on these profitability assessments, a prioritization of interventions is possible, analogous to that used in public health (Hasler et al., 2013, Rushton et al., 2012). Integrated approaches, combining human and animal health as One Health interventions, have a high potential in pastoralist areas. Depending on the prevailing diseases, disease control should be packaged and aim to control several diseases simultaneously, further reducing incremental cost. There has never been better global coordination between animal and public health, which should be harnessed to work towards global solidarity for freedom from animal diseases in the poorest countries of the world and in pastoralist areas in particular.

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CHAPTER 9: HUMAN AND ANIMAL HEALTH SURVEYS AMONG NOMADS

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Human and animal health surveys among pastoralists

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Human and animal health surveys among nomads

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Summary

Valid human and livestock health surveys, including longitudinal follow-up, are feasible among mobile pastoralists and provide fundamental information to agencies for interventions that are responsive to realities and effective in addressing needs of pastoralists. However, pastoralists are often excluded from studies, surveillance systems and health programmes. Preventable and treatable diseases like perinatal tetanus, measles and tuberculosis are indicative of limited access to health providers and information. Health services are challenged to include effective outreach with their available financial and human resources. One consequence is that maternal mortality rates among pastoralists are unacceptably high. Environmental determinants such as the quality of water and the pasture ecosystems further influence the morbidity of pastoralists. In the Sahel, the nutritional status of pastoralist children is seasonally better than that of settled children; but pastoralist women tend to have higher acute malnutrition rates. Pastoralist women are more vulnerable than men to exclusion from health services for different context-specific reasons. Evidence-based control measures can be assessed in cluster surveys with simultaneous assessments of health among people and livestock, where data on costs of disease and interventions are also collected. These provide important arguments for governmental and non-governmental agencies for intervention development. New integrated One Health surveillance systems making use of mobile technology and including experiences, local concepts and priorities of pastoralist communities, combined with sound field data, are essential to develop and provide adapted human and animal health services that are inclusive for mobile pastoralist communities and allow them to maintain their mobile way of life.

Key words

Health, pastoralism, human, livestock, joint assessment, study design

General introduction to health of pastoralists

Mobile pastoral production is poorly captured by standard systems of appraisal; for example, it is less likely to be included in health surveys and surveillance or in development programme designs. However, increasing the economic and environmental sustainability of dryland production is unlikely without reaching producers in pastoral systems with health and education services. By acknowledging the economic and environmental rationale of mobility, the constraints of static health and education services must be overcome.

Experiences in various settings show that more progress towards universal health coverage is achieved when coverage among disadvantaged groups is increased first (Gwatkin and Ergo, 2011). The physically demanding livelihood of pastoralists requires good human and animal health. Livestock keeping confers human health benefits as well as health risks, and the relationships are not always linear (Zinsstag et al., 2011c). Only enhanced understanding of the production logic of pastoral mobility allows for the design of contextually-appropriate programmes and the ability to monitor and evaluate their actual effectiveness – as, indeed, is true for any other setting. Sound health and socio-economic surveys and follow-up studies are feasible among mobile pastoralists. Joint integrative human and animal health intervention development within a One Health logic can lead to beneficial health outcomes (Zinsstag et al., 2005c). This fact should be more widely advertised. Below, results from studies on general health and demographics in pastoralists' communities that were carried more than 20-30 years ago are summarized together with more recent examples, illustrating the positive impact of integrative approaches.

Highly contagious diseases of livestock such as 'Peste des Petits Ruminants' (PPR) and Rift Valley fever contribute to significant human food and nutritional insecurity (Bechir et al., 2015). The last pockets of rinderpest remained among pastoralists because they had too little veterinary assistance. Only participatory approaches enabled reaching these remote communities for successful disease eradication (Jost et al., 2007). Veterinary services successfully controlled many severe cattle diseases and now focus on endemic diseases such as intestinal parasites and zoonoses – also including other livestock than cattle. (OECD, 2012). Some livestock diseases are associated to poor animal nutrition and watering (see Abakar et al., Chapter 30) and lead to clinical signs i.e. from selenium or vitamin E deficiency (Akiyama, 2007).

Pastoralists seek effective livestock vaccines and drugs when available and apply successful herd management practices such as cross-breeding for more trypano-tolerant cattle. Mobility allows them to actively avoid areas with year-round infected vectors or anthrax spore contaminated fields – but flexibility and mobility are constrained by fragmentation of grasslands (Galvin, 2009) and conflicts (see Haller et al., Chapter 7 and Bonfoh et al., Chapter 14 this volume).

The main human health conditions found among mobile pastoralists of three different ethnic groups in Chad did not differ substantially from morbidity typical for the Sahelian population. Frequent diarrhoea and fevers (Nathan et al., 2005), respiratory infections, including lower tract infections in children and tuberculosis in adults, and malaria had more impact on health than food-poisoning and zoonotic diseases such as brucellosis in studies of West, Central and East Africa (Schelling et al., 2005b, Chabasse et al., 1985, Ilardi et al., 1987).

However, pastoralists' mortality and morbidity is affected by barriers of access to health services (see Abakar et al., Chapter 30). Mortality due to infections such as measles and tuberculosis are clear signs of insufficient access to good quality health services and exclusion from vaccination campaigns and appropriate information (Lawson et al., 2014), although transmission, for example of measles, was low among Tuareg nomads in Niger due to their dispersion (Loutan and Paillard, 1992). Periodic nutritional shortage as well as safety-related issues such as political insecurity impact importantly on human health among pastoralists. Several studies have shown marked differences in nutritional and health status between pastoralists and agro-pastoralists, but no larger scale study assessed demographic parameters including mortalities in the past two decades (Weibel et al., 2011). In the 1980ies, higher infant mortalities among pastoralists compared to settled, crop-farming populations were reported from Mali, Kenya and Tanzania (Brainard, 1986, Chabasse et al., 1985). The use of unsterilized instruments during childbirth and female genital mutilation or inability to gather health information partly explain why some pastoral communities struggle with unprecedented HIV/AIDS morbidity (Morton, 2006).

Women are particularly vulnerable to political-ecological changes. In post-Soviet countries the decline of professional delivery assistance led to poor reproductive health and increased maternal mortality (Janes and Chuluundorj, 2004). Besides unavailability of transport, perceived quality of care related to language barriers and not being treated respectfully by health staff, pastoralist women in Muslim African ethnic groups cannot visit health centres or outside traditional services unaccompanied and without permission from husbands or fathers. In other contexts, women experienced difficulties to access health services because they lack support of their social system and network (Hampshire, 2002a). Additionally, women might feel ashamed or embarrassed to ask their husbands, particularly for sexual and reproductive health issues (Grolimund, 2010). The absence of a customary male chaperone due to spatial separation may make it impossible for women or their children to receive the needed treatment. Recently, the use of mobile phones showed advantages and disadvantages regarding health care seeking. Pastoralist women could call their husband anytime, but in areas with weak network coverage, this can delay treatment because women no longer asked the most easily accessible male chaperone (Corradi and Schurr, 2011, Jennings and Gagliardi, 2013). Education initiatives to empower pastoral women (e.g. credit and literacy classes) showed a positive impact on the household member's health, since women tend to reinvest their income, for example, by paying medical fees (Flintan, 2008).

It is difficult to draw coherent conclusions on linkages between human and animal health from separated human and livestock health studies. Designing studies with a One Health approach to simultaneously assess human and animal health risk factors, perceptions and outcomes lead to a better understanding of the specific context of pastoralism, particularly when diverse disciplines such as social sciences, epidemiology and geography are associated (Zinsstag et al., 2011c).

Joint human and animal health surveys are done concurrently in time and/or space and at different levels of aggregation: from individual, household or village level, to communities and their animals, provinces or country. The ideal outcome promotes improved human, animal and ecosystem health (Schelling and Hattendorf, 2015).

The content of this article is structured in two main parts, the first part is on results and lessons learned from comparative or integrated One Health studies and the second part is on study design and recommendations. We rely on our own work in Africa and Central Asia, alongside a review of findings of relevant working groups and literature. In the first part, we highlight the linkages of the pastoralists grassland ecosystem use with human and animal health outcomes. Where possible, results are shown as comparison of pastoralists to a reference group to better perceive the specificities of pastoralist communities within the remote rural context. Risks but also benefits of a pastoralists' way of life are critically discussed. In the second part, we present methodological considerations for epidemiological human and animal health studies and monitoring and surveillance among mobile populations and discuss potential strategies and recommendations towards the use of health information to develop inclusive and effective health interventions.

Selected health outcomes from comparative studies

Nutrition in pastoralist settings

In rural Chad, proportions of acute malnutrition were not higher in pastoral children compared to sedentary children. But both populations showed acute malnutrition proportions above 10% at the end of the dry season (Bechir et al., 2010c, Schelling et al., 2005b) (Figure 1). In contrast, pastoralist women were significantly more under-nourished (up to 48% in the dry season) than settled women, and obesity was only seen among settled women (Bechir et al., 2011) (Figure 2).

Acute malnutrition in children was significantly associated with anaemia and selected intestinal parasites (Bechir et al., 2012a). Other authors have observed that pastoralist mothers deprive themselves when nutrition is in short supply (Shell-Duncan, 1995). Among the Ariaal and Rendille in East Africa, children of three settled communities, one in a famine-relief based town, showed three times the level of stunting and wasting when compared to the surrounding nomadic and semi-mobile pastoralists.

These differences were attributed to greatly reduced access to milk and higher reliance on cereals in the settled communities (Fratkin et al., 2004). During the wet season, when milk was abundant and grain prices were highest, milk provided almost 90% of dietary energy to Turkana

pastoralists and 80% to the Maasai (Galvin, 1992, Nestel, 1986, Lawson et al., 2014). Milk selling tended to be the domain of women and who have decided how much milk is allocated for home consumption. However, there is a growing number of reports since three decades on how commercialization of pastoral milk in peri-urban zones or with new dairy plants in pastoral zones has become a cash-making business taken over by men.

Extra income from sales to dairy plants is sometimes invested in buying fodder for the animals to keep milk production more stable throughout the year. Also, poorer pastoralist households consume fewer milk because they need the milk income to buy grains. These new milk selling strategies led to a relative reduced milk consumption of pastoralists (Flintan, 2008, Sadler et al., 2009).

Vitamin A levels may indicate the linkages from environment to animals through milk to humans. Milk from cows grazing on green pastures had higher β -carotene levels while the pastoralist consumers of such milk had fewer deficiencies in vitamin A (Zinsstag et al., 2002). Retinol levels showed strong seasonal variation (Crump, 2014). Still, milk as the primary source of vitamin A for pastoralists is insufficient. Serum retinol deficiencies were high among pastoralists, up to 32% in the cold season (Crump, 2014). Another study found a high prevalence of moderate serum retinol deficiency in settled children younger than five years at the end of the rainy season, whereas, during the same period, it was as low as 1% among nomadic children (Bechir et al., 2012b). Low fruit and vegetable consumption were seen in several studies in West and East Africa (Holter, 1988), which also applies to poorer pastoral households in Central Asia and Mongolia (Children, 2013).

Many pastoralist families have diversified their activities through crop-farming and commercialization of milk. Diets previously rich in animal protein through milk and meat, though often calorically deficient, are changing to diets based on cereals. Also sugar and oils became new important sources of energy for pastoralists (Schelling et al., 2005b) and, as in other settings, may cause diabetes and hypertension.

In drought situations in the Sahel or winter disasters called *Zud* in Mongolia, the economic value of livestock drops rapidly. Timely ‘commercial destocking’, or taking animals off the land to prolong management of vegetation yield until the end of the drought, benefits the environment. Dried meat provides nutritional energy and protein, while money earned by selling can be used to buy supplemental fodder. Pastoralist communities are commonly willing to sell livestock but often lack access to markets. Interventions that facilitate livestock purchase by providing transport subsidies to traders are successful and cost-effective. Timely replenishment of the livestock economy and continued generation of alternative livelihoods and sources of income are targeted in the post-drought period (Morton and Barton, 2002, Simpkin, 2005, Ericksen, 2014).

Human and animal parasitic diseases

In dry areas, natural and man-made water sources are highly frequented by humans, livestock and wildlife, and the density of livestock can be very high. Pastoralists sometimes use surface water rather than safer wells because they have lost traditional access rights to wells or because only surface water is available. Where possible, pastoralist groups access surface water during the rainy season, also because waterholes and wells rapidly become contagious places and a source of disease (Foggin et al., 1997, MacPherson et al., 1987), for example for cholera and typhus during the rainy season (Cummings et al., 2012, Schelling et al., 2005b).

In Africa, mainly *Schistosoma haematobium* and *Schistosoma mansoni* in humans and *Schistosoma bovis* in cattle cause schistosomiasis (also known as bilharzia or “snail fever”). Highest prevalences in humans and in cattle were found among ethnic groups which pasture their livestock on the shores or islands of Lake Chad where the intermediate hosts - several species of freshwater snails – are present. Other ethnic groups - skilled in building wells - had markedly lower prevalences (Greter et al., 2015a). Another study showed that the main source of the liver fluke fascioliasis in ruminants was the lake rather than rain-fed surface water areas (Jean-Richard et al., 2014b). The increased concentration of people due to population growth and utilization of resources by, for example, pastoralists, fishermen, agriculturists and tourism, with following degradation of wetlands, potentially favours an environment for disease transmission between people, livestock and wildlife populations as groups are forced into small isolated areas with limited available water (Mazet et al., 2009).

In central Asia, Mongolia and the Tibetan plateau, grasslands are populated with rodents - the intermediate host for another parasite, *Echinococcus multilocularis* - that causes the severe human and animal disease alveolar echinococcosis (AE) (Giraudoux et al., 2013). Human cystic echinococcosis is caused by infection with the hydatid cyst or larval stage of the dog tapeworm *Echinococcus granulosus*. The parasite is transmitted between dogs and domestic ungulates, especially sheep. One third of all households in Mongolia keep sheep in extensive pastoral systems. *E. multilocularis* is found in wildlife (Ito et al., 2013) and *E. granulosus* in livestock (e.g. 9.2% seropositivity in goats) (Chinchuluun et al., 2014). Both echinococcosis species are found in people (Chinchuluun et al., 2014, Ito et al., 2013). After a substantial decrease of human echinococcosis, the disease spread again after the breakdown of health and veterinary services during the transition from socialist planned economy to market economy and privatization (Davaatseren et al., 1995). In the Turkana region of northwest Kenya, and also among Tibetan nomadic populations, abdominal ultrasound screening surveys have detected hydatid cysts in 5-19% of pastoralists, with 10-20% prevalence in the age group of 20-50 years (MacPherson et al., 1987).

Furthermore, parasitic diseases considered less important for livestock and people, such as bovine cysticercosis, gain momentum with the advent of export slaughterhouses in pastoral areas. When cattle are infected with bovine cysticercosis, the carcasses are condemned, causing large economic losses to pastoralists and entire regions (Asaava et al., 2009).

Bacterial zoonoses

If brucellosis was not present, milk and meat production in traditional cattle production systems in sub-Saharan Africa would increase an estimated 5 - 11% and 12 - 35%, respectively (FAO, 2002). The main human infection routes of several bacterial zoonoses, e.g. brucellosis, Q-fever and bovine tuberculosis, vary between communities: direct contact and particularly contact with abortion by-products dominate in livestock keeping communities, whereas contaminated raw milk products put consumers at risk of infection. Establishing correlations between human and livestock zoonotic infections at household level is rarely straight forward in mobile livestock-keeping communities, because the composition of people and livestock commonly changes in a next season when e.g. different brothers and co-wives move together for the next months and new herds are re-composed. Zoonotic transmission, however, could occur during another composition of people and livestock than the one found in a cross-sectional study. For example in Kyrgyzstan, human brucellosis seropositivity was related to sheep seropositivity at higher district level, but not at the household level (Bonfoh et al., 2011). Human seroprevalences were very high (up to 30%) among pastoralists in Kyrgyzstan and Mongolia (Zolzaya et al., 2014, Bonfoh et al., 2011). In Mongolia, non-pastoralist communities also showed high prevalence (Tsend et al., 2014). In Togo, human seropositivity was un-expectantly low (below 1%), although cattle seropositivity was high (9% in village and 7% in transhumant cattle) (Dean et al., 2013). The Togolese *Brucella abortus* strains from cattle had a large deletion in a gene that might influence virulence and/or host predilection (Dean et al., 2014). In Chad, human Q-fever seropositivity was associated with keeping camels but not cattle (Schelling et al., 2003). High Q-fever seropositivities in camels were confirmed in other studies, for example in pastoral settings in Ethiopia (Gumi et al., 2013b).

Among pastoralist communities of south-eastern Mauritania, the illness ‘tuberculosis’ - thus how the communities describe and perceive a disease – had several names compared to the one biomedically defined tuberculosis . Tuberculosis (TB) was part of different illness concepts according to different stages and perceived causes (hereditary, warm or bitter foods [*Iguindi*], lack of sufficient milk [*Timchi*]). Three types of tuberculosis-like illnesses were treated by the healer, two by the faith healer and one by the medical doctor depending on the name of the local illness (Ould Taleb, 2007). In a recent population-based study in south-eastern Ethiopia, the prevalence of presumptive TB cases was not higher among pastoralists than villagers, but high among both and indicating that the whole rural population is deprived of quality diagnostics and treatment (Lô, 2016). Possible cattle-human transmission of tuberculosis was not a local illness transmission concept among pastoralists in south-eastern Mauritania, whereas two-thirds of mycobacterial adenitis patients in Tanzania knew about this zoonotic transmission possibility (Mfinanga et al., 2005). The proportion of human tuberculosis due to *Mycobacterium bovis* was generally lower (<10%) than expected two decades ago. A recent review found a median proportions of 2.8% among human TB patients in Africa and 1.4% in the rest of the world (Muller et al., 2013b). A combined field, slaughterhouse and hospital study in Ethiopia showed

that *M. bovis* in human TB infection was low – among 1000 *M. tuberculosis* complex isolates from clinical suspects of pulmonary and extra-pulmonary TB, only 4 isolates were *M. bovis* (Berg et al., 2015a). Interestingly, *M. tuberculosis* was isolated from several cattle and from one camel, suggesting more frequent transmission of TB strains between livestock and people (Gumi et al., 2012b). *M. bovis* causes production losses in cattle, especially in African peri-urban dairy farms with ‘exotic breeds’. However, it does not seem to cause major economic losses in extensive systems (Tschopp et al., 2012a).

Human and animal health survey designs

The previous sections presented findings from joint human and animal health surveys and intervention assessments. We outline below some considerations for the design of such studies. It is rarely possible to select a simple random sample among pastoralists because this requires an accurate list of community members. Multi stage cluster sampling is commonly used when complete registries, of humans or animals, do not exist. Herds and pastoralist camps where members move together, represent natural clusters. In contrast to settled communities where a list of villages is either available or can be compiled, a random selection of mobile pastoralist camps from a list is usually not possible. Sampling at water bodies or wells has been suggested, but ethnic and seasonal heterogeneity in migration routes might introduce bias (Kalsbeek, 1986). Alternatively, random transects have been employed for random selection although smaller camps might risk being overlooked with this approach. Generating random geo-coordinates and sampling all camps within a predefined circumference proved to be useful. However, bias can also be introduced because camps in sparsely populated areas have a higher probability of selection than those in densely populated areas. The use of aerial photography and remote sensing has been considered to estimate population sizes, but might be less useful in the context of sampling (Animales, 1993).

Once camps are selected, either all people and/or animals of a group or a random subset are enrolled. If only a single or fixed number of household members or animals within herds are selected, a “household size bias” can be introduced. Therefore, the samples must be weighted according to the number of individuals within each camp for unbiased estimates. If animals are randomly chosen from each herd, the animal prevalence estimate will be an unbiased estimate, but this is not true for the herd prevalence. There are formulas available to calculate the corresponding herd level prevalence, which are particularly useful where not all animals of a herd were sampled or when estimates need to be corrected for imperfect test sensitivity and specificity (Faes et al., 2011). A combined analysis of human and animal data can be challenging. However, for many research questions – for example, evaluation of the effectiveness of an intervention - a joint statistical analysis would be less important than joining presentation and interpretation of the results (Schelling and Hattendorf, 2015).

Health impact assessments of industrial development projects (Winkler et al., 2012) should be extended to simultaneously assess livestock health. Construction of dams or mines can also adversely affect the health of the livestock, have a direct implication on livelihoods and income of communities and can also indirectly affect human health.

Estimation of achieved intervention coverage, for instance, vaccination, is challenging in the absence of total population size estimates for mobile pastoralist groups, who are chronically underrepresented in censuses, particularly in sub-Saharan Africa. We have estimated that 70% of the total pastoralist population in a Chadian region was no longer present in the same area in the following year (Schelling et al., 2007b). There are pressing needs for baseline demographic and health-related data to plan, implement and evaluate health interventions.

A biometric identification system based on the registration and identification of digital fingerprints was acceptable to pastoralist communities in Chad and allowed unique identification of individuals who did not hold governmental identification cards (Weibel et al., 2008). It also reduced the needed minimum number of re-encounters to estimate the total population size. However, re-encounters during random transects were still too few (5%) to derive estimates with a meaningful precision or to establish a retrospective cohort on reported data (Weibel et al., 2011). More recently, a randomized cohort was equipped with mobile phones, and this pilot study encouraged the further use of mobile phones to plan larger trials. The pilot study led to estimates of densities for pastoralist and sedentary people and livestock over both seasons and years (Jean-Richard et al., 2014c, Abakar et al., 2014). Human and livestock densities peaked at the end of the dry season: While the densities of pastoralists remained lower than those of villagers, the pastoralist livestock density was three times higher than that of the villager livestock. The in total very high livestock densities raised concern about carrying capacity of pastures and ecosystem health (Jean-Richard et al., 2015).

Conclusions

Joint human and animal field health surveys are central for understanding the disease dynamics and the underlying context and for the planning of evidence-based testing of control measures. Aggregated data do not capture the complexities of disease dynamics. Also cost estimates of disease and interventions can be collected – and costs are important arguments for interventions supported by governments or non-governmental organizations. Including pastoralists in surveys is as feasible as for other rural communities. The additional inclusion of a non-pastoralist comparison community in the same region sheds light on specific health needs of pastoralism – and often more commonalities than differences are found. In future, further alternative surveillance systems will continue to be evaluated; among these syndromic surveillance, participatory epidemiology (Mariner et al.) and risk-based joint surveillance systems (Abakar et al., Chapter 30).

Near real-time reporting systems should be established together with the ability to respond to reported events. There is a need for consistent, reliable data flow over a longer term. In developing health interventions and programmes for rural communities, including pastoralists, successful implementation of control measures is further strengthened by the exchange and cooperation between neighbouring countries within regions.

Health of pastoralists is shaped by access to health and veterinary services and the ecosystem they live in - grasslands, the quality of the available water sources and marked seasonal and inter-annual variations of weather and climate. Essentially, the health of pastoralists and their livestock are within the context of remote rural populations. But the performance of health services and the governmental commitment to provide quality services are still weaker among mobile pastoralists than other communities, whereas to maintain the mobile livestock production is also a precondition of healthy animals, ecosystems and people. Identification of specific factors that influence human and animal health in a pastoralist setting and within their geographical and cultural context, and relating these to those of settled communities of the same area, shows what needs to be particularly addressed when developing adapted intervention strategies for pastoralists and in remote rural zones.

CHAPTER 10: A VISION FOR THE FUTURE OF PASTORALISM

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A vision for the future of pastoralism

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A vision for the future of pastoralism

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Abstract

Pastoral regions are challenged by social and ecological changes. Yet, there is increasingly robust evidence that pastoralism is a viable and sustainable livelihood and pastoralists contribute to the Sustainable Development Goals (SDGs). In this thematic issue, we take a broad view on pastoralism and pastoral livestock production from animal and human health, but also societal and ecological, points of view. They are complemented by regional perspectives from Central Asia, China, Europe, East, Central and West Africa, and Latin America. It is in the most genuine interest of the World Organization for Animal Health (OIE) to reflect on the broader issues of pastoral livestock production and its future implications to improving and sustaining animal health. Summarizing the diverse contributions, it appears that pastoral social-ecological systems are hotspots of cultural and biological diversity. They are multifunctional by generating diversified sources of income and contributing to sustained natural resource management. Pastoral populations require favourable institutional and legal frameworks and governance improvements and reforms through effective participation and empowerment. To sustain functional pastoral production systems, decentralized governance of natural resources and better locally adapted social services plus high flexibility for maintaining mobility are key ingredients. Young people should be actively encouraged to engage in pastoral livelihoods, which should be supported by improved legal systems for land use by all interested parties. Extensive livestock production still has an untapped potential for adapted genetic improvement and better transformation, stocking and marketing of animal source food. Modern concepts of disease surveillance and response, combining human and animal health as “One Health”, are particularly suited to pastoral systems. OIE’s interest in pastoralism is highly justified given its livelihood, economic and environmental importance. Sustainable improvements require understanding and discussion of diverse social and ecological interactions to which the authors and editors of this special issue have endeavoured to contribute.

Keywords

Pastoralism, mobility, multifunctional, social services, One Health, animal health, institutions, legal framework, tripartite, development impact bond, global fund

Introduction

In this thematic issue we take a broad view on pastoralism from an animal and human health, but also cultural, social, economic, ecological and climatic, conservation, institutional, governance and security point of view. Thematic reviews are complemented by regional perspectives from Central Asia, China, Europe, East, Central and West Africa and Latin America. Pastoralism as a livelihood and way of land use is a highly dynamic and interrelated issue for which we must base our mode of thinking on theories of complexity (Niamir-Fuller, 2016, Krätli, 2016). We use the framework for the achievement of the Sustainable Development Goals (SDG) of the 2030 Agenda for Sustainable Development <http://www.un.org/sustainabledevelopment/sustainable-development-goals/> (Box 1) (Fluckiger and Seth, 2016) and the questions posed in the introduction (Zinsstag, 2016b). The *cantus firmus*, as an underlying melody of pastoralism, is mobility to access and make use of the extensive, mostly dry grasslands for livestock husbandry. Pastoral livestock systems that productively use the vast grasslands of the world are in the most genuine interest of the World Organization for Animal Health (OIE). But this also means to reflect on broader issues of pastoral livestock production and its future with regard to improving and sustaining animal health, while balancing with other implications (Éloit, 2016). In this synthesis of a rich thematic issue, we argue for the sustainable use of pastoral ecosystems drawing on innovative ideas from the contributions to this issue for livelihoods, economic development, sustained ecosystem services and social and institutional development as the context for animal and human health and wellbeing. Rather than offering another review, we knit together the assembled information in this thematic issue with minimal additional references. This paper addresses the pathway towards a modern multifunctional pastoralism, locally adapted institutions and governance, sustainable livestock production and natural resource management and the implications for the World Organization for Animal Health and international animal health.

Towards a multifunctional pastoralism

There is increasingly robust evidence that pastoralism is a viable and sustainable livelihood, and that pastoralists have profound skills in productively managing uncertainty and risk in diverse arid land ecosystems (Dyer, 2016). Furthermore, pastoral social-ecological systems are hotspots of cultural and biological diversity (Ben Hounet, 2016, Kaufmann, 2016, Lankester, 2016). Therefore, they represent human and natural resources of global interest, warranting their protection as UNESCO World Heritage Centres (<http://whc.unesco.org/en/list/>). While such a status has been granted for many pastoral areas, there is a risk that they would be seen as a “museum” which must be conserved rather than as a dynamic social-ecological space with a considerable potential for development contributing to the SDGs (particularly SDGs 1, 2, 3, 15, 16). The contributions in this issue recognize the vulnerability of the ecosystems and the fragile economic base of pastoralism including industrialized countries (Catley, 2016, Grünwaldt, 2016, Liechti, 2016, Seid, 2016). Pastoral communities are highly resilient with an impressive endurance. They are engaged in continuous adaptive societal transformation and merit a stronger support to sustain their livelihood and contribution to public

goods. While livestock production remains at the centre of pastoral activities it can often not provide a sufficiently robust income as a single activity. Pastoral livelihoods should diversify in a multifunctional way by the development of new products, e.g. yak down and baby camel wool in Mongolia, and seeking other sources of income such as tourism and small and middle-scaled industry and by the contribution to sustained natural resource management, for instance by setting aside pasture buffer zones, preserving water resources, protecting trees and ensuring that pasture set seeds before allowing livestock to graze, maintaining ecological diversity and aesthetic scenery of rangelands, protecting rangeland against fire and contributing to carbon sequestration (Liechti, 2016, Köhler-Rollefson, 2016, Ouedraogo, 2016, Seid, 2016). Importantly, these often more punctual alternative income sources such as mining, oil or tourism should not destroy future longer-term uses of grasslands. Governments and the international community should recognize the created public goods of multifunctional pastoral systems. Engagements with mining, oil and tourism enterprises should include social and environmental impact assessments to secure pastoral livelihoods at the same time. Decentralized governance, providing adapted social services (Abakar et al., 2016), microcredit and insurance schemes, and compensations for ecological services (Liechti, 2016) are ways forward to empower pastoralists to state their needs and rights, as elaborated below.

Towards locally adapted institutions and governance

Prevailing institutions and governance were and are confronted with geostrategic, societal, colonial and extremist influences and pressures (Haller, 2016, Kasymov, 2016, Fokou, 2016), overlaid by fragile ecosystems and climate change issues (Herrero, 2016). Even though these contextual circumstances are highly diverse, there seems to be consensus in most papers dealing with institutions and governance.

1) Pastoral social-ecological systems require adapted institutions and governance improvements and reforms (SDGs 8, 10, 26). It is unlikely that sustainable pastoral development can be achieved by centralised decision making and planning (Yu, 2016, Krätli, 2016). It requires **effective participation by the local population** (Haller, 2016) with adequate mechanisms of **stakeholder engagement and decentralised governance**, strengthening pastoral capabilities and organizations (Kasymov, 2016, Schelling, 2016). In this way, acceptable ways of mobility, e.g. among Sami pastoralists in Norway (Liechti, 2016), access to higher value dairy (Bonfoh, 2016) and international meat markets can be secured (Rueff, 2016). New ways of payment for performance or payment for ecosystem services (Liechti, 2016) and community conservation agreements (Ouedraogo, 2016) for natural resource management and wildlife conservation represent innovations for the future. Altogether, they validate the theory of decentralized economic governance of the commons posited by Elinor Ostrom (Haller, 2016). However, such endeavours must be accompanied by locally adapted legal frameworks for land use which are acceptable to all interested parties (Anonymous, 2013).

2) Pastoral populations need **better and locally adapted social services** for education (Dyer, 2016), human and animal health (Grünwaldt, 2016, Schelling, 2016, Abakar, 2016) social security like microfinance and insurance schemes (Janzen, 2016). Specifically, young people should be encouraged to engage in pastoral livelihoods and not increase the ranks of the impoverished in urban centres. Many pastoral zones harbour areas under extremist rule which become inaccessible to national governments (de Bruijn, 2016). The re-establishment of basic security and legitimate rule with reduced corruption requires regional and international partnership efforts as a pre-requisite for the provision of urgently needed social services.

3) Pastoral social-ecological systems require **high flexibility and mobility** to remain functional. There is nothing more precarious to sustaining pastoralism than fragmented landscapes and forced sedentarisation (Krätli, 2016, Seid, 2016, Niamir-Fuller, 2016). Participatory stakeholder process engaging communities, mining companies, industries and local and central governments can develop a mutual consensus on securing mobility, for example by securing time schedules and couloirs of transhumance together with the communities to move livestock seasonally to available pasture, water and mineral resources. Specifically, mining companies must actively contribute to rehabilitate exploited rangeland and water resources.

Towards sustainable livestock production and cultural and economic viability

In pastoral areas hardly any agricultural activity is possible apart from livestock production. This close interdependence of humans and animals is rarely observed elsewhere and is the source of a highly diverse cultural heritage. Livestock is the cornerstone of pastoral cultural identity. The use of livestock and the related production of milk, milk products (Jans, 2016), meat and meat products, hides, wool and hair are the most efficient uses of pastoral ecosystems, not to neglect emotional value, animal traction and the use of manure for household energy and as fertilizer.

Despite modern technologies in transport and communication, the use of livestock can hardly be replaced given the diversity of their uses. To improve livestock genetic resources in pastoral areas, modern molecular and breeding approaches should be combined with local knowledge and methods. Breeding objectives under maximized feed and management conditions and quantitative traits alone are of limited value because of the complex resource constraints and multi-gene determinants of disease resistance. A mutual learning between modern science and local knowledge would allow for identification of locally adapted breeding goals which are context-dependent. For example, on the shores of Lake Chad the ideal cow should be the one that grows best and produces the most milk with the best conversion of the available roughage, while resisting seasonal malnutrition, biting insects and liver fluke challenge (Kaufmann, 2016, Köhler-Rollefson, 2016).

A high untapped potential lies in better food hygiene, particularly in milk and milk products. Modern hygienic principles from milking to milk transport, transformation and marketing also apply to extensive pastoral systems and provide access to markets and contribute to SDGs 1, 2 and 3 (Jans, 2016). Such improvements require community engagement, for instance as milk producer associations to introduce quality control and acquire equipment for transformation (Bonfoh, 2016). Specifically, active collaboration between milk industry and pastoralists, e.g. in Mauritanian camel milk and Mongolian cow milk production, along the production chain is strongly encouraged. Similarly, meat and meat conservation methods may be further optimized for food security management, including destocking during droughts. Further improvements, albeit in a limited way can also be expected from improved feed conservation and enhanced use of crop residues. Livestock genetic improvement, production and marketing of livestock products is embedded in the broader context of the above determinants of multi-functionality of pastoral livelihoods (Ouedraogo, 2016), rangeland management (Breu, 2015), improved institutional and governance conditions, sustained mobility and animal health.

Implications for the World Organization for Animal health

In complement to the above summarized social-ecological challenges, pastoral areas still carry the highest burden of animal diseases and are among the most poorly served areas for animal and human health. Transdisciplinary processes, within a One Health context, have proven effectiveness in delivering acceptable services and reaching mobile pastoralists in remote areas (Abakar, 2016). New integrated One Health surveillance systems which make use of mobile technology and include experiences, local concepts and priorities of pastoralist communities, combined with sound field data, are essential to develop and provide adapted services, which are in the remote rural zones inclusive for mobile pastoralist communities and allow them to maintain their mobile way of life (Schelling, 2016). In the future, community based syndromic (symptom based) surveillance and response systems in pastoral areas will likely benefit from modern communication, geographical positioning systems and the use of drones for sample collection and drug and vaccine delivery (Abakar et al., 2016).

Remote pastoral areas, where visits by veterinarians are costly, would benefit the most from integrated health care combining preventive services for several diseases. During one field visit, ruminants could be vaccinated against brucellosis, anthrax, peste des petits ruminants (PPR), and foot and mouth disease (FMD). Dogs could be dewormed and vaccinated against rabies. However, integrated animal health care is highly context dependent and requires preparatory epidemiological and operational research and testing for the efficacy of combinations of vaccinations administered at the same time, for example brucellosis and FMD (Zinsstag, 2016a). Such studies have been recommended for a long time and could be assessed by committed national and international experts without extensive investments but with potentially high impact.

Compared to the World Health Organization, with about seven thousand staff for eight billion people, OIE already achieves a very high efficiency in preventing and controlling animal diseases, with less than 200 staff worldwide for 8 billion head of livestock. But the leverage of OIE, particularly in pastoral areas could be greatly increased by federating OIE member states to create and manage a global fund for transboundary animal diseases like FMD, PPR and others, analogous to the Global Fund to Fight AIDS, Tuberculosis and Malaria (<http://www.theglobalfund.org>). Such an endeavour could be a One Health output of the tripartite engagement of OIE, FAO and WHO. It is in the interest of all countries to control transboundary diseases in pastoral areas of low income countries to reduce the global risk of transmission. Both the engagement of high income countries with low income countries and regional cooperation, e.g. between Russia, Mongolia and China, is needed to eliminate transboundary animal diseases effectively. Novel financial instruments like development impact bonds (DIB) share the risk of investment in the control of animal disease between institutional donors, national governments and private investors. A first DIB is currently underway for the elimination of East African sleeping sickness in Uganda (Welburn and Coleman, 2015). As an international organization for animal health, OIE's interest in addressing pastoralism is highly justified. Animal health and the provision of animal health services in pastoral areas are outcomes of complex social-ecological systems (Zinsstag et al., 2011d). Animal health status and the related status of human health are only the tip of the iceberg of interwoven human-environment interactions. Sustainable improvements require an in-depth understanding and discussion of these interactions to which the authors and editors of this special issue hope to have contributed.

CHAPTER 11: GENERAL DISCUSSION AND CONCLUSIONS

1. HEALTH INTERVENTIONS EFFECTIVENESS

The Sustainable Development Goals (SDGs) target the reduction of inequities with universal policies considering the needs of disadvantaged and marginalized populations. Between the efficacy of a given health intervention and its effectiveness at the community level, a considerable distinction should be made as the effectiveness is influenced by additional factors related much more to the society and the health system (Vlassoff and Tanner, 1992).

Evidence and methods are lacking to assess the effectiveness of interventions in the health sector especially with regard to different population groups in order to reduce inequalities within a population. In view of that, an “Equity Group” has been initiated by the “Campbell Collaboration Equity Methods Group and the Cochrane Collaboration Equity Field” aiming to establish a global evidence repository to fill this gap of knowledge (Tugwell et al., 2006b). Important disparities remain despite gains in average health worldwide. Hence, it is important to look more deeply than average effects to recognize the hidden differences within groups, especially those related to socio-economic status, e.g. between the wealthy and the poor and the easiest to reach/to serve and the difficult to reach and to serve (Tugwell et al., 2006b, Zinsstag et al., 2011a).

Chad represents a particular case of inequity, as, for instance, maternal mortality rate is one of the highest in the world at 1099 per 100,000 live births with only 30 per cent of women being assisted by qualified personnel during childbirth in 2010 (MICS, 2010). Looking at within country distributions, this figure is even lower in the remote areas (Swiss TPH, 2016). Furthermore, nomadic pastoralists in Chad are particularly affected by low access to and provision of health services (Zinsstag et al., 2011e).

With regard to vaccination delivery, barriers to health services were predominantly determined by issues classified as programme mistrust driven by insufficient information (IREC 2016). Extreme examples occurred among mobile pastoralist communities where vaccination coverage among livestock was significantly higher than that of children (Zinsstag et al., 2006, Schelling et al., 2007b). Equitable progress is needed to reduce the disproportionate burden of poor maternal health in Chad and to close the gaps between population groups.

Policies need to be informed through equity sensitive evidence assessing differences in health needs and particularly the effectiveness of interventions and models of care (Tugwell et al., 2006a). Therefore, an equity effectiveness loop framework has been proposed to quantify equity effectiveness at the community level.

An analytical framework was presented which identifies five relevant dimensions of access to health care: availability, accessibility, affordability, adequacy and acceptability (Obrist et al., 2007). An effectiveness model to quantify and optimize the effectiveness of dog rabies mass vaccination

campaigns in Bamako, Mali was developed based on this framework (Muthiani et al., 2015, Mosimann et al., 2017).

Building on this approach, we assess (chapter 2 of the present thesis) the community effectiveness of maternal health service coverage in two rural districts in Chad. The approach allowed for quantifying the health system's determinants of effectiveness. Our work extends the methodological framework described earlier by Zinsstag et al. (Zinsstag et al., 2011a) through the target population being divided into rural sedentary and mobile populations in order to highlight equity issues inherent in the effectiveness of maternal health services and to ensure that interventions may be tailored to population needs. The extended framework also introduces probabilistic sensitivity analysis to test for uncertainty around the estimated effectiveness parameters. Our findings provide a baseline to monitor the progress of a health system intervention focusing on maternal and infant health in these districts.

The key recommendation is to translate these findings into practice by proposing an iterative action cycle to inform policy in order to tailor interventions to achieve better effectiveness at the community level. The sensitivity analysis of the different parameters enables much clearer understanding on what should be prioritized in order to gain more effectiveness and equity.

2. VACCINE HESITANCY AMONG MOBILE PASTORALISTS IN CHAD: A HEALTH SYSTEM'S ISSUE

In our findings, issues related to lack of trust in the programme and health system issues were most frequently reported. Nomadic communities are reluctant to vaccinate their children because they did not have enough information about the benefit of vaccines or the location of vaccination services in their district. A substantial number of participants in our study complained that health personnel were unpleasant or that they felt neglected or humiliated because they were nomads. They raised concerns about the capacity and qualification of vaccinators and their cultural distance from them as one of the most important disincentives to get their children vaccinated.

Although standard communication programmes exist, participants in our study stated that there is essentially no communication taking place between mobile pastoralist communities and the local health system, especially regarding vaccination. Hence, we postulate, in the absence of earlier similar studies, that these communication programmes did not address the real concerns of nomadic communities' caregivers in the Danamadji health district. Therefore, advocacy could be directed towards exploring new channels of communication with nomadic communities in the Danamadji health district by involving the community through local social mobilization teams and maintenance of a permanent contact network, e.g. using mobile phones, with camps and nomad group leaders.

The health system in Danamadji, where we conducted our study, fails to provide vaccination services to nomadic communities, which translates into substantial immunization inequities when compared to

sedentary populations in the same district. To reduce health inequities in light of the SDGs, modern health system interventions must ensure that mobile pastoralists are included in the benefits of such policies. Based on the results of this study, barriers to existing vaccination services among mobile communities could be substantially reduced by improving the information exchanges between the provider (health district) and the population. Furthermore, cultural differences between vaccination providers and communities would be reduced by involving the representatives of the nomadic communities in service delivery and communication activities.

3. TOWARDS MAINSTREAMING OF JOINT HUMAN AND ANIMAL VACCINATION PROGRAMME: CHALLENGES AND PERSPECTIVES

We examined the feasibility and sustainability of the Joint Human and Animal Vaccination Programme (JHAVP) and its potential for integration into the existing public health system in Chad. We found both the feasibility and the sustainability of the programme have a strong basis from an organizational point of view. The magnitude of the joint vaccination event, marked by a large-scale official launch, played an important role in the acceptability and awareness of immunization in the nomadic community in Danamadji. The presence of the authorities during these events had an incentive effect, since they represented a mark of consideration which the nomadic populations generally declared to be previously lacking.

The implementation of JHAVP was a great success mainly because of ongoing coordination and exchanges between the public health and livestock sectors and also the decision to gather the nomads en masse in a location which facilitates the operations and has a mobilizing media effect. Another factor was using social mobilizers from the nomad communities, since distrust of local health systems contributes to limit access to vaccination among nomads (IRED-SwissTPH, 2016). Finally, offering an additional package of health services such as prenatal consultations, distribution of impregnated bed-nets, and vitamin A supplementation (Report of the Joint Immunization Campaign, 2013).

It should be noted here that all joint immunization campaigns organized in the past have been supported by partners and implemented by central structures. This led us to examine campaign sustainability from the point of view of possibility for integration into the local health system at the district level through a budget impact analysis. Considering the affordability of the intervention at the district level through the lens of a BIA, this study shows that the financial burden on the local health system would be relatively high to maintain the current funding scheme for the Danamadji health district in the coming years.

With no external funds available, the implementation of a yearly campaign would use up around one third of the district health budget. This implies substantial consequences regarding budget reallocation, which applies particularly to the most constrained budget categories like human resources. Combined

vaccination campaigns, being an outreach activity, do not rely on substantial infrastructural investments such as buildings and fixed equipment. Interpreted from a costing perspective, this implies only minor shares of fixed cost with little room for economies of scale, even though operational costs of sharing transport and cold chain between veterinary and public health sectors have proven effectiveness (Schelling et al., 2005c). As a consequence, increasing the target population through geographical expansion of the intervention to other districts will bring only minimal efficiency gains.

Building on these findings, we conclude that for mixed campaigns to be delivered as a part of the routine district health system, a considerable increase in financial resources would be required. If external funding is available, local health systems should continue to implement mixed campaigns in order to establish contact between nomadic communities and the health district to increase vaccination coverage. However, since the approach does not appear to be financially feasible at the local level long term, health districts need to enable less cost-intensive regular communication and information activities aimed at enhancing service utilization of vaccination services at fixed health facilities. Our result is in agreement with earlier work noting that lack of information is one of the principle demand-side barriers for vaccination among these communities, whereas geographical barriers do not appear to be a major concern (IRED-SwissTPH, 2016).

A current representative survey in the Danamadji district showed that 57% of mobile pastoralist households own a mobile phone (SwissTPH, 2016a). Efforts to sustain regular communication and exchange of vaccination-related information with the pastoralist communities between the sporadic occurrence of the campaigns in a less cost intensive way could be managed through the systematic application of mobile phone technology.

4. OUTLOOK ON SYNDROMIC SURVEILLANCE AND RESPONSE IN AFRICA

The proof of principle demonstrated by Jean-Richard et al. 2014 (Jean-Richard et al., 2014c) on the feasibility of demographic and health surveillance among mobile pastoralists in the southeast shore of Lake Chad using mobile phones motivated development of a project on integrated human and animal syndromic surveillance system in rural Chad.

In Chad, mobile pastoralists conduct seasonal migrations across ecological zones from the fringe of the Sahara in the north through the Sahel to the sub-humid areas in the south. The planned project expands the geographical scope from the Lake Chad Basin westward to the Lake Fitri Basin (Yao) in the Sahel and southward to the middle Chari River valley in the sub-humid zone (Danamadji). These two areas are also intervention zones of the SDC funded project PADS, which would contribute to implement interventions identified by the project (Figure 11.1.).

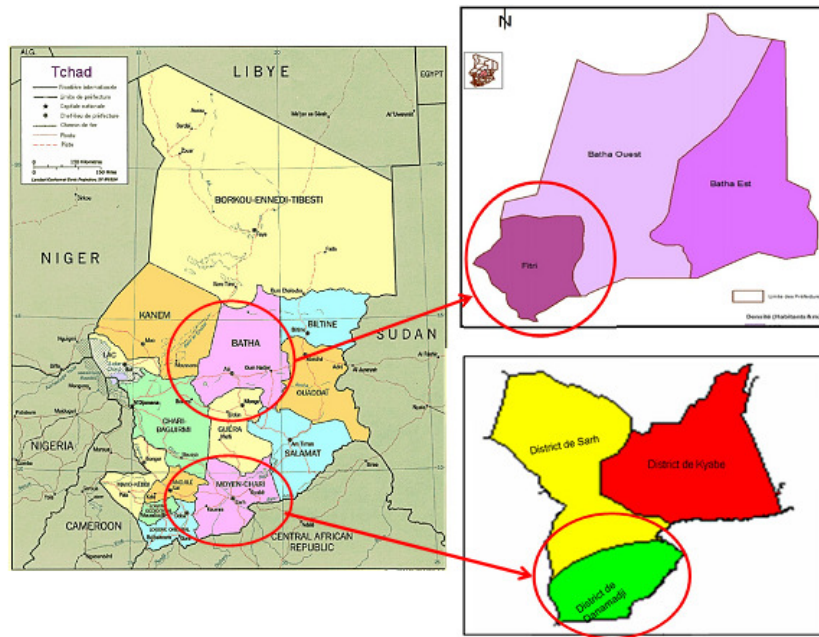


Figure 11.1. Study zones in Chad (red circles)

The Wellcome Trust funded project Afrique-One ASPIRE would contribute to the planned activity through its Thematic Training Programme 5 (TTP5) on surveillance response of zoonotic diseases especially in the region of Hadjer Lamis (Massakory), including the capital city N'Djamena and its surrounding area. In parallel, PADS and the Swiss federal veterinary office (BLV) and the Wolfermann-Nägeli foundation co-funded project (CBSyS-OH) will focus on the Yao and Danamdji health districts.

We suggest that improved veterinary service provision and livestock extension services are potentially powerful entry points for an improved state-pastoralist dialogue. Since many agriculturalists also keep livestock and some pastoralists cultivate food crops, it seems reasonable to speak of an agro-pastoral continuum or “agro-pastoralists” when referring to all the ethnic groups in the study districts. Previous research from the Lake Chad Basin has shown that agro-pastoralists suffer from a broad burden of illnesses including those caused by respiratory diseases, malaria, diarrheal diseases and malnutrition (Daugla et al., 2004), (Bechir et al., 2010b). Biomedical etiological causes are rarely assessed. Poliomyelitis reemerged among Chadian pastoralists likely due to low vaccination coverage (Ndiaye et al., 2014a), and there may be other not-yet-detected pathogens.

Socio-culturally inadequate health services among agro-pastoralists is perceived as a main determinant for poor health service utilization (Münch, 2012) and hence, a culturally sensitive approach to surveillance and interventions through participatory processes is critical as a foundation for a more effective and faster surveillance and response system. We therefore propose a synergistic combination of an epidemiological, anthropological, and advanced molecular diagnostic approach, of which all components are essential complementary elements to anticipate emerging diseases from perceived illnesses (syndromes) (Figure 11.2.).

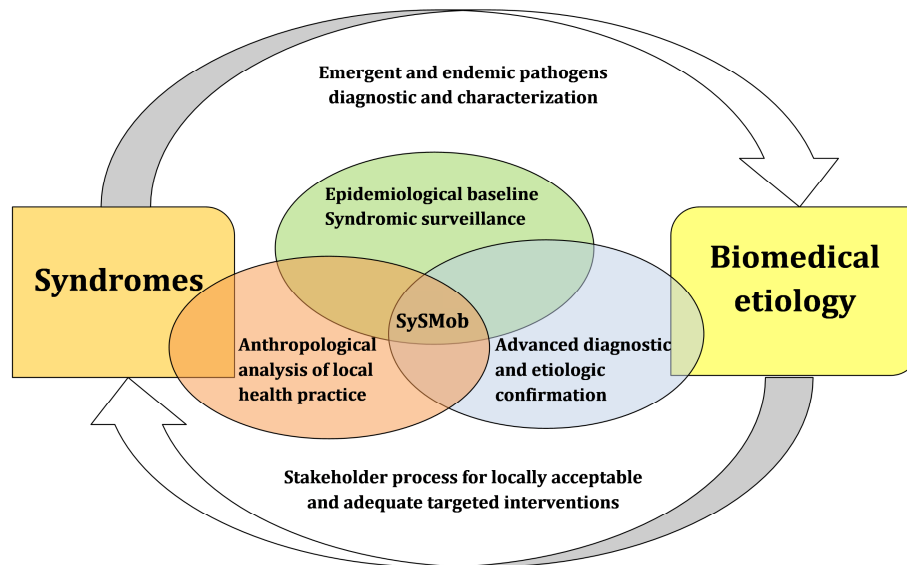


Figure 11.2. Epistemological interface of explanatory models of locally perceived illnesses and biomedical diseases

On a theoretical level, the project is positioned at the epistemological interface of biomedical explanatory models which are iteratively addressed through the analysis of epidemiological baseline data on human and animal health (epidemiological component) and local explanatory models of illness examined through a social analysis of local health practice (anthropological component). Communication across explanatory models will be improved through direct and mediated communication, using culturally validated mobile surveillance (SySMob) and advanced etiological diagnostics (infection biology component).

This approach is complemented by a transdisciplinary participatory stakeholder process which should lead to near real-time mobile surveillance and response, allowing for rapid etiologic diagnosis of emerging and endemic pathogens and effective, locally adequate targeted interventions. For further research in the framework of the upcoming Afrique One ASPIRE programme, we propose the following hypotheses:

Hypothesis 1: Integrated One Health surveillance addressing local and biomedical explanatory models reduces time to detection and accelerates etiologic confirmation and response when compared to the current surveillance systems.

Hypothesis 2: Integrated One Health surveillance leads to the identification of novel emerging pathogens not previously identified in Chad and contributes to global alert information increasing the level of anticipation of emerging diseases.

Hypothesis 3: Integrated One Health response will improve acceptability and adequacy of interventions through increased etiological precision and cultural adaptation.

5. POTENTIAL OF ZONOSIS ELIMINATION: CASE OF BOVINE TUBERCULOSIS

The presence of bovine tuberculosis (BTB) in cattle in different regions in Chad is well documented (Delafosse et al., 2002, Schelling et al., 2000). Beside the health impact, BTB has an economic impact by causing considerable loss in livestock production which affects the livelihood of herders. However, a cost estimate of BTB for Ethiopia demonstrated only a moderate cost of 1-20 US\$ per cow per year (Tschopp et al., 2012b). In Chad, BTB has been reported as an important cause of condemnation during meat inspection in abattoirs because of the destruction of the whole carcass (Maho et al., 1999). Hence, controlling and eliminating BTB in Chad would be an ambitious objective with great potential for economic and health impact.

Our paper presented the first cattle to cattle and cattle to human compartmental deterministic mathematical model. Differential equations were used to describe different pathways within and between compartments at human and animal level. Sensitivity analysis of the model was used to determine the most sensitive parameter. Additionally, different scenarios of test and culling interventions were simulated by considering different proportions of the tested population per year.

BTB prevalence was found to reach less than one per thousand in less than 20 years when the proportion of tested cattle was above 60%. The annual cost for this potential intervention was nearly 77 million Euros. The intervention in cattle was found to impact the prevalence of human TB due to *M. bovis*, which decreased from 5 per 10,000 to 1 per 10,000 after 17 years. If the proportion of cattle subjected to test and slaughter was greater than 60%, freedom from disease would be reached in less than 20 years. Although, this economic assessment presented in our work is preliminary, it clearly shows the possibility of eliminating BTB in one lifetime generation through applying an effective control strategy of test and slaughter. For such a control strategy to be effective, human resources and technical and logistical capacity in veterinary services are required.

Furthermore, our model simulation results suggested that switching from a 4mm cut off of the Single Intradermal Comparative Cervical Tuberculin skin test (SICCT), which is recommended by the OIE, to a 2mm cut-off would be likely to result in significantly shorter duration of elimination programmes and much cheaper elimination campaigns. Earlier work by Ngandolo et al. (2009) suggested that using a 2mm cut-off instead of 4mm cut-off would lead to better performance of the test (Ngandolo et al., 2009).

As noted in the introduction of this thesis, the economic burden of such an intervention would be out of reach for a developing country like Chad which is going through an economic crisis due to falling prices of raw materials, especially oil. However, one could envision starting with disease free zones with relatively lower intervention costs and economic potential through better valorisation of the animal production chain. Furthermore, a development impact bond (DIB) could be foreseen as a potential resource to fund such an intervention.

6. CONCLUDING REMARKS, RECOMMENDATIONS TOWARDS AN INTEGRATED SURVEILLANCE AND RESPONSE SYSTEM AND THE WAY FORWARD

6.1. INTERVENTIONS EFFECTIVENESS: LACK OF METHODS AND ITERATIVE CYCLES OF ACTION

Disparities within populations in access to health care between the poor and the rich still persist. Methods are lacking to assess interventions effectiveness which is an important element in providing much more equitable health services with enhanced community effectiveness. Health policies need to be continuously informed based on evidence in order to fill gaps in health service provision and reach universal access to health care for the population especially those who need it most, i.e. the marginalized groups. This could be achieved by translating the research findings into actions within a participatory iterative cycle in which all the essential elements and factors were taken into account.

6.2. VACCINES HESITANCY AMONG MOBILE PASTORALISTS: A RESULT OF INADEQUATE HEALTH SERVICES

Inadequate health service was a leading factor behind vaccination hesitancy among mobile pastoralists in Chad. Lack of tailored communication and issues with the health system were the main reasons for these communities to not vaccinate their children. Health staff being unpleasant or asking for money despite that the service was supposed to be freely available was the main health system related issue. Hence, local health systems must be flexible and adaptive to better respond to the needs of different communities with evidence based interventions. Advocacy of better awareness towards pastoral communities should be promoted by health systems, civil and religious leaders and decision-makers, for example using mobile technology for information and maintaining contact with mobile communities, which could greatly contribute to vaccination acceptance and help the government to achieve SDGs.

6.3. JOINT HUMAN AND ANIMAL VACCINATION PROGRAMMES: A “ONE HEALTH” SUCCESS, YET CHALLENGES REMAIN

While the operational feasibility and sustainability for joint human and animal vaccination programmes among nomad communities is not problematic, concerns exist about some weaknesses and threats to this health programme. These weaknesses, which influence the regularity of the programme, could constitute serious long-term handicaps for its survival. Although its integration as a routine activity at the district level depends on the mobilization of additional financial resources, the district could benefit from joint immunization to maintain a contact network with the nomads in order to promote the use of already available immunization services at district level.

6.4. BOVINE TUBERCULOSIS: A POTENTIAL CANDIDATE FOR ELIMINATION IN DEVELOPING COUNTRIES?

Starting with disease free zones and using development impact bonds (DIB) as a potential fund resource, the dream of controlling BTB and aiming towards elimination could become a reality. In Chad, with the Sahara desert serving as a natural barrier in the north, the idea of starting a strict test and slaughter intervention using the appropriate test cut-off in some specific zones where there is limited cattle herd movement could be foreseen. More enhanced and context specific models should be developed in order to give insight into the feasibility of such an intervention in the Chadian context.

6.5. INTEGRATED HEALTH SYNDROMIC SURVEILLANCE-RESPONSE AND BEYOND: THE PROMISING KICK-OFF

Implementing a culturally adapted, low cost and near-real time integrated human and animal syndromic surveillance using mobile phones as the tool for transmitting health related information would have a great potential and impact on population health. Linking such a system to etiologic confirmation of freshly collected samples would lead to adapted and highly evidence based interventions and increases the potential of anticipating outbreaks of emergent, re-emergent and endemic diseases. Beyond disease surveillance, such a system could be used for advocacy towards health service utilization, health specific case management, for example, pregnancies and vaccination among hard to reach communities and integrating animal zoonotic diseases into existing Health and Demographic Surveillance System (HDSS).

An integrated framework of human and animal health surveillance and response in remote rural settings in Africa should benefit from the rapidly growing field of modern communication technology, for instance, mobile phones. In fact, use of mobile phones is increasing even in remote areas including mobile pastoralists in the Sahel region of sub-Saharan Africa and in Chad (De Bruijn et al., 2016, SwissTPH, 2016a). Not only does expansion among users of mobile phones seem to be increasing, but the network quality and the proposed technical offers by mobile phone companies are also increasing. For example, the two main mobile phone companies in Chad (Tigo and Airtel) currently offering G4 coverage with relatively high speed internet connection in the main cities, while G3 and other lower technical options are more and more available in smaller towns and even in remote areas. During field data collection phases of the present thesis, it was technically possible to successfully upload data online to the server from remote villages and camps. This highly positive dynamic situation in the world of technology should be further exploited in proposing internet based applications with visual support (pictograms for instance) representing the symptoms of the priority selected diseases. A prototype of such an application with georeferenced ability has already been successfully tested in Switzerland and in Chad in the frame of a bachelor thesis in applied science (Lauber, C., 2014, Bachelor thesis, (FHNW)).

A better understanding of the role of mobile communication on the potential of disease surveillance among rural sedentary and mobile people is needed to ensure efficient use in health surveillance. The socio-anthropological understanding of mobile communication in addition to local perception of illnesses among these communities is important. Transdisciplinary methods through participatory processes would co-produce knowledge towards locally adapted and culturally validated systems in order to establish an appropriate social mechanism to identify perceived priorities among communities and health professionals for a well-functioning surveillance and response system. Furthermore, it is important to establish an equity effectiveness assessment process as part of the social process in order to bridge the gaps and provide more equitable interventions.

Beyond diseases surveillance, such a framework could be further used in health information advocacy, for example, vaccines uptake, sanitation and hygiene in addition to medical case management (pregnancies, medication uptake). Linking the framework with laboratory confirmation and proposing points of care through context adapted sample collection, storage and transport. The use of drones should be considered and linked to this framework. Drones are recently being utilized in public health, for instance, in transporting clinical diagnostic specimens, or for environmental monitoring and mapping infectious diseases landscapes (Capolupo et al., 2015, Amukele et al., 2015, Fornace et al., 2014). Fixed wing drones were used in Rwanda for the delivery of blood to urgent remote cases (Gwatkin, 2017).

The use of drones has many advantages particularly in Africa where the delivery of medical supplies and collection of fresh samples are challenging tasks because of poor ground transportation infrastructure and remoteness of rural populations. They offer much cheaper cost in transportation compared to cars or other means of transportation and, most importantly, they save time and overcome spatial barriers such as mountains, rivers and hard to reach places. Introducing economic analysis for the whole surveillance response system with a new effectiveness indicator of cost per case and time to effective response, aiming at the lowest cost and fastest etiological case detection would be a promising path towards a highly performing, equitable and increasingly efficient health system in Africa.

ANNEXES

i. ETHICAL CLEARANCES:

ii. SUPPORTING INFORMATION 1

Supporting Information 1: Calculation of the cattle to cattle transmission rate

The equations for the cattle population are given by

$$\frac{dS(t)}{dt} = bS(t) + r_b b(E(t) + I(t)) - \beta \frac{S(t)I(t)}{N(t)} - \mu S(t) - (1 - s_p)pS(t), \quad (1a)$$

$$\frac{dE(t)}{dt} = \beta \frac{S(t)I(t)}{N(t)} - \alpha E(t) - \mu E(t) - s_{cp}E(t), \quad (1b)$$

$$\frac{dI(t)}{dt} = \alpha E(t) - \mu I(t) - s_{cp}I(t), \quad (1c)$$

where $N(t) = S(t) + E(t) + I(t)$ and

$$\frac{dN(t)}{dt} = bS(t) + r_b b(E(t) + I(t)) - \mu N(t) - (1 - s_p)pS(t) - s_{cp}(E(t) + I(t)).$$

If $b > \mu$ and $p = 0$ the total cattle population, N , increases exponentially. In order to calculate the pre intervention endemic equilibrium we therefore define the proportion of susceptible, exposed and infected cattle as

$$s(t) := \frac{S(t)}{N(t)}, \quad e(t) := \frac{E(t)}{N(t)}, \quad i(t) := \frac{I(t)}{N(t)}.$$

Using the chain rule and equation (1b) we get

$$\frac{de(t)}{dt} = (b - r_b)e(t)^2 - \beta i(t)^2 + (b - r_b - \beta)e(t)i(t) - (b + \alpha)e(t) + \beta i(t).$$

and from equation (1c)

$$\frac{di(t)}{dt} = (b - r_b)i(t)^2 - (b - r_b)e(t)i(t) + \alpha e(t) - bi(t).$$

There exists an equilibrium proportion of exposed cattle, e_* , and infective cattle, i_* , such that

$$0 = (b - r_b)e_*^2 - \beta i_*^2 + (b - r_b - \beta)e_*i_* - (b + \alpha)e_* + \beta i_*$$

and

$$0 = (b - r_b)i_*^2 - (b - r_b)e_*i_* + \alpha e_* - bi_*.$$

We now choose the transmission rate β such that

$$e_* + i_* = \phi,$$

where ϕ is the endemic prevalence before the intervention. This yields

$$i_* = \frac{\alpha \phi}{\alpha + b - (b - r_b)\phi},$$

$$e_* = \phi - i_*$$

and

$$\beta = \frac{(b - r_b)e_*^2 + (b - r_b)e_*i_* - (b + \alpha)e_*}{i_*^2 + e_*i_* - i_*}.$$

iii. SUPPORTING INFORMATION 2

Supporting Information 2: Calculation of the cattle to human transmission rate

The equations for the human population are given by

$$\frac{dS(t)}{dt} = bS(t) - \beta \frac{I_C(t)S(t)}{N(t)} - \mu S(t), \quad (1a)$$

$$\frac{dE(t)}{dt} = \beta \frac{I_C(t)S(t)}{N(t)} - \alpha E(t) - \mu E(t), \quad (1b)$$

$$\frac{dI(t)}{dt} = \alpha E(t) - \delta I(t) - \mu I(t), \quad (1c)$$

where $I_C(t)$ is the number of infected cattle at time t , $N(t) = S(t) + E(t) + I(t)$ and

$$\frac{dN(t)}{dt} = (b - \mu)N(t).$$

If $b > \mu$ the total human population, N , increases exponentially. In order to calculate the pre intervention endemic equilibrium we therefore define the proportion of susceptible, exposed and infected humans as

$$s(t) := \frac{S(t)}{N(t)}, \quad e(t) := \frac{E(t)}{N(t)}, \quad i(t) := \frac{I(t)}{N(t)}.$$

Using the chain rule and equation (1b) we get

$$\frac{de(t)}{dt} = \beta i_C^* - \beta i_C^* e(t) - \beta i_C^* i(t) - \alpha e(t) - be(t).$$

where i_C^* is the equilibrium proportion of infected cattle. Equation (1c) yields

$$\frac{di(t)}{dt} = \alpha e - \delta i - bi.$$

There exists an equilibrium proportion of exposed humans, e_* , and infective humans, i_* , such that

$$0 = \beta i_C^* - \beta i_C^* e_* - \beta i_C^* i_* - \alpha e_* - be_*$$

and

$$0 = \alpha e_* - \delta i_* - bi_*.$$

We now choose the transmission rate β such that

$$e_* + i_* = \phi,$$

where ϕ is the endemic prevalence before the intervention. This yields

$$i_* = \frac{\alpha \phi}{\alpha + \delta + b},$$

$$e_* = \phi - i_*$$

and

$$\beta = \frac{(\alpha + b)e_*}{i_C^* e_*}.$$

iv. FIELD PICTURES



Working sessions (data collection) with rural communities in Yao and Danamadji health districts in Chad (April-June 2015)



Health infrastructures: old health centers (left) and newly constructed health centers by PADS (right) in Danamadji (Djeke-djeke 1 & 2) and Yao (Abregna-breka 3&4) health districts



Transdisciplinary workshop with communities, authorities, health officials and scientists to feedback the results and plan for future activities, January 2016, CEFODE, N'Djamena, Chad

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